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THE IOWA ORTHOPAEDIC JOURNAL

2008 • Volume 28

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The Iowa Orthopaedic Journal
Any original article relevant to orthopaedic surgery, orthopaedic science or the teaching of either will be considered for publication in The Iowa Orthopaedic Journal. Articles will be enthusiastically received from alumni, visitors to the department, members of the Iowa Orthopaedic Society, residents, and friends of The University of Iowa Department of Orthopaedics and Rehabilitation. The journal is published every June. The deadline to receive articles for the 2009 edition is Monday, January 5, 2009.

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

Submit manuscripts and accompanying figures to diana-johannes@uiowa.edu. It is essential to include:

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Additional copies of these instructions may be obtained at www.uihealthcare.com/depts/med/orthopaedicsurgery/reseach/ioj.html or by writing to Diana Johannes, University of Iowa Hospitals and Clinics, Department of Orthopaedics and Rehabilitation, 200 Hawkins Drive – 01006 JPP, Iowa City, Iowa, 52242-1088 or by emailing diana-johannes@uiowa.edu.
We are pleased and honored to present the 2008 edition of The Iowa Orthopaedic Journal (IOJ). As in previous years, this issue of the IOJ contains original works of research, surgical techniques, and case reports. It even contains encouragement from a past president of the American Academy of Orthopaedics.

Since the summer of 2007, when the IOJ became available in electronic format via PubMed, its popularity has been growing. The number of downloads per month has averaged about 13,000, with a total number of downloads of over 100,000 in only seven months; the numbers seem to be increasing. This number is not representative of the number of times the IOJ is “hit” during literature searches, or the number of times abstracts are scanned. We are excited about what this means to the overall readership of the IOJ and dissemination of its articles.

As in previous years, this year we had a wide variety of submissions from a wide variety of locales, perhaps reflective of the increased electronic availability of the IOJ. We received submissions from across the globe, including the Middle East, western Europe, and the Caribbean. We also had many articles submitted from across the United States. Finally, we reviewed several articles from current faculty and residents. We would like to express our gratitude to everyone who submitted articles, as this assimilation of information serves to enrich the knowledge of all who pursue it.

We, as a collective group of residents, would also like to express our gratitude to the current group of graduating senior residents: Drs. Chang, Christiansen, Daines, Fairchild, and Lavery. Over the past five years, they have contributed much to each individual resident’s assimilation of knowledge, whether in instruction in the operating room, Socratic questioning, or leading by example. While none of them would claim perfection in the realm of medicine, they certainly have demonstrated many attributes intrinsic to dedicated professionals from which less-experienced residents can learn much. We thank them for their hard work and the sacrifices they have made.

When mentioning sacrifice, hard work, and leading by example, one would be remiss if he or she did not recognize Tess Sommer. This year’s edition of the IOJ is dedicated to her. For those who do not know her personally, she is the staff nurse assigned to clinical duties for the trauma team at the University of Iowa. Very quietly, and through endless, tireless hours, she keeps the trauma team functioning. Ask any summertime trauma chief about the contributions of Tess Sommer, and you’ll hear one recurring theme . . . invaluable. Although her formal academic contributions to orthopaedics do not number substantially, her overall contribution to resident education and to the patients of the trauma team cannot be measured. She truly deserves to be lauded for her work, and she is an example for us all.

Clearly the IOJ would not be possible without those who are working behind the scenes. We would like to thank Diana Johannes for her many hours poring over articles and checking (and rechecking) our work. She surmounted the not-insignificant task of keeping manuscripts organized, submitting articles to our printer, and keeping us on task with deadlines. As a note to next year’s editors, she has a very sharp stick in her office that she uses as a motivator. All joking aside, working with Diana was a pleasure; she was the mother hen who kept us going in the right direction.

We also thank our corporate sponsors for their educational contributions to the IOJ. Amid turbulent times, while clarifying relationships between industry and orthopaedics, they were willing and forthright in their sponsorship of our education, not only with the IOJ but also with regard to patient care, and we thank them. Without their input and products, patient care in orthopaedics would be impossible.

Finally, we thank Dr. Jose Morcuende and Dr. Joseph Buckwalter for their mentorship and continued support of the IOJ. They act as our faculty advisors, and we are indebted to them for their input and leadership.

Congratulations to all who had input into putting together this year’s Iowa Orthopaedic Journal. We hope your knowledge is deepened and your patient care is enriched by reading it.

Christopher J. Van Hofwegen, M.D.
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This year’s publication of the Iowa Orthopaedic Journal provides the perfect forum to honor a member of our department to whom such a dedication has been long overdue. Her contribution to the daily function of the trauma service, education of residents, and thoughtful patient care distinguish her as invaluable. With pleasure we dedicate the 2008 Iowa Orthopaedic Journal to Tess Sommer, R.N.

Tess grew up in the small town of Crawfordsville, Iowa, the third of four children. She recalls that, in those days, women became teachers, secretaries, or nurses. Nursing suited her. She attended nursing school in Burlington, Iowa, and was part of the last class to graduate from that institution in 1973. At that time, local nuns taught the curriculum at the old Burlington hospital.

Following graduation, Tess stayed in Burlington to work, despite the lengthy commute. In 1978, nurses formed a union in Burlington. Conflict between the union and the hospital grew more intense, and Tess chose to leave for Iowa City, where there was no union. She began as a floater, working vacation relief, then worked her way into an orthopaedic clinic nurse position. Eventually, the orthopaedic department hired her as the Trauma Team Coordinator, and she has held that position ever since.

Being the Trauma Team Coordinator requires long hours, rigorous direct patient care, and plenty of patience. Rather than fulfilling all these expectations, Tess exceeds them. She arrives for AM rounds before anyone else, prepared with patient lists and a roster of patients admitted overnight. For each patient, she knows the issues and the plan; a boon to every junior resident caught clueless by a question from an attending or a floor nurse. Throughout the day, Tess keeps clinics running smoothly, executes plans for inpatients, and coordinates the influx of new admits.

Every resident owes Tess for her willingness to educate. She passes along her knowledge of direct patient care, including an unparalleled knowledge of pre-and-post-operative care such as traction and wound care, along with coordination of social work and physical therapy. And at the end of each day, she answers every “Thanks” with a self-deprecating shrug and hurriedly returns to her work.

What motivates Tess for such arduous work? “Look at who I get to work with!” she smiles, referring to Drs. Marsh, Nepola, and McKinley. She quickly adds she has an affinity for the residents as well. She enjoys teaching them, watching them progress, and hearing their stories (and she assures me, “what happens on Trauma Team, stays on Trauma Team”).

Tess also makes time for life away from the hospital. She and her husband own an acreage with a pond and wetlands, inhabited by pheasants and deer (no hunting, please!). They enjoy their Harley rides together and have two children; Jake works at the local Ronald McDonald House, and Sarah works at Edward Jones.

To all staff, residents, and patients, Tess imparts a continuing legacy of service, education, and excellence. With deep gratitude for all she has taught us, has done for us, and will continue to do, we dedicate the 2008 Iowa Orthopaedic Journal to Tess Sommer.
2008-2009
DEPARTMENT OF ORTHOPAEDICS AND REHABILITATION
SCHEDULE OF LECTURES AND CONFERENCES

(Larson Conference Room, 01090 JPP)

2008 Senior Residents Day
June 13-14, 2008
Dr. James Waddell, Toronto, Ontario, Canada
Dr. Kenneth DeHaven, Rochester, New York
*Contact Linda Croy, (319) 353-7660

Iowa Orthopaedic Alumni Association Meeting
2009 speakers and date to be announced
*Contact Peggy Stover, (319) 356-2332

24th Annual Hawkeye Sports Medicine Symposium
December 5-6, 2008 (speakers to be announced)
Marriott Hotel and Conference Center
300 East 9th Street, Coralville
*Contact Kris Kriener, (319) 353-7954

Carroll B. Larson Shrine Memorial Lecture
March 28-29, 2008
Dr. B. Stephens Richard III
Texas Scottish Rite Hospital
Spring 2009, to be arranged
*Contact Nancy Love, (319) 356-1872

Ponseti Clubfoot Treatment Symposium
October 3-4, 2008
*Contact Gloria Yorek, (319) 356-3469

Eighth Biennial Johnston Lectureship in Hip Reconstruction
October 2008
*Contact Lori Yoder, (319) 356-3110

*Please check with us later for exact dates, times, and speakers
Department of Orthopaedics

The University of Iowa
Roy J. and Lucille A. Carver College of Medicine
DEPARTMENT OF ORTHOPAEDICS AND REHABILITATION STAFF 2007-2008

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Dr. Sergio Mendoza  Dr. Jose Morcuende  Dr. James Nepola  Dr. Nicolas O. Noiseux  Dr. Michael O’Rourke  Dr. Ignacio Ponseti

Dr. Neil Segal  Dr. Joseph Smucker  Dr. Stuart Weinstein  Dr. Brian Wolf  Dr. Robert Yang
2008 GRADUATING ORTHOPAEDIC RESIDENTS

Michael S. Chang, M.D.
Michael Chang was born in Galion, Ohio, and raised in Orlando, Florida. He received his bachelor of science degree in engineering at Harvard University and later went on to Harvard Medical School where he met his future wife, Faye. They were married in 2007.

Next year, Michael will head off to Washington University in St. Louis for a spine fellowship and to continue the trend of not sleeping as much as he likes. After the year of fellowship, Michael and Faye plan on settling in a large coastal city (yet to be determined), as Michael has learned that being around friendly, well-meaning midwesterners makes him paranoid.

Michael and Faye are very grateful for the chance to work with such talented and brilliant residents. It is an experience they will treasure forever. They also feel it has been a privilege to work under some of the most accomplished faculty in the world.

Cory Christiansen, M.D.
Cory was born and raised in Muscatine, Iowa. He attended the University of Northern Iowa and then came to the University of Iowa for medical school. His wife, Erin, is also from Muscatine and they have been incredibly fortunate to be close to family and friends throughout residency.

Upon completion of residency, Cory and Erin will be traveling to Tauranga, New Zealand, for Cory’s year-long fellowship in Sports Medicine. They will then return to Iowa City where Cory will begin a general orthopaedics practice at the Steindler Clinic.

Cory and Erin have truly enjoyed their time in Iowa City and appreciate the friendships and camaraderie that have come along the way.

Michael T. Daines, M.D.
Michael was born in Falls Church, Virginia, while his father was completing his orthopaedic residency at George Washington. He was raised in Boise, Idaho, before moving to Salt Lake City to attend the University of Utah in 1993. He served as a missionary for the Church of Jesus Christ of Latter-Day-Saints from 1994-1996 and returned to Salt Lake to complete his undergraduate degree in Biology with a minor in Chemistry. He met his sweetheart, Natalie, during his final year as an undergraduate on a blind date arranged by his younger brother. They were married a little more than one year later, after Michael had completed his first year of medical school.

Michael moved to New York City for medical school and attended Columbia University College of Physicians and Surgeons from 1999 to 2003.

Michael and Natalie are the proud and exhausted parents of three very energetic and wonderful children. Sophie Brianne was the first on the scene and is currently in kindergarten. Riley Michael is four and into breaking things. Our youngest, Lucy Isabelle, is our little darling and is routinely spoiled by everyone else in the family.

Michael is the recipient of the 2008 Girdlestone Scholarship from Oxford, England, and will be completing his fellowship in shoulder and elbow surgery there. After that he hopes to return west and is currently deciding between a career in academics or in private practice.
Todd A. Fairchild, M.D.

Todd is from Muncie, Indiana. After studying economics at Harvard, Todd and his two brothers ran a small business in central Indiana. He met his wife Amy during this period of time and their son Luke was born. After deciding to pursue a career in medicine, Todd attended medical school at Yale. He particularly enjoyed a one-year hiatus during medical school in which he conducted basic science research under a Howard Hughes fellowship. After their return to the midwest for an Iowa orthopaedics residency, Todd and Amy were blessed with two more sons, Will and Charlie.

After residency, Todd will pursue a one-year spine fellowship at Twin Cities Spine Center in Minneapolis. Todd and Amy are currently looking to permanently relocate to the central Wisconsin area.

Matthew Lavery, M.D.

Matt Lavery is a native Midwesterner, born and raised in Quincy, Illinois. He had a brief stint in Iowa City as an unde grad prior to transferring to Millikin University in Decatur, Illinois, to play football with his twin brother, Mark. Matt received his undergraduate degree in finance. He then spent a year in Colorado working at the Breckenridge Ski School before returning to the midwest for medical school at Southern Illinois University.

Matt met his future wife, Jessica, while a third-year medical student in Springfield. Jessica was the junior resident on the Orthopedic Service at SIU during Matt’s clerkship rotation. She credits herself with influencing Matt to pursue a career in Orthopaedics; Matt is convinced that Jessica was simply trying to get a date with her med student. They survived a long-distance relationship for four years while Jessica finished her Plastic & Reconstructive Surgery Residency. Matt and Jessica were married in August of 2007 in Indianapolis.

Next year Matt will head to Los Angeles to complete a fellowship in Sports Medicine at the Southern California Orthopedic Institute. He plans to return to the midwest to practice General Orthopaedics and Sports Medicine. Matt credits much of his success to his loving wife, family, and friends.
2008 GRADUATING FELLOWS

David Vasconcellos, M.D.

David is a Nebraska native and attended Creighton University in Omaha, earning his bachelor’s degrees in psychology and biology. Medical school was also accomplished at Creighton, and his residency in orthopaedics took him to the University of Hawaii. He performed a year of locums tenans work in Nebraska before arriving at The University of Iowa for his Sports Medicine Fellowship. He will celebrate the end of his UI fellowship by taking a cruise to Italy with his parents, brother, sister-in-law and niece. He has not accepted a position yet but is considering Hawaii, California, the west coast, and the midwest.

He enjoyed this year in Iowa very much. It was especially great working with the sports faculty, residents, staff and athletic trainers. The highlight of his year here was working with the UI football team—the coaching staff and players—and working with Dr. Amendola made it a great experience. He felt it was kind of a big family and he got to know everyone really well over the course of the year.

He also enjoyed being part of the great Iowa orthopaedic tradition and being around so many talented people. He commented that the Hawkeyes are a great team and he thinks they will just keep getting stronger and stronger.

Christina Ward, M.D.

Christina Ward was born and raised in Kansas. She received her undergraduate degree from Grinnell College in Grinnell, Iowa, and her medical degree at Washington University in St. Louis. She has enjoyed the last year of fellowship training with Drs. Adams and Lawler and greatly appreciates their help and support.

Christina and her husband Nathan are expecting their first child this summer. She will remain on faculty at The University of Iowa while her husband completes his pathology residency. She has accepted a position as a hand surgeon at the University of Minnesota/Regions Hospital for 2009.
Elizabeth R. Cohen was born in Atlanta, Georgia, and raised in Ohio. She received her bachelor of science from Pennsylvania State University where she studied microbiology, biochemistry, and molecular biology. Following graduation, she returned to Ohio to begin her medical training at the Northeastern Ohio Universities College of Medicine.

Elizabeth began her research career at Pennsylvania State University where she worked in a kinesiology lab for two years studying pressure distribution in diabetic feet and also evaluating exercise programs for NASA astronauts. She was able to continue with her work on diabetes at the Cleveland Clinic Lerner Research Institute. She spent her last two years at Pennsylvania State University conducting virology research. At Cincinnati Children’s Hospital and Medical Center, her study of the role of the immune system in gastrointestinal disorders sparked her desire to pursue a more in-depth clinical research experience through the Doris Duke Clinical Research Fellowship. Her time in the University of Iowa Sports Medicine Department as a Doris Duke Fellow enhanced both her research and clinical skills more than anticipated.

After her fellowship, Elizabeth will return to Ohio to complete a final two years of medical school. She looks forward to a career in Orthopaedics and supporting academic medicine.

Elizabeth is extremely grateful for the opportunity the Doris Duke Clinical Research Fellowship program provided and the training she has received at the University of Iowa Hospitals and Clinics. It has been a privilege and great pleasure to work so closely with the faculty and residents throughout the entire department.
Nicolas Noiseux, M.D.

Nicolas Noiseux joined The University of Iowa Department of Orthopaedics and Rehabilitation in August of 2007 as part of the Adult Reconstruction and Joint Replacement team. He is originally from Montreal, Canada. He obtained his B.Sc. degree between 1993 and 1996, and his M.D.C.M. from 1996 to 2000. He completed his residency training from 2000 to 2005 at McGill University in Montreal.

After that, Dr. Noiseux went on to the Mayo Clinic in Rochester, Minnesota, where he did postdoctoral research and completed a fellowship in orthopaedic surgery from 2005 to 2006. He then went into a clinical fellowship in Adult Hip and Knee Reconstruction from 2006 to 2007.

His research interests include femoro-acetabular impingement; diagnosis, treatment, prevention, and causes of hip arthritis; outcomes of joint replacements in obese patients; minimally invasive hip and knee surgery; new technology performance in hip and knee replacement; and hip resurfacing.
The Michael Bonfiglio Award for Student Research in Orthopaedic Surgery

The Iowa Orthopaedic Society Medical Student Research Award for Musculoskeletal Research

As has been the tradition, the University of Iowa Department of Orthopaedics and Rehabilitation, along with the Iowa Orthopaedic Society, sponsor two research awards involving medical students.

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

This year the selection committee, consisting of the president of the Iowa Orthopaedic Society (Dr. Scott Meyer), as well as members of the Orthopaedics and Rehabilitation Department (Dr. Charles Clark, Dr. Joseph A. Buckwalter, Dr. Brian Wolf, Dr. Jose A. Morcuende, and Dr. John Femino), recommended that Roberto I. Diaz, M4, receive the 2008 Michael Bonfiglio Student Research Award. Roberto’s award was based on his project, “Computer Assistance in Quantification of Cartilage Defects at Surgery.” His advisor was John P. Albright, M.D., and his co-investigators were M. Bridget Zimmerman, Ph.D., and Craig Lyon, M.D.

The selection committee recommended that the Medical Student Research Award be given to William Shyy, M1, for his research titled, “Dual Polymorphisms in GPR50 Receptor Are Strongly Associated with Adolescent Idiopathic Scoliosis.” His advisor was Jose. A. Morcuende, M.D., Ph.D.

The Michael Bonfiglio Award and the Iowa Orthopaedic Society Medical Student Research Award for Musculoskeletal Research are very prestigious, recognizing student research on the musculoskeletal system. These awards have indeed attained their goal of stimulating such research and have produced many fine projects over the years.

Charles R. Clark, M.D.
Michael Bonfiglio Professor of Orthopaedic Surgery
From left to right: Charles Clark, M.D., Michael Bonfiglio Professor of Orthopaedic Surgery; Jose Morcuende, M.D., Ph.D., advisor to William Shyy; William Shyy, M1, winner of the Iowa Orthopaedic Society Medical Student Research Award for Musculoskeletal Research; Roberto Diaz, M4, winner of the Michael Bonfiglio Award for Student Research in Orthopaedic Surgery; John Albright, M.D., advisor to Roberto Diaz; and Department Chair, Joseph A. Buckwalter, M.D.
ACCESSORY ANTEROLATERAL TALAR FACET AS AN ETIOLOGY OF PAINFUL TALOCALCANEAL IMPINGEMENT IN THE RIGID FLATFOOT: A NEW DIAGNOSIS

Jeffrey E. Martus, M.D.; John E. Femino, M.D.; Michelle S. Caird, M.D.; Lawrence R. Kuhns, M.D.; Clifford L. Craig, M.D.; Frances A. Farley, M.D.

ABSTRACT

A retrospective review identified six patients with seven painful rigid flatfeet. In each case, pain was localized laterally to an accessory facet of the anterolateral talus. Cross-sectional imaging demonstrated no evidence of tarsal coalition. In five of the six, preoperative magnetic resonance imaging (MRI) was obtained and in each case demonstrated focal abutting bone marrow edema consistent with impingement between the accessory facet and the anterior calcaneus.

Seven feet in six patients underwent resection of the accessory facet with additional subtalar joint-sparing reconstructive procedures. At an average follow-up of 11 months, clinical results were graded as four good and two fair.

An association between this accessory facet and pain in the rigid flatfoot has not been previously reported. Obesity was universal and may represent a risk factor for facet impingement. At early follow-up, facet resection with subtalar joint-sparing flatfoot reconstruction provided good results with symptomatic and functional improvement in the majority of patients.

INTRODUCTION

Primary flatfoot deformity is a common source of referral in orthopaedic surgery. The distinction between the flexible and rigid flatfoot is important for diagnosis and treatment. The painful, rigid flatfoot requires further investigation. A rigid flatfoot is distinguished from the flexible variety by physical exam. Subtalar motion is restricted and attempted motion may be painful. Peroneal spasm or contracture may be evident with attempted passive inversion. The toe-rise test is performed with difficulty and the longitudinal arch does not reform. Medial midfoot callosities may be present due to prominence of the talar head or navicular.

Radiographs and computed tomography (CT) with coronal and sagittal reconstructions are useful to identify tarsal coalitions, the most common etiology of the rigid flatfoot in adolescents and young adults. Computed tomography or magnetic resonance imaging may assist in detecting incomplete coalitions (cartilaginous or fibrous). Other established etiologies of the rigid flatfoot include infectious, inflammatory, or degenerative arthritides, neoplastic or neurologic processes, and osteochondral fractures. Laboratory studies or radioscintigraphy may help in making diagnoses such as osteoid osteoma or inflammatory arthritides.

Most patients with a symptomatic, rigid flatfoot will have an identifiable causation. However, there are several reports of idiopathic rigid flatfoot in the literature. These authors have reported that the idiopathic rigid flatfoot is difficult to treat and is often recalcitrant to conservative and operative measures. We present a retrospective review of patients with rigid flatfoot deformity treated operatively for painful talocalcaneal impingement associated with an accessory facet of the anterolateral talus. The clinical presentation, radiographic studies, and treatment course in this population are reviewed. Our hypothesis was that accessory facet resection combined with subtalar joint-sparing reconstructive procedures for residual deformity would provide improvement in symptoms.

MATERIALS AND METHODS

All patients treated operatively by a single surgeon (JEF) from 2000 to 2005 for primary rigid flatfoot in association with an accessory anterolateral talar facet were retrospectively reviewed. This study was conducted with Institutional Review Board approval. Hospital charts and imaging studies were reviewed for each patient. Inclusion criteria included pediatric patients with a history of hindfoot pain and primary flatfoot deformity; physical examination demonstrating painful rigid flatfoot deformity; lateral hindfoot pain upon attempted passive hindfoot eversion, and tenderness in the sinus tarsi; and radiographic studies demonstrating the absence of tarsal coalition and the presence of an accessory anterolateral talar facet. Exclusion criteria included age greater than 18 years at presentation (two patients), nonoperative
management (three patients), an accessory facet associated with tarsal coalition (four patients), or an accessory facet associated with subtalar arthrosis (two patients). Data collected included age, symptom duration, radiographic findings, treatment method, and response at most recent follow-up. Outcomes were graded by the seven-point postoperative outcome score described by Comfort and Johnson in their report of the results of talocalcaneal coalition resection. This outcome measure grades postoperative pain, function, and subtalar motion describing the clinical result as excellent, good, fair, or poor (Table 1).

The diagnostic evaluation included physical examination, standing radiographs, and cross-sectional imaging (CT and/or MR). Most patients were referred after having been treated with multiple non-operative interventions by another physician. Initial management included physical therapy, a trial of immobilization, orthotics, and non-steroidal anti-inflammatory medications. Surgical intervention was offered when pain persisted despite non-operative treatment. Maximal pain was localized to the sinus tarsi in all patients. The principle of preserving the subtalar joint and avoiding subtalar arthrodesis guided operative treatment. Talocalcaneal impingement was treated with resection of the accessory anterolateral talar facet; residual deformity, in these rigid flat feet, was addressed with subtalar joint-sparing flatfoot reconstruction. Deformity correction was approached stepwise, e.g., adding additional procedures as required for residual deformity: Gastrocnemius recession first; peroneal lengthening second. After gastrocnemius recession and peroneal lengthening, all subtalar joints became mobile intra-operatively. If necessary, medial displacement calcaneal osteotomy for hindfoot valgus and/or lateral column lengthening for forefoot abduction were then performed.

### OPERATIVE TECHNIQUE

The operative technique of resecting the accessory anterolateral talar facet was performed through a longitudinal incision centered over the sinus tarsi. This incision was made from the posterior tip of the fibula and directed distally toward the base of the fourth metatarsal. The incision was extended proximally along the

<table>
<thead>
<tr>
<th>Points</th>
<th>Pain</th>
<th>Function</th>
<th>Subtalar Motion</th>
<th>Outcome Score (Rating)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>None</td>
<td>Unlimited activity</td>
<td>-</td>
<td>7 (Excellent)</td>
</tr>
<tr>
<td>2</td>
<td>Slight (with sports/running)</td>
<td>Limited sports/running</td>
<td>-</td>
<td>5-6 points (Good)</td>
</tr>
<tr>
<td>1</td>
<td>Moderate (walking, ADL,* light activity)</td>
<td>Walking, ADL,* light activity</td>
<td>Present</td>
<td>3-4 points (Fair)</td>
</tr>
<tr>
<td>0</td>
<td>Severe (no relief, same as preoperative)</td>
<td>No improvement over preoperative</td>
<td>None</td>
<td>0-2 points (Poor)</td>
</tr>
</tbody>
</table>

(*ADL - activities of daily living)

Figure 1. Intraoperative photos of a 16-year-old patient. (F - accessory anterolateral talar facet, ATFL – anterior talofibular ligament, P – peroneal tendons, DF – distal fibula, CN – calcaneal neck)
Accessory Anterolateral Talar Facet as an Etiology of Painful Talocalcaneal Impingement in the Rigid Flatfoot

The incision was deepened dorsal to the peroneal tendons below the fibula and in each case a bony protrusion with a cartilaginous cap was found filling the sinus tarsi. This originated from the lateral talo-fibular ligament (ATFL) and extended distally, abutting the calcaneus. This accessory anterolateral talus facet was resected in a semi-coronal plane with an osteotome, perpendicular to the posterior facet articular surface and flush with the insertion of the anterior talofibular ligament on the lateral process of the talus. The resulting cancellous surface was rasped smooth and impregnated with bone wax (Figure 1). In patients with contractures, a gastrocnemius recession and/or peroneal Z-lengthening above the superior peroneal retinaculum was performed. Remaining planovalgus deformity was corrected with a medial displacement calcaneus osteotomy and/or lateral column lengthening with calcaneocuboid distraction arthrodesis (Figure 2).

The series consisted of six patients (seven feet) with painful rigid flatfoot, an accessory facet, and no tarsal coalition by CT and/or MR imaging (idiopathic rigid flatfoot). Accessory facets were present bilaterally in all four of the patients with bilateral imaging studies; the facet was symptomatic bilaterally in two of these four patients. The average age at presentation was 15.0 years (range 13-17 years) with average symptom duration of 1.8 years prior to presentation. All six patients were male. The average body mass index (BMI) was 34.6 (range 29.8–44.5) (Table 2).

RESULTS

All patients were evaluated with radiographs and cross-sectional imaging (CT and/or MR). The lateral radiograph often suggested an accessory anterolateral talus facet with broadening of the antero-inferior lateral talar process; sometimes the facet was difficult to appreciate on plain radiographs due to the semi-coronal plane of the lateral talar process and associated hindfoot deformity (Figure 3a). Associated dorsal talar beaking was observed in four of the six patients. CT multiplanar reformats assisted in defining the accessory facet (Figure 3b). In five of the six patients, MR imaging was obtained and demonstrated abutting bone marrow edema between the talus and calcaneus, on sagittal fat-saturated T2-weighted images, in all five cases (Figure 4). This was localized to the accessory anterolateral talar facet and the adjacent calcaneus anterior to the posterior facet. This edema was interpreted as consistent with talocalcaneal impingement. Intraoperatively, the accessory facet was noted to have a hyaline cartilage surface, often with mild degenerative changes. Synovitis was also present within the sinus tarsi. Histologic evaluation demonstrated

<table>
<thead>
<tr>
<th>Case</th>
<th>Age at Presentation (years)</th>
<th>Symptom Duration (years)</th>
<th>Body Mass Index</th>
<th>Gender</th>
<th>Symptomatic Accessory Facet</th>
<th>Bilateral Accessory</th>
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<tbody>
<tr>
<td>1</td>
<td>13.3</td>
<td>1.0</td>
<td>29.9</td>
<td>M</td>
<td>Right</td>
<td>Yes</td>
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<tr>
<td>2</td>
<td>14.3</td>
<td>0.8</td>
<td>44.5</td>
<td>M</td>
<td>Bilateral</td>
<td>Yes</td>
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<tr>
<td>3</td>
<td>16.7</td>
<td>3.6</td>
<td>40.9</td>
<td>M</td>
<td>Left</td>
<td>Unknown</td>
</tr>
<tr>
<td>4</td>
<td>14.5</td>
<td>0.7</td>
<td>30.5</td>
<td>M</td>
<td>Bilateral</td>
<td>Yes</td>
</tr>
<tr>
<td>5</td>
<td>17.4</td>
<td>3.6</td>
<td>29.8</td>
<td>M</td>
<td>Left</td>
<td>Unknown</td>
</tr>
<tr>
<td>6</td>
<td>13.9</td>
<td>1.2</td>
<td>31.9</td>
<td>M</td>
<td>Right</td>
<td>Yes</td>
</tr>
</tbody>
</table>
that within the resected facet, there were regions of normal hyaline cartilage intermixed with areas of thin, fissured cartilage, early fibrocartilaginous changes, and thickened subchondral bone with microscopic cyst formation (Figure 5). Continuity between the articular surface of the posterior facet of the talus and the accessory facet was noted both on MR and clinically at the time of surgery. No tarsal coalitions (osseous or fibrous) were observed.

All six patients underwent resection of the accessory facet; one bilaterally. One was treated with isolated facet resection; one with unilateral facet resection and peroneal lengthening; one with bilateral facet resection, gastrocnemius recession, and peroneal lengthening; and three with unilateral facet resection, gastrocnemius recession, peroneal lengthening, calcaneal osteotomy, and lateral column lengthening (Table 3).

<table>
<thead>
<tr>
<th>Case</th>
<th>Symptomatic Accessory Facet</th>
<th>Accessory Facet Resection</th>
<th>Additional Procedures</th>
<th>Postoperative Follow-up</th>
<th>Outcome Score (Rating)</th>
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<tr>
<td>1</td>
<td>Right</td>
<td>Right</td>
<td>1.2.3.4</td>
<td>12 months</td>
<td>3 (Fair)</td>
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<tr>
<td>2</td>
<td>Bilateral</td>
<td>Bilateral</td>
<td>1.2</td>
<td>28 months</td>
<td>4 (Fair)</td>
</tr>
<tr>
<td>3</td>
<td>Left</td>
<td>Left</td>
<td>None</td>
<td>8 months</td>
<td>5 (Good)</td>
</tr>
<tr>
<td>4</td>
<td>Bilateral</td>
<td>Left</td>
<td>1.2.3.4</td>
<td>4 months</td>
<td>5 (Good)</td>
</tr>
<tr>
<td>5</td>
<td>Left</td>
<td>Left</td>
<td>1.2.3.4</td>
<td>5 months</td>
<td>5 (Good)</td>
</tr>
<tr>
<td>6</td>
<td>Right</td>
<td>Right</td>
<td>2</td>
<td>9 months</td>
<td>6 (Good)</td>
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</tbody>
</table>

Figure 3. Clinical example. Figure 3a. (left) Lateral radiograph of accessory anterolateral talar facet (F – accessory facet, B – dorsal talar beak). Figure 3b. (right) CT scan (F – accessory facet, B – dorsal talar beak).

Figure 4. MR imaging demonstrating abutting bone marrow edema between the accessory facet (F) and the calcaneal neck (N).

Figure 5. Histologic evaluation of excised accessory facet with hematoxylin and eosin (A – normal hyaline cartilage, B – early fibrocartilaginous change, C – thin, fissured cartilage, D – thickened subchondral bone with cysts).

**TABLE 3. Treatment Methods and Outcomes**
Outcomes were graded with the seven-point scoring system as described by Comfort and Johnson. There were no excellent results (outcome score of seven). Four patients had a good result (score of five to six) and two had a fair result (with a score of three to four). The fair results occurred in the two patients with the longest clinical follow-up (12 and 28 months). There were no poor results. The average pain and function scores were 2.2 and 1.7, respectively. Five of the six patients had subtalar motion postoperatively that was not present preoperatively. There were no complications in this series. The average postoperative follow-up was 11 months (range 4 months to 28 months); one patient was lost to follow-up (Table 3).

**DISCUSSION**

The association between the accessory anterolateral talar facet and symptomatic rigid flatfoot has not been previously reported. This anatomic variant represents a new etiology for painful talocalcaneal impingement in the rigid flatfoot. Cross-sectional imaging is useful for identifying the anomaly, and MRI can demonstrate evidence of impingement with localized bone marrow edema. In our patients with an isolated accessory facet, facet resection with subtalar-sparing flatfoot reconstruction provided good results with early pain relief and a return to function in four of six patients.

The stiff, painful flatfoot was first described as the “peroneal spastic” flatfoot by Sir Robert Jones in 1897. The “spastic” flatfoot does not require a constant state of peroneal contraction, although active spasm may be produced by irritation of the painful hindfoot with motion and weight bearing. Chronic subtalar eversion may result in adaptive shortening of the peroneal musculature. The term “rigid flatfoot” is now preferred for description of the foot with limited subtalar motion and planus deformity. The link between structural anomalies of the tarsus and rigid flatfoot was established by Slomann in 1921, Badgley in 1927, and Harris and Beath in 1948. In a study of 3600 Canadian Army recruits, Harris and Beath found a 2% incidence of spastic (rigid) flatfoot and a 6% incidence of flexible flatfoot. Tarsal coalitions were the underlying etiology in 88% of the rigid deformities; two-thirds of the coalitions were talocalcaneal and one-fifth were calcaneonavicular.

Radiographic features classically associated with tarsal coalition include dorsal beaking of the talonavicular joint and subsequent gradual osseification of the elevated talar neck periosteum. Molding of the talar head by the navicular as a result of the increased talonavicular motion has also been suggested as a mechanism. Cowell stated that the broadening of the lateral talar process in the patient with tarsal coalition was a secondary finding resulting from impingement of the lateral process of the talus upon the sulcus calcaneus as the calcaneus is forced into valgus.

Patients with painful rigid flatfoot in the absence of tarsal coalition or systemic abnormality have been described by multiple authors. These reports suggest that the idiopathic rigid flatfoot is difficult to manage and treatment options are limited when standard conservative measures fail to provide relief. In 1961, Braddock reported on 28 patients with 43 symptomatic peroneal spastic flatfeet, evaluated with anteroposterior, lateral, oblique, and Harris-Beath radiographs. In this series there were 27 feet with “normal” radiographs (anteroposterior, oblique, lateral and axial; however no cross-sectional imaging), although “slight beaking” of the talus was included in the normal group. Patients were treated with manipulation under anesthesia, a walking cast, and/or an iron with T-strap. Interestingly, the “normal”-radiograph group (without coalition) had greater initial pain and disability than patients with positive radiographs (coalition), and 4 of the 27 normal feet had long-term subtalar rigidity. In 1974, Rankin presented a series of 24 military recruits with rigid flatfoot evaluated with plain radiographs only. Seven of the 24 patients were without tarsal coalition. In all patients, symptoms subsided upon withdrawal from basic training; although the patients were followed for an average of only one month after the diagnosis of rigid flatfoot.

Luhmann reported a series of 13 idiopathic rigid flatfeet in nine patients. Two of the 13 feet had dorsal talar beaking, and tarsal coalition was not identified by CT or MR in any of the 13 feet. Our review of the radiographs and CT images from Luhmann’s publication suggests that some of these patients had accessory facets. All patients underwent examination under anesthesia with subtalar injection (methylprednisolone and/or bupivacaine). Improved motion was noted intraoperatively in nine feet; the remaining four feet were treated with fractional peroneal lengthenings. All patients were casted in maximal inversion for three weeks. Outcomes at an average 18-month follow-up demonstrated five feet with sustained pain relief and eight feet with persistent pain. There was no correlation of the clinical results with the treatment method. Luhmann theorized that the rigid flatfoot in their series was a progression from the flexible flatfoot of childhood to a rigid planovalgus deformity.
secondary to obesity. All of the patients in the series were greater than the 75th percentile of weight for age, and seven of the nine patients had weights greater than the 95th percentile. The six patients in our series with idiopathic rigid flatfoot who required accessory facet resection had an average body mass index (BMI) of 34.6 (normal range is 18.5-25). Four patients had a BMI less than 32, but two of the six had a BMI greater than 40 which is defined as “extreme obesity”. Luhmann also implicated “malicious malalignment” (combined femoral retroversion and external tibial torsion) as an etiologic factor where increased foot progression angle leads to a “medial rollover” gait with minimal passive ankle dorsiflexion and eventual equinovalgus contracture.

The anatomy of the talocalcaneal articulation has been studied and significant anatomic variation exists. The accessory facet of the anterolateral talus was first described by Sewell, in a 1904 study of 1006 Egyptian tali. He characterized a number of variants of talar anatomy, including the accessory anterolateral talar facet which he termed \textit{facies externa accessoria corporis talus}. He found this to be present in 10.2% of the tali examined. Figure 6 is a diagram from Sewell’s original paper demonstrating the accessory facet originating from the anterior aspect of the lateral talar process inferior to the anterior talo-fibular ligament. The diagram also suggests continuity of the accessory facet with the posterior facet articular surface, which is a feature we noted in all of our cases. Interestingly, the specimen depicted in this diagram also has a dorsal talar beak (Figure 6). Through an osteologic study of 100 tali, Sarrafian identified large accessory talocalcaneal facets in 4% and small, variable-sized facets in 34%.22

The biomechanics of the subtalar joint may explain the development of symptomatic impingement between the accessory anterolateral talar facet and the anterior process of the calcaneus. At foot strike, the subtalar joint is partially everted, which is maximized by the point of flatfoot. In this portion of gait, the subtalar joint externally rotates approximately six degrees in the normal foot and 12 degrees in the flatfoot due to the greater horizontal inclination of the subtalar joint in the flatfoot. Mosca described that the flatfoot deformity has excessive subtalar eversion with altered relationships of the calcaneus, talus, and navicular. The increased subtalar eversion characteristic of flatfoot deformity permits impingement of the accessory facet on the anterior process of the calcaneus and subsequent facet degeneration. A study of CT scans in a group of adult patients with acquired symptomatic flat feet found evidence of talocalcaneal impingement in the sinus tarsi in 92% of 76 scans, and none in a control group of 20 normal feet. The bony changes noted by the authors included direct bone abutment between the talus and calcaneus with sclerosis and cystic changes in the sinus tarsi. They did not note any cases with an abnormal prominence of the anterolateral talus or a cartilaginous cap. This suggests that there are two etiologies of talocalcaneal impingement: a primary impingement caused by the presence of an accessory facet in a pediatric or young adult rigid flatfoot deformity, and a secondary impingement due to acquired subtalar joint subluxation seen with advanced acquired adult flatfoot deformity. It seems likely that the onset of symptoms in the patients in the present series is related to increasing body mass with growth, flatfoot deformity, and subsequent accessory facet impingement due to increasing subtalar joint eversion.

In a study reviewing the detection of tarsal coalitions with CT and MRI, Newman described the association between coalitions and bone marrow edema at the margins of the abnormal joints. A similar finding was present in these patients with accessory anterolateral talar facets, with focal abutting bone marrow edema at the articulation between the accessory facet and the anterior process of the calcaneus. This sign was consistently present on MR imaging and correlated with intraoperative demonstration of accessory facet impingement with associated local synovitis. The histologic evaluation of an excised accessory facet from a patient in this series was consistent with impingement and consequent early degeneration of the hyaline cartilage of the facet (Figure 5).

Four patients with an accessory anterolateral talar facet and tarsal coalitions (three talocalcaneal and one calcaneonavicular) were excluded from the present series. These four patients presented with pain localized to the region of the accessory anterolateral talar facet, not the coalition. Direct palpation of the sinus
Luhmann, there may be an association between obesity and the anterior process of the calcaneus. As suggested by facet and MR imaging demonstrated abutting edema and the location of maximal pain (sinus tarsi) as indicated by Radiographs and CT imaging delineated the accessory patients with rigid flatfeet in which an accessory anterolateral talar facet was identified, and corresponded to the location of maximal pain (sinus tarsi with talocalcaneal impingement or is retrofibular due to peroneal spasm. The presence of lateral hindfoot pain with a medial subtalar coalition may be an indication of lateral impingement, and the possibility of an accessory facet. The authors have presented a retrospective series of patients with rigid flatfeet in which an accessory anterolateral talar facet was identified, and corresponded to the location of maximal pain (sinus tarsi) as indicated by patient history and confirmed by physical examination. Radiographs and CT imaging delineated the accessory facet and MR imaging demonstrated abutting edema adjacent to the articulation between the accessory facet and the anterior process of the calcaneus. As suggested by Luhmann, there may be an association between obesity and the painful idiopathic rigid flatfoot. Our series indicates that obesity may be associated with rigid flatfoot deformity with symptomatic talocalcaneal impingement from the accessory anterolateral talar facet. Our experience with the accessory anterolateral talar facet has led to the development of a stepwise subtalar-sparing operative strategy. Although this is a small series, we have been encouraged by our early clinical results with resection of the accessory facet in the absence of radiographic subtalar arthrosis or an associated coalition. Patients with a persistently painful rigid flatfoot have been treated with subtalar or triple arthrodesis in the past. Saltzman has demonstrated universal radiographic tibiotalar degeneration in patients treated with a triple arthrodesis at long-term follow-up. We believe that the loss of subtalar or hindfoot motion at an early age will eventually lead to symptomatic degenerative arthritis of the ankle in adulthood in many patients. In our patients with flatfoot deformity, resection of the accessory facet and subtalar joint-sparing flatfoot reconstruction improved symptoms and allowed for realignment of the hindfoot.

Further study of the association between rigid flatfoot and the accessory anterolateral talar facet is needed, particularly by longer-term follow-up of our patients. Prospective studies to define the natural history of this anatomic variant and the associated pathologies, such as peroneal spasm or contracture, will improve our understanding of this clinical problem.

REFERENCES


A METHOD FOR THE ESTIMATION OF NORMATIVE BONE SURFACE AREA TO AID IN OBJECTIVE CT-BASED FRACTURE SEVERITY ASSESSMENT

Thaddeus P. Thomas, M.S. 1,2; Donald D. Anderson, Ph.D.1,2; J. Lawrence Marsh, M.D. 2; and Thomas D. Brown, Ph.D.1,2

ABSTRACT
The reliable assessment of fracture severity plays a critical part in treatment, providing essential information to guide clinical decision-making. However, current classification schemes such as the AO/OTA are constrained by limitations intrinsic to subjective categorical systems. A recently developed objective CT-based assessment methodology quantifies fracture severity by calculating the mechanical energy expended during bony fragmentation. Specifically, fracture energy is determined by comparing the bone free surface area in the fractured limb to that in the intact contralateral limb. Unfortunately, the contralateral limb is not routinely scanned in the course of fracture assessment. Consequently, fracture energy can not be obtained, since there is no datum against which to compare the fractured limb. To facilitate the application of this novel technique to large multicenter and retrospective studies where the intact contralateral CT scan is unavailable, this study aimed to establish a normative, anthropometrically scaled intact bone model to be used as a substitute datum. A mathematical model that estimated free bone surface area along the intact contralateral limb was regressed from a study group of 22 tibial plafond fracture patients. The regressed tibia model provided suitably accurate estimates of the directly measured intact surfaces areas (average error of 15%). The differences between regressed and actual bone surface areas did not ultimately affect the stratification of fracture severity, as fracture energy measures using the regressed model maintained a 0.90 concordance with the original analysis. The results from this study suggest that normative bone surface area can be incorporated into the novel CT-based objective fracture severity assessment technique.

INTRODUCTION
Severe trauma to weight-bearing joints is often followed by eventual joint degeneration and the development of post-traumatic osteoarthritis (PTOA). The resultant chronic pain and decreased joint function impose a severe burden, not only to the patients, but to the US economy as well, costing $12 billion annually.1,2 The pathomechanical determinants that govern the progression of this disease are poorly understood, in part due to the multi-factorial etiology of this disease.

Although factors such as joint instability and residual incongruity have been shown to correlate with degeneration, clinical evidence suggests that the acute injury severity plays a dominant pathologic role. Unfortunately, the fracture severity assessment schemes currently used in clinical care fail to provide the information necessary to make this linkage objectively. Classifications such as the AO/OTA and other categorical schemes are able to reliably group fractures with broadly similar characteristics, but they are unable to formally and reproducibly quantify fracture severity per se.3

The reliable assessment of fracture severity plays an integral part in clinical decision-making, so improved assessment practices have broad implications for immediate treatment as well as long-term outcome of intra-articular fractures. Until recently, there has been no practical way to objectively measure comminution and fracture severity, which has limited compilation of a suitable body of collective experience to guide care of these patients. A new CT-based methodology was recently developed to objectively quantify fracture severity, working from the principle that mechanical energy is necessarily expended to create new free surface area in a brittle solid. The amount of energy thus expended is proportional to the amount of de novo interfragmentary surface area (Figure 1).
This new objective fracture severity metric has been shown to agree with experienced orthopaedic traumatologists' subjective opinions of injury severity, drawn from standard-of-care plain radiographs. The objective metric has also been shown to correlate better with the incidence of PTOA in tibial plafond fracture patients than does clinician opinion ($R^2 = 0.73$ vs. 0.47, respectively). However, since pre-existing and de novo surfaces are both present in fracture fragments, contralateral limb scans have been required to provide datum bone surface areas over a comparable distal segment of the patient's tibia. With this information in hand, the pre-existing datum bone surface area could be subtracted from the full fractured bone surface area, to yield de novo interfragmentary surface area (i.e., the area colored red in Figure 1c).

While feasible in an academic medical center research setting, availability of a contralateral limb scan is problematic in broader orthopaedic practice. Since CT scans of the intact contralateral limb are not routinely obtained during fracture evaluation, this novel energy-based severity assessment methodology can only be used in a limited number of patients. This impedes large multicenter and retrospective studies that could provide high statistical power for establishing the relative efficacy of alternative treatment regimes for these difficult injuries. Toward overcoming this difficulty, a study was designed using CT scan data collected previously from twenty-two different intact tibias. The study aimed to establish a normative anthropometric intact distal tibia model, from which to derive tare bone surface areas, for fracture cases where an intact contralateral CT scan is unavailable. It was hypothesized that an allometrically scaled tibia model would serve as a surrogate datum capable of accurately measuring interfragmentary surface area.

**METHODS**

Routine CT studies were obtained retrospectively from the clinical care of twenty-two tibial plafond fractures. The cases chosen represented the spectrum of injury, from simple partial articular fractures to severely comminuted fractures involving the entire tibial plafond (Figure 2). Informed consent was obtained from each patient, under institutional review board approval. Contralateral scans of the unaffected limb provided the anatomy of intact distal tibias, over varying lengths chosen to correspond with the fracture zones. The establishment of an anthropometric distal tibia model required that bone free surface area measurements be made from corresponding locations along the tibia. Subject stature (height) is the dominant factor correlated with limb length. Published allometric scaling data were used to estimate the total tibial length, which allowed normalization of surface area measurements based upon subject height.

A semi-automated edge detection algorithm (coded within MATLAB software) had previously been developed to identify periosteal and endosteal bone surfaces (Figure 1a). In this algorithm, the corresponding bone free surface areas were calculated along the distal tibia at specific increments, according to patient-specific CT scan settings (Figure 1b). Cumulative areas were reported by summing the surface areas over the imaged portion of the tibia. A dataset containing a range of tibial lengths and their corresponding cumulative areas was assembled from these twenty-two studies. Distal tibial lengths were then normalized to an overall stature-regressed tibial length to regress height-dependent variation in bone lengths within this cohort.

The patients’ predicted tibial lengths ($l$) were calculated as a function of their height ($h$) using the anthropometric equation, $l = 0.246h$. In addition to length normalization, the edge-detected cumulative surface area measurements were scaled by a patient height-dependent function. This function was determined by maximizing the correlation coefficient of a second order polynomial relating the scaled surface area measurements to normalized spatial locations within the tibia. The resultant polynomial yielded an equation predictive of the tibia’s total free surface area, based upon relative tibial lengths measured proximally from the base of the medial malleolus.

The regression model's capability to predict datum surface area was subsequently investigated, by comparing model-estimated measurements of surface area to the original CT-based measurements. The datum cumulative free bone surface area for the imaged portion of each patient's intact contralateral distal tibia was predicted and compared to the directly measured total cumulative.
mild – fracture severity spectrum – moderate high

areas over that same range. Since the fractured scans extended less proximally than their intact contralaters, errors in interfragmentary surface area calculations were not linearly proportional to the differences found between modeled and directly measured contralateral datum surface areas. Therefore, interfragmentary surface areas based upon actual versus regressed surfaces areas were also compared. The concordance between rankings of interfragmentary area derived from the actual (contralateral limb-measured) versus normatively regressed datum surface areas was evaluated to further establish the model’s accuracy.

RESULTS

There was large variability as to the proximal extent of CT scans obtained for the intact distal tibias, where the extent of scanned segments ranged from 4.2 to 15.4 (8.5 ± 3.7) cm proximal from the base of the medial malleolus. This was because CT scans were typically obtained over only the portion of each intact tibia corresponding to the fracture zone in the injured contralateral tibia. The patients included in this study ranged in height from 160 to 190 cm (175 ± 9.3). The observed relationship between intact contralateral tibia segment length (\(h\)) and datum cumulative bone free surface area (\(SA\)) was reasonably well fit by a second-order polynomial. The optimal cumulative surface area scaling function was determined to be the square of the patient’s height, \(h^2\), from correlation maximization (Figure 3).

\[
\frac{SA}{h^2} = -1.47 \left(\frac{x}{h}\right)^2 + 3.24 \left(\frac{x}{h}\right) - 0.003 ; \quad (R^2 = 0.098) \quad [1]
\]

Re-arrangement of equation [1] enables calculation of the cumulative surface area, given simply a patient’s height (\(h\)) and the physical distance of interest along the tibia (\(x\)):

\[
SA = -24.3x^2 + 13.17xh - 0.003h^2 \quad [2]
\]
The anthropometric distal tibia model provided suitably accurate estimates of the directly measured intact surfaces areas (average error of 15%). From linear regression, the slope relating actual to modeled intact surface areas was approximately 0.75 (Figure 4a). The difference between actual and modeled intact data correspondingly changed the absolute interfragmentary surface area magnitudes (Figure 4b). However, when the actual rank ordering of fracture severity was considered, rather than just magnitude, measurements based on predicted intact area agreed very well with the original results (concordance = 90%).

**DISCUSSION**

Methods to facilitate objective assessment of fracture severity in large series of cases would provide unifying information helpful to systematically improve the treatment of these complex injuries. Presently, treatment decision-making depends largely on subjective visual assessment, which has questionable reliability and documented poor inter-observer agreement. The results from this study show that reasonably accurate, objective fracture severity metrics can be obtained in distal tibia fracture cases for which an intact contralateral CT scan is not available, through use of allometrically scaled normative surface area.

Using patient height as the sole scaling parameter, the allometric model was able to predict cumulative intact surface areas with reasonable accuracy. Differences between the modeled and actual data were inevitable, since height is only a partial predictor for total tibial length, and given that distal tibia datum bone surface area is somewhat variable. The model’s performance could likely be improved by including additional shape parameters and/or actual tibial lengths. Future models might draw from nearby unaffected anatomic structures such as the talus to provide that additional scaling information, however, an attraction of the present approach is that only patient height is required in order to formulate the model. And, results from the present study suggest that acquiring such additional information may add unnecessary complexity, since the current model reproduces fracture energy assessments with a 90% concordance.

The tibial plafond fracture is useful as an intra-articular model for investigating PTOA, since the ankle rarely degenerates in the absence of trauma. However, the ankle is by no means the only joint subject to the limitations of subjective injury severity assessments. Since side-to-side symmetry exists between contralateral limbs, this technique is equally well suited for other joint injuries, such as the much more frequently occurring tibial plateau fracture. Not only does this modified technique support other injuries, but avoidance of the need for an intact contralateral scan enables the analysis of patients with concomitant injuries or contralateral deformities. Patients with bilateral fractures or with developmental abnormalities are not compatible with a methodology
that relies on a healthy contralateral for reference measurements, whereas fracture severity measures using allometric models are free from such limitations.

In addition to being a valuable clinical tool for assessing trauma, this technique could help answer other interesting research questions. For some applications such as correlating cell death to impact energy, parity of fracture energy magnitudes is critical for acquiring meaningful data. In these instances, an allometric methodology may not be appropriate due to errors introduced by anatomic variation. However, absolute magnitude becomes less important for this methodology’s principal purpose, the stratification of an injury within a spectrum of fracture severity. For such purpose, it suffices to reproduce the relative energy magnitudes, so that the ordering of severities is not disturbed. The results from the present study show a level of accuracy in predicting the distal tibia’s cumulative surface area that is very satisfactory for incorporation into the objective CT-based injury severity methodology.

CONCLUSION

It has been shown that a distal tibia’s cumulative surface area can be accurately modeled using a second order polynomial, for a diverse group of ankle fractures. The developed mathematical model based upon this finding not only aids research of OA treatment in the clinical setting, but it also opens new research possibilities pertaining to related anatomic pathologies of the distal tibia.

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TIBIAL FRACTURE DECREASES OXYGEN LEVELS AT THE SITE OF INJURY

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ABSTRACT

Objectives: Oxygen is an essential component for many aspects of tissue repair. However, the effect of oxygen levels on differentiation of stem cells into osteoblasts and chondrocytes during fracture healing is unknown, in part because of the difficulty in measuring oxygen during fracture healing. In this study we tested the feasibility of using electron paramagnetic resonance (EPR) oximetry to assess tissue oxygen partial pressure (pO2) after tibial fractures in mice.

Methods: Transverse tibia fractures were created by three-point bending in adult mice. Paramagnetic material, lithium phthalocyanine (LiPc), was implanted into the fracture site or adjacent to the periosteum in the contralateral leg immediately after fracture. Tissue pO2 was assessed by EPR 90-110 minutes after implantation of the crystals. In a second experiment, LiPc was implanted into the fracture site and fracture repair and the biocompatibility of LiPc were assessed at 14 and 28 days after injury.

Results: At the very early stage after fracture, injury significantly decreased tissue oxygenation at the fracture site. When animals were breathing 21% oxygen, pO2 at the fracture site (30.6 ± 12.7 mmHg, n=7) was lower than that in contralateral legs (45.5 ± 15.3 mmHg, n=7, p<0.01). Breathing 100% inspired oxygen increased the pO2 in both the fractured (72.8 ± 28.2 mmHg; n=7) and contralateral legs (148.4 ± 59.2 mmHg; n=7, p<0.01). In addition, LiPc crystals implanted into fracture sites did not interfere with normal fracture healing at 10 and 28 days post-injury.

Conclusions: EPR oximetry is a valuable tool for monitoring oxygen levels during fracture repair in mice.

INTRODUCTION

Fractures are usually accompanied by local tissue hypoxia due to the disruption of vasculature. Oxygen levels at fracture sites are initially very low, and they gradually increase as re-vascularization occurs. During wound repair, oxygen is required for cell survival, collagen and extracellular matrix deposition, angiogenesis, epithelialization, and production of the oxidative burst used for intracellular bacterial killing. However, the role of oxygen in fracture healing has not been extensively studied. Previous studies have shown that chronic systemic hypoxia inhibits and oxygen supplementation enhances bone repair. These studies suggest that oxygen is important for fracture healing. Therefore studying the role of oxygen during bone repair could greatly increase our understanding of mechanisms that regulate skeletal regeneration.

In order to examine the role of oxygen during fracture healing in detail a reliable method of measuring tissue oxygen levels in vivo is required. Oxygen-sensing electrodes are widely used to measure tissue PO2 directly. However, this technique has several disadvantages when it is used to measure oxygenation at fracture sites. First, inserting an electrode into tissue is invasive and affects O2 measurement immediately after injury. Second, microelectrodes are fragile and may be damaged during insertion into the fracture callus. Last, measuring tissue O2 repeatedly at the same location in the same animal is not possible. An alternate approach of measuring oxygen concentration in vivo utilizes spectroscopic relaxation methods (reviewed by Vanderkooi et al.). Oxygen affects the relaxation times of excited species such as luminescent or magnetic probes. These relaxation times can be measured optically or magnetically and used to determine pO2 directly. Among all spectroscopic relaxation methods, electron paramagnetic resonance (EPR) is a particularly promising method to use for studying tissue oxygenation in murine fracture models. In vivo EPR oximetry is non-invasive after the initial implantation of the oxygen-sensitive paramagnetic probe.
into the tissue of interest. \textsuperscript{16,17,18} This procedure causes only minimal injury as materials such as lithium phthalocyanine (LiPc) can be placed with a 25-gauge needle, and the amount deposited is less than 50 micrograms. Furthermore, these paramagnetic probes are biocompatible and induce minimal or no tissue reaction.\textsuperscript{18} In the brain, repetitive and reproducible measurements of pO\textsubscript{2} using EPR have been achieved for more than 30 days.\textsuperscript{18} Importantly, the location of paramagnetic material in the tissue can be determined on histological sections, allowing the exact site of pO\textsubscript{2} measurement to be determined. In this study, we tested the feasibility of using EPR oximetry to assess tissue oxygenation at the fracture site in mice.

\section*{Materials and Methods}
Animals and creation of tibia fractures

All procedures in this work were approved by IACUC (Institutional Animal Care and Use Committee) at Dartmouth Medical School, Hanover, NH or at the University of California at San Francisco, San Francisco, CA. Male C57BL6 mice (8 weeks old) were purchased from Charles River Laboratories, Inc. and accommodated in a conventional animal facility for 1 week before initiating experiments. Animals were anesthetized with 2\% isoflurane in 100\% oxygen. A transverse closed fracture was created in the mid-shaft of the right tibia.\textsuperscript{19} To create ischemic tibial fractures, the right femoral artery and its branches were ligated and removed immediately prior to fracture.\textsuperscript{20} Briefly, using aseptic technique, a small incision was made over the right groin to expose the femoral vessels. The femoral nerve and vein were separated from the femoral artery, and the femoral artery and its branches between the inguinal ligament and the popliteal bifurcation were ligated. Then the femoral artery was removed. Immediately after resection of the femoral artery, a transverse closed fracture was created in the mid-shaft of the right tibia.

\section*{EPR Oximetry}
Immediately after the creation of tibia fractures, LiPc crystals (20 -30 micrograms) were implanted into the fracture site and, as controls, adjacent to the periosteum in the contralateral legs using a 25 gauge needle. Tissue pO\textsubscript{2} was then sequentially assessed by EPR oximetry using an \textit{in vivo} EPR spectrometer, with a custom made low-frequency microwave bridge operating at 1.1 GHz and an extended loop resonator (11 mm diameter).\textsuperscript{18,21} Animals were placed in the magnetic field and maintained under general anesthesia (1.8\% inspired isoflurane). Euthermia (37.5\degree C ± 0.5\degree C) was monitored with a rectal temperature probe and maintained with a circulating water blanket. The leg of interest was positioned under the extended loop resonator. The EPR spectrum was then acquired with the spectrometer. Although spectrometer settings varied slightly from scan to scan, typical settings were: incident microwave power-10mW, magnetic field center-425G, scan range 1G. Modulation amplitude was set less than one third of the EPR line width. Scan time was approximately 2 to 3 minutes and 3 to 5 individual scans were averaged to achieve a better signal to noise ratio. The line-width was determined from the EPR spectra, and the partial pressure of tissue oxygen was calculated from an existing calibration curve specific to the given batch of LiPc.\textsuperscript{16,18}

\section*{Determining the Time Course of Tissue pO\textsubscript{2} Change after Injury}
The length of time required to obtain a steady state of pO\textsubscript{2} after fracture was determined in 4 animals with tibia fracture and intact femoral artery, 1 animal with femoral artery resection without fracture (ischemia only), and 1 animal with femoral artery resection with a tibia fracture (ischemic fracture). Animals were administered 100\% oxygen and pO\textsubscript{2} at the fracture sites was measured every 15 minutes after injury for 90 minutes. The time required to reach pO\textsubscript{2} equilibration after changing the inspired oxygen level was also determined using one animal with a tibia fracture and an intact femoral artery. This animal was switched to 21\% oxygen and pO\textsubscript{2} was measured every 5 minutes for 20 minutes. Inspired oxygen for this same animal was again changed back to 100\% and pO\textsubscript{2} was monitored for another 20 minutes.

\section*{Determining the Effects of Fracture on Tissue pO\textsubscript{2}}
Tibia fractures were created in 7 animals and LiPc crystals were implanted into the fracture sites and adjacent to the periosteum in the contralateral legs. Following randomization, animals were initially administered either 100\% or 21\% oxygen for 90 minutes and pO\textsubscript{2} at the fracture sites or periosteum in the contralateral legs was measured. The inspired oxygen level was then changed to 21\% or 100\% respectively and pO\textsubscript{2} measurements were performed again 20 minutes later.

\section*{Determining the Effects of Femoral Artery Resection on Tissue pO\textsubscript{2} at Fracture Sites}
Tibia fractures with femoral artery resection were created in 4 animals and LiPc crystals were implanted into the fracture sites. Animals were administered 100\% O\textsubscript{2} and oxygen concentration was measured at 90 minutes after injury. No measurements were made in 21\% oxygen.
Histological analysis of crystal placement
To correlate the position of crystals with measurements of $pO_2$, animals from the above experiments were sacrificed immediately after the completion of oximetry and both the fractured and contralateral tibiae were collected. Tissues were processed to decalcified paraffin sections as described above. Sections were stained with Hemotoxylin and eosin.

Assessing the long term biocompatibility of LiPc
The long-term biocompatibility of LiPc was firstly assessed by implanting LiPc crystals (20-30 micrograms) with a 25 gauge needle into fracture sites right after injury and analyzing fracture healing at 10 (n=4) and 28 (n=3) days post-fracture. Fractured tibiae were collected, fixed in 4% paraformaldehyde, decalcified in 19% EDTA, and then dehydrated and embedded in paraffin. Longitudinal sections (10µm) were prepared. Sections were stained with Hall and Brunt’s Quadruple stain (HBQ^22,23) to stain cartilage blue and bone red.

Statistical analyses
A one-sided paired (one-sample) t-test was used to determine whether fracture and inspired oxygen altered the $pO_2$ in vivo. The effect of femoral artery resection on the $pO_2$ level at fracture sites was determined using a t-test. Data are presented as mean ± one standard deviation. A power analysis on current data demonstrated that a sample size of 7 in each group is sufficient to detect a 30% decrease in $pO_2$ in fractured legs compared to contralateral legs, assuming a power of 80% and a significance level of 5%.

RESULTS
Assessing equilibration of $pO_2$ after fracture and after changing inspired oxygen
The length of time required to reach a steady state of $pO_2$ after fracture and after changing the inspired oxygen level was determined in a small group of animals. In fractures without femoral artery resection (n=4), tissue $pO_2$ equilibrium was achieved in 90 minutes after fracture with animals breathing 100% oxygen (Figure 1). After changes in the inspired oxygen concentration, $pO_2$ equilibrated within 20 minutes (data not shown). In the animals with femoral artery resection (n=2), $pO_2$ in the hind limb remained low and unchanged during the first 90 minutes after injury (Figure 1). Therefore all measurements throughout this work were made at 90 minutes after fracture with constant administration of

Figure 1. Time course of $pO_2$ change at the fracture site. When animals breathed 100% oxygen, tissue oxygen equilibrium was achieved in 90 minutes in fractures with intact femoral artery. After femoral artery resection, very low tissue $pO_2$ was detected at fracture sites, which remained low even after 90 minutes of inspiring 100% oxygen.
Tibial Fracture Decreases Oxygen Levels at the Site of Injury

the same concentration of oxygen and 20 minutes after changing the inspired oxygen level (i.e., 110 minutes after injury).

Injury decreases tissue oxygenation at fracture sites

Our next objective was to determine the immediate effects of traumatic injury on tissue oxygen levels at the fracture site. At the fracture site in animals breathing 21% oxygen, the mean pO₂ (30.6 ± 12.7 mmHg; n=7) was significantly lower than that at the periosteum in contralateral limbs (45.5 ± 15.3 mmHg; n=7; p<0.01. Figure 2). pO₂ was significantly increased in both the fractured limbs (72.8 ± 28.2 mm Hg, p<0.01) and contralateral legs (148.4 ± 59.2 mmHg, p<0.01) during 100% oxygen administration (Figure 2). However, the pO₂ at fracture sites still remained significantly lower than that in the control tibial periosteum (Figure 2, p<0.01), suggesting that disruptions to the vasculature had occurred that limited the functional capacity of the blood supply. To further assess the ability of EPR to measure vascular oxygen delivery after skeletal injury, we measured fracture and periosteal pO₂ levels in animals breathing 100% oxygen, that had undergone femoral artery resection as an additional ischemic insult; this injury is sufficiently severe to delay fracture healing. Femoral artery resection significantly reduced pO₂ at the fracture site (1.4 ± 0.7 mmHg; n=4) compared to 72.8 ± 28.2 mm Hg in fractures with intact femoral artery (n=7; p<0.01).

Crystal placement

In the majority of limbs with skeletal injury, LiPc crystals were located within the injured muscle near the fracture site (Figure 3). The location of LiPc crystals does not appear to correlate with the variation of pO₂ measurements, suggesting that extensive muscle and vascular injury was present around fracture sites.
Our last goal was to examine the biocompatibility of LiPc crystals during fracture repair. LiPc crystals were placed at the fracture site and then the injuries were allowed to heal for 10 days to assess endochondral ossification and for 28 days to assess union of the fractured bone ends. At 10 days after injury (n=4), hypertrophic cartilage and newly formed bone were observed in fracture calluses indicating endochondral ossification was under way (Figure 4A). LiPc crystals were embedded in granulation tissue (Figure 4B) or were in direct contact with newly formed bone (Figure 4C) and cartilage (Figure 4D). At 28 days (data not shown), all fractures (n=3) had healed by bony bridging. LiPc crystals were observed in direct contact with bone or in surrounding soft tissue. A thin layer of fibrous tissue was occasionally observed around LiPc crystals at this time. Compared to previously published data, LiPc crystals did not significantly alter the normal progress of tibia fracture healing in mice. Mice typically heal experimental tibia fractures by day 28 post-injury and this was the case in our current study. Furthermore, the crystals were in direct contact with cartilage and bone, and there was no evidence of a large population of inflammatory cells in adjacent space. Thus, LiPc crystals do not induce much inflammatory response and they have excellent biocompatibility during fracture healing.

**DISCUSSION**

The results of this study indicate that EPR oximetry will be a valuable tool for monitoring oxygen levels during fracture repair in mice. EPR oximetry detected significantly lowered tissue oxygen levels at fracture sites after injury and it also successfully detected the expected changes of tissue oxygen levels after switching the
Tibial Fracture Decreases Oxygen Levels at the Site of Injury

breathing oxygen concentration from 21% to 100%. These data suggest that the sensitivity of EPR oximetry is adequate to assess tissue pO$_2$ during fracture healing. In addition, we confirmed that the paramagnetic probe used in current study, LiPc, is biocompatible. LiPc crystals did not induce obvious inflammatory response and interfere with normal fracture healing. Further, LiPc crystals gave us the ability to make repeated measurements in the same location and to assess tissue formation at each site, providing a unique opportunity to examine the effect that oxygen has on stem cell differentiation and function. For instance, this technique will allow us to assess pO$_2$ at a particular site and then at a later time point we can examine what type of tissue has formed in this region using histologic methods. Developing and employing these technologies for studying fracture repair in mice is of great importance, because compared to other rodent models, a murine model offers the advantage of using a multitude of genetically engineered strains, and there is an abundance of reagents for molecular and cellular analyses available.

The level of tissue oxygenation may affect fracture repair. Decreasing tissue oxygenation by inducing chronic systemic hypoxia$^{11}$ or by ligating femoral artery$^{20}$ delays fracture healing. Increasing tissue oxygenation by providing hyperbaric oxygen, on the contrary, can accelerate bone repair.$^{25}$ Understanding the mechanisms underlying these effects is of great important. There is evidence suggesting that oxygen levels may have direct effects on stem cells. For example, the function and differentiation of chondrocytes and osteoblasts is affected by oxygen levels in vitro.$^{26,27,28}$ Under experimental conditions that induce chronic hypoxia, fractured femurs did not exhibit signs of bone formation. Rather the calluses

Figure 4. Histological analysis of fracture healing with the presence of LiPc crystals. (A) At 10 days after injury, hypertrophic cartilage and newly formed bone were observed in fracture calluses. (B) High magnification of box B in (A) shows a LiPc crystal is embedded in granulation tissue with minimal fibrosis. (C) High magnification of box C in (A) shows a LiPc crystal is in direct contact with newly formed bone. (D) High magnification of box D in (A) shows a LiPc crystal is in direct contact with cartilage.
were comprised of abundant cartilage which indicates that chondrocyte differentiation can occur in a more hypoxic environment than osteoblast differentiation. In addition to the effect of hypoxia on stem cells, tissue oxygen levels may play other important roles during bone repair. Studies on wound healing have demonstrated that oxygen is involved in multiple processes, including cell survival, collagen and extracellular matrix deposition, angiogenesis, epithelialization, and production of the oxidative burst used for intracellular bacterial killing. When tissue pO2 falls below 40 mmHg, angiogenesis, extracellular matrix formation, and resistance to infection are all impaired. In current study, we detected that tissue oxygen level at fracture sites dropped below this level after injury, especially after femoral artery ligation, warranting further studies on the effects of oxygen on cell death, angiogenesis, and infection during fracture healing.

In summary, these data illustrate that EPR oximetry is a promising technique to assess tissue oxygenation in murine fracture models. We have used EPR to examine the effect that tibial fracture has on pO2 during fracture repair. We have demonstrated that these fractures generate vascular damage that significantly reduces tissue oxygen levels to levels that could impair healing. However, mice exhibit exceptional regenerative capacity. Normally no difficulties in skeletal healing are detected without the inclusion of a major traumatic insult such as cautery or resection of the femoral artery. Even in the latter situation the mice salvage their limbs, and eventually the skeletal injury heals. These results suggest that tissue oxygenation returns to normoxic levels rapidly after injury. Thus, understanding this time course and evaluating the role that oxygen plays during fracture repair are important parameters for elucidating and exploiting the mechanisms that underlie the regenerative potential during fracture repair in mice.

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REFERENCES


RESULTS OF THE PONSETI METHOD IN PATIENTS WITH CLUBFOOT ASSOCIATED WITH ARTHROGRYPOSIS

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ABSTRACT

Clubfoot associated with arthrogryposis has been traditionally considered very resistant to manipulation and casting, and therefore has required surgical correction. The purpose of this study was to evaluate the results of the Ponseti method of clubfoot casting in this patient population. We reviewed the records of patients with clubfoot associated with arthrogryposis consecutively treated at our respective institutions from January 1992 to December 2004. All patients were treated by serial manipulations and casting following the principles of the Ponseti method. Main outcome measures included initial correction of the deformity, relapses and the need for surgical releases or any other surgeries. Average age at last follow up was 4.6 years. There were 16 patients, all with bilateral deformities (32 clubfeet). There were 11 males and 5 females. Nine patients had both upper and lower extremity involvement. Seven patients had previous treatment elsewhere and one patient had an Achilles tenotomy. Initial correction was obtained in all but 1 patient. Average number of casts required for correction was 7 (range: 5 to 12). Average post-tenotomy dorsiflexion was 5 degrees. One patient required a posterior-medial release (PMR) for insufficient initial correction. Four cases required subsequent surgery for relapses (1 bilateral PMR with a repeat left PMR; 2 posterior releases (PR), 1 PR and anterior tibialis transfer (ATT), and 1 ATT). No taelectomies were required. This study demonstrates that the Ponseti method is very effective for the correction of patients with clubfoot associated to arthrogryposis. Although this deformity is more rigid than in idiopathic clubfoot, many cases can be corrected when started in the first few weeks after birth.

INTRODUCTION

Arthrogryposis includes a heterogeneous group of disorders characterized by multiple, generally non-progressive joint contractures. More than 100 disorders are included in that classification, but most of these disorders share common deformities including clubfeet, flexed or extended knees, hip dislocations, and upper extremity deformities. Clubfoot in arthrogryposis is very rigid, difficult to correct, and tends to recur. As in other cases of club foot, the goal in treating this deformity “is to convert a deformed, rigid foot into a plantigrade platform,” as stated by Lloyd-Roberts and Lettin. However, because of the clinical features, the method of correction is controversial. Traditional manipulation and serial casting usually required months of treatment and frequently resulted in incomplete or defective corrections. As a result, the alternative of extensive corrective surgery had been indicated in the majority of the cases; unfortunately, surgery still often resulted in a high failure rate and number of complications. These disturbing results led some authors to recommend primary correction by taelectomy. The excellent results obtained using the Ponseti method in patients with very rigid idiopathic clubfoot led to the expansion of our traditional indications to include arthrogryposis rather than defaulting to extensive corrective surgery or taelectomy. The purpose of this study was to evaluate the results of the Ponseti method in this patient population.

METHODS

We reviewed the records of 16 patients diagnosed with clubfoot (32 clubfeet) associated with arthrogryposis treated with the Ponseti method. Studies were performed with the approval of our Institutional Review Board (IRB). We evaluated the following variables: age of the patient at first visit to our institution, previous treatment and type of treatment before referral, number of casts, previous Achilles tenotomy, number of casts required for correction at our institutions, need for

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Figure 1. Newborn patient with distal arthrogryposis affecting both upper and lower extremities. A) Hand deformities. B) Bilateral clubfeet with mild knee flexion contracture. C) Note the severe hindfoot deformity. D) Results after manipulation and casting (12 casts) at the age of 8 months. Note the increased flexibility of the ankle and maintenance of the full correction of the deformity. E and F) Clinical results of the upper and lower extremity deformities at 4 years of age. Note full correction of the clubfeet.
percutaneous Achilles tenotomy, and degree of ankle dorsiflexion after tenotomy. Main outcome measures included successful initial correction of the deformity, relapses and the need for surgical releases or any other surgeries. The average age at last follow up was 4.6 years (range, 10 months to 12 years).

RESULTS

There were 11 males and 5 females. Average age at first visit was 3 months (range: newborn to 12 months). Nine patients had both upper and lower extremity involvement. Eight patients had an ultrasound during pregnancy, five of which were diagnosed with clubfoot at an average of 16 weeks (range: 10 to 20 weeks). Seven patients had previous casting treatment elsewhere with an average of 6 casts (range: 1 to 18 casts) and one patient had an Achilles tenotomy. No patient had surgical releases prior treatment at our institutions.

Initial correction by manipulation and casting was obtained in all but one patient. Thirteen patients required less than 7 casts for correction, with one patient requiring 12 casts (Figure 1). Fifteen patients required an Achilles tenotomy with an average post-tenotomy dorsiflexion of 5 degrees (range: 0 to 15 degrees). One patient had skin breakdown secondary to cast problems and one patient had overcorrection at the midfoot that resolved spontaneously over time (Figure 2). No infections, profuse bleeding or skin slough were observed after tenotomy. The post casting brace was worn for an average of 3.6 years (range: 3 months to 4.5 years).

One patient required a primary posterior-medial release for insufficient initial correction. Four patients had a relapse (25%) and required subsequent surgery: one case of bilateral postero-medial releases with repeat left postero-medial release; two cases of posterior releases; one case of posterior release and anterior tibialis transfer, and one case of bilateral anterior tibialis transfers. No surgical complications were noted in these cases. No talectomies were required (Table 1).

DISCUSSION

Arthrogryposis represents a large group of disorders, all of which include multiple joint contractures and dislocations present at birth. There are 113 entries for distinct syndromes coded under the term “arthrogryposis” on the Online Mendelian Inheritance in Man (OMIM) website, caused by a wide variety of etiologies. Although individual syndromes have different clinical courses and prognoses, orthopaedic management for many of these disorders follows similar guidelines: self care with the upper extremities and ambulation with stable, aligned lower extremities. Overall outcomes tend to be better when treatment is started at a younger age, usually before adaptive changes occur. Early motion and avoidance of prolonged immobilization may increase joint stability, thereby improving function.

A severe, resistant clubfoot is the most common foot deformity associated with arthrogryposis. Its correction has been always been very difficult and fraught with complication and relapses. Surgery for clubfoot was traditionally delayed until after the management of larger joints such as the knee, usually after 1 year of age. The orthopaedic literature suggests that primary talectomy is the procedure of choice for correction because of the high incidence of failed soft tissue surgery. However, recent reports show better outcomes with circumferential release alone if performed before 1 year of age.

Drummond and Cruess reported clubfeet associated with arthrogryposis that underwent posterior releases relapsed in 74% of cases. And all children eventually had recurrence of their deformity, measured at an average of 12 years of age. Other authors have found similar rates of failures. Interestingly, Zimbler and Craig and...
Widmann et al. found that radical releases performed in younger patients (less than 1 year) had a lower relapse rate than posterior releases only. However, these patients required circumferential tendon resections, Steinmann pinning across the tibio-talar joint for 6-8 weeks postoperatively, and full time use of orthotics after surgery until skeletal maturity.

In this study, we found that manipulation and casting resulted in the initial correction of the clubfoot deformity in 90% of the patients. This correction could be achieved with an average of 7 casts changed weekly. In only one case, 12 casts were required, and this patient was the oldest in this series (12 months old at the initiation of treatment at our institution). Only one patient failed correction and required early surgical releases. One patient had overcorrection of the midfoot, which spontaneously resolved over time. To avoid this, we believe it is better to obtain only 40-50 degrees of abduction of the foot rather than overstressing the foot to get the usual 70 degrees recommended with idiopathic clubfeet.

We found that after Achilles tenotomy, ankle dorsiflexion (average 5 degrees) is less than in cases of idiopathic clubfeet (average 20 degrees). However, we have observed clinically that the foot and ankle flexibility improves over time with the use of the brace. Furthermore, several cases surprisingly improved dramatically by 3-4 years of age with feet looking very similar to idiopathic clubfeet.

When it comes to maintenance bracing, it is important to adjust the rotation of the shoes to the degree of abduction and dorsiflexion provided by the final cast post tenotomy. In general, we have found that the 70 degrees of abduction recommended in idiopathic clubfeet is difficult to achieve and in most cases an average of 50 degrees the most that is possible. The shoes of the brace should be placed accordingly. Since ankle dorsiflexion is usually only 5 degrees in a corrected foot, bending the bar between the shoes may put extra pressure on the feet, so much so that the child may not tolerate the brace. Therefore, since the brace is of utmost importance

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### TABLE 1

<table>
<thead>
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<th>Age first visit (months)</th>
<th>Gender</th>
<th>Extremity Involvement</th>
<th>Previous Treatment (# cast)</th>
<th># Ponseti casts</th>
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PMR: Postero-medial release; PR: Posterior release; TAL: TendoAchilles lengthening; ATT: Anterior Tibialis Transfer to third cuneiform
to maintain the child’s foot correction, it is important to remove only enough bend for compliance. As flexibility of the feet progresses over time, more bend in the bar can be added.

Finally, relapses are relatively common (25%) and not always related to non-compliance using the brace, but to the underlying stiffness associated with the disorder. Relapsed feet can be treated with repeat manipulations and casting, followed by Achilles tenotomies. In older children (>3 years of age), if flexibility is restored, an anterior tibialis transfer could be added to balance the foot and prevent further relapses. In only 3 cases a posterior release was required to obtain full correction. Importantly, this was a relatively small operation without complications in our hands. To date, no patient has required a talecctomy.

In conclusion, the Ponseti method of manipulation and serial casting is very effective for initial correction of patients with clubfoot associated to arthrogryposis. Although surgery may be necessary, it is less extensive than previously report and has minimal rate of complications.

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ABSTRACT

Background: Type III growth disturbance (T3GD) following reduction for developmental dysplasia of the hip (DDH) is a relatively rare, but potentially devastating complication. This study evaluated the long-term outcomes of patients treated for DDH who developed a T3GD hip compared to those who didn’t, with an emphasis on possible risk factors.

Methods: A case-control design was used. All radiographs of a consecutive set of patients with DDH were evaluated. Twenty-two patients (29 hips) developed T3GD. The control group consisted of 57 patients (72 hips) without any sign of growth disturbance. Variables examined included age at reduction, type of reduction and serial radiographic parameters reflecting pre- and post-reduction status. Average age at final follow up was 26 years in the T3GD group and 34 years in the control group.

Results: Evidence of T3GD was first noticed radiographically at 11 months after reduction and healing of the epiphysis occurred an average of 8.5 months later. Univariate analysis demonstrated no increased risk of T3GD related to age at presentation, presence or absence of the ossific nucleus, type of reduction, initial acetabular index or Smith’s centering ratios. However, the Tönnis grade was significantly associated with an increased risk of T3GD. Tönnis grade 4 hips (high-degree dislocations) had 3.43 times greater risk of developing T3GD compared to those with lower dislocations. At maturity, 90% of the T3GD hips were classified as Severin III/IV, compared to 35% of the controls. At last follow-up, 7 of the 29 T3GD hips (32%) had undergone total hip replacement at an average age of 39 years (range 19 to 57 years).

Conclusions: T3GD remains the most severe and devastating complication after treatment of DDH in children. In most cases, poor acetabular development and flattening of the femoral head lead to early degenerative changes in the hip joint. The risk increases in high-degree dislocations, independent of the treatment performed.

INTRODUCTION

Growth disturbance of the capital femoral epiphysis, commonly referred to as avascular necrosis, is one of the major complications in the treatment of developmental dislocation of the hip.1-10 The reported prevalence varies from 0 to 73 percent and some investigators believe the difference among series depends on the rigor of the diagnosis and the variability in the length of follow-up.1,5,9,11-19 The cause remains unknown, but is thought to be due to vascular or mechanical damage.3,6,7,9,20-22 Interestingly, several cases of growth disturbance have been described in the non-dislocated hip of treated children,3,7,9,12,21,23-25 but growth disturbance does not occur in children with untreated dislocations.26

Factors associated with all types of growth disturbance of the proximal femur include: Age at reduction,2,3,6,7,9,20-22,27,28 absence of the ossified nucleus,21,22,29,30 height of the dislocation,31 an inverted labrum32 or soft-tissue interposition,32,33 the use of preoperative traction,1,2,5,7-9,21,24 the type of reduction,1,6,9,20,22,26,28,34 forceful reduction,5,19 not achieving a concentric reduction,25,36 casting in abduction more than 60 degrees or in full internal rotation,2,3,6,7,9,21,27 and adductor tenotomy.27 Most likely, growth disturbances are the result of multiple, simultaneous factors.6

According to the systems of Bucholz and Ogden3 and Kalamchi and MacEwen,8 type III growth disturbance (T3GD) is characterized by severe damage to the femoral head and the central part of the physe. This damage is characterized by symmetrical growth retardation of the femoral neck, relative overgrowth of the greater trochanter, and abnormal growth of the...
whole epiphysis. Identical findings were classified more recently by Kruczynski as type V. Prevalence of T3GD has been estimated to range from 14 to 30 percent. Reported sequelae of T3GD include joint incongruence, femoral head eccentricity, marked coxa vara, acetabular dysplasia, osteoarthritis of the hip joint and limb-length inequality. However, we are not aware of any studies providing quantitative data and long-term follow-up to support the relationship between T3GD and these outcomes. The purpose of this study is to describe the outcomes of T3GD, focusing on acetabular development and the prevalence of osteoarthritis, relative to similarly treated hips that did not develop a growth disturbance.

MATERIAL AND METHODS

Patient Selection

We reviewed the charts of 229 children with DDH treated by either closed or open reduction at the University of Iowa Hospitals and Clinics from 1938 to 1990. Of these, 29 hips in 22 patients had a T3GD: Six patients had bilateral disease with bilateral T3GD, one had bilateral disease but unilateral T3GD, and sixteen had unilateral disease and unilateral T3GD. These hips comprise the case group. The control group was composed of patients gathered previously for a study of acetabular development after initial reduction for DDH. This group (selected from the same patient population as the cases) included patients who had no further treatment prior to skeletal maturity and no growth disturbances. Seventy-two hips in 57 patients were used as controls. The remaining patients in the initial cohort did not have follow-up past maturity.

Treatment

Closed reduction was achieved through gentle manipulation under general anesthesia, applying traction with the hip and knee flexed while the greater trochanter was pushed anteriorly. The children then wore a hip-spica plaster cast for three months. Concentric reduction of the femoral head was maintained after plaster cast removal with an abduction brace at night and napping for several months. Open reduction was indicated when a congruent, stable, closed reduction under anesthesia and arthrographic control was not possible, or when extreme abduction was necessary to maintain reduction. Open reduction was performed through an anteromedial approach followed by a plaster cast in the human position for three months. After the cast was removed, patients wore an abduction brace full time for two months, and then at night and during napping hours for a period of one or two years.

Radiographic Evaluation

The diagnosis of T3GD was determined using the classification system of Bucholtz-Ogden. All cases were confirmed by two authors who were not the treating physicians (C.A.F. and J.A.M.). The time to first appearance of T3GD was recorded in months after reduction. The following measurements and classifications were recorded for both the cases and controls: Age at reduction, type of reduction, pre-reduction Tönnis grade of dislocation, the presence and characteristics of the ossific nucleus, serial measures of the Smith centering ratios and the acetabular index from reduction until skeletal maturity. Additionally, the skeletal maturity film was evaluated for the following: Acetabular index, acetabular width and depth, femoral head sphericity index, Severin classifications, acetabular roof orientation (upsloping, horizontal or downsloping), presence of coxa magna, and the presence of degenerative joint disease using the Boyer classification.

Radiographs were taken at different times post-reduction; therefore, not all patients had radiographs at all follow-up periods of interest in this study. This is common in any study of clinical practice. Since missing data can lead to biased estimates of risk (due to the use of incomplete data or the exclusion of cases with incomplete data), values for missing data are commonly imputed. To partly correct for this source of bias, all analyses were performed on a dataset that included both observed and imputed values for the acetabular index, acetabular floor thickness, and lateral and superior centering ratios. Using a linear spline function, we estimated missing values of given predictors based on the magnitude and pattern of each individual patient’s existing measurements. Simultaneously, the function adjusted these values to estimate what would have been observed if all radiographs had been taken at the same time relative to the reduction, namely, six, twelve and eighteen months, and two through seven years post-reduction. This function creates a complete series of data for each patient, with measurements corresponding to a standardized follow-up protocol. This procedure was used in a previous paper.

Statistical Analyses

Cases and controls were compared using a combination of parametric and non-parametric tests as appropriate, including Fisher’s exact test, odds ratios, and Student’s t-tests. Alpha was set at 0.05.
RESULTS
Cases with Type III Growth Disturbance
Of the 22 patients in the case group, 20 were female (87%), 7 had bilateral DDH (33%), and the left hip was affected in 7 of the 14 patients with unilateral disease. The initial treatment was open reduction in 12 hips (41%) and the remainder were treated by closed reduction. The average age at reduction was 21 months: 7 patients were treated at less than twelve months of age (32%), 9 between 12 and 24 months (41%), and 6 after 25 months of age (28%). The growth disturbance was first noted, on average, at 11 months post-reduction (range 5-19 months). Only one of the patients with bilateral DDH did not develop bilateral growth disturbance. The average time until healing was 8.5 months after the appearance of the growth disturbance (range: 3-84 months). One patient underwent an acetabular shelf and various derotation osteotomy procedures at age ten years for acetabular dysplasia, and a second patient underwent a trochanteric arrest at age seven for femoral dysplasia. Only data prior to these procedures was used for this evaluation, resulting in an average age at final follow-up of 26 years (range: 19-57 years).

Controls
Of the 57 control cases (71 hips), 47 were female (82%) and 43 had a unilateral dislocation (75%). The left hip was involved in 28 of the unilateral cases (65%). Initial treatment consisted of open reduction in 24 (33%) and closed reduction in the remainder. Average patient age at reduction was 16 months: 21 patients (37%) were treated before the age of 12 months, 26 between 13 and 24 months (46%), and 10 after the age of 24 months (18%). The average age at last follow-up was 34 years (range: 18-60 years).

CASE/CONTROL COMPARISONS
Pre-Reduction to Skeletal Maturity
Table 1 summarizes the case and control-group comparisons. There was no difference in the prevalence of T3GD dependent on the age at reduction (p=0.09) or type of reduction (p=0.49). However, the odds of developing T3GD were 3.36 (p=0.008, 95% CI 1.36 to 8.30) in Tönnis grade 4 hips compared to grades 2 and 3. Of the 37 hips without an ossific nucleus at reduction, 9 (24%) developed T3GD, compared to 19 of 63 hips (30%) without a nucleus (p=0.65). There was no difference in the acetabular index (AI) between the two groups until 5 years after reduction, when the improvement slowed for the T3GD hips relative to that in the control hips. At that time, the average AI was 25.69 degrees in the T3GD cases compared to 22.74 degrees in the controls (p=0.03). By 7 years after reduction, the AI in T3GD hips averaged 26.59 degrees compared to 20.73 degrees in the control hips (p=0.001).

In looking at the relationship between the femoral head and the acetabulum over time, there was no difference in the lateral Smith centering ratio until 3 years after reduction; from that point on, the T3GD hips consistently had a significantly larger ratio than did the control hips (all p-values <0.05). Likewise, the superior ratio in the cases was significantly smaller than that in the controls beginning at three years after reduction (all p-values <0.05). In these hips, a smaller ratio reflects the collapse of the femoral head (bringing the metaphysis closer to Hilgenrein’s line) and not a greater degree of superior subluxation.

Skeletal Maturity
At skeletal maturity, 3 (10%) of the T3GD hips were Severin I or II, compared to 47 (65%) of the controls; 20 (69%) were Severin III compared to 16 (21%); and 6 (21%) were Severin IV compared to 10 (14%) of the controls (p=0.0001). The acetabular sourcil was downsloping in only 3 (10%) of the T3GD cases compared to 39 (53%) of the controls (p=0.0002). Coxa magna was present in 15 (52%) of the T3GD cases and 19 (26%) of the controls (p=0.02). On average, the acetabulum was shallower in the T3GD cases (14.66 versus 17.44, p=0.008) and the femoral head spherical index was also smaller (22.48 versus 26.69, p=0.003). Signs of degenerative joint disease (grades 1-2) were already present in 7 (24%) of the T3GD cases but in none of the controls (p<0.001).
Final Follow-Up
At final follow-up, the average age of the T3GD group was 26 years (range: 19-57 years), and the control group averaged 34 years (range: 18-73 years). Of the T3GD hips, 7 (24%) have undergone total hip replacement compared to 7 (10%) of the control group (p=0.02). Of the T3GD Severin II hips, none have yet undergone total hip replacement, compared to 1 (15%) of the Severin III hips, and 6 (43%) of the Severin IV hips. In terms of the Stulberg classification, none of the Stulberg II hips have undergone total hip replacement, compared to 4 (19%) of the Stulberg III and 3 (75%) or the Stulberg IV hips.

DISCUSSION
Growth of the proximal end of the femur is a complex process likely determined by genetic factors, pressures across the hip joint, joint nutrition and vascular circulation,18,21,46,47 Disturbance of one or several of these processes during treatment of DDH could lead to a growth abnormality of the proximal femur.

Several treatment factors have been hypothesized to cause a growth disturbance including age at reduction,2,4,7,9,48-50 absence of the ossified nucleus,27,48,49,51-53 height of the dislocation,53 an inverted labrum36 or soft-tissue interposition,35,36 the use of preoperative traction,1,2,3,6,7,9,21,27 type of reduction,1,6,20,22,26,28,34 forceful reduction,5,19 not achieving a concentric reduction,35,36 casting in abduction more than 60 degrees or in full internal rotation,2,3,6,7,9,21,27 and adductor tenotomy.27

Some controversy exists about the age of the child at the time of treatment and the development of a growth disturbance. Most authors agree that the younger the patient, the worse the prognosis, due to the fragility of the femoral epiphysis (composed mostly of cartilage and end-arteriolar network without anastomotic circulation).7,9,18,21,29,30,54 In addition, Segal et al.,32 Tönnis52 and Clarke et al.,51 proposed that treatment should be delayed until the appearance of the ossified nucleus and an effective collateral circulation is established. However, this concept has recently been challenged.19 With the data available from the current study, we did not find a significant difference in the risk of T3GD due to the age at reduction or the presence or absence of the femoral ossific nucleus.

The prevalence of T3GD is difficult to estimate, and likely varies due to the diversity of treatments used to treat DDH. Soft-tissue interposition after closed reduction in DDH has been related to an increased risk of growth disturbances.35,36 Increased pressure in the hip joint is thought to occlude cartilaginous canals or venous outflow, leading to growth disturbances of the femoral epiphysis.27,51 Damage to the central part of the physis could lead to a definitive growth arrest or impair the development of the whole femoral head. Some investigators report an increased risk of growth disturbances after closed reduction,7,9,34 and others after surgical treatment, either by anteromedial50,51 or anterolateral approaches.56-59 Conversely, closed and open reduction have been associated with the same rates of growth disturbance in other reports.36,38 In this series, we were unable to find any significant difference in the prevalence of T3GD between closed or open reduction by the anteromedial approach.

Several early radiographic signs are thought to predict later appearance of T3GD. We found the ossified epiphysis always showed an anarchical and complete fragmentation with a subsequent broadening and collapsing pattern. When the epiphysis was absent, we saw a delay of ossification and subsequently, the same pattern described previously. But the most precocious and consistent findings were seen in the physis and metaphysis, such as metaphyseal irregularity, osteolysis or cyst formation and medial beaking of the femoral neck. We could not detect bridging bone across the physis. Physeal growth arrest was followed by appositional periosteal bone around the neck of the femur and normal growth of the greater trochanter, leading to a short, broad femoral neck and a reversal of the epiphysal-trochanter relationship. These changes were observed within the first year after treatment, and healing time was also quickly established. However, long-term and careful follow-up is necessary because there may be pattern changes over time, as previously described.38,50

Another controversial point is the height of the dislocation at the time of reduction. Cooperman et al.,34 in a 30-year follow-up, and Gibson et al.,37 pointed out that the high degree of initial displacement was not a factor in subsequent growth disturbance. But in this study, the severity of anatomical dislocation was a strong predictor of T3GD. Patients with Tönnis grade IV dislocation were at a three-times greater risk of developing this complication. Because of this, we suggest that other alternative treatments, combining an open reduction by anterolateral approach and a femoral shortening osteotomy, should be considered in the case of a high dislocation. Combined procedures are usually indicated in older children,13,18,58,60,62 but in special circumstances might be applied in those younger than two years.44

Acetabular remodeling, measured by the acetabular index, proceeded normally in this series until approximately five years after reduction, when development slowed in the T3GD hips. The sourcil was upsloping or horizontal in 90% of the T3GD hips. On the other hand, the superior Smith ratio was not different between T3GD hips and the controls within the first three years post-reduction, but from that point it became smaller,
Natural History of Type III Growth Disturbance after Treatment of Developmental Dislocation of the Hip

The results of this study demonstrate that T3GD leads to acetabular dysplasia even if a concentric reduction was obtained at the time of reduction. At skeletal maturity, 90% of the T3GD hips were classified as Severin III or IV. There is also strong evidence that residual acetabular dysplasia leads to early degenerative joint disease. Signs of osteoarthritis were already present in 24% of the T3GD cases at the time of skeletal maturity. In addition, the Severin classification was a strong predictor of total hip replacement: None of the T3GD-Severin II hips underwent total hip replacement compared to 15 percent and 43 percent of the T3GD-Severin III and IV hips, respectively. The Stulberg classification was also predictive of degenerative joint disease and subsequent total hip replacement: None of the Stulberg II hips developed osteoarthritis, compared to 19 percent of the Stulberg III and 75 percent of the Stulberg IV hips. Therefore, residual acetabular dysplasia, as assessed by the Severin and Stulberg classifications, predicts total hip replacement. Figures 1 through 5 summarize the treatment and outcomes of a patient who underwent closed reduction at six months of age for a Tönnis grade 3 dislocation.

Figure 1. Pre-reduction radiograph of a 6-month-old female with a Tönnis grade 3 dislocation of the right hip.

Figure 2. Patient at 10 months post reduction. There is evidence of delay of the ossific nucleus on the right side. Note a small defect in the ossific nucleus of the left, non-affected hip.

Figure 3. Patient at 5 years post reduction. Note the femoral head deformity, horizontal epiphyseal line, and the abnormal metaphysis on the right side. The acetabulum is developing normally. Note horizontalization of the left femoral epiphysis indicating a mild case of type II growth disturbance in the passively treated non-affected hip.

Figure 4. Patient at 35 years of age. There is a significant deformity of the femoral head and neck, with a decreased articular-trochanteric distance. Signs of early degenerative joint disease include decreased joint space, sclerosis and cyst formation.
At skeletal maturity her hip was classified as Severin III and by adulthood (Figure 4), it was classified as Severin IV and Stulberg IV. Figure 5 shows the hip immediately prior to total hip arthroplasty, with severe osteoarthritis causing pain and functional deficits.

Relative narrowness and insufficiency of the acetabulum plus early cessation of hip remodeling and coxa magna observed in the T3GD cases may have indicated the need for pelvic osteotomy. Relative narrowness and insufficiency of the acetabulum plus early cessation of hip remodeling and coxa magna observed in the T3GD cases may have indicated the need for pelvic osteotomy.6,65 Some investigators suggest these procedures should be performed at an early age, while the femoral head has its highest remodeling potential.1,27,66 Depending on joint congruence or incongruence, the age of the patient, and the need to increase the acetabular volume, it seems logical to perform a redirectional osteotomy, or the more commonly performed shelf procedure, or Chiari osteotomy.56,66 Prospective long-term studies are required to validate these indications.

In conclusion, T3GD remains the most severe and devastating complication after treatment of developmental dysplasia of the hip in children. Acetabular dysplasia developed in 90% of the hips in our series. In most of the cases, poor acetabular development and flattening of the femoral head led to early degenerative changes in the hip joint. The risk increases in high-degree dislocations, independent of the treatment performed.

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HAMSTRINGS ACTIVITY DURING KNEE EXTENSOR STRENGTH TESTING: EFFECTS OF BURST SUPERIMPOSITION

Chandramouli Krishnan*, Glenn N. Williams*,**

ABSTRACT

Quadriceps muscle strength is often used as a criterion for functional progression and return to activity after knee joint injury or surgery. Previous research has demonstrated that noteworthy antagonist activity is present during knee strength testing. The countermoment associated with this antagonist muscle activity may lead to an underestimation of knee strength. The burst superimposition method of strength testing is considered by some to be the current gold standard. The effect of burst superimposition on antagonist activity is unknown. The purpose of this study was to test the hypothesis that burst superimposition diminishes antagonistic hamstrings activity during knee extensor strength testing. Isometric knee strength testing was performed in 22 (11 males, 11 females) active young people with no history of serious lower extremity injuries using the burst superimposition method. The magnitude of hamstrings muscle activity was assessed just before and after burst superimposition. Contrary to our hypothesis, a small, but statistically significant increase in antagonistic medial hamstrings activity was observed with burst superimposition (7.23 vs. 9.62; \( P < 0.001 \)). Higher lateral hamstrings activity was also observed, but this did not reach statistical significance (15.03 vs. 13.50; \( P = 0.087 \)). Though statistically significant, the small increase in hamstrings activity is unlikely to be clinically meaningful.

INTRODUCTION

A primary goal of rehabilitation after knee joint injury or surgery is to safely return individuals to activities they desire to participate in. Quadriceps muscle strength has been shown to correlate strongly with knee function and is postulated to be a critical factor in knee joint health.\(^{15}\) Accordingly, clinicians often use quadriceps muscle strength as a criterion for return to activity, especially sports participation. Research from our lab and that of others has shown that noteworthy antagonist muscle activity is present during knee strength testing.\(^{6,8}\) This antagonist muscle activity may be problematic as the associated moments may lead to measurement error resulting in an underestimation of the knee strength, which could impact clinical decision making.

Muscle force generation capacity is a product of both the size of a muscle’s fibers and the ability to fully activate the fibers within a muscle. Traditional isokinetic, isometric, and isotonic strength testing provide meaningful information about one’s ability to voluntarily produce joint torque, but may underestimate the true strength of a muscle group due to the inability of these methods to account for activation failure. For this reason, scientists interested in quantifying knee extensor strength often superimpose an electrical stimulus on the quadriceps muscle during maximal voluntary contraction (burst superimposition or twitch interpolation method) to obtain a more complete picture of strength.\(^{1,5,9-11}\) If the muscle is fully activated the superimposed electrical stimulus will not augment torque, whereas when activation failure is present the supramaximal electrical stimulus will cause the inactive muscle to become active resulting in a torque increment (Figure 1).\(^{11,13}\) Thus, burst superimposition and twitch interpolation methods allow assessment of voluntary strength, activation failure, and theoretically, true muscle strength. Consequently, this approach is considered by many to be the current “gold standard” for assessing knee extensor strength. The effect of burst superimposition on antagonistic hamstrings muscle activity during knee extensor strength testing is unknown. There is evidence that peripheral electric stimulation can affect spinal and cortical excitability.\(^{14}\) Hence, it is reasonable that the burst superimposition method of strength testing may alter antagonistic muscle activity and thereby affect the accuracy of strength testing. The purpose of this study was to evaluate the effect of burst

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superimposition on antagonistic hamstrings muscle activity during isometric knee extensor strength testing. We hypothesized that burst superimposition would decrease antagonistic hamstrings muscle activity.

**METHODS**

Twenty-two (11 males, 11 females) uninjured young people volunteered to participate in this study. All subjects were regular participants in fitness activities or sports (Tegner Activity Score > 4). Exclusion criteria included a history of significant lower extremity muscle injury, major knee ligament injury, signs and symptoms of patellofemoral joint dysfunction, abnormal KT-2000™ evaluation (>3 mm side-to-side difference in laxity), history of lower extremity surgery, lower extremity nerve injuries, or an abnormal gait pattern. Subjects were asked to refrain from any strenuous physical activity for 24 hours prior to participation. All subjects provided written informed consent that was approved by the University of Iowa Human Subjects Research Institutional Review Board prior to their participation.

**TESTING PROCEDURES**

Subjects performed a five minute warm-up on a cycle ergometer followed by self-directed stretching of the quadriceps, hamstrings, and gastrocnemius muscles prior to testing. The order of limb testing was randomized a priori using a computer-based random number generator in order to minimize any effects associated with the order of testing. Electromyographic preamplifiers (model 544, Therapeutic Unlimited, Iowa City, IA; 35x differential gain, 87 dB common-mode rejection at 60 Hz, input impedance > 25 MΩ, noise < 2 μV RMS) were applied over the bellies of the semitendinosus and biceps femoris longus muscles. Electrode placements were standardized according to the recommendations of Perotto. Self-adhesive stimulating electrodes (2.75 × 5.00 inches, Dura-Stick II, Chattanooga Group, Hixson, TN, USA) were placed over the proximal and distal surface of the quadriceps muscles and connected to a high voltage constant current stimulator (model DS7AH, Digitimer Ltd., Hertfordshire, England) that was used to provide electrical stimuli during testing. Subjects sat on a small platform placed on the HUMAC NORM Testing and Rehabilitation System’s (Computer Sports Medicine, Inc., Stoughton, MA, USA) chair during testing in order to limit noise associated with pressure on the EMG preamplifiers. Subjects were tightly secured to the test system’s chair using a waist strap, chest straps, and a thigh strap according to the manufacturer’s guidelines. The lateral epicondyle of the femur (theoretical axis of motion) was aligned with the axis of the dynamometer (Figure 2). The knee was positioned in 60° of flexion and the hip in 90° of flexion. The test system’s torque arm pad was fixed to the shank approximately 7.5 cm proximal to the medial malleolus.

In preparation for testing, brief electrical pulses of submaximal intensity were then delivered to familiarize
the subjects to the electrical pulses. The intensity of electrical stimuli used during testing was determined while the subjects were seated at rest by sequentially stimulating the quadriceps muscle with pulse trains (10-pulses, frequency:100 Hz, pulse duration: 200 μs, 400V) in current steps of 100 mA until the torque associated with the stimulation-induced contractions no longer increased, but decreased. Current was then reduced by 50 mA and a final stimulus was provided. The current that produced the greatest torque was selected for use during testing.

Four submaximal isometric knee extension and flexion trials (approximately 50% to 85% maximum effort) and one five second maximal voluntary isometric contraction (MVIC) were then performed to familiarize the subjects with performing the isometric test and potentiate their quadriceps muscles. Just prior to maximal testing, three baseline EMG recordings were obtained while subjects sat at rest. The results of these trials were later used to remove baseline noise from the signals in post-processing. After a two minute rest period, subjects performed three knee extensor and three knee flexor MVICs (five second duration) in an alternating order. Loud verbal encouragement and visual feedback of the real-time torque was provided during maximal contractions to facilitate maximal effort. Approximately three seconds after the onset of each MVIC trial, a supramaximal train of electrical pulses at the predetermined stimulus intensity was superimposed on the subject’s maximal effort. Each maximal trial in extension or flexion was separated by three minutes to minimize fatigue. When testing was completed on the first side, subjects were positioned for testing of the opposite side. The testing procedures for the opposite leg were identical to those used when testing the first side.

DATA MANAGEMENT AND ANALYSIS
A custom-written LabVIEW program (version 7.0, National Instruments Corporation, Austin, TX, USA) was used to trigger the stimulator and collect EMG and torque data during testing. The EMG signals were low pass filtered at 500 Hz using an 8th order analog Butterworth filter and torque signals were low pass filtered at 4 Hz using a 3rd order analog Butterworth filter. All signals were sampled at 1000 Hz. Torque signals were converted to torque values (N·m) using calibrated conversion factors that were validated onsite prior to testing. After removing the recorded baseline values, the EMG signals were full-wave rectified. The average hamstrings muscle activities observed in the 200 ms epoch immediately prior to and after burst superimposition were used in analysis. Hamstrings activity during knee extension trials was normalized using the average hamstrings activity recorded during the 200 ms epoch preceding peak torque in the maximal knee flexion trials. The average of the values recorded during the three test trials was used in analysis. Quadriceps voluntary activation was determined for each leg using the following formula:

\[
\% \text{Activation} = \frac{1 - \text{Stimulation Induced Torque during MVIC}}{\text{Stimulation Induced Torque at Rest}} \times 100
\]

All statistical analyses were performed using SPSS for Windows version 15.0 (SPSS Inc., Chicago, IL, USA). Descriptive statistics were calculated for subject demographics, voluntary activation values, and hamstring activity during knee extension. Gender, time epoch (before and after stimulation), and side were the independent variables. Quadriceps voluntary activation values and magnitude of medial and lateral hamstrings activity were the dependent variables. A one-way analysis of variance (ANOVA) was used to assess differences in demographics by sex. Repeated measures ANOVA with two within-subjects factors (time, side) and one between-subjects factor (sex) was used to evaluate the effects of burst superimposition on the hamstrings muscle activity. Repeated measures ANOVA with side as within-subjects factor and sex as a between-subjects factor was used to evaluate side-to-side and sex differences in the estimates of voluntary activation. A significance level of \( \alpha = 0.05 \) was set for all statistical analyses.

RESULTS
As expected males and females differed significantly in their height and weight; their age and activity-level were similar, however (Table 1). The mean estimates of voluntary activation of the quadriceps muscles were similar by sex \( (P = 0.353, \text{Figure 3}) \). No side-to-side differences in voluntary activation values were observed \( (P = 0.318, \text{Figure 3}) \). Burst superimposition did not reduce the magnitude of antagonistic hamstrings muscle activity observed (Figure 4). Conversely, antagonistic medial hamstrings activity was significantly higher after burst superimposition \( (P < 0.001, \text{Figure 5}) \). Antagonistic lateral hamstrings activity was also higher after burst superimposition, but did not reach statistical significance \( (P = 0.087, \text{Figure 5}) \).

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<th>TABLE 1. Subject Demographics</th>
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C. Krishnan and G. N. Williams
Hamstrings Activity in Burst Superimposition Strength Testing

DISCUSSION

The aim of this study was to evaluate the effects of the burst superimposition method of knee extensor strength testing on hamstrings muscle activity during testing. Consistent with previous findings, noteworthy hamstrings activity was observed during voluntary knee extensor MVICs. Males and females were able to activate their quadriceps muscles to a similar extent. This finding and the mean voluntary activation values obtained using the burst interpolated twitch technique are consistent with those reported in the literature. The results of the study indicate that hamstrings activity is not minimized in burst superimposition strength testing. Contrary to our hypothesis, we observed a small (approximately 2%), but statistically significant increase in hamstrings activity with burst superimposition. A practical mathematical model previously described in work from our laboratory predicted that the small increase in hamstrings activity after burst superimposition only increases the error in strength testing by approximately 0.84%. Hence, we do not believe that the small increase in antagonist activity is clinically meaningful.

Restoring quadriceps muscle strength and function is a primary focus for patients and therapists after knee joint injury and surgery. Knee extensor strength tests are advocated in the clinical management of patients who sustain serious knee injuries or undergo knee surgery because a growing body of evidence indicates that quadriceps strength and control are important to knee health. Accordingly, strength testing accuracy is important. Previous research from our laboratory and other researchers suggests that antagonist activity is a source of measurement error in knee strength testing. Minimizing antagonist activity, therefore, may lead to more accurate strength tests. We hypothesized that superimposing an electrical stimulus on the quadriceps MVIC, a method already considered to be the “gold-standard” for knee strength testing by some, may reduce antagonistic hamstrings activity based on evidence that cortical reciprocal inhibition (reduced cortical excitability of antagonist muscles) occurs with peripheral electrical stimulation. Our results, however,
indicate that hamstrings activity increased to a small degree.

There are several possible explanations for the observed increase in hamstrings activity with burst superimposition. It is plausible that the sudden increase in the rate of motor unit discharge with burst superimposition excited Renshaw cells and resulted reciprocal excitation as Renshaw cells are known to have an inhibitory effect on Ia inhibitory interneurons that mediate reciprocal inhibition.22 Another possible explanation relates to the so-called “common drive phenomenon”, which states that the agonist and antagonist motor neuron pools are governed as if they belong to the same motor neuron pool.23 Accordingly, the increased activation of quadriceps muscle with burst superimposition may have lead to a parallel increase in antagonist hamstrings muscle activity. The rather small increase in hamstrings activity after burst superimposition is likely due to the fact that most of our subjects had near complete quadriceps activation (Figure 3). One of the limitations of this study is that we are unable to evaluate muscle activity during the period when the burst was being delivered due to the large stimulus artifact associated with the pulse train (Figure 4). It is possible that there was a brief, but significant increase in hamstrings activity as a result of volume conduction of the pulse train during this epoch. Such an increase in hamstrings activity could have potentiated and increased the excitability of the hamstrings motor neurons. Finally, it is possible that the increase in knee extensor torque resulting from burst superimposition increased the strain in the connective tissues of the knee and thereby provoked reflexive hamstrings excitation. Though plausible, we believe that this mechanism is unlikely when the magnitude of change in knee extensor torque, the hamstrings activity patterns, and the angle of testing are considered.

It should be noted that a selection bias was introduced by only including active young people with no history of serious lower extremity injuries. We selected this population because prior research had clearly demonstrated that noteworthy antagonistic hamstrings activity could be expected in active young people. The population used, therefore, was appropriate for our research question. We excluded people with a history of knee injuries because we believe it was advantageous to minimize the potential confounding effects and the variability associated with strength testing after injury. Yet, we acknowledge that the generalizability of the results was limited by using this approach.

**CONCLUSION**

Our results indicate that the burst superimposition knee extensor strength testing method results in a small increase in hamstrings activity rather than more complete reciprocal inhibition. This increased antagonistic activity, however, is not believed to be clinically meaningful as practical mathematical modeling suggests the associated error is approximately 1%.

**REFERENCES**


PATELLOFEMORAL RESURFACING ARTHROPLASTY: LITERATURE REVIEW AND DESCRIPTION OF A NOVEL TECHNIQUE

Anthony Cannon; Mary Stolley, R.N.; Brian Wolf, M.D.; and Annunziato Amendola, M.D.

ABSTRACT

There are a variety of operative and non-operative modalities that can be used to address patellofemoral pain secondary to arthrosis. Patellofemoral Arthroplasty (PFA) is one of the latest alternatives designed to address the pain caused by severe, isolated osteoarthritis (OA) of the patellofemoral joint (PFJ). In the past, PFA has experienced variable success rates, and as a result many surgeons prefer Total Knee Arthroplasty. Arthrosurface, Inc. (Patellofemoral HemiCAP) has developed a new, minimally invasive, anatomic resurfacing technique with advantages to the performance of the traditional PFA components that may provide more consistent success rates. This paper outlines the surgical procedure for the patellofemoral HemiCAP for isolated PF arthrosis.

INTRODUCTION

History

Patellofemoral arthroplasty is a relatively new procedure with a legacy that dates back to 1955. At that time, McKeever and associates published the first account of patellar resurfacing as a better alternative to patellec- tomy and patellar shaving to ease the pain associated with patellofemoral OA.1,2 In 1973, Levitt compiled a study similar to McKeever’s that expanded the follow-up time. His conclusion reinforced McKeever’s initial conclusion that patellar resurfacing was indeed a better way to treat patellofemoral OA.2 Long term success of this procedure was established by Pickett and Stoll, who found satisfactory results in 39 of 45 patients with McKeever prostheses at 22 years of follow-up.2

In 1974, Richards Medical developed the Bechtol I system, which introduced the concept of resurfacing both sides of the PFJ.4 Richards subsequently introduced the Type II system in 1976. The updated design featured an extension of the trochlear component that extended toward the intercondylar notch.6 Following these developments, Blazina and associates published the first report of patellofemoral resurfacing.1 Recent developments include custom patellofemoral arthroplasty where computer software and tomography data are employed to manufacture implants to the exact specifications of the patient’s knee. The study, published by Sisto, had a follow-up time of 73 months, which makes it difficult to draw conclusions regarding the superiority of this method.2,4 From the time of Blazina’s first publication in 1979, published success rates of PFA vary from 44-90%.1

From the variable outcomes, at present, PFA remains a controversial treatment for advanced patellofemoral OA. Many surgeons perform total knee replacement for isolated advanced patellofemoral OA, rather than PFA, as means of achieving more consistent outcomes. Some of the current issues surrounding isolated PFA are the fact that extensive exposure is necessary, a lack of long term outcome studies, and the variable success rate of this procedure. To this effect, a minimally invasive, anatomic, joint preserving PFJ resurfacing component may provide some of the solutions required to succeed in this area.

Anatomy

PFA is primarily indicated for isolated degenerative arthropathy of the PFJ. This degeneration often occurs in an area called the trochlear groove, a recessed region between the lateral and medial condyles of the femur. The trochlear groove is essential for correct patellar tracking during movement and is a very important point as to why a less invasive, focal resurfacing may be advantageous to a complete joint replacement of the PFJ. Arthritis and chondromalacia of the patella, therefore, are common pathologies that may lead to advanced degeneration requiring PFA.

Alternatives to PFA

There are many non-surgical treatments of patellofemoral arthritis or chondromalacia which include rest, non-steroidal anti-inflammatory drugs, modification of activities which may aggravate the joint, and strengthening exercises.1,2,4,7 Physical therapy has been shown to alleviate patellofemoral pain in the short term. A randomized, double-blind study conducted by Crossley, et al. showed that patients who underwent a physical
therapy regime consisting of stretching and exercises reported greater patellofemoral pain relief than patients in the placebo group who were subjected to taping and sham ultrasounds.\textsuperscript{8}

In addition to non-surgical modalities, there are also many surgical alternatives which include anterior advancement of the tibial tubercle, debridement with lateral release, chondrectomy, patellectomy, and facetectomy. Anterior advancement, which was concluded to be a durable solution by Heatly, encountered four of 29 knees that degenerated in condition with only six years of post-operative follow-up.\textsuperscript{9} Karlsson observed degeneration over a 10 year time frame, and after encountering poor results in 27 of 71 cases (38\%) went so far as to advocate that anterior advancement should not be used to treat patients with patellofemoral pain syndrome.\textsuperscript{10} Silvello, et. al. concluded that a long rehab regime could lead to satisfactory results in patients with chondromalacia but observed limited success in patients with osteoarthritis.\textsuperscript{11} Recently, a trend toward anteromedialization has emerged. Pidoriano observed mostly good results, however, all patients with central trochlear lesions had poor results with this procedure.\textsuperscript{12,13} There are also inconsistencies in the literature regarding the optimal elevation of the tubercle, incision and soft tissue approach, as well as the ideal surgical candidate.\textsuperscript{14}

Debridement with lateral release is primarily used to alleviate symptoms of early osteoarthritis, particularly with lateral tilt and lateral overload. With more advanced arthritis, this surgical procedure has unpredictable results, and may not alleviate pain. Debridement with lateral release may be useful as a precursor to more definitive procedures, if indicated.\textsuperscript{13}

Chondrectomy is the removal of defective cartilage. Often this is accompanied by micro-drilling into the bone to stimulate new cartilage growth. Chondrectomy with drilling had diminished success in patients over 30 years of age. Four patients of the 29 in this series were over 30 years of age. Of these four, two experienced failures. This is significant because there were only three failures in the entire series.\textsuperscript{15}

Patellectomy has been known to weaken the knee joint and usually requires a long rehabilitation scheme for success.\textsuperscript{7} This surgical procedure can also leave residual pain, especially if some of the trochlea has been degraded as part of the disease.\textsuperscript{16}

Facetectomy is a good procedure for the middle aged and elderly.\textsuperscript{14} However, it appears to be a temporary solution as it deals with the pain but not the predisposing factors. Radiographic analysis of patients who underwent a facetectomy showed the reappearance of osteoarthritis at approximately eight years of follow-up.\textsuperscript{14} Partial lateral facetectomy does not jeopardize the results of future operations.\textsuperscript{14}

Knowledge regarding autologous chondrocyte implantation is relatively limited. Brittberg encountered a 33\% failure rate.\textsuperscript{17} Results improved, however, when realignment of the extensor mechanism and patellar tracking was addressed.\textsuperscript{11} In addition, a long period of rehabilitation is required following this procedure to allow the cartilage implantation to heal. Because little is known and the results of this procedure are unpredictable, it is recommended that the application of this procedure should be limited.\textsuperscript{13,18}

Total knee arthroplasty (TKA) is generally not indicated for patellofemoral arthrosis in young patients, but many surgeons perform TKA for isolated PF arthrosis in the older patient.\textsuperscript{19} Patients over 55 were successfully treated and avoided realignment and osseous procedures like patellectomy.\textsuperscript{20}

**INDICATIONS**

At this time, the most prominent contraindication for PFA is tibiofemoral arthritis. Leadbetter quantifies the degree of tibiofemoral arthritis as a contraindication to be Kellgren Grade I.\textsuperscript{1,2,5,6,21-23} Because PFA deals only with pain in the patellofemoral compartment, all other compartments of the knee joint are left intact, leaving any tibiofemoral arthritis unresolved. The localization of PFA has a disadvantage in that some patients who undergo PFA require revision to TKA upon the development of tibiofemoral arthritis.\textsuperscript{15} Therefore it is essential to ensure the tibiofemoral compartment is not contributing to the arthrosis and patient's symptoms.

Conversely, because PFA is a localized procedure, the original menisci, condylar surfaces, and cruciate and collateral ligaments are spared.\textsuperscript{24} This feature of PFA allows it to be indicated in younger and more active patients. Indeed, the mean age of subjects in the literature reviewed was around 50 years of age where TKA would be considered a more aggressive procedure.\textsuperscript{2,19,24} Many of these younger patients have had no previous history of arthritis, meaning their arthrosis is more likely to be isolated, and may be post-traumatic, a circumstance in which the results of PFA are better.\textsuperscript{5,19}

It is also very important that the pain localized to the patellofemoral compartment is correctly identified as a result of joint degeneration. Chondromalacia or any superficial or partial cartilage injury is a contraindication for this procedure.\textsuperscript{16,23} In addition, any significant malalignment must be addressed before performing PFA.\textsuperscript{21}

A trial of non-surgical modalities like stretching and strengthening exercises should be attempted and must have failed prior to PFA. In summary, the author’s indication for this procedure is patellofemoral pain secondary to isolated PF arthrosis that is not responsive to conservative treatment modalities, and is occurring in patients older than 40 years of age (Table 1).
The purpose of this paper is to describe a relatively new technique for a minimally invasive, anatomic resurfacing of the PFJ for isolated advanced degenerative OA. The technique described herein is unique in that the resurfacing components, developed by Arthrosurface, Inc. attempt to restore the anatomic contour of the trochlear groove and to minimize the area resurfaced to the area of the lesion only, by not making extensive bone cuts. This procedure affords immediate stability to begin rehabilitation.

A medial parapatellar incision is made in the usual fashion through the medial skin, retinaculum, and capsule into the PFJ. The medial tibiofemoral compartment, fat pad, and meniscus are left intact. The exposure should allow visualization of the trochlea, and allow elevation of the patella to a vertical position for resurfacing (Figure 1).

Once the PFJ is exposed, establish the working axis with the drill guide and guide pin. Place the drill guide on the trochlear lesion so that it is stable with four points of contact in the superior/inferior and medial/lateral axes. Having these points of contact is crucial in establishing a working axis that is normal to the articular surface which helps to optimize implant fit (Figure 2). The guide pin is then placed into the center of the lesion through the drill guide.

The third step is the preparation of the femoral implant bed. Drill the pilot hole until the proximal shoulder of the drill bit is flush with the articular surface. After drilling the pilot hole, advance the tap into the pilot hole to the depth specified by the etch marking on the tap. The fixation stud is then advanced into the pilot hole to the depth specified by the colored line on the hex-driver. The fixation stud should be flush with the contour of the native articular cartilage at the superior and inferior poles.

Once the correct depth of the fixation stud has been established, a contact probe is used to take measurements of the superior/inferior and medial/lateral offsets of the trochlea. This measurement determines the curvature of the femoral or trochlear component. The measurements are taken by reading where the graduations on the contact probe match an etch on the centering shaft; higher numbers indicate a higher radius.

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<td>Indications for Patellofemoral Arthroplasty</td>
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<tr>
<td>1. Failure of conservative treatment modalities</td>
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<td>2. Absence of symptomatic tibiofemoral arthritis</td>
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<tr>
<td>3. Patient has no malalignment (or has been corrected)</td>
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<tr>
<td>4. Surrounding menisci, and cruciate and collateral ligaments are intact and stable</td>
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Figure 1. The incision and exposure of the patella and trochlea prior to any surgical work. Focal areas of wear on both the patella and trochlea.

Figure 2. The working axis is established by centering the drill guide over the defect with four points of contact on the trochlear articular surface.
Patellofemoral Resurfacing Arthroplasty: Literature Review and Description of a Novel Technique

of curvature (Figures 3B, C). Superior/inferior offsets are positive and medial/lateral offset values are negative. These values are recorded by marking the maximum between the superior/inferior measurements and the minimum between the medial/lateral measurements (Figure 3A). These values tell which trial cap and femoral resurfacing component will be the best fit and will be used later in the procedure.

The circular scalpel is used to score the edge of where the implant is to lie, followed by drilling the implant bed with the appropriate color-coded femoral reamer. Advance the femoral reamer over the guide pin until the reamer contacts the top of the fixation stud, creating the femoral component surface. The trial cap is selected based on the offset values measured earlier. The femoral implant bed is now prepared and a trial implant is inserted to ensure congruity (Figure 4A).
The fourth step involves the preparation and fixation of the patellar implant. Place the alignment guide so that the pin fits in the taper of the femoral fixation stud. While observing the range of motion of the knee, the needle of the alignment guide will transfer the central axis of the femoral fixation stud. This betrays the target placement of the patellar component. Then, in a fashion similar to the femur, use the drill guide to assess the size and location of the lesion. Place the central axis of the drill guide over the indentation made by the alignment guide, making sure of four points of contact in the superior/inferior and medial/lateral directions. These four points of contact are crucial in obtaining the correct working axis and proper implant fit. With the centering shaft secure in the patella, place the contact probe over it and measure the superior/inferior and medial/lateral offsets. Record the maximum superior/inferior measurement and the minimum medial/lateral on the patellar sizing card. These measurements indicate which patellar trial cap and patellar resurfacing component to use. The patellar component is aligned based on the superior and inferior orientation of the patella. The patellar resurfacing component is cemented into place in the usual fashion (Figures 5A, B).

The final step is seating the femoral implant. The femoral resurfacing component is aligned in two planes to ensure a proper fit. Assuring proper implant positioning in the holder and with the anatomic offsets will afford a proper implant orientation and fit. The final implant is shown in Figure 4B.
The advantage of this technique is to perform an anatomical resurfacing by minimizing the amount of bone resection, replacing the degenerative component of the joint and maintain the normal mechanics of the joint. The post operative x-ray (Figure 6) demonstrates the congruent resurfacing implant in place, which restores the patellofemoral anatomy.

Postoperative rehabilitation is straightforward, with local modalities and compression to control swelling. Early ROM is encouraged, muscle exercises, and weight bearing as tolerated immediately after surgery. Initially crutches can be used, but the patient can progress off the walking aids as tolerated.

DISCUSSION AND CONCLUSION

This paper describes a novel technique for the anatomical resurfacing of the focal degeneration of the PFJ. Isolated PF degeneration continues to be a significant and common problem in the older active adult. In these patients that are generally younger and more active than the traditional arthritic population, it does make some sense to limit the surgical reconstruction to the area involved in the degeneration. The Arthrosurface HemiCAP provides a limited resurfacing technique that allows immediate rehabilitation, and a return to activity as tolerated. If there is progression of tibiofemoral arthrosis and a TKA is required, this implant can be easily revised as a primary procedure without compromise of the bony preparation for the TKA.

REFERENCES


SUTURE REPAIR OF POSTERIOR STERNOCLAVICULAR PHYSEAL FRACTURES: A REPORT OF TWO CASES

Christopher Van Hofwegen, M.D., Brian Wolf, M.D.

BACKGROUND

Posterior fracture dislocations of the medial sternoclavicular joint represent less than 1% of all fractures of the clavicle in children and young adults. Complications from this injury can be severe, including compression of the great vessels or even the airway. Immediate closed reduction is required to prevent potential catastrophe followed by an assessment of fracture stability. For unstable fractures, irreducible fractures or late presentations of displaced posterior fractures, operative intervention has been recommended. However, no universally agreed upon method for stabilization exists. Fixation options ranging from Kirschner wires to plates to suture wires have been proposed. We report 2 cases of successfully treated, posteriorly displaced, medial physeal fractures of the clavicle with suture fixation and their 2 ½ year follow-up.

CASE 1

A seventeen-year-old wrestler felt a “pop” in his anterior chest wall after being body slammed to the mat. Initially he avoided medical contact in an effort to work through the injury. However, pain in the chest and inability to use right his arm persisted, so he presented to the emergency room the following morning. On radiographs and computed tomography (CT) scan, he was found to have a physeal fracture of the medial clavicle with significant posterior displacement on the right side (Figure 1). Under a general anesthetic, the clavicle was manually reduced to a normal appearance, and his arm was immobilized in a sling. However, during transfer to the CT scanner for post-operative confirmation of his reduction, he felt another “pop” and recurrent dislocation. This was confirmed via CT scan. He underwent definitive surgical fixation the next day using the technique that is described. His post-operative course was uneventful.

At his 2½ year follow-up, he reported no problems with the shoulder. He felt no crepitance or pain. He said the shoulder functioned at least as well as the contralateral shoulder. He participated fully in golf four months following his injury during his junior year of high school. As a senior, he went on to play football, wrestle, and golf. His shoulder function continues to allow him to participate in recreational sports and lift weights in college.

On examination at his follow-up appointment, he had a small, curvilinear scar over the medial sternoclavicular joint with a slightly posteriorly displaced end of the clavicle compared to the left side. There was no crepitance or tenderness over the SC joint or in the shoulder. There was no evidence of instability at the medial sternoclavicular joint.

His right shoulder range of motion was identical to the unaffected left shoulder. Both forward flexion and abduction measured 180 degrees. Internal and external rotation with his elbow to his side and with elbow abducted 90 degrees all measured equally at 90 degrees. He had 70 degrees of extension.

His functional assessment using the patient self-reported section of the American Shoulder and Elbow Score Activities of Daily Living (ASES) was equivalent between right and left shoulders at 27 of a possible 30, an excellent score. This measures both pain and function. He also scored the maximum possible using the Marx Shoulder Activity scoring system, 20 of 20, meaning the frequency at which he is able to perform stressful shoulder activities is not limited. Using the Disabilities of Arm, Shoulder and Hand scoring system (DASH), he scored the best possible at zero, meaning he had no pain or disability.

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CASE 2

A twenty-year-old hockey player suffered a medial clavicle physeal fracture on the right after getting body checked during a game. He complained immediately of chest and right shoulder pain. He also had some difficulty breathing, which resolved spontaneously. Initially, his exam and plain radiographs were deemed to be normal. However his pain persisted. At his follow up visit 3 weeks later, a CT scan was ordered that revealed a physeal fracture of the medial clavicle with significant posterior displacement and compression of the underlying great vessels. He was referred to our institution for further care. At his initial encounter, his physical exam was notable not only for posterior displacement but also for the amount of mobility he had at the medial sternoclavicular joint, even after three weeks. He then underwent uncomplicated open reduction and suture wire fixation using the described technique. He recovered uneventfully and has experienced a full return of function.

At his 2½ year follow-up, he reported no problems with the shoulder. He felt no pain or crepitance with any range of motion or activities. He had stopped playing hockey for personal reasons but has taken up triathlons and reported swimming 10-15 miles per week without problems.

On examination, he had a small hockey-stick-shaped scar over the medial sternoclavicular joint with slight posterior displacement of the clavicle compared to the left side. No crepitance or tenderness over the SC joint or in the shoulder.

His shoulder range of motion was excellent and identical when compared from right to left. Forward flexion and abduction both measured 180 degrees. Internal and external rotation with arms at the side and in 90 degrees of abduction measured 90 degrees. Extension measured 70 degrees.

His shoulder function was also excellent using three different instruments: ASES, Marx shoulder activity scoring system, and DASH. His raw scores were 30/30 for the ASES (30 being the best function), 16/20 for his Marx activity score (16-20 being excellent shoulder activity), and 0/100 for the DASH (0 being completely asymptomatic).

SURGICAL TECHNIQUE

A hockey-stick-shaped incision is made over the clavicle and curved inferiorly onto the sternum. Dissection is carried down to the level of the platysma muscle, which is then incised. The superior and clavicular fibers of the medial pectoralis major muscle are dissected off the clavicle to expose the medial end of the clavicle. The anterior fibers of the medial sternoclavicular joint are then encountered and opened in line with the clavicle. The physeal fracture, which typically occurs slightly lateral to the sternoclavicular joint, is stripped of surrounding soft tissue. The fracture is then reduced with a towel clip (Figure 3).

A vertical row of three 2 mm holes on each side of the fracture is drilled, being careful to perforate only the anterior cortex of the clavicle. This safely avoids the deep, mediastinal structures. Again, care is taken to preserve the sternoclavicular joint medially. Three #2 Fiberwires® (Arthrex, Inc., Naples, Florida, USA) are threaded through the physeal cartilage medial to the sternoclavicular joint in a simple suture fashion (Figure 4A). These sutures are then tied down securely over the fracture (Figure 4B). Once fixed, gentle pressure is applied to assure fracture stability. The wound is irrigated and closed in layers.
POST-OPERATIVE PROTOCOL

We recommend sling immobilization for three weeks, coming out for pendulum exercises only. From three to six weeks, the sling may be removed for full shoulder passive range of motion in addition to the pendulums. From six to twelve weeks, active range of motion may be attempted, modifying activity according to pain. At twelve weeks, patients can be released to full activities, including weights and contact sports if asymptomatic.

DISCUSSION

Because the physis of the medial clavicle ossifies and fuses from ages 22-25, most injuries around the sternoclavicular joint are physeal fractures. Posteriorly displaced physeal fractures of the medial clavicle are rare injuries, representing only 1% of fractures to the clavicle in children. Wirth and Rockwood reported in 1996, the world's literature revealed fewer than 110 cases. Acutely, posteriorly displaced physeal fractures can be life threatening if the displaced fragment puts pressure on the mediastinal structures. Complications include brachial plexus compression, pneumothorax, respiratory distress, vascular compromise and death. There have also been multiple reports of late complications from chronically unreduced, posterior fracture dislocations.

Because of the potential for catastrophe, these injuries require prompt but carefully controlled reduction followed by an assessment of stability and decision about further stabilization. However, two schools of thought exist regarding the manner of reduction in the acute setting. Some have recommended an attempt at closed reduction without stabilization for all posterior fracture dislocations that present within 7-10 days of injury. For fractures that present beyond that time period or unstable fractures, immediate operative stabilization is recommended. On the other hand, other surgeons maintain open reduction and fixation is the index procedure of choice. Eskola cites his experience with 5 of 8 redislocations after initially successful closed reductions. Three of 8 of those patients went on to have poor outcomes. In contrast, he had good results in all of his patients who underwent primary fixation.

Once the decision to operatively stabilize the fracture has been made, the definitive procedure of choice is still up for debate. Fixation options using Kirschner wires, plates, or suture wires have all been proposed. Kirschner wires have largely been abandoned due to severe complications with pin migration, including death. Plates, although successful, have the potential for a second, hardware removal operation. More recently it has been reported that posteriorly displaced sternoclavicular dislocations can be stabilized safely with sutures confined to the anterior osseous/joint structures. Our report further contributes to the idea that the deep mediastinal structures can be safely avoided during surgical stabilization of posteriorly displaced physeal fractures of the medial clavicle. The approach is direct, and there is no need to violate any of the deep structures. There is no concern for pin migration using this method of stabilization, nor of hardware irritation. The amount of stability achieved clinically was sufficient to allow these two patients to return to full sporting activities 4 months after surgical repair. They have persisted with excellent function since then. While we agree that an initial attempt at closed reduction is warranted in patients with these injuries, we feel that for patients with unstable (case 1) or late presenting (case 2) injuries this method of open reduction and stabilization provides excellent fixation and long term outcomes.
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ABSTRACT
Reconstruction of the radial border of the index metacarpophalangeal (MCP) joint after band saw amputation is described. The entire radial MCP collateral ligament unit was cleanly retained within the amputated segment, still attached to wafers of corticocancellous bone from the radial aspect of the metacarpal head and base of the proximal phalanx. Acute bone to bone osteosynthesis of the amputated segment led to successful osseous integration of both bone fragments and restoration of stability of the joint. Surgical repair of the radial collateral ligament of the index MCP joint is crucial in achieving an optimal outcome after such an injury.

INTRODUCTION
Traumatic injuries to the hand in the work place, including saw blade injuries, are common occurrences. Although transverse and oblique partial fingertip amputations are known to occur commonly, sagittal injuries are quite rare. We present a case of a sharp, traumatic, sagittal plane amputation of the index finger MCP joint involving complete loss of the entire radial collateral ligament complex and partial loss of the first dorsal interosseus muscle. This unique case report provides a vivid illustration of the surgical anatomy at the index finger MCP joint and emphasizes the importance of reconstructing the radial collateral ligament in order to best preserve overall hand function. In 1977, Fitzgerald accurately stated, “The fundamentals of treatment in mutilating hand injuries include surgical debridement of devitalized tissue, excision of foreign material, and stabilization of fractures.” 1 Treatment with early debridement and osteosynthesis allowed the reconstruction of the radial collateral ligament complex and enabled the patient’s unrestricted return to employment by four months postoperatively.

CASE REPORT
A 35-year-old right-hand dominant male butcher injured his dominant hand with a meat band saw while butchering a piece of pork. He presented to the emergency department (ED) within 30 minutes of the injury, along with the amputated portion of his index finger.

Examination of his right hand demonstrated a clean-cut seven-centimeter wound on the radial side of the index finger extending from the mid-portion of the first web space to a point just distal to the MCP joint, with minimal active hemorrhage (Figure 1). The amputated segment contained the radial border of both the index metacarpal and the proximal phalanx, with the MCP radial collateral ligament visibly intact, connecting the two bony wafers (Figure 2). The first dorsal interosseus muscle was partially amputated, and a volar sesamoid was also sectioned and contained within the amputated segment.

The patient’s neurovascular exam was fully intact. On both the radial and ulnar sides of the distal index finger, sensation was intact to light touch and two-point discrimination was less than five millimeters. Motor examination showed he could adduct but not abduct his index finger. Both the flexor digitorum profundus and flexor digitorum superficialis tendons were intact to the index finger. Pulses and capillary refill were normal.

In the ED, a forearm tourniquet and local anesthetic were utilized for both initial wound exploration and irrigation and debridement. The amputated portion of his finger was cleaned with sterile saline, wrapped in saline soaked gauze, placed in a plastic bag, and then preserved on a bed of ice. Tetanus toxoid booster and cefazolin were administered in the ED, and the patient was then taken to the operating room.
In the OR, under general anesthesia and tourniquet control, the wound was pulse lavaged with normal saline and the amputated segment was cleaned with Technicare (Care-Tech Laboratories, Inc., St. Louis, MO) solution. The bony wafers with the attached radial collateral ligament were dissected from the overlying amputated tissue. The metacarpal wafer was preliminarily fixed with a Kirschner (K)-wire and then with two 1.5 mm modular screws (Figures 3A-C).

The radial collateral ligament was tensioned by flexing the MCP joint to 50 degrees. The distal bone wafer was temporarily secured to the proximal phalanx with a K-wire, then fixed with 1.3 mm and a 1.5 mm modular screws. The abductor mechanism was re-attached using simple interrupted 4-0 Vicryl suture. Intraoperative varus/valgus joint stability was satisfactory. The wound was closed primarily by raising local skin flaps.

Postoperatively, intravenous cefazolin was continued for 24 hours, and the patient was discharged home. The MCP was immobilized in a splint flexed to 50 degrees for two weeks, followed by a course of physical therapy for range of motion. The patient returned to light duty work at six weeks with continued hand therapy.

By 16 weeks, the patient’s MCP joint had full range of active motion from 0-90 degrees of flexion, and was stable to varus and valgus stresses throughout the flexion arc. Grip strength measured by Jamar dynamometer was 65% of the contralateral side and pinch strength was 10 kg on the injured side compared to 13 kg on the left. Follow-up radiographs revealed progressive healing of the wafers with no change in alignment (Figure 4), and
he returned to his full duties as a butcher. He was lost to further follow-up following his return to work.

DISCUSSION

To our knowledge, we present the first case report of a band saw sagittal amputation of the radial collateral ligament complex of the index finger with successful reconstruction. This unique injury illustrates the complex anatomy of the metacarpophalangeal joint and underscores the importance of proper surgical repair in the restoration of function.

The MCP joint is crucial to hand function from a functional perspective, because of its critical importance in stability and mobility, allowing adequate dexterity for the digits. The anatomy of this joint has been carefully investigated over the years, and bears great clinical relevance to the structural changes seen in MCP injuries and dislocations, rheumatoid arthritis, and MCP arthroplasty.

The gross morphology of the MCP joint has been well described by Wise and Minami. This diarthroidal joint allows flexion, extension, abduction, adduction, and rotation of the proximal phalanx on the metacarpal head. Joint stability is maintained by the articular structure, the joint capsule, and the forces of the musculo-tendinous unit. The muscle and tendon forces are assumed to be primary joint stabilizers acting to sustain pinch and grasp, while the joint ligaments and capsule provide initial stability to instantaneous forces and provide second-line defense in maintaining stability during static loading conditions.

The fibrous capsule of the MCP joint is attached to the circumference of the base of the proximal phalanx just distal to the articular surface. The thick volar plate of the flexor tendon sheath is itself anchored to these fibers, with negligible attachment to the fibers of the joint capsule attachment to the metacarpal; thus, the volar plate is able to move with the proximal phalanx independently of the metacarpal. Capsular thickenings on either side of the joint form the collateral ligaments, which run from the metacarpal tubercles in two parts to insert onto the volar two-thirds of the lateral margin of

Figure 3A, 3B, 3C. Fluoroscopic guidance for sequential K-wire and modular screw placement.

Figure 4. AP radiograph taken at 16 weeks demonstrates healing of the reattached bony fragments with maintenance of index MCP joint congruity and MCP extension.
the phalangeal base and the lateral margin of the palmar plate (Figure 5).

Both the ulnar collateral ligament (UCL) and radial collateral ligament (RCL) are separable into two layers, one superficial and one deep. The ligaments are eccentrically oriented such that ligament length changes depending on the relationship to the fixed joint axis (Figure 6), an intrinsic property known best as the “cam” effect.6 Glickel has estimated collateral ligament length of 14 mm with 20 degrees of MCP extension, 17 mm with 0 degrees of flexion, 19 mm with 50 degrees of flexion, and 18 mm with 90 degrees of flexion.6 A recent isolated analysis of the index MCP joint suggests that the stability of tightening the MCP in flexion is directly related to a change in collateral ligament length, and not to a dynamic biomechanical change in the ligament structure.7 These observations provide the justification for splinting the MCP in 50 degrees of flexion to prevent an extension contracture.

The UCL and RCL play primary roles in stabilizing the MCP joint in all four modes of joint displacement, reported as distal distraction, dorsopalmar dislocation, abduction-adduction rotations, and supination-pronation rotations in a biomechanical analysis.8 In addition, the skin and soft tissue around the MCP joint, the transverse intermetacarpal ligament, and the flexor retinaculum through the sagittal bands all play a stabilizing role. To clinically test the integrity of the MCP collateral ligaments, the joint should be placed into 90 degrees of flexion with force applied in a radial and ulnar vector, testing for laxity compared to the similar contralateral digit.8

CONCLUSIONS

The observed successes of operative intervention for closed collateral ligament ruptures and avulsions to restore MCP stability9-16 highlights the specific importance of the RCL and UCL in conveying proper hand function. The established benefit of collateral ligament repair suggests that early ORIF for osteosynthesis of bony fragments created by MCP collateral ligament avulsion should be considered by the orthopaedic surgeon when conservative methods fail and MCP instability exists. Such fragments may be primarily repaired with screws, if possible, but may need to be reconstructed with suture or suture anchors if the bone fragments are too small for screw purchase.

When a surgeon is faced with an amputation injury with loss of substance as seen in this case, the “filet flap” approach should always be considered with inspection of the amputated part for any and all possible tissues that can be salvaged to allow for primary reconstruction of joint congruence and stability. An open injury to the MCP complex, such as the unusual index finger RCL border amputation described in this case, justifies an acute operative repair whenever encountered.
Metacarpophalangeal Collateral Ligament Reconstruction after Band Saw Amputation

REFERENCES


XANTHOMA OF BONE:
A REPORT OF THREE CASES AND REVIEW OF THE LITERATURE

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ABSTRACT
Xanthoma of bone is a rare bone disorder characterized as a lytic lesion, often with cortical expansion or disruption. Because of its aggressive radiographic appearance, other primary bone tumors and metastatic lesions need to be ruled out. We present three cases of intraosseous xanthoma: one occurring as a pathologic fracture in the distal tibia, one discovered incidentally in the iliac crest in a patient with hip pain, and one discovered incidentally in the occipital bone of the skull in a child with widespread Hodgkin's lymphoma. All patients were treated with curettage of the lesions; craniectomy followed by cranioplasty for the ocipital lesion, and curettage followed by internal fixation and bone grafting for the tibial lesion. The lesion in the iliac crest was treated with curettage and bone grafting. At the most recent follow-up (12, 15, and 24 months for patients with occipital, iliac crest, and tibial lesions, respectively), there was no evidence of local recurrence.

INTRODUCTION
Xanthoma of bone is an exceedingly rare benign primary bone tumor histologically characterized by mononuclear macrophage-like cells, abundant foam cells, and multinucleated giant cells. Occasionally, spindle cells are present, which has led investigators to include this lesion as a subset of benign fibrous histiocytoma (BFH) of bone.1 However, BFH lesions typically have spindle cells arranged in a storiform pattern. When BFH occurs as an inactive lesion in the metaphyseal portions of long bones, the complex is known as nonossifying fibroma. BFH, a rare, fibroblast-like spindle cell lesion with varying degrees of multinucleated giant cells and foamy histiocytes, may be the end stage of a reparative phenomenon secondary to extensive bone resorption. The precise classification of these types of lytic lesions relies on the presence of fibrous tissue, foam cells, and giant cells, as well as the overall clinical and radiographic appearance of the lesion.1 In addition, histologically, these lesions may vary in their proportion of giant cells, lipid-filled macrophages, spindle cells, and hemorrhagic and cystic changes.1 Intraosseous xanthomas are lytic, expansile lesions composed of lipid-laden histiocytes,2 often seen in patients with hyperlipidemic conditions.3,4

Three patients at our institution were discovered to have an intraosseous xanthoma in the absence of hyperlipidemic conditions. These three lesions were distinctive and did not have the histologic or radiographic features of BFH. Although they had abundant giant cells, mononuclear cells, and foam cells, the storiform pattern of spindle cells was lacking. We present three recent cases of intraosseous xanthoma, review the existing literature, and suggest treatment options for this rare benign bone tumor.

CASE REPORTS
We received informed consent from all patients in this study in accordance with our institutional regulations.

Patient 1
A healthy 44-year-old man felt a popping sensation in the distal aspect of his right leg while running to catch a bus. After this episode, he had severe pain and was unable to bear weight on the leg. The patient was evaluated in the emergency room and referred to an orthopaedic oncologist secondary to a pathologic fracture through a lytic lesion in the right distal tibia. The patient was healthy except for an extensive cigarette-smoking history and a remote history of intravenous drug abuse. He had had no antecedent leg pain and had been able to walk and run without difficulty before this pathologic fracture. Of note, he had a longstanding malunion of the calcaneus secondary to a fall with substantial subtalar and midfoot arthritis. The ipsilateral calcaneal fracture was unrelated to the pathologic fracture of the distal tibia.

The physical examination showed diminished range of motion of the ankle secondary to his malunited calcaneus fracture and decreased motor strength in the anterior tibialis, which was secondary to pain. He had tenderness and swelling along the distal right tibia. Radiographs revealed a destructive lesion of the distal right tibia with a pathologic fracture (Figures 1A, B). Because it was a new lytic lesion in an adult, a metastatic workup
was performed, which showed no other lesions in the chest, abdomen, or pelvis. The patient had undergone open reduction and internal fixation of a right calcaneus fracture 15 years before presentation and subsequently developed a malunion with moderate arthritis in the foot and ankle. To define more clearly the extent of the lytic tibial lesion and potential articular involvement, a computed tomography (CT) scan of the distal tibia was obtained, which showed cortical destruction of the medial tibia (Figure 1C). A magnetic resonance imaging (MRI) scan of the right leg revealed extension of the lesion into the adjacent soft tissues (Figure 1D).

A CT-guided needle biopsy was nondiagnostic, and a subsequent open biopsy showed a xanthoma of the right tibia. The patient was treated definitively with curettage, bone grafting, and internal fixation of the distal tibia. He remained nonweightbearing on the right leg for 3 months until there was radiographic evidence of healing and bone graft consolidation. His pain has resolved, and at the 24-month follow-up, there was no evidence of local recurrence (Figure 1E).
A healthy 23-year-old man sustained a fall onto his right flank and hip 3 weeks before presentation. He had immediate right flank and hip pain that did not improve with nonsteroidal antiinflammatory medications. The patient stated that he had had no antecedent pain in the right flank or hip before his fall. The pain was exacerbated by forceful activities, including sit-ups, coughing, and sneezing; however, he had no pain during the night or at rest. After 2 weeks without resolution of his painful symptoms, he sought medical treatment. The physical examination showed no tenderness to palpation over the right iliac crest, and the patient had full, symmetric, and pain-free range of motion of bilateral hips, knees, and ankles. He had right hip flexion to 110°, internal rotation to 30°, and external rotation to 60°, which was symmetric to the contralateral side. He had 5/5 motor strength throughout the bilateral lower extremities and normal sensation in the lower extremity dermatomes. He was afebrile, and all of his laboratory studies were within normal limits.

Radiographs of the pelvis showed a lytic lesion in the right iliac wing with a well-defined border and no matrix (Figure 2A). An MRI scan (Figures 2B, C) showed a
bone lesion in the right iliac wing that was bright on T1-weighted images and isointense on T2-weighted images with expansion of the inner table of the iliac wing. A CT-guided needle biopsy revealed a xanthoma of bone. Intralesional curettage and bone grafting with particulate allograft was performed, and the inner table of the ilium was removed with the lesion. Postoperatively, the patient was restricted to protected weightbearing on the right side for 6 weeks. The patientís pain completely resolved and he was free of local recurrence at the 15-month follow-up (Figure 2D).

**Patient 3**

A 9-year-old boy with a history of stage IVB Hodgkin’s lymphoma had an expansile, lytic bone lesion in the right upper occipital region of the skull at the level of the transverse sinus, measuring approximately 1.7 cm X 1.0 cm (Figure 3A). A bone scan showed a focus of moderately increased uptake in the right occipital skull. Because of the history of Hodgkin’s lymphoma and the possibility that this lesion was related to that diagnosis, a biopsy was recommended. The patient was asymptomatic and was nontender to palpation over the mass; his ocular and neurologic examinations were normal. The patient was taken to the operating room by the neurosurgery service for open biopsy, subtotal curettage of the lesion, and subsequent cranioplasty via titanium mesh plate (Figure 3B). The final histologic evaluation showed xanthoma of bone without evidence of lymphoma. Postoperatively, the patient had no sequelae secondary to the biopsy and was discharged from the hospital on postoperative day 2. At 12 months after surgery, he had no sequelae of his surgery, was pain free, and had no radiographic progression of the lesion. He continued to be treated by a pediatric oncologist for his Hodgkin’s lymphoma.

**DISCUSSION**

Xanthoma is an exceedingly rare bone tumor (<50 cases reported in the appendicular and axial skeleton). Often, lesions consist of sheets of foam cells and occasional nonfoamy mononuclear macrophage-like cells. The lesions have numerous multinucleated giant cells; occasionally, the Touton-type giant cells (Figure 4). Spindle cells are not a prominent feature of these lesions.
All three of the lesions we have presented stained heavily with Factor 13-A, a marker characteristic of certain histiocytic proliferations. The lesions had histologic similarities to pigmented villonodular synovitis, but they were not located in synovial-lined tissues. Radiographically, these lesions are generally well-defined, yet some of the borders blended imperceptibly with normal bone. In our series of patients, each lesion lacked a sclerotic rim and had no radiographic similarities to nonossifying fibroma. MRI examination of the tibia showed that this lesion extended into the adjacent soft tissues, a feature uncharacteristic of BFH of bone. Based on their unique histologic and radiographic features, these three lesions are distinctive and best referred to as xanthoma of bone; we do not believe that they can be categorized as BFH. These lesions were benign and amenable to complete curettage. In addition, no patient had evidence of a systemic lipid disorder.

With respect to its anatomic distribution, xanthoma has been described in several intraosseous locations: femur,\cite{2,6} skull,\cite{2,8-11} hand,\cite{5} ribs,\cite{2} calcaneus,\cite{2,17-20} pelvis,\cite{2} mandible,\cite{21-23} sacrum,\cite{24} ulna,\cite{25} radius,\cite{2} humerus,\cite{2} spine.\cite{2,26,27}

The differential diagnosis for patients presenting with lytic lesions is broad and depends on the patient’s age and the presence of other disease states. It includes primary bone tumors and metastatic bone disease. The particular lesions described in our case series, similar to many benign bone tumors, may be discovered incidentally from imaging studies taken for other reasons. In addition, patients may present with a pathologic fracture,\cite{7} as demonstrated by the patient with the tibial lesion. Because of the similar radiographic appearances, a tissue diagnosis is often necessary. For this reason, each patient had a confirmed tissue diagnosis before definitive treatment. These tumors are described radiographically...
as sharply defined, lytic lesions with an expansile border\(^2\) that can often extend into the surrounding soft tissues.\(^1\) The lesions reported in our patients matched this description, with a cortical disruption and extension into the soft tissues surrounding the ilium and tibia. Because the pelvis and tibia are prone to pathologic fracture, the optimal treatment, once a biopsy has confirmed the presence of xanthoma, consists of curettage and bone grafting. The necessity to perform internal fixation, and protect the extremity from full weightbearing, depends on the location of the lesion. Intralesional curettage removes all gross disease and usually is sufficient for local control.\(^3\) In locations such as the spine or skull base, complete curettage may be impractical, and adjuvant treatments, including irradiation, have been used.\(^2\) To date, there has been no identified local recurrence in our three patients.

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**REFERENCES**


ASYMMETRIC SPONDYLOLISTHESIS AS THE CAUSE OF CHILDHOOD LUMBAR SCOLIOSIS—CAN NEW IMAGING MODALITIES HELP CLARIFY THE RELATIONSHIP?

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ABSTRACT
The etiology of idiopathic scoliosis is likely genetic. Research is proceeding to identify the responsible genes. Although genetics accounts for the majority of idiopathic scoliosis, a subset of curves occur secondary to mechanical “foundation” issues at the lumbosacral junction. The most common mechanical “foundation” issue at the lumbosacral junction is spondylolisthesis. A relationship between lumbar scoliosis and spondylolisthesis has been well documented. Modern imaging studies are providing an opportunity to cast new light on this inter-relationship. First, computerized tomography (CT) studies, and now 3-D CT studies of the lumbosacral area have been performed in an attempt to further elucidate this matter. The purpose of this paper is to provide an introduction to the topic and to present images that suggest an etiologic relationship between lumbar scoliosis and spondylolisthesis with mild asymmetric spondylolisthesis proposed as the cause of the lumbar curve.

INTRODUCTION
The precise etiology of idiopathic scoliosis remains unknown. A complex mixture of inherited biochemical abnormalities of the discs, ligaments, and/or bone of the spinal column likely predisposes individuals to development of spinal curves. Extensive research is proceeding to identify the responsible genes, with some success. This new molecular information predicts an era in which genetic testing will be utilized to distinguish true scoliosis from curves secondary to anatomic disorders.

Thoracic and thoracolumbar curves likely develop secondary to the aforementioned genetic abnormalities during periods of rapid growth. Lumbar scoliosis may be explained by similar mechanisms in some cases, but mechanical “foundation” issues also need to be considered because of the lumbar spine’s proximity to the sacrum and pelvis. “Foundation” issues are especially pertinent in cases of lumbar scoliosis in which there is no family history of spinal asymmetry.

In some cases, curvature of the lumbar spine is associated with structural abnormalities of the lumbosacral junction, ranging from asymmetry of the sacrum to L5 lateral masses (Bertolotti syndrome) to spina bifida occulta. The most common known structural abnormalities at the lumbosacral junction are spondylolysis at the L5 level and associated spondylolisthesis with the L5 vertebra slipping anteriorly on the sacrum.

Approximately 6% of children will develop spondylolysis by adulthood and 74% of those children will develop spondylolisthesis. Additionally, children with spondylolisthesis commonly develop spinal asymmetry and/or scoliosis. This increased incidence of spinal curvature in patients with spondylolisthesis has been well documented. Studies have shown that up to 48% of children with spondylolisthesis develop at least five degrees of lumbar spinal asymmetry. Although most experts would agree that patients with spondylolisthesis and scoliosis of the upper spine likely have two separate and unrelated conditions, asymmetry in the lumbar spine presents a different possibility.

Modern imaging studies (CT and 3-D CT of the lumbosacral area) are providing an opportunity to cast new light on this inter-relationship. Review of multiple cases suggests that L5 spondylolisthesis commonly does not displace symmetrically as evidenced by a greater space in the pars defect on one side versus the other, leading to rotation of the L5 vertebrae as it relates to the sacrum. This asymmetric slip is a probable cause of lumbar scoliosis in some children.

We suggest an etiologic relationship between lumbar scoliosis and spondylolisthesis with mild asymmetric spondylolisthesis proposed as the cause of the lumbar curve. This report previews a larger retrospective study being conducted at our institution.
CASE REPORTS

Case 1

A ten-year-old female with a history of possible mild Ehlers-Danlos syndrome presented with lower back pain. A postero-anterior standing spine film showed mild lumbar scoliosis (Figure 1A) and a lateral spine film showed grade 1-2 spondylolisthesis (Figure 1B). A CT study of her lumbar spine was obtained to evaluate possible pars interarticularis defects and spondylolisthesis.

The CT study (Figure 2) showed bilateral pars interarticularis defects with associated grade 1-2 spondylolisthesis of L5 on S1. Of note, the olisthetic L5 vertebrae had

Figure 1A. (left) (Case 1) Postero-anterior scoliosis radiograph of a 10-year-old female.
Figure 1B. (above) (Case 1) A lateral radiograph demonstrates grade 1-2 spondylolisthesis at the L5 level.

Figure 2. (Case 1) A CT study at the L5 level demonstrates asymmetric spondylolisthesis. We refer to this pattern as an “asymmetric ring.” The pars displacement on the left (arrow) is greater than on the right.
Asymmetric Spondylolisthesis as the Cause of Childhood Lumbar Scoliosis

An asymmetric rotational slip with the pars defect greater on the left than on the right. We refer to this pattern of CT imaging as an “asymmetric ring.” The anatomy of the asymmetric spondylolisthesis was then visualized using a 3-D CT study (Figures 3A, 3B).

Case 2
An otherwise-healthy twelve-year-old male presented to our clinic with a complaint of right hip pain. Initial x-rays were obtained and the patient was found to have a sclerotic lesion of the right pedicle of L5 consistent with osteoid osteoma versus a healing spondylolytic lesion (Figures 4A, 4B). A CT study was ordered to further investigate the lesion and demonstrated bilateral pars interarticularis defects at the L5 level and grade 1 spondylolisthesis with sclerosis along the margins of the right-sided spondylolytic lesion (Figure 5). In this case the pars lesions appeared to be symmetric and there was no associated lumbar scoliosis.

Case 3
An eight-year-old female with a previous diagnosis of L5-S1 grade 1 spondylolisthesis and both lumbar and thoracic juvenile idiopathic scoliosis presented to clinic with a complaint of worsening spinal deformity. Radiographs confirmed the presence of spondylolisthesis and a worsening scoliosis (Figures 6A, 6B). A CT study was obtained to investigate the progression of the spondylolisthesis. Imaging showed an asymmetric grade 1 spondylolisthesis (Figure 7) with an “asymmetric ring” at the L5 level.

The patient underwent in situ posterior spinal fusion of L5-S1 via the Wiltse technique, was placed in a single-leg spica cast for one month and was then transitioned to a Boston-type scoliosis brace. The brace was worn for 23 hours per day the first 3 months and 16 hours a day thereafter. Despite the successful L5-S1 fusion with stabilization of her spondylolisthesis, she continued to have progression of her scoliosis (Figure 8).
DISCUSSION

Both idiopathic scoliosis and spondylolysis are very common childhood conditions. The incidence of scoliosis in this age group is estimated to be 0.5-3% of the population\(^{10,11,12,13,14,15}\) while spondylolysis is far more common at 6%.\(^3\) Patients with true scoliosis often have a strong family history for curve progression due to its complex genetic etiology. Spondylolysis and spondylolisthesis also have a familial predisposition,\(^{17,18}\) however, only a very small percent of the population are aware that they have the condition. When spondylolisthesis and adjacent scoliosis are seen together in a child with no family history of scoliosis one might reasonably query as to whether the spinal curvature was in some way caused by the adjacent structural abnormality.

A high incidence of lumbar scoliosis associated with spondylolisthesis has been shown in several series.\(^4,9\) In fact, studies have shown that up to 48% of children with spondylolisthesis develop at least five degrees of scoliosis.\(^8\)
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Spinal curvatures occurring concomitantly with spondylolisthesis have been divided into three main categories. First, the curvature can simply be idiopathic scoliosis of the upper spine, likely unrelated to the olisthetic defect. Second, the curvature can be of the “sciatic” type in which irritation associated with the olisthetic defect induces scoliosis via muscle spasm. Third, the curvature can be the result of an asymmetric olisthetic defect as first described by Tojner. In this case, the displaced vertebra is translated in both the sagittal and coronal planes and additionally rotated around the vertical axis thereby creating an asymmetric foundation leading to a rotatory deformity of the spine above.

In most prior studies, scoliosis in association with spondylolisthesis has been thought to be of the sciatic type. Only one series, in which olisthetic scoliosis was found in 30% of patients with symptomatic spondylolysis, supported the asymmetric foundation view. A better understanding of the relationship between scoliosis and spondylolisthesis using modern imaging techniques should help clarify the issue.
The three cases presented are meant to provide an overview of the possible relationships between spondylolisthesis and scoliosis.

Case 1 demonstrates a patient in which lumbar scoliosis is associated with obviously asymmetric spondylolisthesis. It is important to note that there was no family history of scoliosis over several generations. The current view that idiopathic scoliosis is a genetic, inherited condition makes the appearance of scoliosis in a patient with no family history for the disorder somewhat problematic and adds suggestive evidence that the spinal asymmetry associated with spondylolisthesis may be due to the olisthetic disorder rather than a true scoliosis.

This case illustrates the key issue of this paper and focus of our study: Asymmetric spondylolisthesis may prove to be of value in predicting progression of lumbar scoliosis associated with spondylolisthesis. Two mechanisms may be responsible for this association. First, asymmetric olisthesis may be more likely to trigger muscle spasm via tissue irritation inducing sciatic scoliosis. In fact, prior studies have shown that lumbar curves with rotatory olisthesis are more likely to be associated with radicular pain. Second, the asymmetric olisthesis may create an asymmetric foundation which causes the vertebrae above the slip to rotate into a torsional lumbar scoliosis.

It is interesting to note that previous investigators have found that the incidence of scoliosis associated with spondylolisthesis is much greater when the pars defect is at the L4-L5 level versus the L5-S1 level. These investigators found that eight out of nine patients with L4-L5 spondylolisthesis also had scoliosis. They attributed the higher incidence of scoliosis in these patients to the absence of stabilizing ligaments, such as the iliolumbar ligament, at the L4-L5 level. It’s likely that the olisthetic vertebrae in patients with ligamentous laxity, such as the

![Figure 7. (Case 3) A CT study shows bilateral pars defects with an asymmetric ring at the L5 level.](image1)

![Figure 8. (Case 3) Postero-anterior radiograph taken eight months after in situ L5-S1 fusion. The lumbar curve has progressed moderately.](image2)
Asymmetric Spondylolisthesis as the Cause of Childhood Lumbar Scoliosis

girl in case 1 with an Ehlers-Danlos variant syndrome, would have more freedom to rotate and slip in an asymmetric fashion. Perhaps children with ligamentous laxity are more prone to develop lumbar scoliosis if they have spondylolisthesis. Case 2 demonstrates a patient with grade 1 symmetric spondylolisthesis without an associated scoliosis and is meant to serve as a contrast to case 1. Without significant vertebral rotation there is no asymmetric foundation for the proximal vertebrae and there is less tissue irritation to induce muscle spasm. Hence, the mechanisms for the olisthetic induction of scoliosis are absent.

Case 3 demonstrates a patient with lumbar scoliosis and a secondary thoracic curve. She was also noted to have grade 1 spondylolisthesis. She was initially treated with physical therapy but she had both an increase in her scoliosis and greater lumbosacral pain. A CT scan demonstrated an “asymmetric ring” at L5. She was treated with a Wiltse-type L5-S1 fusion which relieved her back pain. Unfortunately her scoliosis continued to progress despite the successful fusion.

There are two explanations for the progression of her scoliosis. First, the vertebrae may have been fused in situ into a position of permanent asymmetry. Hence, the suspected force driving the lumbar scoliosis may have remained post-operatively. Of note, Seitsalo reported that spondylolisthesis fusions often fail to correct the scoliosis when a significant rotatory component was present. Perhaps de-rotational correction of the ring asymmetry will be considered in the future when these relationships become better established. Alternatively, the child could have true genetic scoliosis unrelated to the spondylolisthesis.

Important questions arising from our study will focus on treatment options. Should asymmetric spondylolisthesis be treated aggressively with reduction and fusion? Should asymmetric spondylolisthesis be treated in the absence of symptoms to prevent the development of scoliosis? Previous studies have shown that fusion of the lumbosacral area does not effectively treat thoracic or thoracolumbar curves (as in our case 3), but lumbar curves typically disappear post fusion. The resolution of lumbar curves is presumed to be the result of relieving muscle spasm caused by the spondylolisthesis. However, lumbar curves with a significant torsional component are sometimes, but not always, relieved by an in situ lumbosacral fusion. These curves have been described as “fixed structural scoliosis” and attributed to long-term muscle contraction. Perhaps these curves are caused by asymmetric spondylolisthesis, and reduction of these slips at the time of a single-level fusion may be necessary to prevent curve progression and even potentially reverse the scoliosis.

Although the majority of children with asymptomatic spondylolisthesis do not require treatment and can have a normal childhood, certain children may benefit from early fusion of asymmetric spondylolisthesis to avoid development of scoliosis and associated morbidity. If significant rotatory change at the L5 level is noted (i.e., an “asymmetric ring” is present on CT imaging), pedicle screw rotational reduction plus fusion could be considered rather than the currently favored in-situ fusion. Such an approach would seem radical at this time, however future analysis (and similar surgical methods) may make such an approach reasonable.

The relationship between scoliosis and spondylolisthesis in children is well established, but the actual etiologic relationship requires further research. Modern imaging modalities, specifically CT and 3D-CT studies, should help to elucidate the relationship.

REFERENCES


Contemporary locking plates promote biological fixation through indirect reduction techniques and by elevating the plate from the bone. They have improved fixation strength in osteoporotic bone. Periarticular locking plates are rapidly being adopted for bridge plating of periprosthetic femur fractures. When these plates are used for indirect reduction and bridge plating osteosynthesis, fracture union occurs by secondary bone healing with callus formation which is stimulated by interfragmentary motion. In two patients with similar periprosthetic femur fractures treated with periarticular locking plates one fracture healed by ample callus formation while the other resulted in a non-union and had no callus formation six months post-operatively. The case, which progressed to secondary bone healing with callus formation, exhibited varus migration as a result of loss of fixation. The non-union case retained stable fixation. The difference in outcome may indicate that callus formation was promoted by interfragmentary motion secondary to loss of fixation. Conversely, in absence of fixation failure, callus formation was suppressed by stable fixation with a stiff locking plate construct which reduced interfragmentary motion. These observations suggest that locked plating constructs should be sufficiently flexible when applied for bridge plating of comminuted fractures to promote callus formation.

INTRODUCTION

Periarticular locking plates are increasingly being used for fixation of periprosthetic femur fractures. They feature fixed-angle screws to improve fixation strength in osteoporotic bone. The improved fixation strength of locking plates has expanded their indication to bridge plating of comminuted fractures. In addition to providing sufficiently strong fixation, locking plates have to enable a mechanical environment at the fracture site that facilitates fracture healing. For bridge plating of periprosthetic femur fractures with locking plates, fracture healing occurs by secondary bone healing, whereby callus formation is stimulated by interfragmentary motion. In this regard, concerns are emerging that the stiffness of locked plating constructs may have the potential to suppress interfragmentary motion and callus formation.

These case reports present two comparable periprosthetic femur fractures treated with periarticular locking plates. One fracture healed by ample callus formation while the other resulted in a non-union after deficient callus formation. Additionally, biomechanical factors that may have contributed to the difference in callus formation are discussed.

CASE 1

Patient one was a 77-year-old female with a past medical history of diabetes mellitus type II, hypertension, hyperlipidemia, osteoarthritis, gastroesophageal reflux disease, and mild mitral valve regurgitation. Her diabetes was adequately controlled with an insulin regimen. She had mild chronic kidney disease but no neuropathy or retinopathy. She was a community ambulator who used a cane for balance. She had no history of tobacco or alcohol use. The patient fell after stepping from a curb and suffered a left periprosthetic supracondylar femur fracture. This was a Rorabeck type II (displaced and prosthesis intact) closed injury and the limb was neurovascularly intact.

She was taken to the operating room on post injury day two for open reduction internal fixation. A nine hole Synthes AO-LISS plate with eight 5.0 locking screws was utilized. She had no post-operative complications other than requiring a short course of oral antibiotics for a superficial wound infection that cleared. The patient was evaluated in follow-up at 7 weeks and 15 weeks with radiographs. The fracture united with ample callus seen on radiographs. She was weight bearing without pain at the fifteen week follow-up. Close inspection of the radiographs demonstrates increasing varus compared to immediate post operative films suggestive of loss of fixation (Figure 1).
Case 2

Patient two was a 74-year-old female with a past medical history of diabetes mellitus type II, valvular heart disease, hypertension, osteoarthritis, and obstructive sleep apnea. Her diabetes was adequately controlled with an insulin regimen, with HgA1c ranging from 5.0-6.0. She had no known nephropathy or retinopathy, but did have mild peripheral neuropathy affecting her toes only. She was an independent community ambulator. She had no history of tobacco or alcohol use. The patient fell while walking in her house and suffered a left periprosthetic supracondylar femur fracture. This was a Rorabeck type II closed injury and the limb was neurovascularly intact.9

She was taken to the operating room on post injury day one for open reduction internal fixation by the same surgeon as the previous patient. A Smith and Nephew Peri-Loc distal femur plate was used with one 6.5 mm and seven 4.5 mm locking screws. She had no perioperative or wound complications. She was evaluated in follow up at 4, 8, 12 and 16 weeks from injury with radiographs at each of these visits. She had very little callus formation on radiographs. Her alignment was maintained during this follow up period (Figure 2). She had continued pain at the fracture site throughout clinical follow-up and could not tolerate progression of weight bearing past toe touch. She was confirmed to have a non-union by CT

Figure 1. Post-operative and 6-months follow-up radiographs of case 1. Secondary fracture healing occurred by ample callus formation in the presence of varus migration.

Figure 2. Post-operative and 6-months follow-up radiographs of case 2. The fixation construct provided stable reduction but callus formation at six months remained deficient, requiring revision by bone grafting.
scan at 6 months from injury and was indicated for revision fixation with bone grafting. There was no evidence of infection at the time of revision surgery.

**DISCUSSION**

Periarticular locking plates have been increasingly used for periprosthetic femoral fractures after TKR, especially in the setting of osteoporosis. These locking plates support biological fixation by plate elevation and yield improved fixation strength in osteoporotic bone.

However, the fixation concept of locked plating is entirely different from conventional plating and requires a revised understanding of plate fixation. In the absence of anatomic reduction and interfragmentary compression, locking plate constructs rely on secondary bone healing by callus formation.

The two cases of periprosthetic fractures described in this report were remarkably similar patients with similar injury mechanisms, fractures and treatments, but very different outcomes. Both patients were female non-smokers of similar age who sustained a Rorabeck type II closed fracture in a fall from standing. The major identifiable difference between the two cases was that case 1 exhibited increasing varus migration due to a loss of metaphyseal fixation which in turn permitted increased interfragmentary motion and medial gap closure. In case 2, alignment was maintained even after 16 weeks, suggesting that implant fixation remained intact. Since the locked plate remained securely fixed to the bone, the construct likely retained its original fixation stiffness throughout the post-operative period limiting interfragmentary motion and continuing to support a small medial gap. This leads to the speculation that increased interfragmentary motion secondary to a loss of fixation promoted callus formation and secondary bone healing in case 1. Conversely, the continuously high construct stiffness in case 2 suppressed callus formation and maintained a medial gap.

This speculation is supported by biomechanical factors known to promote secondary bone healing. Secondary bone healing is induced by interfragmentary motion in the millimeter-range and can be enhanced by passive or active dynamization. Clinically, secondary bone healing is expected to occur with use of external fixators. Monolateral fixators have an axial stiffness in the range of 50 - 400 N/mm. Ilizarov ring fixators exhibit an initial stiffness of 50 N/mm under small loads that increases to approximately 140N for loads greater than 800 N. Their low initial stiffness enables average interfragmentary motion between 1-3 mm in the early post-operative phase under reduced weight bearing conditions to promote callus formation in the acute healing phase. The benefit of this interfragmentary motion is well supported by the clinical success of the Ilizarov method and by the original work of Goodship and Kenwright.

While locking plate constructs have been termed internal fixators, they can be several-fold stiffer than external fixators. The stiffness of the LISS locking plate tested in an unstable fracture model of the distal femur has been reported to range from 200 N/mm to well over 1000 N/mm, whereby the large range may be explained by differences in axial loading constraints, bone quality and screw patterns. These reports demonstrate that locked plates can approach the flexibility of an external fixator, but they also can be considerably stiffer, allowing for less than 0.5 mm motion in response to axial one-body-weight load bearing. The stiffness of locking plate constructs has led to recent speculations that locking plates can potentially act like extremely rigid internal fixators which may run the risk of preventing callus due to their high stiffness and close proximity to the bone.

Clinically, non-unions of periprosthetic femur fractures treated by periarticular locking plates occur at a rate of 0%-13%. Ricci et al. published a series of 22 patients with periprosthetic supracondylar femur fractures treated with a Locking Condylar Plate. Nineteen fractures healed with an average time to union of 12 weeks. Two cases developed infected non-unions and one case had an aseptic nonunion. In a preliminary report, Althausen et al. observed no non-unions in a series of five cases treated with the LISS plate. Kregor et al. reported one non-union in 13 periprosthetic femoral fractures treated with the LISS. The mean time to weight bearing was 13 weeks.

While these reported non-unions can arise from a multitude of factors, the present case report suggests that locked plating constructs may have the potential to suppress interfragmentary motion to a level insufficient for promotion of fracture healing by callus formation. Further research is needed to study callus formation and healing rates of these fractures as a function of the stiffness of the fixation construct.

**REFERENCES**


ABSTRACT
Because of the increased number of patients with neuromuscular scoliosis receiving intrathecal baclofen therapy, we report a clinical case of withdrawal. We hope to make physicians aware of this potentially serious complication where signs and symptoms may be difficult to interpret due to population characteristics.

INTRODUCTION
Intrathecal baclofen (ITB) is increasingly being used for the treatment of spasticity in cerebral palsy patients. The response rate has been reported as being up to 97 percent with use of less than one percent of the systemic dose.1,2,3,4 Intrathecal baclofen withdrawal symptoms (IBWS) are less frequently reported than withdrawal from oral baclofen.5 Symptoms are difficult to interpret and in some cases can be life threatening.5,6,7,8,9,10,11,12 Symptoms develop when central nervous system levels of baclofen decrease over a short period of time. This may be precipitated by pump malfunction or failure, catheter obstruction or failure, or decline in pump reservoir drug level. Of these possible problems, complications related to the catheter itself are by far the most frequent and affect up to 40 percent of patients with ITB pumps.13 Patients usually return to a baseline level of spasticity, frequently became agitated, and experience sleeplessness with IBWS. Other symptoms include pruritis, paresthesia, hyperthermia, hypotension, hallucinations, delusions, confusion, psychosis and seizures.6 Auditory and visual hallucinations have also been reported in patients with oral baclofen withdrawal.14,15 According to the manufacturer, advanced IBWS may resemble autonomic dysreflexia, sepsis, malignant hyperthermia, neuroleptic malignant syndrome, or other conditions associated with a hypermetabolic state or widespread rhabdomyolysis.16 These symptoms are seen mostly in spinal-cord injury patients where the diagnosis may be difficult to make due to possible confusion with autonomic dysreflexia.

In the pediatric population, we are aware of only one case (following posterior spinal fusion for scoliosis) where baclofen was not delivered despite a normal-functioning pump. This report offered no details concerning the type of surgery or possible cause for catheter malfunction.17 Because of the increased number of patients with neuromuscular scoliosis receiving intrathecal baclofen therapy, we report a clinical case of withdrawal to make physicians aware of this potentially serious complication where signs and symptoms may be difficult to interpret due to population characteristics.

CASE REPORT
An 18-year-old female with spastic quadriplegia and scoliosis was treated with posterior spinal fusion and instrumentation necessitated by curve progression and increased difficulty sitting. She had low-normal intelligence, mild dysarthria and no psychiatric history. Her first baclofen pump had been inserted four years previously and was revised eight months prior to her spinal fusion (Figure 1).

A T2 to sacrum fusion was performed using Luque-Galveston instrumentation. During this procedure, the catheter entrance into the lumbar spine was carefully localized and dissected free in order to protect it during the procedure. The surgery was uneventful with no complications and blood loss was estimated at 400cc (Figures 2 and 3).

The initial postoperative course was uncomplicated. On postoperative day (POD) two the patient had an abrupt onset of multiple symptoms of delirium, including fluctuating levels of awareness and orientation, but mainly hallucinations. She was dysarthric but was able to describe visualization of insects all over the room. She
was afebrile, heart rate was 133 beats per minute, blood pressure was 109/59 mmHg and respiratory rate was 18 per minute. Hemoglobin and hematocrit were 12.2 g/dl and 33 percent, respectively. The metabolic workup was normal. She was on hydromorphone (Dilaudid), morphine, codeine, acetaminophen, diphenhydramine, and promethazine. With the hypothesis of drug-related delirium, the morphine was discontinued. Despite these measures, the patient continued to be symptomatic with increased spasticity and visual hallucinations, and sleep disturbance. On POD 3 all hydromorphone, codeine, and diphenhydramine was discontinued and she was switched to oral acetaminophen and Ambien® (zolpidem tartrate). On POD 4 a pediatric psychiatry consultation was obtained and the hypothesis of ITB withdrawal was suggested. Pump malfunction was now considered. Haloperidol (2.5 mg at night and 2.5-5 mg PRN as a rescue dose for breakthrough agitation) was ordered. Telemetrics ruled out pump malfunction (setting: 225μg/day, 9.4 μg/hour). The last refill had been two months before surgery. Cerebro-spinal fluid results were as follows: glucose 54 mg/dl (normal >50% serum level), protein 160 mg/dl (normal, 14 - 45 mg/dl), 150 nucleated cells/μL (normal, <5 cells/μL) and 7534 red blood cells(RBC)/μL (normal =0 RBC/μL) with xanthochromia evident. After the reservoir was filled with a radionuclide, a significant accumulation of the isotope tracer was revealed outside the spinal canal by scintigram (Figures 4, 5). Therefore, the most likely diagnosis for the symptoms was baclofen withdrawal syndrome caused by a catheter leak. Oral baclofen with rapid titration up to 60mg/day and haloperidol were started with resolution of the symptoms within 72 hours. The patient was discharged on POD 8 and was kept on oral baclofen until six months post-operatively when the catheter was revised.

DISCUSSION

Intrathecal baclofen withdrawal syndrome should always be considered as a possible complication after posterior spinal instrumentation for cerebral palsy patients with a baclofen pump. Compromised communication abilities in these patients and the possible confusion with epileptic seizure or post-operative sepsis can challenge
the proper diagnosis. When IBWS is suspected, a complete work-up may have to be undertaken to delineate the problem.9,18,19

Hallucinations in this setting can be very disturbing, as patients tend to develop paranoid ideas with intense anxiety. This has also been reported in patients with Parkinson's disease who take oral baclofen, but usually disappears soon after reintroduction of the drug.14,15

In this case, the probable cause for the withdrawal syndrome was a small nick created in the catheter tubing during the dissection process. To prevent this complication, three options are available to the surgeon: The catheter can be removed during exposure and reintroduced at the end of the procedure with aThuhy needle; catheter preservation can be attempted through delicate dissection and isolation; or the catheter can be sectioned and reattached at the end of the procedure with a connector.

Although the first option seems straightforward, it has been related to low-pressure headaches secondary to presumed cerebrospinal fluid (CSF) leakage. Segal et al. presented five patients with spastic quadriplegia having a baclofen pump who underwent posterior spinal fusion and then developed persistent positional headaches and vomiting, with an inability to sit upright for some time in two patients. These symptoms were due to cerebrospinal fluid leaks after reintroduction of the catheter. These potentials should always be anticipated when this first approach is used.20

For a number of years, the senior author has performed posterior spinal fusion by isolating the catheter, mobilizing as much of it as possible, and protecting it during surgery (the second alternative). Although this method avoids the morbidity associated with CSF leaks and the need for additional procedures to restore the pump catheter system, this approach has some potential complications. Injury to the catheter may occur at many points in the procedure. During dissection and mobilization, the catheter can be breached accidentally; if this is recognized, it should be repaired by a proper tube connector. During the procedure, the catheter can also be caught by one of the many instruments in the field and pulled out to a level distal to the intended level or even from the spinal canal itself. If a unit rod is used, passage under a taut catheter can be problematic unless a reasonable amount of catheter has been mobilized. This technical difficulty can be avoided if the neurosurgeon leaves extra catheter coiled near the spine, or by using a modular system. For example, Alden et al. reported a case where the catheter was left in place during posterior spinal fusion for scoliosis. The patient was readmitted for hyperthermia and severe spasms with clonus in both upper and lower extremities. Pump interrogation showed no problems, but catheter exploration and division near the spinal entrance revealed no spontaneous CSF return.17

The last alternative that may be considered is to section the catheter during the procedure and then reconnect it with the appropriate connector at the end of the procedure. If this is done, it must be coordinated with the neurosurgical service to insure that the pump catheter system is functioning properly afterward.

Treatment of IBWS relies on reinstitution of the intrathecal baclofen infusion. In severe cases, bolus administration via lumbar puncture may be needed until catheter reinsertion is attempted. In the case related above, the differential diagnosis has to be made between autonomic dysreflexia, malignant hyperthermia and neuroleptic malignant syndrome. Dantrolene (10mg/kg) or benzodiazepine infusions can be very effective and even life-saving.9,21 If the problem is recognized early, high-dose oral or enteric baclofen (>120 mg/day in six to eight divided doses for adults) can be effective if the patient’s condition permits.9 In children younger than 12 years of age, lower doses may have to be used since safety is not well established and the manufacturer’s recommended maximum daily dose is 80 mg. Side effects such as sedation, general nervous system depression and hypotension should be well monitored.

CONCLUSION

Increasing numbers of patients with spastic cerebral palsy are being treated with ITB. Those scheduled for posterior spinal fusion and instrumentation should be made aware of the potentially devastating complications associated with interruption of intrathecal baclofen which may occur as a complication of surgery. Surgeons must be aware of this potential risk and develop strategies to prevent interruption of baclofen delivery and to deal with a disruption, should it occur. Early recognition of ITB withdrawal syndrome is mandatory, as it can be a

Figure 4 (left) and Figure 5 (right). Radionuclide study at 0 minutes and at 94 minutes showing tracer leak outside spinal column.
potentially life-threatening complication. Full investigation, according to established protocols, is essential to rule out all possible causes for ITB delivery failure.

REFERENCES


ACUTE INTRAOPERATIVE REACTIONS DURING THE INJECTION OF CALCIUM SULFATE BONE CEMENT FOR THE TREATMENT OF UNICAMERAL BONE CYSTS: A REVIEW OF FOUR CASES

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ABSTRACT

Unicameral bone cysts can predispose patients to pathologic fracture and deformities of growth. Treatment options vary from continuous decompression with transcortical placement of a cannulated screw to percutaneous aspiration and injection of medical-grade calcium sulfate. From 2005 to 2007, we treated 22 patients with unicameral bone cysts using aspiration and injection of calcium sulfate. Three patients experienced acute laryngospasm and one patient developed tachyarrhythmia, temporarily, associated with injection of calcium sulfate. All reactions occurred in patients under age 18 without predisposing risk factors and resolved spontaneously with supportive care. Although the mechanism is unclear, we hypothesize that these reactions are either due to the nociceptive stimulus of the calcium sulfate injection or a systemic calcium bolus. Clinicians using this product for this indication should be aware that such reactions may occur. We suggest endotracheal intubation and communication to the anesthesiologist about the time of the injection in preparation for these idiopathic responses. Further research is necessary to determine exactly how this reaction occurs and how it can be avoided.

INTRODUCTION

The unicameral bone cyst (UBC) is a benign bone tumor most frequently seen in the pediatric population. The exact etiology is still debated; however, many believe this phenomenon arises from one of three possibilities: 1) An intramedullary synovial cyst, 2) Intramedullary venous congestion, or 3) Disturbances of skeletal development. Whatever the mechanism, these lesions are often asymptomatic and are discovered only incidentally, or they may come to the attention of the orthopaedic surgeon when there is a pathologic fracture through the lesion. Treatment begins conservatively, as these defects sometimes fill in as development progresses. However, there are certain cases where surgical intervention is warranted to prevent progression of an expanding lesion and/or a possible pathologic fracture, especially in locations associated with severe complications (e.g., the femoral neck).

Several interventions have been reported to be successful, but more recently, minimally invasive procedures have become popular. These new techniques are not free of complications. We previously reported several cases of local soft-tissue reactions to Osteoset® surgical-grade calcium sulfate bone graft substitute (Wright Medical Technology). In this study, we report four cases of acute systemic reactions to the injection of calcium sulfate-containing bone substitutes (Pro-Dense Injectable bone graft substitute and Minimally Invasive Injectable Graft – MIIG 115, Wright Medical Technology, Inc., Arlington, TN).

REVIEW OF CASES

Patient 1

An otherwise-healthy 11-year-old male presented to his local physician after being hit in the right wrist by a baseball. Radiographic studies obtained locally were negative for any fracture but demonstrated a lytic lesion in the proximal radius. The patient was referred to our center for further treatment. On our evaluation, we felt the lesion to be most consistent with a unicameral bone cyst, and because of its size and the patient’s symptomatology, the indication was made for percutaneous aspiration, irrigation and injection of bone graft substitute.

General anesthesia was induced and the patient was ventilated using a laryngeal mask airway (LMA). After the usual preparation and draping, two large-bore needles were introduced into the lesion. The contents of the lesion were aspirated and draping, two large-bore needles were introduced into the lesion. The contents of the lesion were aspirated, confirming the diagnosis of UBC. After irrigation, MIIG 115 calcium sulfate bone graft substitute was injected into the lesion. After several seconds, the patient experienced severe laryngospasm, making ventilation through the LMA impossible. The patient desaturated acutely and required intubation. He was extubated shortly following the procedure, without further complications.
Patient 2

A 15-year-old, healthy, active male presented to our clinic with pain in the left distal tibia while jogging. Radiographic evaluation of the tibia revealed a lucent lesion and cortical reaction consistent with a non-displaced pathologic fracture through a cyst, possibly UBC versus fibrous dysplasia.

The patient was taken to the operating room for aspiration, irrigation and calcium sulfate injection using two large-bore needles. After aspiration and irrigation, MIIG 115 calcium sulfate was injected. Immediately following injection, the patient had an increase in his airway pressures and became difficult to ventilate with a bag mask. This case of mild laryngospasm resolved without the need for intubation.

Patient 3

An otherwise-healthy, six-year-old male tripped and fell onto his left hip. He complained of persistent pain in the hip and walked with a limp. He underwent radiographic evaluation by his pediatrician, which revealed a lucent lesion in the left femoral neck. He was subsequently referred to our center for further care and the diagnosis of UBC was made.

After an initial trial of non-operative therapy, the patient underwent injection of corticosteroids into the cavity which caused near-complete obliteration of the cyst. However, after about 18 months the cyst recurred, and the decision was made to proceed with aspiration, irrigation and injection of calcium sulfate.

The procedure was uneventful until injection of the MIIG 115 calcium sulfate, when the patient demonstrated increased resistance to ventilation consistent with laryngospasm. His oxygen saturation dropped to a low of 46% during the incident, however, within 30 seconds of the start of the incident his condition improved because of increasing positive pressure ventilation applied by bag mask. There were no further respiratory events and the patient did not suffer any adverse sequelae.

Patient 4

A nine-year-old, otherwise-healthy female presented to our emergency treatment center with pain in the left distal tibia, sustained after a twisting motion. Initial radiographic evaluation revealed a lucent lesion with a pathologic fracture through the medial cortex (Figure 1). The patient’s past medical history was unremarkable and she had no significant positive findings on review of systems. This lesion was determined to be consistent with a UBC. She was initially treated in a long-leg cast and although the fracture healed, the UBC enlarged. Furthermore, the patient continually complained of focal pain in the area of the lesion. She was indicated for aspiration, irrigation and injection of calcium sulfate bone graft substitute.

Intraoperatively, the aspirate findings were consistent with UBC. The case initially progressed without complication until the Pro-Dense Injectable calcium sulfate/calcium phosphate cement was introduced. At that time, the patient’s heart rhythm changed to a supraventricular tachyarrhythmia with a rate of approximately 120 beats per minute, representing a 40% increase over baseline
rate. This resolved without intervention and the patient remained hemodynamically stable throughout the incident. The patient was taken to the post-operative care unit and monitored closely, with no further arrhythmias.

**DISCUSSION**

Treatment of a unicameral bone cyst by aspiration and injection of bone substitute is a well-described technique. This treatment is used mainly for cases recalcitrant to other treatments, or cases in which the lesion is located in an area of high mechanical stress. The goal of therapy is to prevent pathologic fracture and limb deformity in the developing pediatric skeleton.

There are several bone substitute products available. Products composed of calcium sulfate are desirable because they provide an osteoconductive matrix that can be delivered in a slurry form, making the compound amenable to injection through a minimally invasive approach. These compounds are approved by the FDA, are widely used, and in our experience have been generally well tolerated and safe in a wide variety of patients and clinical scenarios. Adverse effects due to the application of these products have been described, however.

Reactions have been previously reported with calcium sulfate pellet treatment (OsteoSet®, Wright Medical Technology, Arlington, TN) of benign bone lesions. In a series of 58 patients there was a 13.8% incidence of delayed reactions observed, with no clear risk factors identified to forming a reaction. These delayed reactions consisted of painful, self-limiting soft tissue responses that resolved with symptomatic anti-inflammatory therapy. Similar local reactions have previously been reported with calcium phosphate and calcium sulfate materials.

Interestingly, some studies suggest calcium sulfate demonstrates local cytotoxic properties. In addition, it has been reported that injections of calcium-based cement can have a potential for adverse reactions. Krebs et al. demonstrated that intravascular injection of calcium phosphate cement can induce pulmonary embolism in an animal model. This may be clinically important because UBC membranes are very permeable and can allow passage of contrast materials into the circulation.

The mechanisms of the observed reactions in our study are unclear and no such reaction is described in the literature. These patients did not demonstrate any readily identifiable risk factors which would predispose them to such a reaction. At the present time, our best hypothesis to explain these cases would be that the injection of calcium sulfate induced laryngospasm and tachycardia through a pain stimulus which overcame the level of anesthesia. As reported above, these products have some potential for local toxicity, and a dissolution of calcium sulfate is believed to lead to an acidic microenvironment. The MIIG 115 is designed to absorb quickly in soft tissues and synovium to prevent problems with extravasation. It is possible that absorption of calcium sulfate into the soft tissues, and the subsequent local acidic and inflammatory environment, could be a significantly noxious stimulus, enough for the patient to overcome relatively “light” anesthesia usually provided during minor procedures.
Another hypothesis is that rapid systemic dissemination of calcium from the local environment causes these idiopathic reactions. One animal study demonstrated injection of calcium chloride into sheep caused "laboured respiration" and tachycardia. In addition, there have been case reports of intravascular calcium infusion causing vasoconstriction and death. Previous studies have been case reports of intravascular calcium infusion 2. Lee GH, Khoury JG, Bell J, Buckwalter JA. J Am Acad Orthop Surg. 2000;8:217-224.


ABSTRACT
Osteoid osteoma is a benign, neoplastic lesion, characterized by a less-than-2-cm pea-like mass of abnormal bone, the nidus. Traditional treatments have involved either conservative management with pain control or operative excision of the nidus. Today, radio-frequency ablation (RFA) is being used more commonly for the treatment of osteoid osteomas. There have been numerous studies showing the effectiveness of RFA.1-11 Complications of the procedure are rare but have been reported.7,11-15 We report a patient with a full-thickness cutaneous burn after RFA of a tibial osteoid osteoma.

CASE REPORT
A 16-year-old female was referred to our clinic for pain over the anterior aspect of her tibia for four months. She had good relief of her pain with non-steroidal anti-inflammatory drugs (NSAIDs) but difficulties with sporting activities secondary to pain. Her pain did not respond to limited activity and restricted weight bearing. Computed tomography (CT) scan confirmed an anterior tibial cortically based mass consistent with an osteoid osteoma. Treatment options were discussed and radio-frequency ablation was recommended.

After written informed consent was obtained from the patient’s parents, the patient was taken to the CT suite and placed under general anesthesia. A CT scan of the right tibia was performed. The osteoid osteoma was localized within the anterior tibial cortex and the proper trajectory for the drill bit was confirmed. The skin was marked to confirm this location.

The area was then prepped and draped. A small skin incision was made to accommodate a 2.7 mm drill bit. Then, a Stryker cordless drill the with a 0.045-inch-diameter, six-inch-long Kirschner (K)-wire was advanced through the anterior cortex of the tibia into the intramedullary space. Serial CT scans were performed to confirm the location of the K-wire. Once the K-wire was positioned immediately posterior to the nidus of the osteoid osteoma, the 2.7 mm cannulated drill bit was used to over-drill the K-wire and position itself into the nidus of the osteoid osteoma. This was confirmed with CT scan (Figure 1).

The radio-frequency electrode was inserted through the drill track into the osteoid osteoma and confirmed with CT. RFA was performed for five minutes at 90 degrees Celsius. Once the RFA probe was removed, the incision was dressed. The patient tolerated the procedure well without immediate complications and was discharged home.

The patient experienced a change in the character of her post-operative pain four days after the procedure. Her parents called our office for her increased localized pain on the anterior tibia and the pain medications were adjusted. Nine days after RFA, she presented to the ER with a small rim of redness in the area of the incision.

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and mild serous drainage. There was no fluctuance in the area. Her erythrocyte sedimentation rate (ESR) was five and her C-reactive protein (CRP) was <0.5, both normal by our institutional standards. Eleven days after the procedure she had her first post-operative clinical visit. Examination of the wound revealed a 7 mm-diameter area of full-thickness skin necrosis in the area of the incision surrounded by a 2-to-3 mm rim of erythematous skin discoloration. There was some clear drainage from the central area (Figure 2). The wound was managed with Silvadene dressing changes twice a day. Fifteen days after the procedure her wound was re-evaluated (Figure 3). There had been a slight spread in erythema and a demarcation of the area of full-thickness skin necrosis. By six weeks from the time of the procedure, the erythema had resolved and the wound was filling in with healthy granulation tissue.

**DISCUSSION**

Osteoid osteoma is a benign neoplastic lesion, characterized by a less than 2 cm, pea-like mass of abnormal bone, the nidus. The nidus is richly innervated, causing considerable pain usually without systemic symptoms. It has no malignant potential and usually does not grow. It represents 12% of all benign tumors and 3% of primary bone tumors. It is uncommon in African-Americans and has a 2.3:1 male predominance. Fifty percent of patients are between 10-20 years old and 90% are between 5-25 years old. It is most commonly found in the long bones.

There are three different methods of treatment for osteoid osteoma: Non-operative, open, and percutaneous. Non-surgical treatment involves use of NSAIDs, which typically relieve most of the pain. Osteoid osteomas will regress, but the time frame for symptom resolution is uncertain. Symptoms are usually severe enough that patients are reluctant to accept this mode of treatment.

Surgical excision of the nidus is a reliable method of treatment. However, osteoid osteomas can present in difficult locations. Locating the nidus and confirming that it has been excised can be challenging. Further, occasionally significant unaffected bone is destroyed to reach the nidus.

Thus, radiographically guided thermal ablation is now the most common method of treatment. Radiofrequency energy can selectively ablate limited and controlled volumes of tissues, causing necrosis by thermal coagulation. The RF electrode alternates polarity causing charged particles in the area to be attracted and repelled in rapid oscillation. This increase in energy heats the surrounding tissue. A simple straight electrode with a 5 mm exposed tip heated to 90°C will expose a 1 cm sphere of surrounding tissue to lethal temperatures. This, along with the ease of targeting the device under CT guidance, makes RFA an ideal method for obliterating small, solitary, osteoid osteomas.

Success rates have been reported from 78-100% across many different series. Complications in these series have been rare, with cellulitis and superficial skin burns being most common. Venbrux reported a full-thickness skin burn 0.5 × 0.8 cm in diameter over the medial border of the distal tibia at the site of an RFA probe insertion. The burn healed with local wound care and no adverse outcomes. Pinto described treating an osteoid osteoma of the subcutaneous tibia resulting in a fistula. Donkol reported two skin burns from his series of 21 pediatric patients. There was one other case report which described a full-thickness skin burn with almost the exact time course and clinical picture as our patient. It was also a burn of the subcutaneous border of the tibia.
Ablation cannula. The RFA device is discarded at our institution after use, so this could not be confirmed in our case.

Skin and soft tissue thermal necroses are unusual complications. The areas at greatest risk are those without much subcutaneous fat or muscle, such as the anterior tibia. Thermal necrosis to adjacent tissues should be considered and discussed with patients prior to recommending and performing RFA. Several precautions have been recommended to prevent unwanted damage to at-risk tissue. These include using a probe appropriate for the size and depth of the lesion as well as retracting the cannula to insure the insulation is intact.

With the correct indications and proper technical steps, RFA is a safe, effective method for treatment of osteoid osteoma. It is prudent to be aware of and prevent the rare complications associated with the procedure.

REFERENCES
INTRODUCTION
Heterotopic ossification is the process of pathologic bone formation in soft-tissue structures that usually do not form bone. This pathologic process may occur in tissue such as skin, subcutaneous tissue, skeletal muscle and periarticular tissue. It was reported in the literature as early as 1740, and is frequently reported in modern literature. Two forms of heterotopic ossification are commonly described. The post-traumatic form is localized, whereas the systemic form occurs in fibrodysplasia ossificans progressiva.

CASE REPORT
A 39-year-old man presented with nearly two decades of lower back pain with stiffness in trunk flexion. The patient reported a previous baseball injury in which he forcefully flexed his torso throwing the ball. This resulted in acute onset of right flank pain. Over the twenty years since that event, he had experienced primarily right-sided, low-grade, activity-related back pain. In the months prior to his clinical presentation, he experienced a significant, atraumatic increase in pain. The patient’s medical and surgical histories were otherwise unremarkable. He had a sedentary job; however, he was quite active recreationally.

On physical examination, he was very tender over his right posterior iliac wing and the inferior aspect of his rib-cage. An AP pelvis radiograph revealed an approximately 12 cm x 5 cm (craniocaudal by transverse) heterotopic mass (Figure 1). A CT scan revealed a large area of ossification extending from the right iliac wing to the inferior aspect of the right twelfth rib. It was located lateral to the psoas and appeared to be within the quadratus lumborum (Figures 2, 3, 4). Given the patient’s chronic and progressively increasing low back pain and stiffness, he was indicated for operative excision.

OPERATIVE TECHNIQUE
The patient underwent general anesthesia and was placed in the prone position. A direct approach over the lesion was made through a 10 cm incision. Subcutaneous dissection was made down to the latissimus dorsi muscle fascia. The lateral fascial edge of the latissimus dorsi was incised and the muscle was retracted from lateral to medial, allowing direct visualization of the heterotopic mass (Figure 5). We then performed a subperiosteal dissection. The heterotopic mass was excised from both ends with an osteotome. The mass was noted to be well...
corticated with an intramedullary cavity. Great care was taken to protect the kidney and pleural cavity. The wound was irrigated and closed. The patient underwent five sessions of post-operative radiation therapy for heterotopic ossification prophylaxis. Post-operative radiographs (Figure 6) revealed some residual heterotopic ossification on both the iliac crest and twelfth rib.

**DISCUSSION**

Traumatic heterotopic ossification of muscle, or myositis ossificans circumspecta, results from the proliferation of fibroblasts, bone and cartilage usually after an inciting event. Although there have been reports of spontaneous myositis ossificans, the process is initiated by trauma in 60 to 75% of cases. Most cases occur in the first three decades of life. The most common locations include the thigh, hip, upper arm, calf and foot. Functionally significant deficits typically occur in 10 to 20%
of patients. Symptoms tend to be localized and usually consist of localized swelling, tenderness and decreased mobility of adjacent joints. The inciting trauma stimulates an inflammatory response mediated through hematoma formation followed by a cascade of events. Initially, granulation tissue forms, which is subsequently replaced by cartilage. Bone is then formed either by intramembranous or endochondral ossification. Woven bone is eventually replaced by lamellar bone. The mature heterotopic ossification lesion often has a neocortex and medullary cavity, as was the case in our patient. Complications of mature lesions can occur. Although it is rare, malignant transformation to osteosarcoma has been described. Mature lesions may fracture after direct trauma. In our patient, symptoms had acutely worsened three months prior to presentation, causing us to consider the possibility of fracture and subsequent nonunion through the base of the lesion (Figure 4). Excision is reserved for mature lesions only, since excision of immature lesions may lead to further trauma, albeit surgical, and local recurrence. Although much of the evidence supporting radiation therapy for heterotopic ossification is related to the hip (arthroplasty and acetabular fractures), we reasoned that the best chance to minimize the risk of local recurrence was to proceed with radiation therapy. Initial follow-up revealed near-complete pain relief with no clinical or radiographic evidence of recurrence.

CONCLUSION

Traumatic heterotopic ossification is not an uncommon sports-related injury. After review of the literature, we believe this to be the first reported case of traumatic heterotopic ossification of the quadratus lumborum. Although traumatic heterotopic ossification usually can be treated conservatively in an acute setting, our patient reported chronic and progressive low back pain for nearly two decades. We performed elective excision followed by prophylactic radiation therapy. Understanding the physiology of traumatic heterotopic ossification will enable the physician to more effectively treat the pathologic process whenever and wherever it may occur.

REFERENCES

METACARPOPHALANGEAL JOINT SYNOVIAL
OSTEOCHONDROMATOSIS: A CASE REPORT

Bryan A. Warme, M.D.; Dean-Yar Tigrani, M.D.; and Christina M. Ward, M.D.

ABSTRACT

We describe a case of primary articular synovial chondromatosis in a metacarpophalangeal (MCP) joint of a 48-year-old male. The patient initially presented with MCP joint swelling and pain with normal plain radiographs. Following a fourteen month course of conservative management, surgical debridement of the joint revealed multiple loose bodies consistent with primary articular synovial chondromatosis. Though synovial chondromatosis rarely occurs in hand joints, the diagnosis should be considered in cases of metacarpophalangeal pain when common etiologies have been excluded.

CASE REPORT

A 48-year-old, left-hand dominant male was referred to our orthopedic hand clinic by rheumatologists after a long course of failed conservative therapy for pain and swelling in his left index and long metacarpophalangeal (MCP) joints of unknown etiology. The patient originally presented to the rheumatology clinic with a four-year history of pain that was interfering with his work as a Braille typist. Radiographs taken during the rheumatology evaluation did not reveal any loose bodies, erosions or joint space narrowing (Figure 1a). Past medical history was unremarkable for any trauma, infections, or rheumatologic conditions. Family history was positive for Systemic Lupus Erythematosus in a maternal female cousin but negative for rheumatoid arthritis or any seronegative spondyloarthropathy. After a trial of nonoperative treatment including high dose NSAIDs, intra-articular injections, oral corticosteroids, hydroxychloroquine, acetaminophen, Tramadol, topi-
cal capsaicin, and narcotic analgesics, the patient had persistent joint pain and swelling, prompting an MRI to further work-up the condition. The MRI revealed joint effusions with synovial proliferation and erosive changes in the long MCP joint and no changes in the index MCP (Figure 2). Because a diagnosis remained elusive, referral to an orthopedic hand surgeon was made for second opinion and possible biopsy. Upon presentation to our clinic, the patient reported his condition had forced him to discontinue his work as a Braille typist. He had moderate tenderness to palpation in the left index and long MCP joints. There was palpable swelling and thickening over the long MCP joint, but minimal swelling of the index MCP. Repeat plain radiographs were taken in the orthopedic clinic, fourteen months after the initial radiographs taken during the rheumatology work-up, which demonstrated several calcifications in the long MCP joint (Figure 1b). The differential diagnosis at this time included pauciarticular inflammatory arthritis, degenerative changes, or chronic infection from either fungal or mycobacterial origins.

Because the patient continued to have substantial functional deficits and pain, he was indicated for joint exploration and synovial biopsy. At surgery, multiple firm, smooth, white nodules were found in the long finger MCP joint. No evidence of similar pathology was found in the index MCP joint. The gross appearance of the nodules was consistent with synovial chondromatosis (Figure 3). Histologic studies revealed hypercellular nodules filled with binucleate chondrocytes lined by benign synovial tissue (Figure 4), further supporting the diagnosis of synovial chondromatosis. Mycobacterial and fungal cultures were negative.

Physical therapy for range of motion was initiated two weeks after surgery. Three months after surgery, the patient’s pain has decreased, and his MCP range of motion has improved to 0 to 75 degrees in his index finger and 0 to 84 degrees in his long finger.

**DISCUSSION**

Primary synovial chondromatosis results from benign metaplasia of synovial tissue into cartilaginous tissue. The primary form of synovial chondromatosis is distinct from the more common secondary osteochondromatosis that consists of free articular cartilage fragments resulting from either degenerative disease or trauma. Primary synovial osteochondromatosis may arise from either articular synovium or tendon sheath synovium. Males are affected twice as frequently as females, and presenting symptoms can include pain, swelling, or decreased range of motion. The knee is the most common articular location followed by the hip and elbow. For lesions arising from tendon sheaths, the feet and

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Figure 2. MRI demonstrates long finger metacarpal head bony edema with adjacent synovial proliferation and joint effusion.

Figure 3. The loose bodies removed were firm, white, smooth, chondroid nodules with homogeneous cut surfaces.

Figure 4. Histologic examination reveals lobules of cartilage, with slightly increased cellularity, but no significant cellular atypia. The lobules are lined by benign synovium.
hands are the most common locations. Review of the literature demonstrates that primary articular synovial chondromatosis of the MCP joint, as seen in our patient, is exceedingly rare. To our knowledge, the articular MCP location of this case of primary synovial chondromatosis has been previously reported only a handful of times. All of these reported cases were monoarticular in nature, and all were treated successfully with surgical debridement without recurrence.

The disease can also be classified based on the phase of maturation of the lesion. Milgram proposed three phases of the disease in 1977: early, transitional, and late. In early synovial chondromatosis, no loose bodies are present, but active synovial disease exists. In the transitional phase, there are both loose bodies and active synovial disease. Finally, in late synovial chondromatosis, there is no longer active synovial disease, but loose bodies persist. As in this case, patients that present in the early phase may have synovitis and pain without any radiographic changes, obscuring the diagnosis. In cases of refractory monoarticular synovitis, repeat imaging may be indicated to look for the appearance of loose bodies. The presence of multiple intraarticular loose bodies on plain radiographs should raise suspicion of primary synovial chondromatosis, even in joints such as the MCP joint that are not typically affected by the disease.

Nonoperative treatments may ameliorate symptoms for some patients, but synovectomy and removal of loose bodies is indicated for persistent symptoms. Recurrence after resection has been reported, likely resulting from incomplete excision. Malignant degeneration of synovial chondromatosis is exceedingly rare.

In conclusion, primary synovial chondromatosis should be included in the differential diagnosis of monoarticular synovitis of the MCP joints. Though plain radiographs may appear normal during the early phase of the disease, subsequent imaging may reveal intraarticular calcifications suggestive of loose bodies. Synovectomy successfully relieves pain and swelling in most cases.

REFERENCES

Mr. President, distinguished members of the Council, Fellows, New Fellows and guests:

I am honored and humbled to be made an Honorary Fellow of the Royal College of Surgeons. My induction today is one of the highlights of my professional career.

I am most grateful to Mr. Ian Leslie, immediate past president of the British Orthopaedic Association, for my nomination, and to the Council for granting this honor. To be made a Fellow of this venerable institution is quite a thrill for someone from the colonies; and I thank you for the honor.

Firstly, let me offer my sincere congratulations to the new members; it is a great day for you and your families and I am so pleased to be able to participate in the festivities.

I was very flattered to be asked to provide you some words from a “wise old hand”. In fact until I received the invitation I hadn’t thought of myself as an old hand but instead one who is just reaching the peak of my career. I am not at the point in my career that I am what is referred to as a “podium surgeon.” I am still operating two full days per week; seeing patients two days a week; doing research; taking level one emergency call; and working on various outside national orthopaedic activities. So as I share my comments with you, I hope you realize that, I have for the last 36 years and continue, to “walk the walk.”

However, on further reflection I realized that if one compares a surgical career to a round of golf; one might say I am on the “back nine”. As I look back; I have learned a thing or two about the course and I hope that these ruminations will be of some help to those of you who are about to tee off.

I would briefly like to touch on six guideposts for your future. The first guidepost, and one that you will need to work on your entire career, is Maintenance of Public Trust. You have chosen a career in a noble profession, one that still enjoys a great deal of prestige and respect in the community; Your contract with society as a physician is totally based on professionalism and your ability to maintain public trust. This public trust is based on the perception by the public that physicians are altruistic; that they always put the patient first; that they employ scientific integrity; and that there is the absence of bias in medical decision making. Each of you, and all of us in the profession, need to constantly work at maintaining these values to ensure that public trust is maintained throughout your professional life.

In the current environment, there are many forces threatening to erode that trust; not the least of which is the ever increasing relationships of physicians and surgeons with industry. While surgery in many instances lacks a strong evidence base; surgeons are the innovators of new procedures and techniques; and they invent devices. In that activity, they must work closely with industry. In fact, surgical translational research is often dependent on collaboration with industry. While these relationships are critical to progress in medicine, as Jerome Kassirir, former editor of the NEJM wrote in his book “On the Take”; “Patients must be able to trust that their doctors’ motives are not subverted by financial gain, that their doctors are recommending treatments that benefit them, and that their doctors are involving them in research projects for the right reasons. Their doctors must not only be at their sides, but on their sides.”

This maintenance of public trust is implied and embodied in this College’s mission statement and must be the main guide post of your career.

The second guidepost relates to Lifelong Learning and Continuing Education. While this may seem obvious to you; you will find that as your practice expands and your family life increases in complexity, this is one of the more difficult areas to budget into your schedule. It is however critically important that you do find the time.

You are currently laying the educational foundation for the future. As I reflect back on my training and what
I am now doing in practice, very little resembles what I was doing in my training. Thanks to dramatic technologic advances the diagnostic tools and therapeutic interventions I am now using have all developed since I finished my training. For all of you and for your patients, these are also especially exciting times to be in medicine as we are currently in the midst of a biologic revolution that will profoundly change our practices. The key to this future is to continually build on the educational foundation that you are laying today through lifelong learning.

In parallel to your lifelong learning, the public is continually educating itself through the internet. Today 7/10 adults in the US, and I imagine it is similar in the UK; get their healthcare information through the internet. As your patient's advocate, it is your responsibility to stay abreast of the scientific developments to help your patients navigate the treacherous waters of internet misinformation, self-promotion advertising, and direct-to-consumer marketing.

The next guide post was alluded to when I spoke about maintaining public trust, and that is Putting patients first by practicing Patient Centered Care. The concept of Patient Centered Care has been around for more than 30 years and has many definitions; the definition I like best is that PCC is “quality health care achieved through a partnership between informed and respected patients and their families, and a coordinated health care team.” The key words are partnership, informed and respected patient.

In this paradigm, the patient is the source of control, not the physician; knowledge is shared as information flows freely; decisions are evidence-based whenever possible; transparency is necessary; and cooperation among physicians is a priority. Patient Centered Care is the cornerstone of the current quality movement in health care.

What does PCC really mean? It is the kind of care process and interaction that you expect for yourself and your family. Put yourself in the situation of a loved one having a serious medical condition for which you are not the expert and then ask the questions; what do you expect from the doctor? from the hospital or clinic staff? and from the entire health care team? I think you can picture in your mind what is meant by PCC.

The delivery of Patient Centered Care offers the strong probability of increasing your job satisfaction, decreasing liability risk, and increasing patient satisfaction. From the patient's perspective, it ensures better outcomes and lower health care costs.

The next guidepost is particularly germane to the surgical disciplines: that is the Avoidance of Overconfidence. You spend years acquiring and enhancing your surgical skills. You will glean great personal satisfaction in your practice using your skills to save lives or limbs; restore function and relieve pain. But it is critical to avoid the natural pitfall of over confidence; it is a matter of patient safety. When you become overconfident you are “at risk” for error that could profoundly affect a patients life. Never view surgery as routine. You must, as a surgeon, always pay attention to detail even if you have done the surgery 1000 times. You are granted a sacred privilege to be entrusted with a human life. Each and every patient puts their trust in you; that you will do your best and take care of them. This is your obligation.

The next to last guide post is that you must pay attention to the external environment. It would be nice if you could practice medicine free from outside influence; but this is increasingly not the case. With healthcare consuming a greater % of GDP in every country and with a better-educated public and increasing focus on medical errors and accidents, everyone has begun looking for quality assessment, including physician performance. In the United States, working under the premise that value purchasing in health care should be the rule as it is in other areas of industry, the US business community has targeted high quality medical care as a significant objective. When Ford Motor Company pays more for healthcare than it does for steel for its cars, it asks the question; are we getting value for our Dollar. While you have a different healthcare system, all payers of healthcare, be it employer or the government are asking that same question: Are we getting good value for our money? In the US, healthcare will be the number one issue in our 2008 presidential election.

Some of you will become health care policy researchers; some will become leaders of the specialty societies; and others leaders of this college; all of you need to keep yourselves informed about the issues and participate in someway. It is not in physician culture to be politically active but I suggest that in the future it will be in your best interests and that of your patients to be involved. You need to be advocates for your patients and your profession. If you don't; government bureaucrats will be making decisions for you. I would strongly encourage you to be an active part of the healthcare debate and have as many seats at the table as possible.

The last guide post is Balance. As your career progresses; the most difficult challenge you will face is balancing your professional career with your personal life. This balance will be affected by pressures from your patients, your colleagues, the government as well as from factors yet unknown. As practitioners of surgical disciplines; much of what you do may not be predictable and fit into neat time blocks like our medical colleagues. You will miss family meals and important family events. For some of you your spouse or partner may also have
a demanding career that needs to be considered. You may become a parent which adds to your responsibility. Sensitivity to the needs of your loved ones and maintenance of a constant homeostasis between personal and professional life will be one of the most important and challenging tasks that confront you throughout your career.

Ladies and Gentlemen, I hope that these six interrelated guideposts—maintenance of public trust; lifelong learning, practicing patient centered care, insuring patient safety by avoidance of overconfidence; being an active participant in the healthcare dialogue and maintaining balance in your personal and professional life will be of some help to you as you embark on the exciting road ahead.

This is a great day for you and I am so happy to be part of this celebration. Congratulations on this wonderful and hard earned honor. I know that your families are justifiably proud of this accomplishment and the many that lie ahead. These are exciting times and you have before you never-ending highways of opportunity. I wish you well on your journey.

Thank you.

REFERENCES

INDUCTION CITATION, PROFESSOR STUART L. WEINSTEIN
Professor Weinstein is the Ignacio V. Ponseti Chair and Professor of Orthopaedic Surgery at The University of Iowa. His name is well known by Orthopaedic Surgeons throughout the world. Professor Weinstein received his A.B. Cum Laude degree in Political Science and History from the University of Illinois in 1968. He received his medical degree (Alpha Omega Alpha) from the University of Iowa in 1972. It was during his medical student years that he made his first contact with British medicine, by being awarded a Fellowship to study at the Radcliffe Infirmary, Oxford, under Professor Sydney Truelove, a great pioneer in Gastroenterology. After interning in Internal Medicine at The University of California San Francisco, he returned to the University of Iowa for a residency in Orthopaedic Surgery. In 1976 he joined the faculty of the Department of Orthopaedic Surgery at The University of Iowa.

Professor Weinstein is an NIH-funded researcher. He has published more than 170 scientific articles in peer review journals on a wide variety of pediatric orthopaedic conditions. His research work has focused on spinal deformity in children, children’s hip and foot problems, and the natural history and long-term outcome of pediatric musculoskeletal conditions. He has edited three major textbooks including The Pediatric Spine: Principles and Practice; Lovell and Winter's Pediatric Orthopaedics and Turek's Orthopaedics. Professor Weinstein’s many contributions to orthopaedics have been recognized by his receipt of the Bristol-Myers Squibb/Zimmer Award for Distinguished Achievement in Orthopaedic Research; The Kappa Delta/Orthopaedic Research and Education Foundation Clinical Research Award; The Russel Hibbs Award for Clinical Research given by the Scoliosis Research Society; and The Arthur H. Heune Memorial Award, given by the St. Giles Foundation and The Pediatric Orthopaedic Society of North America in recognition of outstanding research contributions to pediatric orthopaedics. In 2005, Dr. Weinstein was the recipient of the Alfred R. Shands, Sr., MD Award, presented by the Orthopaedic Research Society and The American Orthopaedic Association. This award is presented each year to a United States or Canadian citizen who has made significant contributions to orthopaedics. This award recognizes the devotion of a significant portion of the professional lifetime to furthering knowledge in the fields of musculoskeletal disease. Professor Weinstein received the 2000 Iowa Board of Regents Award for Faculty Excellence for sustained record of excellence across the spectrum of faculty endeavors. In 2003 he received the Ernest O. Theilen Clinical Teaching and Service Award presented by the Roy J. and Lucille Carver Col-
lege of Medicine. Professor Weinstein was a recipient of an American, British, Canadian (ABC) Traveling Fellowship in 1985. He has been honored for his contributions to Orthopaedic Surgery by honorary memberships in National Orthopaedic Associations around the world including Australia, New Zealand, Germany, Great Britain Thailand and Argentina. Dr Weinstein is past president of the American Academy of Orthopaedic Surgeons (AAOS), The American Orthopaedic Association, The American Board of Orthopaedic Surgery, The Pediatric Orthopaedic Society of North America, The United States National Action Network of the International Bone and Joint Decade and The International Center for Orthopaedic Education (ICOE). He has served as an Associate Editor and a member of the Board of Trustees of the Journal of Bone and Joint Surgery. Professor Weinstein currently serves as Chairman of Doctors for Medical Liability Reform (DMLR), a Washington, DC based advocacy group, and Chairman of the American Association of Orthopaedic Surgeons Political Action Committee. His contribution to the education of British orthopaedic surgeons is immense.

Holbein, Hans the Younger
(b 1497, Augsburg, d, 1543, London)
INTRODUCTION
An interdisciplinary spine center can serve as a model of cost-effective, patient-centered care within an academic medical center. The ideal spine center would serve back or spine pain patients expeditiously, provide a comprehensive range of imaging and physiologic testing, and offer timely surgical or nonsurgical treatment options. Most importantly, however, the ideal spine center should include professionals who are good communicators who can provide patients with appropriate explanations of the cause of their symptoms, take into account the patient preferences and encourage patients to become more actively involved in treatment of their back pain.

Only a minority of back pain patients ultimately needs surgical intervention. The typical yield of spine surgery cases from spine surgery clinics can vary from a low of five percent to a high of 50 percent anecdotally, depending on surgeon preference and whether a successful triage mechanism is in place. If a spine center does not have patient triage, it could be viewed as a "factory," churning out high-cost spine surgeries or procedures, yet not offering much to the majority who do not want or need surgery. We describe herein how the University of Iowa (UI) Spine Center has developed programs to insure that patients are seen by the right provider at the right time, while providing appropriate treatment for each patient. All these programs can improve patient and provider satisfaction. We reviewed the operation of a spine center in an academic medical center over the past 20 years to identify some of the important factors required for success. The most important factor appeared to be dedicated professionals with extensive experience in dealing with complex, difficult, and frustrated patients with chronic back pain.

HISTORY
Iowa’s first interdisciplinary spine clinic was developed in 1985 by Dr. James Weinstein and Dr. Ernest Found, Jr. These well-known orthopaedic spine surgeons realized the complexity of spine care required not only expertise in surgical technique, but also acknowledgement of the physical and psychosocial factors that contribute to chronic back pain. A rehabilitation team was developed that included dedicated professionals from physical therapy, psychology, medical social work, and vocational counseling to help patients manage their chronic back pain.

Initially, the Spine Diagnostic and Treatment Center surgeons evaluated whether surgical intervention would be helpful, while the interdisciplinary team helped teach non-surgical chronic back pain patients how to manage their pain and to take a more active role in their rehabilitation. The team used an innovative one-day evaluation process, and a two-week outpatient rehabilitation program1 filled with physical activities and cognitive-behavioral activities. Favorable results have been published for similar rehabilitation programs and have been studied extensively and validated as being effective in treatment of patients with chronic back pain.2 In 2000, the Spine Diagnostic and Treatment Center was renamed to UI Back Care to become more consistent with internal naming policies. A physical medicine and rehabilitation physician (physiatrist) was hired to assist the spine surgeons in the timely evaluation of back pain patients and serve as medical director of the interdisciplinary team. The physiatrist provided leadership for the entire rehabilitation team as well as the one-day evaluation process and the two-week rehabilitation program. The rehabilitation physician evaluated new musculoskeletal conditions arising during the patient’s rehabilitation process, assisted in teaching group educational sessions on pain and spine anatomy, or simply reassured patients that continued active participation despite increases in pain were both appropriate and a necessary step in their rehabilitation. Now the title “UI Spine Center” best describes the three orthopaedic spine surgeons, three physical medicine and rehabilitation physicians,
five physical therapists, vocational counselor, medical social worker, and health psychologist as well as multiple program and secretarial support staff.

COMPONENTS OF SUCCESS
Orthopaedic spine surgeons at the UI Spine Center accept referred patients from local orthopaedic surgeons and physicians from across Iowa. In distinction from several local and regional spine care providers, the UI Spine Center also accepts self-referred patients with back pain. Surgeons may be asked to provide a recommendation for surgical treatment for acute radiculopathy, or a second opinion regarding further surgery for spine symptoms, or they may attempt to help manage reconstruction or revision of prior failed spine surgeries. Many patients do not need surgery or prefer not to be treated with surgical intervention. Studies now confirm that episodes of acute disc herniation, radiculopathy or spondylolysis may be treated successfully without surgical intervention.6

SPINE PHYSIASTISTS
Physical medicine and rehabilitation physicians (physiatrists) are trained in the management of patients with neuromusculoskeletal conditions. Physiatrists in the UI Spine Center evaluate patients with acute and chronic back pain to determine whether additional diagnostic testing is needed. Frequently, diagnostic imaging may be necessary for patients with chronic pain. All too often, however, diagnostic imaging identifies structural abnormalities that are asymptomatic or may not be a cause of pain. Physiatrists serve an important role in determining the course of treatment as well as explaining whether any findings are truly worrisome or warrant further intervention. Some patients may then be referred for surgical consultation, additional diagnostic testing (such as EMG/nerve conduction studies, diagnostic injections) or development of an initial or revised course of physical medicine treatments or therapy.

INTERVENTIONAL PROCEDURES
Interventional procedures, including transforminal or interlaminar epidural steroid injections, may be helpful for patients with disc herniation and acute back pain. Professionals throughout the medical center, including physiatrists, anesthesiologists, orthopaedic surgeons, radiologists, or neurologists perform these injections using fluoroscopic guidance. Although recent studies criticize over-utilization of spine injections for chronic back pain, evidence-based treatment of patients with radiculopathy and back pain suggests that epidural steroid injections are helpful for many of these patients.5

PHYSICAL THERAPY
It is universally agreed that moderate exercise plays an effective role in the management of chronic back pain.7 Physical therapists can tailor an exercise program for patients with back pain. While the focus of specific exercises is difficult to prove, a combination of abdominal strengthening, pelvic tilt, flexion or extension exercises, and hip abductor strengthening can be helpful for many patients.3 Patients with chronic pain can be especially difficult to treat. A team of professionals is needed who are comfortable in educating and reassuring patients to continue their exercise program despite temporary mild or moderate increases in their back pain.

HEALTH PSYCHOLOGY
Chronic pain can cause stress and stress can cause chronic pain. Effective management of chronic pain (cognitive behavioral techniques and exercises) has been shown to reduce unnecessary and often expensive health care utilization.9 Health psychologists can demonstrate for patients the benefits of self-management techniques for chronic pain. Patients dissatisfied with their care or with the explanation of their symptoms can continue to seek expensive medical treatments.10 Frequently, they hope some new “magical” treatment will cure their back pain and revitalize their aging backs and discs. Depending on the payor mix status, this can be helpful or harmful to a hospital’s bottom line, but in either case, this behavior is likely responsible for escalating health care costs and inappropriate use of medical services.

VOCATIONAL COUNSELING
There is no doubt that many patients with physically demanding jobs have back pain. Many patients worry that because of back pain, they will be unable to return to work. These issues commonly result in additional medical testing which can frequently lead to excessive time off work, and even prolong disability. In certain circumstances, patients who have physically demanding occupations may need to consider alternative work options. A physician who says, “If you can’t work, then just find another job,” doesn’t understand the complexities of finding career employment. It is truly a goal for the chronic back pain patient to be able to return to a productive role in society. Patient education, both about back pain and strategies to become a productive participant in society, are essential goals of successful rehabilitation. The most complex situation can be dealing with medical behavior, and long-standing educational factors. These factors could be addressed by a busy spine surgeon, but a vocational counselor has more experience in providing meaningful direction. Return-to-work and vocational
issues are important determinants of successful back pain treatment.

**MEDICAL SOCIAL WORK**

Many patients in chronic pain need community resources. When patients understand their eligibility for services, this can help them actively manage their personal lives and healthful choices. Many patients believe that if they do not work for 12 months or more, because of their back pain, they can become eligible for federal disability services. Once patients are reassured that they are not likely to be doomed to a life of chronic pain and disability due to back pain, they are more able to take an active role in their medical treatment and rehabilitation.

**KEYS TO SUCCESS**

While back pain can be surgically treated in a minority of patients, successful management of the majority not requiring surgery is the key to a successful spine center. Over the past several years, we have identified several keys to a successful interdisciplinary spine center. One of these keys is having a common mission for the treatment of all patients with spine conditions, regardless of whether they have a surgical indication or non-surgical treatment plan. Another key is an integrated scheduling or triage mechanism to insure that patients see the right physician or provider at the right time. Patient preference is becoming more and more important and patients frequently want to know whether all of their options have been explored. An interdisciplinary team that is in close physical proximity to each other is also important. Weekly interdisciplinary team meetings to discuss a range of treatment options is also an important facet of success.

**METRICS OF SUCCESS**

A variety of metrics of success can be relatively easily obtained with modern hospital accounting methods. The number of clinic visits per provider per specialty can be tracked. The relative value units (RVUs) per provider per specialty can also be followed. Medical Group Management Association (MGMA) data for clinical effort is available for academic health centers. Decisions regarding overall financial productivity should be based on contributions from physician and hospital revenue as well as surgical, non-surgical, imaging and rehabilitation treatments. A focus on only a particular service line’s contribution will unnecessarily lead to more inefficient or excess utilization of services that may not be in the patient’s best interest. A vocational counselor will never generate the same magnitude of revenue that a surgeon generates. If an interventional spine specialist is generating more revenue than a spine surgeon, this may indicate over-utilization of spinal injections. Efficiencies of clinics and the operating room also need to be evaluated.

**BARRIERS TO SUCCESS**

Barriers to success include intra-mural competition among different departments providing similar services. Neurosurgery and orthopaedics may both be able to provide spine surgery. Physicians from anesthesia, radiology, physiatry, and neurology may provide spinal injection expertise. Physiatrists and neurologists may also provide electrodiagnostic testing. A common mission and collaborative value system among all these providers are essential to the success of a spine center. A lack of administrative support within a department or within the hospital can lead to unrecognized losses in market share, referral patterns, clinic efficiency, or operating room efficiency. All of these factors are critical to the successful spine center.

**CONCLUSION**

Although in the near future there will likely be a never-ending source of patients with back pain, a medical center that has an effective method of managing chronic spine pain patients will deliver cost-effective and patient-centered care and should achieve financial success. Not addressing the majority of patients who do not require back surgery will not make them go away, and can actually result in excessive utilization of scarce health care resources and the failure of even the most successful spine center.

**REFERENCES**


