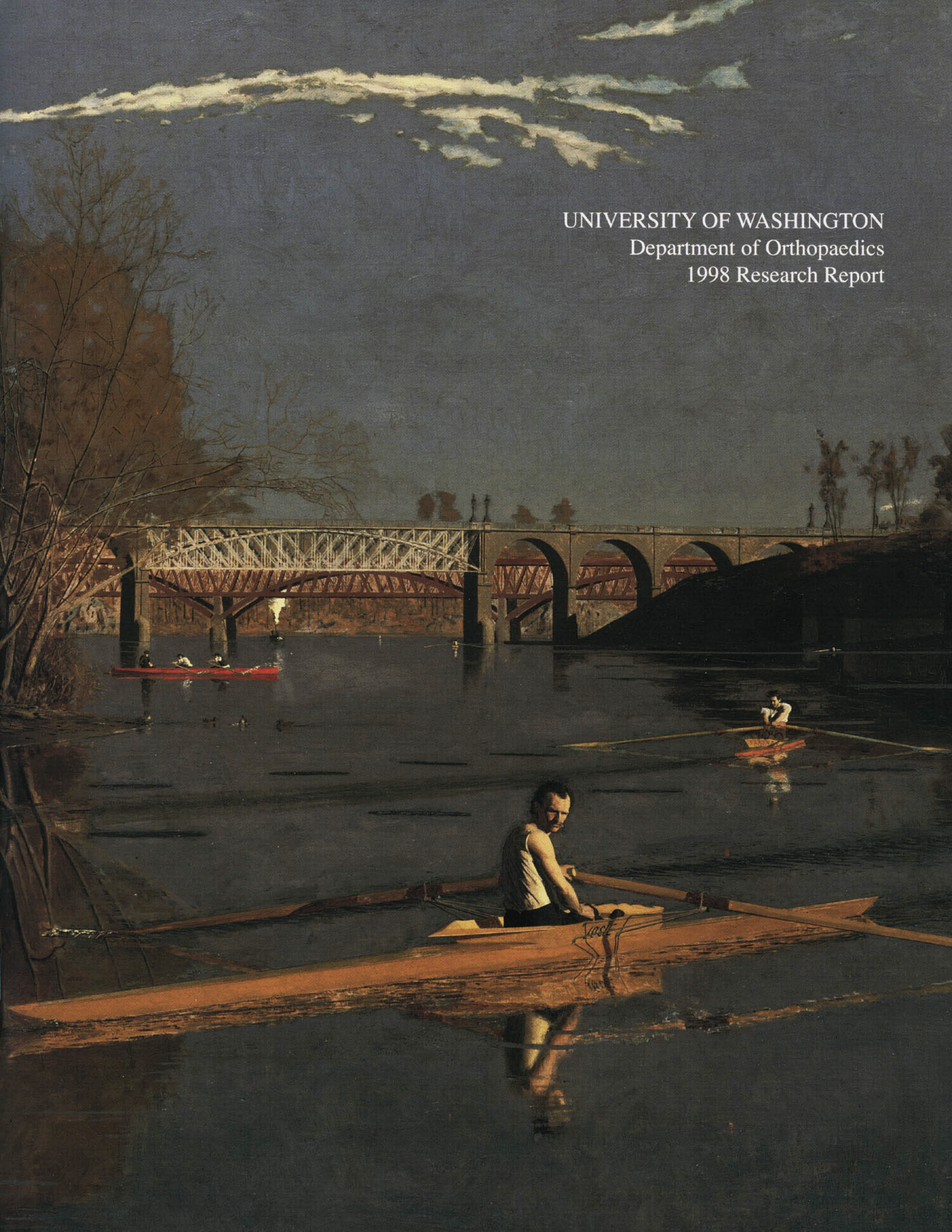
UNIVERSITY OF WASHINGTON
Department of Orthopaedics
1998 Research Report



UNIVERSITY OF WASHINGTON

Department of Orthopaedics

1998 Research Report

UNIVERSITY OF WASHINGTON SCHOOL OF MEDICINE

Department of Orthopaedics
University of Washington
Seattle, WA 98195

EDITORS:
Frederick A. Matsen III, M.D.
Peter Simonian, M.D.
Fred Westerberg
Susan E. DeBartolo

DESIGN & LAYOUT:
Fred Westerberg

Cover Illustration: "The Champion Single Sculls" by Thomas Eakins
The Metropolitan Museum of Art, Purchase,
The Alfred N. Punnett Endowment Fund and
George D. Pratt Gift, 1934. (34, 92)

Contents

Foreword 1

Sports Safety for Women: An Opportunity Whose Time Has Come 2
Frederick A. Matsen, III, M.D., Peter T. Simonian, M.D., and Carol C. Teitz, M.D.

The Effect of Neck Position on Spinal Canal Occlusion in a Cervical Spine Burst Fracture Model 4
Randal P. Ching, Ph.D., Nathan A. Watson, B.S., Jarrod W. Carter, B.S., and Allan F. Tencer, Ph.D.

Differential Localization of Collagen Types I, IIA and III in Human Osteoarthritic Cartilage 7
Yong Zhu, M.D., Howard A. Chansky, M.D., Frederick A. Matsen, III, M.D., and Linda J. Sandell, Ph.D.

Proteolysis of Cartilage Collagens II, IX and XI by Collagenase-3 (MMP-13) 9
Jiann-Jiu Wu, Ph.D., Vera Knauper, Ph.D., Gillian Murphy, Ph.D., and David R. Eyre, Ph.D.

Matrix Metalloproteinase-Mediated Release of Immunoreactive Telopeptides from Cartilage Type II Collagen 11
Lynne M. Atley, Ph.D., Ping Shao, B.S., Vince Ochs, B.S., Kathy Shaffer, B.S., and David R. Eyre, Ph.D.

Peak Growth Age: A New Maturity Indicator for Idiopathic Scoliosis 13
Kit M. Song, M.D., David G. Little, M.B.B.S., F.R.A.C.S. (Orth), Don Katz, C.O., and John Herring, M.D.

Biomechanical Study of Foot Function 17
Bruce J. Sangeorzan, M.D.

Assessing the Value of a Procedure: A Pilot Study Using Total Shoulder Arthroplasty as an Example 20
Jay L. Crary, M.D., Kevin L. Smith, M.D., and Frederick A. Matsen, III, M.D.

The Simple Knee Test: A Quick and Sensitive Self-Assessment of Knee Function 23
Michael H. Metcalf, M.D., Roger V. Larson, M.D., Peter T. Simonian, M.D., and Frederick A. Matsen, III, M.D.

The Response of Cartilage to an Intra-articular Step-Off: A Sheep Weight Bearing Model 26
Thomas E. Trumble, M.D.

Contact Pressures at Osteochondral Donor Sites in the Knee 28
Peter T. Simonian, M.D., Thomas L. Wickiewicz, M.D., and Russell F. Warren, M.D.

The Enzymatic Preparation of Allograft Bone 30
David J. Belfie, M.D. and John M. Clark, M.D., Ph.D.

Angulated Screw Placement in the Lateral Condylar Buttress Plate for Supracondylar Femur Fractures 33
Peter T. Simonian, M.D., Greg J. Thomson, Will Emley, Richard M. Harrington, Stephen K. Benirschke, M.D., and Marc F. Swiontkowski, M.D.

Comminuted and Unstable Iliac Fractures 37
Julie Switzer, M.D., Sean E. Nork, M.D., and M.L. Chip Routt, Jr., M.D.

Early vs Delayed Acetabular Fracture Fixation 39
Oriente DiTano, M.D., William J. Mills, M.D., and M.L. Chip Routt, Jr., M.D.

A Biomechanical Comparison of Some Bone-Ligament-Bone Autograft Replacements for the Injured Scapho-Lunate Ligament 41

E.J. Harvey, J.B. Knight, Doug P. Hanel, M.D., and Allan F. Tencer, Ph.D.

Early "Simple" Release of Post-Traumatic Elbow Contracture Associated With Heterotopic Ossification 43

Randall W. Viola, M.D. and Doug P. Hanel, M.D.

A Prospective Multicenter Functional Outcome Study of Arthroplasty in Glenohumeral Inflammatory Arthritis 44

David N. Collins, M.D., Doug T. Harryman, II, M.D. and Michael T. Wirth, M.D,

Department of Orthopaedics Faculty 46

Incoming Faculty 47

Graduating Residents 49

Incoming Residents 50

Contributors to Departmental Research and Education 51

National Research Grants 53

Foreword

The cover of this year's research report, "The Champion Single Sculls" is a 1871 oil on canvas which hangs in the Metropolitan Museum of Art. Its painter, Thomas Eakins (1844-1916), is one of America's most distinguished artists. Although this painting celebrates a race held on Philadelphia's Schuylkill River, the setting is very reminiscent of the Montlake Cut, the scene of many UW crew victories. We selected this cover in honor of the many Husky student athletes whom we have had the chance to serve this year and also of our new Dean, Paul Ramsey, who himself is frequently found rowing his single scull on the Cut.

This has been an important year for the Department of Orthopaedics. Two of our senior faculty have gone on to assume prestigious positions at other schools of medicine. Marc Swiontkowski is now the Chair of Orthopaedics at the University of Minnesota. Linda Sandell now holds an endowed professorship at Washington University in St. Louis. We wish them both our very best as they assume their new leadership positions.

We have successfully recruited five exciting new regular faculty members who will assume their new roles this summer. Bill Mills, a former UW resident, and Sean Nork, currently a traumatology fellow, will join the faculty based at Harborview. John O'Kane, our first primary care sports medicine fellow will join our Sports Medicine team. Mohammad Diab will join the Pediatric Orthopaedic group after his fellowship in Boston. Finally, Randy Ching will become a member of the core faculty at the Biomechanics Lab.

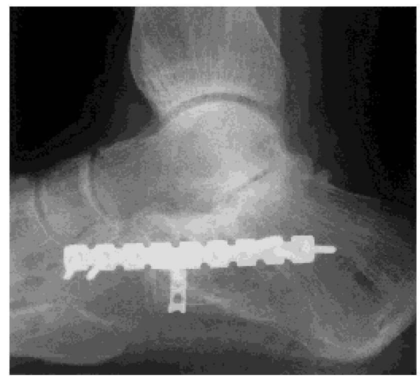
The excellence of the faculty has again been recognized by the Department's inclusion in the top ten Orthopaedic services in the United States by *US News and World Report* and by our ranking in the top five Orthopaedic Departments in terms of grant support from the National Institutes of Health. The American Academy of Orthopaedic Surgeons and its affiliated specialty organizations selected over 50 presentations by Departmental faculty and residents at the annual meeting in New Orleans. Fully as important is the ranking we are given by medical students applying for Orthopaedic training: this year we again matched with five sensational new residents: Tim DuMontier, Scott Hacker, Tim Rapp, Bill Sims, and Carla Smith, who are profiled later in this report.

This year also saw a most special gesture of appreciation by one of our patients who, in recognition of the outstanding care rendered him by Steve Benirschke, has established the Jerome H. Debs Endowed Professorship in Orthopaedic Traumatology. The two X-rays on this page show the type of reconstruction that Dr. Benirschke has pioneered. The upper film shows a severe fracture dislocation involving the subtalar joint. The second film shows an anatomic reconstruction. The Regents of the University of Washington have just approved Steve's appointment to this Professorship. This generous philanthropy will assure that Steve's academic efforts are well supported and that traumatology research will be forever secure in our Department.

This year's Research Report displays only a sample of the breadth and depth of Departmental research. From the most basic biochemical, immunohistological, biomechanical and biological research to new directions of clinical research, including an attempt to assess the value of Orthopaedic interventions, our faculty and residents strive to better understand and better treat the conditions which compromise our patients' comfort and function. We hope you enjoy this brief tour and we welcome your thoughts, suggestions and support.

If you'd like to learn more about the University of Washington Department of Orthopaedics, please visit our internet address at http://www.orthop.washington.edu/ or drop us an Email message at either matsen@u.washington.edu or at peter_simonian@uwortho.orthop.washington.edu.

We would like to conclude with a hearty thanks to all the friends, staff, faculty, residents and students who



make the Department of Orthopaedics what it has become today. Countless acts of service and generosity by you enable the team to achieve at the highest level as we pursue our missions of research, education and patient care.

Best wishes,

Frederick A. Matsen III, M.D.
Chairman

Peter Simonian, M.D.
Associate Professor,
Sports Medicine

Sports Safety for Women: An Opportunity Whose Time Has Come

FREDERICK A. MATSEN, III, M.D., PETER T. SIMONIAN, M.D., AND CAROL C. TEITZ, M.D.

Difficult beginnings. In 1896, when the first modern Olympic games were held in Athens, the only female participant was an unofficial marathoner named Melpomene. Despite attempts by officials to physically remove her from the course, Melpomene completed the 40 km race in 4.5 hours, faster than many men. By 1928, more Olympians were women, but when several collapsed from heat exhaustion at the end of an 800-meter race, the International Olympic committee placed a ban on women competing in races longer than 200 meters—a ban that lasted for 32 years! In the United States the progress women have made in the athletic arena has been slow and anything but steady, both in participation and in funding. It was not until 1973, in fact, when golfer Terry Williams signed on at the University of Miami that a woman athlete received a full-tuition athletic scholarship.

Women are becoming better athletes, but getting hurt more often. Each year more women of all ages participate in organized sports and vigorous physical recreation. Each year the level of competition among women athletes gets higher: faster running, cycling and skiing times, more three pointers and slam dunks in basketball, and more difficult dives, vaults, skating and rock climbing maneuvers. Unfortunately, one fact remains the same: women athletes have more injuries than their male counterparts. For example, women high school cross country runners have the highest injury rate of any group of sports participants, male or female. Knee problems, shin splints and stress fractures have not only ended many promising careers, but have also taken away the joy of participation from many more middle of the pack runners. It is not known if this greater predilection to injury is a result of differences in anatomy, running style, diet, strength, or shoe design. It is clear that the answers will only be found in the study of the woman runner, rather than continuing to apply knowledge gained from research on men to the challenges faced by women.

The ACL Enigma. Perhaps no gender difference is more important and more perplexing than the repeated observation that women basketball players have anterior cruciate ligament (ACL) tears at many times the rate of their male counterparts (Figures 1, 2, 3). In a recent study of almost 12,000 varsity basketball players, high school women were found to be at three times the risk of men, while in at the collegiate level, the risk for women was six times that of men for this season ending injury! ACL injuries account for 25% of all female basketball-related injuries. In football ACL injuries occur from heavy physical contact. However in women's basketball, 96% of these injuries happen without contact with another player, usually during a pivot, a sudden stop or in landing a jump.

The reasons for the disparity in injury rates between the genders are unknown; however a number of theories have been suggested.

Slower neuromuscular response: Some propose that women tend to become interested in sports at a later age than men, and as a result have had fewer years to develop their agility.

Diminished strength: Others propose that women have a lower strength-to-mass ratio than men, giving them less ability to control pivots, sudden stops or awkward landings from jumps. Decreased quadriceps and hamstring strength can increase the risk of knee injury; average quadriceps strength in females is known to be 60% that of males.

Different anatomy: Still others propose that the disparity results from anatomical differences. For example, women have more of a valgus (knock-kneed) alignment of their lower extremities than men (who are more bow-legged as a rule). Landing on such a limb is more likely to cause it to buckle to the inside, tearing the medial collateral ligament and the anterior cruciate ligament. The valgus limb is also associated with an increased "Q-angle" which may make the quadriceps less effective in controlling the landing. Radiographic studies have shown that women tend to have narrower intercondylar notches than men, a fact which could cause the rim of the notch to stress the ligament in

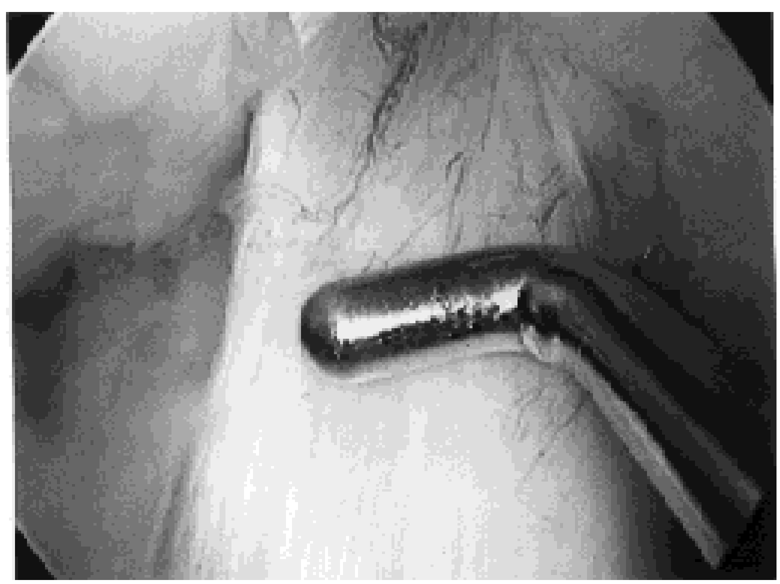


Figure 1: Intact ACL Being Probed

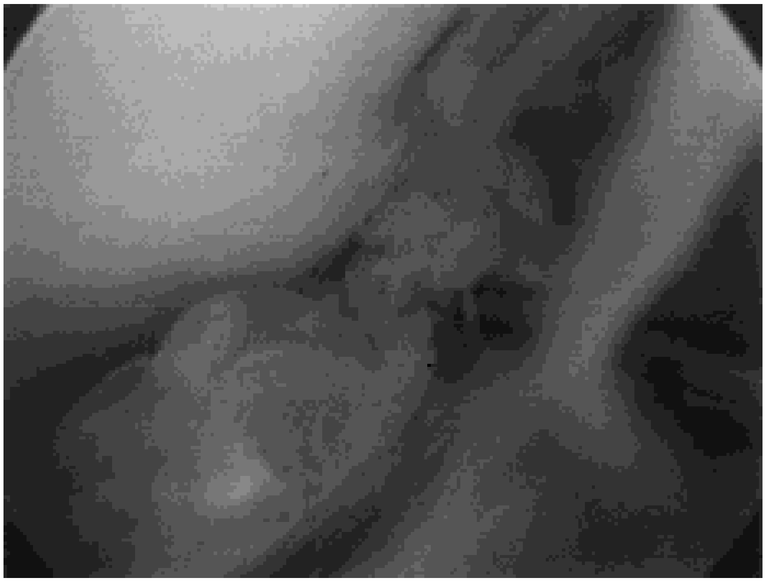


Figure 2: Probe Behind Torn ACL

hyperextension. The narrower notch in women may also reflect a smaller-sized anterior cruciate ligament less able to resist injuring forces.

Joint laxity: Loose or hypermobile knees are at higher risk for ACL tears. The increased joint laxity of women may enable the knee to be stretched away from a stable configuration to one where the ligaments are at greater risk. Estrogen influences connective tissue metabolism and can cause an elevation of endogenous relaxin which increases soft tissue laxity. Recent evidence suggests that during the luteal phase of the menstrual cycle the laxity may be at its peak; furthermore birth control pills prolong the luteal phase increasing the time of increased laxity. Current research is attempting to correlate the timing of ACL injuries with phases of the menstrual cycle and with the use of birth control pills.

Figure 3: ACL Reconstructed with Tendon Graft

Time for action. While these theories are of interest, they have failed to suggest strategies for making basketball, skiing, soccer and running safer for women. The fact that women athletes differ from men has been established; it has finally been recognized that lessons learned from studying men cannot be generalized; it is time to focus on approaches for injury prevention which are specific to women. Unfortunately, due to the greater economic interest in men's sports, it is relatively more difficult to fund a research program to benefit the woman athlete. Recognizing these challenges, the UW Sports Medicine and Fitness Team has dedicated itself to the pursuit of the resources and the knowledge which will lead to safer recreation and competition for women of all ages.

Recommended Reading

Gray, J., Tontine, J., McKenzie, D., and et al.:: A survey of injuries to the anterior cruciate ligament of the knee in female basketball players. Int J Sports Med, 6: 314-316, 1985.

Houseworth, S., Mauro, V., Mellon, B., and et al..: The intercondyar notch in acute tears of the anterior cruciate ligament: A computer graphics study. Am J Sports Med, 15: 221, 1987.

Malone, T., Hardaker, W., WE, G., and et al..: Relationship of gender to anterior cruciate ligament injuries in intercollegiate basketball players. J So Orthop Assoc, In Press: 1993.

Nordgren, B.: Anthropometric measures and muscle strength in young women. J Rehabil Med, 4: 165, 1972.

Powers, J.: Characteristic features of injuries in the knee in women. Clin Orthop, 143: 120-124, 1979.

Tipton, C., Matthes, R., and Martin, R.: Influence of age and sex on the strength of bone-ligament junctions in knee joints of rats. J Bone Joint Surg, 60A: 230-234, 1978.

Arendt E, Dick R: Knee injury patterns among men and women in collegiate basketball and soccer: NCAA data and review of literature. Am J Sports Med; 23:694-701, 1995.

The Effect of Neck Position on Spinal Canal Occlusion in a Cervical Spine Burst Fracture Model

RANDAL P. CHING, PH.D., NATHAN A. WATSON, B.S., JARROD W. CARTER, B.S., AND ALLAN F. TENCER, PH.D.

A significant number of neurological injuries are thought to occur or to be aggravated during emergency extrication, transport and evaluation of patients with spinal injury. In 1980, Cloward reported that, of the patients with fatal injuries treated at the Edinburgh Royal Infirmary, 25% of the fatal complications were related to events occurring between the time of the accident and that of arrival of the patient to the emergency room. A subsequent study by Schriger and associates examined the ability of emergency medical personnel to immobilize the cervical spine of study subjects in neutral position — the commonly advocated position following spinal injury. They reported the lack of an accepted standard for defining neutral position, and concluded that immobilization on a flat wooden backboard would have placed 98% of their subjects into relative cervical extension. Biomechanical studies have shown that the spine displays a "neutral zone" rather than a single neutral position, as is true for many other joints of the body. Hence, because neutral position can neither be precisely defined nor maintained, positioning of a patient lacks consistency and is therefore predisposed to variability. Perhaps, a more effective approach would be to identify —and avoid— those spinal positions that could potentially induce further harm to the spinal cord by increasing canal encroachment or occlusion. Additionally, those positions that reduce post-injury canal occlusion could be advised and pursued.

In the interest of preventing further injury during the management of patients with cervical spine injury, this biomechanical study was conducted at the Orthopaedic Biomechanics Laboratory to examine the effects of neck position on canal occlusion (stenosis). Although previous studies have documented the effects of flexion-extension orientation on canal occlusion in intact (non-injured) specimens, none have explored this relationship using an injury model, or in other cervical orientations (e.g., lateral bending). A burst fracture model was chosen because of the significant degree of spinal canal involvement typically associated with this fracture pattern. In addition, Fontijne and associates, reported that increased spinal canal stenosis was correlated with an increased probability of neurological deficit in patients with thoracolumbar burst fractures. Therefore, this study enabled the investigation of whether neck position had a significant effect on canal occlusion —with potential neurologic consequences.

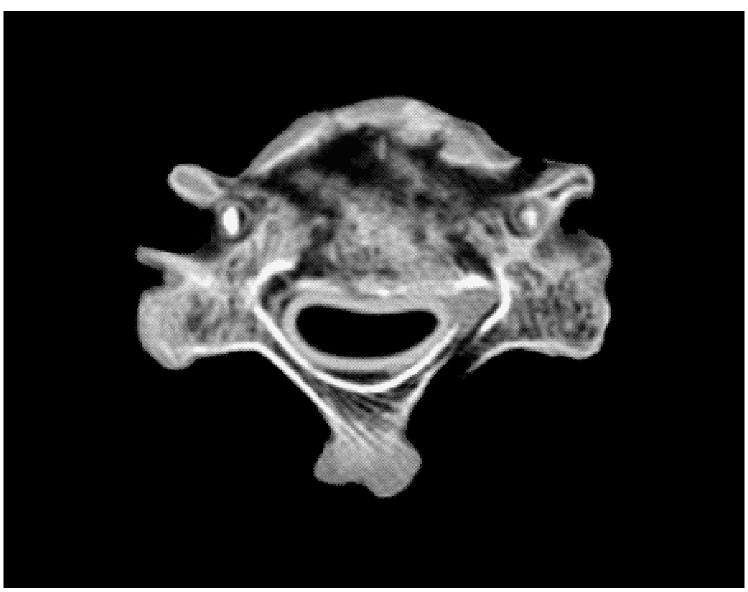


Figure 1: CT image of a burst-fracture specimen.

MATERIALS AND METHODS

Specimen Preparation

Eight fresh human-cadaver, cervical spine specimens (levels C1 to T3) were obtained for this study through the Willed-Body Program of the University of Washington Department of Biological Structure. The specimens were prepared by removing the soft tissues while leaving the osteoligamentous structures intact. Spinal levels C1-C2 and T1-T3 of each specimen were potted in dental plaster providing rigid attachments to facilitate testing. Burst fractures were created using a drop-weight protocol that involved the release of a 4.5 Kg guided weight from a drop-height of 1.5 meters. Post-injury radiographs and computed tomography (CT) scans documented the location and severity of the burst fractures (see Figure 1 for an example).

Instrumentation

Spinal canal occlusion was measured using a custom spinal occlusion transducer system developed in our lab. This transducer consisted of a fluid-flow system (Figure 2) in which water was circulated through a section of highly flexible, peristaltic tubing that was passed through the spinal canal —replacing the cord. Any impingement on the tubing produced a rise in fluid pressure that was monitored by an upstream pressure transducer. To quantify canal occlusion, the relationship between tubing diameter and pressure was established through calibration.

Angular motions across the level of injury were recorded using an electromagnetic three-dimensional tracking system (Polhemus 3-Space Fastrak System, Kaiser Aerospace and Electronics Company, Colchester, VT). Motion sensors were attached to pins inserted into the vertebrae immediately above and below the injury site. An acrylic loading frame was used to position the specimens without interfering with the electromagnetic motion sensors.

Experimental Procedure

Each specimen was tested in eight directions of bending including: flexion, extension, right- and left-lateral bending, and four intermediate (45°) positions. To describe the multi-axis bending applied to each specimen, a clock-face orientation was adopted in which flexion corresponded to the 12:00 o'clock position, while right lateral bending corresponded with 3:00 o'clock. In this study, neutral position was defined as the most central position of the spine aligned within the neutral zone while preserving a normal lordotic curvature. The first occlusion measurement recorded for each specimen was with the spine placed in neutral position. This provided a baseline measurement of the residual canal occlusion resulting from injury and served as the basis for statistical comparison against all other spinal positions.

Two occlusion measurements were taken in each direction of bending, one at the onset of ligament tensioning (i.e., the neutral-zone [NZ] boundary), and the second at full range of motion (ROM). The neutral-zone-boundary positions were established by loading (bending) the specimen twice to its full range of motion before allowing it to return to an equilibrium position. The full range-of-motion positions were produced by fully tensioning the spinal ligaments while being careful not to induce further damage to the specimen. Positioning of the specimens was performed manually with a random positioning order used for each specimen. In addition to bending, measurements were also taken while applying axial torsion (both clockwise and counter-clockwise), tension (traction) and compression to the spine.

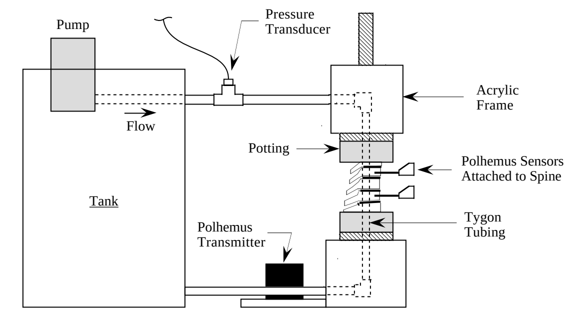


Figure 2: Schematic diagram of the experimental apparatus showing the spinal canal occlusion transducer and sensors for measuring spinal angulation.

Data Analysis

The occlusion data was expressed as a percentage reduction from intact canal midsagittal diameter. Paired t-tests were used to compare the canal occlusion measurements taken at each spinal position against measurements taken at the neutral position. Significance was established based on a computed p-value of less than 0.05.

Results

A contour plot (Figure 3) was prepared showing the relationship between canal occlusion and neck position in different directions of bending. This plot uses a clock-face orientation to describe the bending directions and displays an increasing percentage of canal occlusion as a grayscale gradient. The average canal

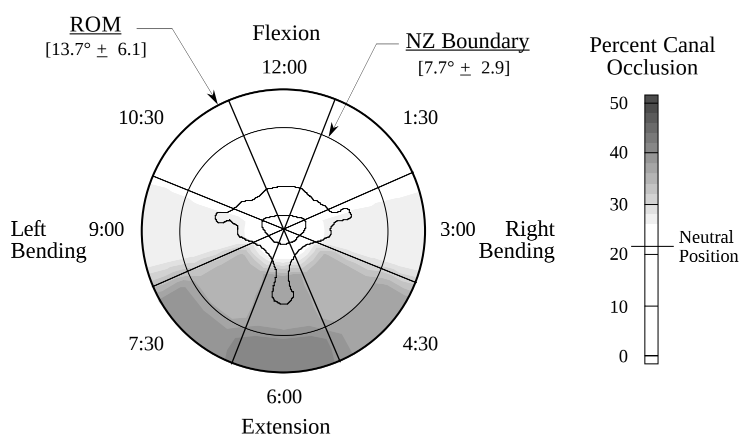


Figure 3: This contour map helps to visualize the relationship between canal occlusion and neck position at the neutral-zone boundary (NZ) and at full range of motion (ROM). Darker shading indicates a greater percentage of occlusion.

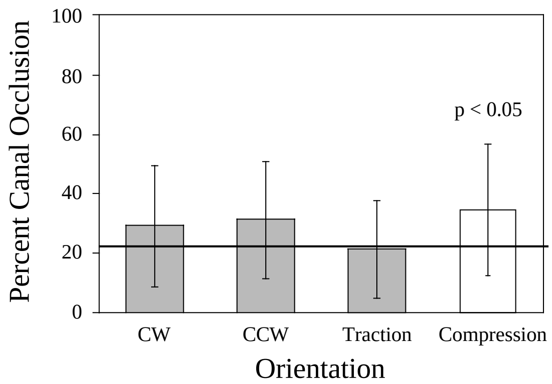


Figure 4: Mean and standard deviations for canal occlusion associated with rotation (both clockwise (CW) and counterclockwise (CCW)), tension (traction), and compression.

occlusion in neutral position was 23% ± 20 which corresponded to the baseline (residual), burst-fracture canal encroachment. Significant increases in occlusion, from neutral position, were found particularly in extension and in lateral bending combined with extension (i.e., 4:30 and 7:30 orientations). For example, at full range of motion, the average measured occlusion in extension increased to 42% ± 20 ($p = 0.01$). Similar increases were observed at the 4:30 position (38% ± 21, $p = 0.04$), and at the 7:30 position (39% ± 20, $p = 0.02$). There was a trend towards reduced (decreased) canal occlusion for flexion (14% ± 22), however, not at a statistically significant level. Figure 4 documents the effect of axial torsion, tension (traction) and compression on canal occlusion. Traction demonstrated no appreciable effect on occlusion, however occlusion increased significantly in compression (35% ± 18, $p = 0.02$). In summary, we found that compression, extension, and lateral bending combined with extension significantly increased canal occlusion for all eight specimens tested.

Discussion

The objectives for this study were achieved by documenting the effect of neck position on canal geometry in a burst fracture model, and subsequently testing the hypothesis that different positions may affect (by increasing or decreasing) canal occlusion. Our findings indicate that for burst fractures, positioning the spine into extension increased canal occlusion considerably. At full range of motion in extension, the residual (baseline) canal occlusion increased from 23% (the average occlusion in neutral position) to 42%, an increase of 19%. Similarly, axial compression resulted in a statistically significant, 12% increase in measured canal occlusion (from 23% to 35%). Although none of the tested neck positions yielded statistically significant decreases in canal occlusion, a trend was observed for specimens placed into flexion (i.e., the average canal occlusion decreased from 23% to 14% in flexion). These responses were observed in all eight of the spine specimens tested. Other spinal positions did not appear to either positively or negatively affect canal occlusion. Therefore, the results of this study suggest that for a patient with a cervical spine burst fracture, positioning the neck into either extension or compression may significantly increase canal occlusion and potentially exacerbate a spinal cord injury.

Recommended Reading

Cloward RB. Acute cervical spine injuries. Clinical Symposia 1980; 32(1):1-32.

Schriger DL, Larmon B, LeGassick T, Blinman T. Spinal immobilization on a flat backboard: Does it result in neutral position of the cervical spine? Ann Emerg Med 1991; 20(8):878-881.

Fontijne WP, de-Klerk LW, Braakman R, Stijnen T, Tanghe HL, Steenbeek R, van-Linge B. CT scan prediction of neurological deficit in thoracolumbar burst fractures. J Bone Joint Surg 1992; 74B(5):683-685.

Ching RP, Watson NA, Carter JW, Tencer AF. The effect of post-injury spinal position on canal occlusion in a cervical spine burst fracture model. Spine 1997, 22(15): 1710-1715.

Differential Localization of Collagen Types I, IIA and III in Human Osteoarthritic Cartilage

YONG ZHU, M.D., HOWARD A. CHANSKY, M.D., FREDERICK A. MATSEN, III, M.D., AND LINDA J. SANDELL, PH.D.

Pain and disability caused by degenerative damage to articular cartilage affect millions of people in the United States. Since articular cartilage has little, if any natural capacity to heal with hyaline cartilage, most current treatments rely on symptomatic care until the patient is considered old enough to receive a prosthetic joint replacement. Both symptomatic care and joint replacement are fraught with side effects and are ultimately temporary solutions. Both can be expensive and neither allow a patient to return to physically demanding jobs. Centers throughout the world are developing techniques to repair or regenerate cartilage in defects. Much publicity and excitement over the most recent of these techniques applied to humans has been tempered as clinical results have not lived up to expectations. Basic scientific knowledge of the response of cartilage to injury is incomplete and the development of successful clinical techniques is unlikely without this knowledge.

Articular cartilage contains a unique assortment of the major and minor collagens in addition to proteoglycans and other less abundant matrix molecules. Little is known about the ability of chondrocytes *in vivo* to regenerate a functional extracellular matrix. A major question is whether chondrocytes "activated" in the early stages of osteoarthritis (OA) can synthesize an extracellular matrix (ECM) that is functionally similar to the cartilage articular surface produced during development. Very few studies have been directed toward the molecular aspects of normal developmental and repair processes of joints. Consequently, it is impossible to determine why the attempts at repair seen in OA are inadequate to regenerate normal hyaline cartilage.

It has been known for many years that the metabolic activity of articular chondrocytes increases in osteoarthritis, although the significance of these changes is poorly understood. The degradation and loss of the extracellular matrix components of osteoarthritic cartilage are accompanied by increased synthesis of types II and III collagen. The newly synthesized type II collagen may represent an incomplete repair response by chondrocytes embedded in degenerating matrix. In addition it has recently been shown that certain collagens are markers of specific stages of cartilage development. For example, type IIA procollagen is a marker of developing cartilage whereas type IIB collagen is synthesized only by mature chondrocytes. As development proceeds the predominant collagen becomes type IIB collagen and the type IIA procollagen is removed.

To investigate the possibility that chondrocytes in osteoarthritic cartilage may revert to a "younger" phenotype to facilitate repair of diseased matrix, we used immunohistochemistry to analyze the synthesis and distribution of type IIA procollagen NH2-propeptide, type II collagen triple helix, type II collagen COOH-propeptide and types I and III collagens in osteoarthritic cartilage.

Methods

Immunohistochemistry is a technique that takes advantage of the humoral immune system's ability to generate antibodies against specific molecules, or portions of molecules. Antibodies can be generated by injecting animals with specific proteins of interest. In this study, the proteins of interest were various collagens and collagen subunits. To visualize the primary antibody-antigen (protein) combination, a standard secondary antibody is attached to the primary antibody and then a chromogen, or fluorescing molecule, is chemically attached to the secondary antibody. The exquisite specificity of these reactions allow the *in vitro* detection of proteins of interest in paraffin-embedded histologic specimens. When a different chromogen is used for each antibody, confocal microscopy can reveal the relative distributions of each protein in a single histological section. We studied 29 samples from 11 patients with advanced osteoarthirits undergoing total shoulder (4), knee (3) or hip (4) replacement. To immunolocalize the collagens of interest, five antibodies were raised against collagen type I, type IIA procollagen NH-2 propeptide, type II collagen triple helix, type II collagen COOH-propeptide, and type III collagen. Confocal microscopy was used to assess the intensity and distribution of staining of the 5 molecules of interest.

Results

There was no significant staining for type I collagen in osteoarthritic cartilage. All 11 cases stained strongly for type III collagen and stained to varying degrees for type IIA procollagen NH-2-propeptide. Type IIA procollagen was mainly localized within the pericellular matrix of chondrocytes undergoing cloning in the middle and deep zones of the osteoarthritic cartilage. Type IIA procollagen was also found in 2 of 2 osteophytes which were studied. Interestingly, the staining for type IIA procollagen was more intense in the cartilage removed from the shoulder and in non-weightbearing regions of the hip and knee than in that removed from weightbearing areas of the knee or the hip. Type III collagen was found throughout the fibrillated matrix in all 29 specimens. Type III collagen was found diffusely within the superficial and middle zones of the cartilage but within the deep zone it was localized to the territorial matrix. The mature type II collagen triple helix was found throughout the cartilage matrix with peak levels found in the vicinity of chondrocytes. The type II carboxy-propeptide was only found within the cytoplasm of chondrocytes. Confocal imaging revealed that type IIA NH-2 propeptide and type II collagen triple helix were co-localized in the pericellular matrix within the lacunae. Appropriate positive and negative control tissues and antibodies were utilized.

Discussion

These results demonstrate that chondrocytes from osteoarthritic cartilage synthesize significant amounts of type IIA procollagen, a type of collagen which is normally found only in developing cartilage. This is consistent with the hypothesis that chondrocytes from diseased cartilage may "dedifferentiate" in an attempt to recapitulate the developmental pathways that result in the formation of articular cartilage. The absence of type I collagen indicates that these phenotypic changes are not those which are commonly seen during the "dedifferentiation" of chondrocytes grown *in vitro*. It is plausible that the phenotypic changes documented in this study reflect an aborted attempt by chondrocytes within damaged matrix to generate a healing response. The type IIA procollagen generated by these chondrocytes remains confined to the pericellular matrix as opposed to the situation that exists during development when the type IIA procollagen is deposited throughout the matrix. The local pericellular environment of damaged matrix may contain inhibitory factors, or may be missing stimulatory factors, which are needed to sustain the repair response. The local mechanical environment may explain why chondrocytes from the shoulder are able to synthesize greater quantities of type IIA collagen than those in weight-bearing joints such as the hip and knee.

Unlike many, if not most tissues, articular cartilage lacks the intrinsic capacity to heal with like-tissue. Based upon many studies it appears that the natural response of a chondrocyte to damage of surrounding matrix is to synthesize new matrix with a structure or ultrastructure different from that of healthy adult cartilage. The findings of this study suggest that the repair tissue assumes a phenotype resembling that of developing cartilage. This abnormal matrix is not able to withstand the normal stresses placed upon the articular surface and is unable to be incorporated into the surrounding matrix, and thus eventually fails. Before scientists and surgeons can develop effective techinques to restore damaged hyaline cartilage we must understand the normal response of joints to damage. This study is one step toward understanding these processes. In the future it may become possible to manipulate these native responses to our advantage with various cytokines, growth factors or genes.

Recommended Reading

Aigner T, Gluckert K, von-der-Mark K: Activation of fibrillar collagen synthesis and phenotypic modulation of chondrocytes in early human osteoarthritic cartilage lesions. Osteoarthritis-Cartilage. 5(3):183-9, 1993

Sandell, L.J., Morris, N., Robbins, J.R. and Goldring, M.R.: Alternatively spliced type II procollagen mRNAs define distinct populations of cells during vertebral development: differential expression of the amino-propeptide. J. Cell Biol. 114: 1307-1319, 1991.

Aydelotte, M.B. and Kuettner, K.E.: Heterogeneity of Articular Chondrocytes and Cartilage Matrix. In: Joint Cartilage Degradation: Basic and Clinical Aspects, J. Frederick Woessner, Jr., and David S. Howell, eds., Marcel Dekker, Inc., New York., 37-66, 1993.

Gerich TG, Fu FH, Robbins PD, Evans CH: Prospects for gene therapy in sports medicine. Knee Surg Sports Traumatol Arthrosc 4(3):80-7, 1996.

Proteolysis of Cartilage Collagens II, IX and XI by Collagenase-3 (MMP-13)

Jiann-Jiu Wu, Ph.D., Vera Knäuper, Ph.D.*, Gillian Murphy, Ph.D.*, and David R. Eyre, Ph.D.

Collagenase-3 (MMP-13) is one of the more recently identified human matrix metalloproteinases. First found in breast carcinomas (1), collagenase-3 is also produced by chondrocytes in human osteoarthritic cartilage. Collagenase-3 produced by chondrocytes is believed to be a key enzyme in the degradation of cartilage in osteoarthritis.

The collagenous framework of cartilage consists of cross-linked copolymers of types II, IX and XI collagens. In this study we have investigated the ability of recombinant collagenase-3 to degrade and depolymerize these three collagen types.

Materials and Methods

Human recombinant procollagenase-3 was expressed in transfected NSO mouse myeloma cells and purified from conditioned cell culture medium (2). The proenzyme was activated by p-aminophenylmercuric acetate.

Slices of fetal bovine epiphyseal cartilage were extracted at 4°C in 1M NaCl, 0.05M Tris-HCl, pH 7.5 for 24 hr then in 4M GuHCl for 24 h to remove non-cross-linked proteins and proteoglycans. The washed residues were minced and digested with pepsin and salt fractionated into types II, IX and XI collagens. From the 1M NaCl extract, newly made intact types II, IX and XI collagen molecules were purified (4).

Each collagen substrate was dissolved at 2mg/ml in 0.5M acetic acid and dialyzed against 0.2 M NaCl, 50mM Tris-HCl, 10mM $CaCl_2$, 0.05% Brij 35, pH 7.5. Aliquots of each were incubated with activated collagenase-3 (substrate/enzyme=200:1, w/w) at 30°C for 24 h. The digests were analyzed by SDS-7.5% PAGE. Protein bands were transblotted to PVDF membrane and identified by amino-terminal microsequencing.

Results and Discussion

Similar to collagenase-1, collagenase-3 degrades type II collagen into 3/4 and 1/4 fragments, and has no activity against triple-helical domains of type XI collagen. However, collagenase-3 was more active than collagenase-1 in degrading native type II collagen. Amino-terminal sequence analysis identified cleavage sites between bonds at Gly 778-Gln 779 and Gly 781-Ile 782 which are three and six residues C-terminal to the collagenase-1 cleavage site, respectively. Cleavage at

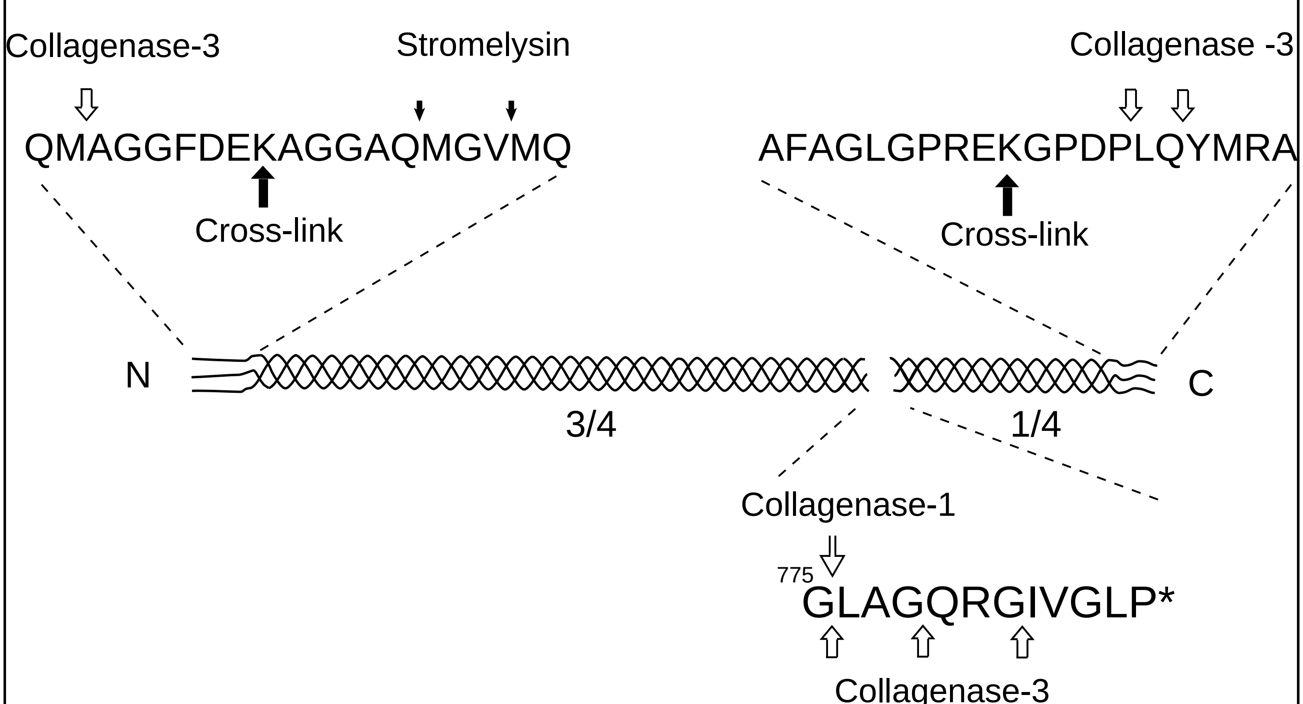


Figure 1: Molecular model summarizing sites of collagenase-3 cleavage in type II collagen

the Gly 775-Leu 776 bond (collagenase-1 site) could only be identified in samples incubated with enzyme under milder conditions (i.e. 22°C not 30°C for 6 hr). Sequence analysis of the 3/4 fragment produced from salt-soluble, intact type II collagen showed a limited cleavage of the N-telopeptide domain, but only exterior (i.e. N-terminal) to the cross-linking lysine residue. Similarly, digestion of synthetic peptides matching the type II C-telopeptide showed no cleavage interior to the cross-linking lysine (Figure 1).

When incubated with intact types IX and XI collagens, collagenase-3 trimmed the N-propeptide extensions from all three chains of intact type XI collagen. It also shortened the a1(IX) chain, consistent with the removal of the NC4 domain. However, unlike stromelysin (3) collagenase did not cut the type IX collagen molecule in its NC2 domain. This may be important in understanding the role of stromelysin in cartilage matrix degradation under conditions when collagenases are not expressed.

Summary

Collagenase-3 rapidly cleaves type II collagen at the Gly-Leu bond as cleaved by collagenase-1. The resulting 1/4 fragments are further cleaved by collagenase-3 removing three or six more amino acids from the amino terminus. Although some cleavage of the type II collagen telopeptide domain can occur, this action exterior to the cross-links has no depolymerizing potential. Therefore, after the initial attack of collagenase 3 on the triple-helix, other metalloproteases (e.g. gelatinase) are probably important in completing the process of depolymerization. The action of stromelysin in cleaving in the interior of type IX collagen may be physiologically important in mediating collagen network swelling in the absence of collagenase(s).

Recommended Reading

Freije, J.P.M. et al. Molecular cloning and expression of collagenase-3, anovel human matrix metalloproteinase produced by breast carcinomas. J. Biol. Chem. 269:16766-16773, 1994.

Knauper, V. et al. Biochemical characterization of human collagenase-3.J Biol Chem 271:1544-1550, 1996.

Wu, J.J. et al. Sites of stromelysin cleavage in collagen types II, IX, X and XI of cartilage. J. Biol. Chem. 266:5625-5628, 1991.

This work was supported by NIH grants AR 36794 and AR 37318.

*Dept. of Cell and Molecular Biology, Strangeways Research Laboratory, Cambridge, UK

Matrix Metalloproteinase-Mediated Release Of Immunoreactive Telopeptides From Cartilage Type II Collagen

LYNNE M. ATLEY, PH.D., PING SHAO, B.S., VINCE OCHS, B.S.**, KATHY SHAFFER, B.S.**,
AND DAVID R. EYRE, PH.D.

Proteolytic degradation of the collagenous matrix of cartilage can lead to loss of tissue and impaired joint function. The full range of proteinases involved in the degradative process and their precise roles are poorly understood, though matrix metalloproteinases (MMPs) are strongly implicated (1). MMPs are over-expressed in the joint tissues and synovial fluid of patients with arthritis (2, 3). In a recent study, MMP activity was correlated with type II collagen degradation in articular cartilage cultures that had been stimulated with interleukin-1a (4).

The aim of this study was to evaluate whether an immunoassay based on a monoclonal antibody (mAb) 2B4, which recognizes a domain of the a1(II) C-telopeptide EKGPDP (5), measures MMP cleavage products of cartilage. This 6-amino-acid core peptide was identified in cross-linked form in urine where it appears to be a protease-resistant end product of type II collagen fibril degradation. Immunoassays that quantitate markers of type II collagen degradation could be useful for understanding normal cartilage turnover and the pathogenesis of arthritic disease.

MATERIALS & METHODS

Immunoaffinity-purified stromelysin (MMP-3) was from IL-1-stimulated human dermal fibroblasts. Collagenase 2 (MMP-8), matrilysin (MMP 7), membrane-type (MT) - 1-MMP (MMP 14) were all recombinant human preparations (generous gifts from Dr. R Martin, Roche Bioscience). Recombinant human collagenase 3 (MMP-13) was kindly provided by Dr. G Murphy, Strangeways Research Lab., Cambridge.

Enzyme digests: 100 mg CNBr-digested human cartilage type II collagen, or 12.5 mg synthetic C-telopeptide domain, were incubated with 0.75 mg enzyme in digestion buffer (0.2M NaCl, 50 mM Tris-HCl pH 7.5, 10 mM $CaCl_2$, 0.05% Brij). Reactions were stopped with 1.10 phenanthroline (or soybean trypsin inhibitor for trypsin) immediately (0 hr), or after incubation for 24 hr at 37∞C (24 hr).

2B4 immunoassay: 2B4 immunoreactivity was quantitated by inhibition ELISA. 96-well microtitre plates were coated overnight at 4∞C with EKGPDP linked to BSA, then blocked for 2 hr at room temperature with buffer containing 0.25% BSA. Digestion buffer or calibrator (glutaldehyde cross-linked EKGPDP) were added, followed by 2B4-horseradish peroxidase conjugate. After incubation for 1.5 hr at 4∞C, the plates were washed and the peroxidase substrate TMB was added. After 15 min color development was stopped with H_2S0_4 and absorbance monitored at 450 nm.

Reverse-phase (RP)-HPLC: Peptides were resolved by RP-HPLC using a macroporous C8 column and a gradient of acetonitrile and 1-propanol containing 0.1% TFA. The UV absorbance of the eluant was monitored at 2 wavelengths; 280 nm (primarily for the tyrosine functional group) and 220 nm (primarily for peptide bonds). Peptides were identified by amino-terminal microsequencing.

Protease	2B4 epitope (ng/ml) 0 h	2B4 epitope (ng/ml) 24 h
Buffer control	2	12
Stromelysin	4	500
Collagenase 3	2	430
Collagenase 2	2	113
Matrilysin	4	3100
MT-1-MMP	3	145
Bacterial collagenase	2	170
Trypsin	2	10

Table 1: Release of 2B4 epitope from denatured cartilage type II collagen following digestion with a panel of proteases.

RESULTS

Compared with the buffer control and trypsin digests, all of the MMPs tested released 2B4 epitope from denatured cartilage type II collagen (Table 1). We then determined the MMP-specific cleavage sites in the C-telopeptide using the synthetic peptide AFAGLGPREKGPDPLQYMRA. Initial screening established that mAb 2B4 recognized MMP-digests of the synthetic peptide, but gave no signal with the intact molecule. When matrilysin digestion products of the peptide were resolved by RP-HPLC several fragments were identified, the most abundant (by 220 nm absorbance) eluting at 40 ml (Fig. 1). Sequence analysis identified this peptide as the product of P-L cleavage. Inhibition ELISA showed that it was the source of all the generated 2B4 immunoreactivity. Digestion with stromelysin or collagenase 3 produced essentially the same range of peptide fragments, including the 2B4-immunoreactive AFAGLGPREKGPDP,

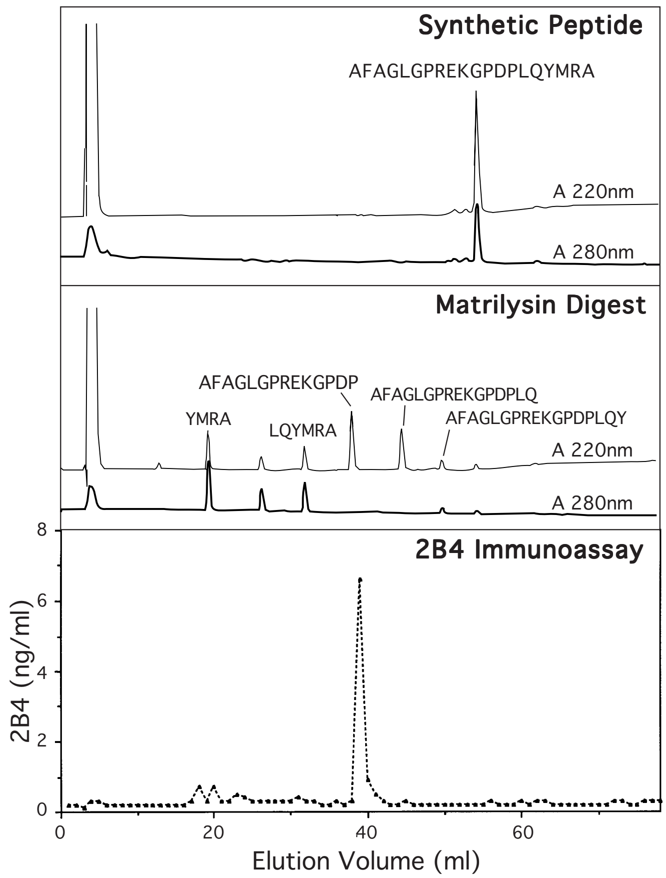


Figure 1: RP-HPLC resolution and 2B4 immunoreactivity of the synthetic peptide following proteolytic cleavage with matrilysin.

but the yield of the latter was much lower than with matrilysin.

Discussion

As part of a study to identify useful biochemical markers of cartilage collagen degradation, we have shown that a proteolytic neoepitope originating in the collagen type II C-telopeptide is generated *in vitro* by several MMPs. Of the MMPs so far tested, matrilysin appeared to be the most potent. In preliminary studies, we have detected 2B4 immunoreactivity in synovial fluid, serum and urine (5). This 2B4 epitope, therefore, has the potential to be a useful marker of type II collagen degradation *in vivo*. We are currently testing this in clinical studies and in animal models of osteoarthritis.

Recommended Reading

Murphy, 1995 Acta Orthop Scand 66: 55-60.

Okada et al., 1992 Lab Invest. 66: 1069-1073.

Lohmander et al., 1993 Arthritis Rheum. 36:181-189.

Kozaci et al., 1997 Arthritis Rheum 40: 164-174.

Eyre et al., 1996 Proceedings of the ASMBR, Seattle, WA.

Supported by grants from NIH (AR 37318 & 36794) and Ostex International, Inc.

** Ostex International, Inc., Seattle, WA.

Peak Growth Age: A New Maturity Indicator for Idiopathic Scoliosis

KIT M. SONG, M.D., DAVID G. LITTLE, M.B.B.S., F.R.A.C.S. (ORTH), DON KATZ, C.O., AND JOHN A. HERRING, M.D.

It is widely accepted that curve progression in idiopathic scoliosis is related to growth. Recommendations for bracing and operative intervention rely upon the ability to assess the growth potential of these patients. Chronologic age, Risser sign and menarcheal status are commonly used to estimate growth potential and the potential for future curve progression. These maturity scales aim to group children in such a way that they behave similarly with regards to growth and development. Buckler performed a longitudinal study of normal adolescents and reported a method of grouping children by the years around the age at which peak height velocity occurred. He found that these methods produced a growth velocity curve most representative of individual growth patterns, and that males, females, early and late developers behaved very similarly with respect to this scale. We have termed this maturity scale as Peak Growth Age (PGA). The purpose of this investigation was to apply this maturity scale to girls with idiopathic scoliosis followed through adolescence. We aimed to see if it predicted growth of the patient and likelihood of curve progression more accurately than existing maturity scales.

MATERIALS AND METHODS

We reviewed the charts and radiographs of 130 girls from a database of 371 patients braced for adolescent idiopathic scoliosis from 1977 to 1995. All patients had a curve magnitude of at least 25 degrees, idiopathic scoliosis, at least 6 visits to our institution over a minimum of 2 years with height measurements recorded through the adolescent growth spurt; progression from Risser 0 to at least Risser 4, and treatment with either a Boston TLSO or Charleston bending brace.

Height measurements for each patient were used to calculate height velocities in centimeters per year. An example of the calculation for an individual patient is shown in Table I. A minimum 6 month interval was used for calculations. The time of maximal height velocity was designated Peak Growth Age zero (PGA 0). For the patient in Table I, this was in February 1990 when the height velocity peaked at 10.1 centimeters per year. We assigned a positive or negative PGA to the years preceding and following peak height velocity (PGA -1, PGA +1, etc.). If the first height velocity available for a patient was greater than nine cm per year, this was designated as PGA 0. Cessation of growth was a height velocity less than 2 cm/year. We plotted height velocity against PGA, Risser sign, chronologic age, and menarcheal age. We looked at the subset of patients with curve progression greater than 10 degrees and examined which maturity scale most closely correlated with curve progression and the likelihood of curve progression to 45 degrees.

Fig. 1

Risser

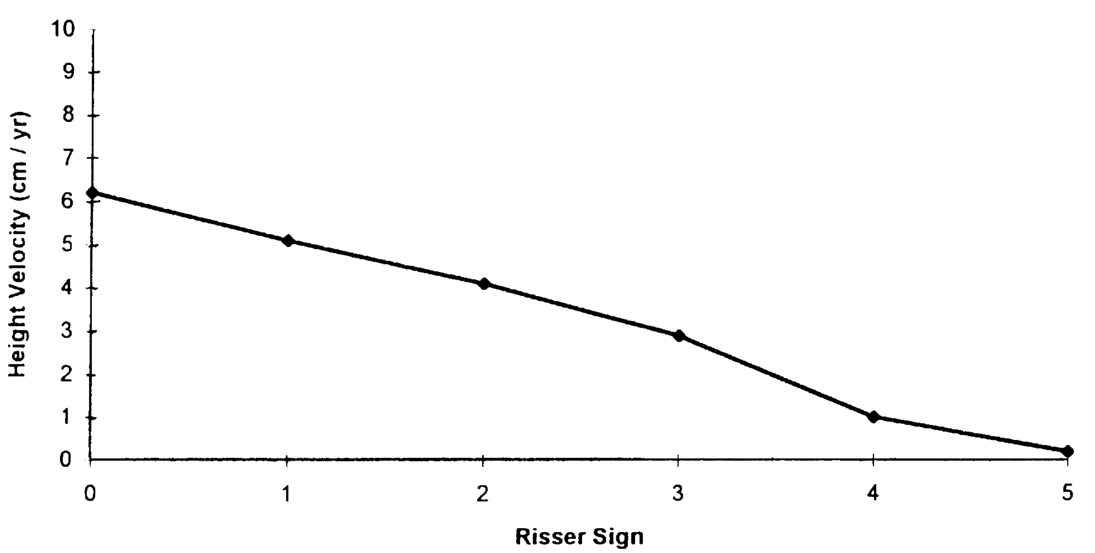


Figure 1: Plot of height velocity versus Risser Sign. Height velocity is greatest at Risser 0 which is not a defined point in time.

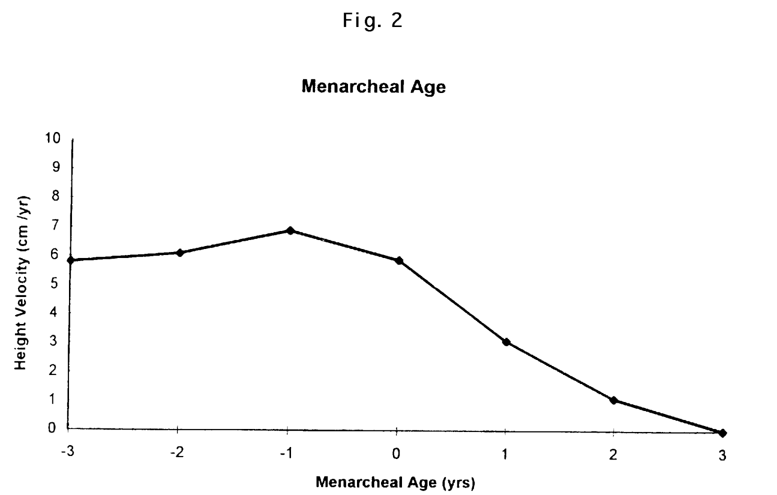


Figure 2: Plot of height velocity versus Menarcheal Age. There is no well defined peak in growth which occurs in relationship to the onset of menses.

Results

We could assign PGA in all cases. The plots for height velocity versus chronologic age, PGA, Risser sign, and menarcheal age are shown in figures 1-4. The median plot for PGA is the only scale which retains the characteristics of an individual plot, with a high peak and sharp decline. Menarche occurred in the year around PGA 0 in 41% of girls in our study. Sixteen patients (12%) had menarche two years or more after PGA 0 and 8% had menarche two years or more before PGA 0. The growth pattern of these patients clearly followed PGA rather than menarcheal age. PGA 0 was an earlier identifiable landmark than the onset of menses or Risser 1 which occurred at a median of 7 months and 9 months after PGA 0.

Ninety-seven curves progressed at least 10 degrees and 61 progressed to 45 degrees or more. The point of maximal curve progression was significantly more closely grouped around PGA 0 than a specific chronological age (F test p=0.0001), Risser sign or menarche (p=0.02). Fifty-nine of 86 curves (69%) greater than 30 degrees at PGA 0 progressed to 45 degrees or more, whereas only 2 of 44 curves (5%) 30 degrees or less progressed to 45 degrees or more. This difference was significant by Chi square (p<0.001).

Discussion

All maturity scales aim to group children in such a way that they behave similarly with regards to growth and development. Other methods are indirect and thus infer the growth of the individual. Peak Growth Age (PGA) is a maturity scale directly related to growth and the adolescent growth peak. It uses the time of the growth peak as a fixed point by which patients are grouped. PGA was found in this study to be more predictive of the time of cessation of growth and the period of most rapid curve progression than the use of chronologic age, Risser sign, or menarcheal status. Although Risser sign is widely used to estimate growth remaining and is the basis of many bracing studies, it has been found to be inaccurate and does not reliably predict the cessation of growth or the timing of the adolescent growth spurt. In this investigation, the majority of our patients had their growth spurt and maximal curve progression while Risser 0 which is not an identifiable point in time. One-third of our patients had not stopped growing by Risser 4 and 10% of our patients had their maximal curve progression after attainment of Risser IV when it is generally thought to be safe to stop bracing. Similarly, 20% of our patients had their major growth spurt more than 2 years away from the onset of their menses with 8% having their growth spurt and maximal curve progression 2 years or more after menarche when most studies have recommended cessation of bracing.

Curve magnitude at PGA 0 was prognostic of the likelihood of curve progression to greater than 45 degrees. A curve magnitude greater than 30 degrees at PGA 0 was highly correlated with curve progression to a surgical

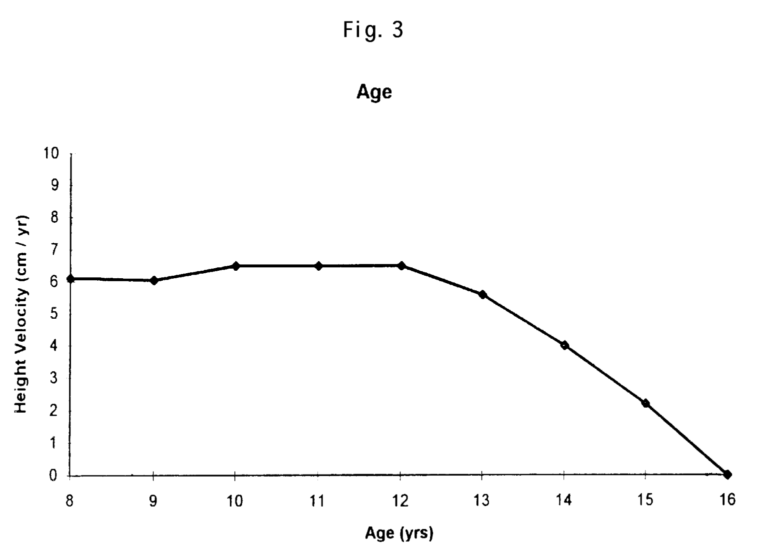


Figure 3: Plot of height velocity versus Chronologic age. There is no specific age at which velocity peaks for the population of children studied.

range in this population of braced patients while very few patients with curves less than 30 degrees at PGA 0 progressed to curves of 45 degrees or more.

It may not be as easy to assign PGA prospectively for patients as it was to assign it in this retrospective review. Height information is often available from families and pediatricians. If only 2 height measurements are available, and the velocity is greater than 9 cm/year, the patient is very likely to be in the growth peak. For smaller velocities, previously utilized methods such as the Risser sign, menarcheal status, and chronologic age can be used to place the patient along the growth curve. The timing of these events relative to PGA 0 is shown in figure 5.

In summary, we believe that PGA is an easily calculated, accurate method for estimating growth remaining for children with idiopathic scoliosis. It is more accurate than the use of indirect methods such as chronologic age, Risser sign, and menarchal status and can help physicians prognosticate cessation of growth and likelihood of curve progression.

Fig. 4

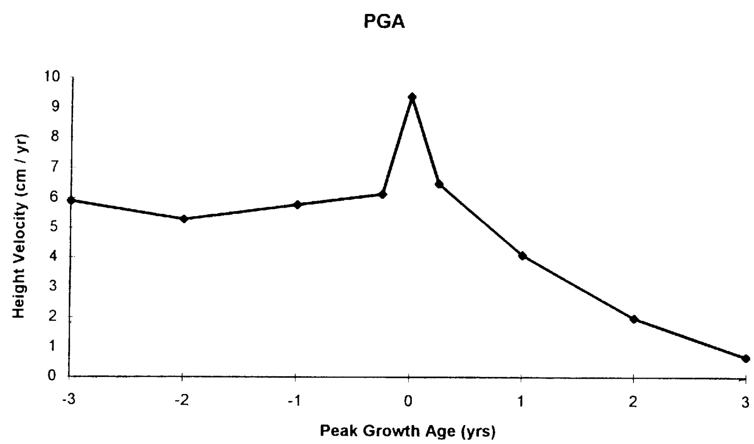


Figure 4: Plot of height velocity versus Peak Growth Age. The plot for the population studied is similar to that of an individual with a well defined peak and rapid decline.

Recommended Reading

Anderson, M.; Hwang, S. ; and Green, W. T.: Growth of the normal trunk in boys and girls during the second decade of life. J. Bone and Joint Surg., 47A:1554-64, 1965.

Buckler, J. M. H.: A longitudinal study of adolescent growth. London,

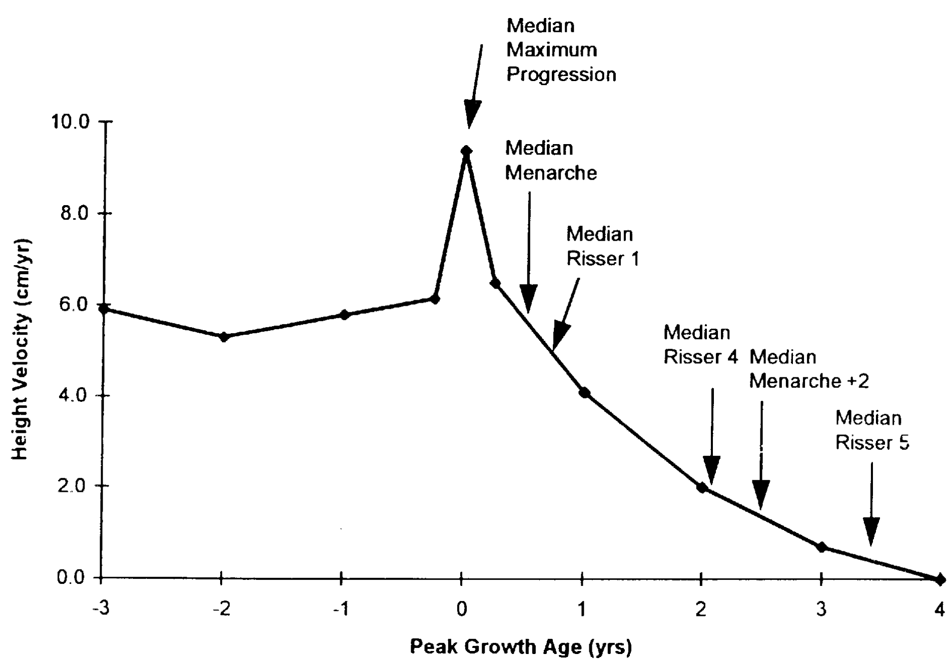


Fig. 5

Figure 5: Relationship of PGA 0 to median menarche, menarche +2, Risser 1, Risser 4, and Risser 5. The onset of menses or being Risser 1 implies that the child is past their major growth spurt.

Date	Int. Mos.	Int. Used Mos.	Ht.(CM)	Ht. Vel. (CM/YR)	PGA
5/2/88	0	0	148	0	-1.7
1/30/89	8.4	8.4	152	5.4	-1
2/12/90	12	12	162.5	10.1	0
4/12/90	1.9	14.4	164	9.8	0.2
8/13/90	4.1	6	165.5	6	0.5
10/15/90	2.1	6.2	166	4.2	0.7
2/11/91	3.9	6	168	5	1.1
9/30/91	7.6	7.6	169	1.6	1.7

Table I

Table I: Sample calculations for height velocity. One should use a minimum of 6 month interval between height for calculation. As an example between 4/12/90 and 8/13/90 there is an interval of only 4 months. The interval from 2/12/90 to 8/13/90 is instead selected for an interval of 6 months. The change in height was 3 cm. which is a height velocity of 6 cm. The peak height velocity is highlighted and is 10.1 cm.

Springer-Verlag, 1990.

Bunnell, W. P.: The natural history of idiopathic scoliosis before skeletal maturity. Spine, 11:773-6, 1986.

Carman, D. L.; Browne, R. H. ; and Birch, J. G.: Measurement of scoliosis and kyphosis on radiographs. Intraobserver and interobserver variation. J. Bone and Joint Surg., 72A:328-33, 1990.

Howell, F. R.; Mahood, J. K. ; and Dickson, R. A.: Growth beyond skeletal maturity. Spine, 17:437-440, 1992.

Little, D. G.; Sussman, M. D.: The Risser sign: A critical analysis. J. Pediatr. Orthop., 14:569-75, 1994.

Loncar-Dusek, M.; Pecina, M. ; and Prebeg, Z.: A longitudinal study of growth velocity and development of secondary gender characteristics versus onset of idiopathic scoliosis. Clin. Orth. and Rel. Research., 270:278-282, 1989.

Peterson, L.; Nachemson, A. L.: Prediction of progression of the curve in girls who have adolescent idiopathic scoliosis of moderate severity. J. Bone and Joint Surg., 77A:823-27, 1995.

Shuren, N.; Kasser, J. R.; Emans, J. B. ; and Rand, F.: Reevaluation of the use of the Risser sign in idiopathic scoliosis. Spine, 17:359-61, 1992.

Veldhuizen, A. G.; Baas, P. ; and Webb, P. J.: Observations on the Growth of the Adolescent Spine. J. Bone and Joint Surg., 68B:724-728, 1986.

Biomechanical Study of Foot Function

BRUCE J. SANGEORZAN, M.D.

The Orthopaedics Biomechanics Laboratory has an ongoing series of research projects designed to better understand foot function, and the surgical repairs of foot trauma and foot deformities. This is a summary of some of our recent activity.

The effect of foot position on tarsal load transfer During gait, load is transmitted down the tibial shaft, and into the talus, where it is transferred to both the hindfoot and forefoot. We have determined the relative load distribution between the posterior and anterior facets of the talocalcaneal joint, and studied the role of the talonavicular joint as part of this mechanism (Figure 1). Using a cadaveric model of the normal foot, we tested the hypothesis that load transmission between the calcaneus and navicular, measured by contact pressure and area, would change with foot position.

Mechanisms for suport of the talus The mechanisms of inferior and medial support of the talus were determined to provide insight into the mechanism of loss of peritalar stability with flatfoot. In the intact foot the tibialis posterior (TP) tendon forms an articulation with the medial plantar aspect of the talar head. When the TP tendon ruptures, there is loss of dynamic support in the midfoot and a gradual change in the position of the tarsal bones. The talus plantar flexes, the calcaneus everts, the navicular abducts, and the foot loses its arch (Figure 2). This change is presumed to occur as a result of loss of static support as the calcaneonavicular ligaments elongate. The goal of this study was to determine (i) the characteristics of interaction between the talar head and the calcaneonavicular ligament, (ii) its relative contribution to support of the talus compared to those of the inferior articulations, and (iii) the effect of the posterior tibialis tendon, by measuring contact pressures using a statically loaded cadaveric foot model.

Reconstruction of the medial longitudinal arch in flatfoot. As a surgical treatment for flatfoot, lengthening the lateral column of the foot restores the anatomic positions of the calcaneus and talus, tensions the plantar tissues and restores the medial longitudinal arch. Two methods have been advocated, the Dillwyn-Evans which lengthens the calcaneus by insertion of a bone graft between the anterior and medial facets, violating the talocalcaneal joint; and the Seattle technique, which places the bone graft at the calcaneocuboid joint, fusing it but maintaining the talocalcaneal joint intact. These studies were designed to compare the joint contact properties after restoration by either method, and to study the effect on kinematics of the foot. For surgical treatment of symptomatic flatfoot, calcaneal lengthening restores the position of the subluxed talus and tensions the plantar soft tissues of the hindfoot. Fusing the calcaneo-cuboid joint maintains the lengthened lateral column and the corrected position of the calcaneus. However, the effect of these procedures on hindfoot kinematics is unknown. Therefore, the kinematics of the hindfoot were measured first in normal

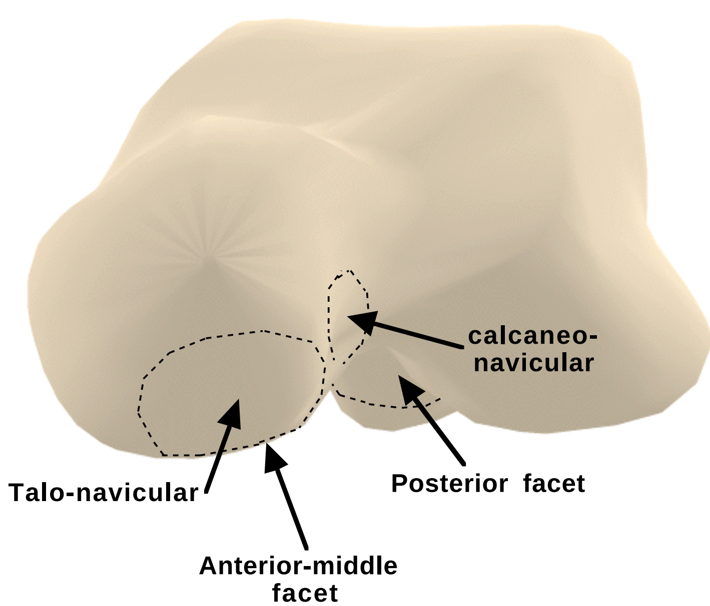


Figure 1: Approximate contact areas on the talus and estimated directions of resultant force on each articular area.

cadaveric feet, then after simulated lateral column lengthening and fusion in different positions.

Treatment of acquired flatfoot Acquired flatfoot deformity has been attributed to the loss of the tibialis posterior tendon. We studied the effect of releasing the tibialis posterior tendon (simulating rupture) on the kinematic positions of the hind foot bones. Another study examined the effect of restoring posterior tibial tendon function in an acquired flatfoot model. Treatments include various fusions, lateral column lengthening, ligament reconstruction and tendon transfer. This study used an acquired flatfoot model to test the hypothesis: restoring the tibialis posterior tendon function (simulating repair) will significantly affect the kinematic orientation of the hindfoot complex in heel strike, stance, and heel off.

METHODS

We have developed several techniques which we use in various combinations. Joint contact measurements are made using transducers made of pressure sensitive film (Prescale Film, Superlow and Low, Fuji, Tokyo, Japan) with an assembled thickness of 0.3 mm. After insertion of the film between the joint surfaces, increasing load, maintaining it for 30 secs, and unloading, the pressure film is imaged along with a set of calibration prints using a flat bed scanner. The imaged films are analyzed for total contact area (>0.5 MPa) and mean pressure. Overall errors are 3.8% for contact area and 9.3% for pressure.

The loading apparatus consists of a shaft applying axial load to the tibia and fibula through a plate which allows flexion/extension of the tibia, and clamps to attach 8 tendons of the foot to cables connected to individual pneumatic cylinders (Figure 3). Each foot is tested in three positions: heel strike (5% of the gait cycle), stance (30%), and near toe off (45%). The contributions of various muscles in these three phases of gait were determined from information on their physiological crossectional area and percent of maximum voluntary contraction in each phase

Figure 2: Lateral radiographs of normal foot (top), and the same foot after creation of a flatfoot deformity by cyclic loading.

The motion tracking system consists of a transmitter which defines the global axis system, located on the tibial shaft, and a set of receivers. An acrylic shaft is placed into the intramedullary canal of the tibia to support the transmitter of an electromagnetic motion transducer (Fastrak 3-D, Polhemus Systems, Colchester, VT) and transmit load to the specimen. Methacrylate cement is placed into holes drilled in the calcaneus, talus, navicular, and cuboid of each foot. A carbon fiber pin is placed into each hole, anchored in the cement, and an acrylic mount fixed to the pin on which is located a receiver of the motion tracking system. Output consists of the direction cosines required to define the orientation of each receiver axis. In this method, the initial and final positions of each receiver axis are known and are projected into each of three planes (sagittal, frontal, horizontal) defined by the global axis system, similar to those which might be obtained by viewing planar radiographs. The transmitter Z axis is aligned with the long axis of the tibial shaft, the X axis is directed towards the medullary canal of the second metatarsal, and its Y axis is approximately medial-lateral. Verification of sensor measurement accuracy (ratio of measured output to known input in the same direction) ranges from 0.944 to 1.006 in rotation, and 0.996 to 1.045 in translation.

RESULTS AND CONCLUSIONS

(i) Contact area and force on the talus are greatest in the posterior facet, followed by the talonavicular articulation, the anterior and middle facets, and the calcaneonavicular ligament.

(ii) The contact force in the calcaneonavicular ligament articulation is best aligned to oppose medial displacement of the talar head.

(iii) Loss of posterior tibialis tendon tension has no effect on contact force in the calcaneonavicular ligament articulation with the talus.

(iv) Flatfoot decreases talonavicular joint area, which is not restored by either reconstruction. The Dillwyn - Evans procedure decreases

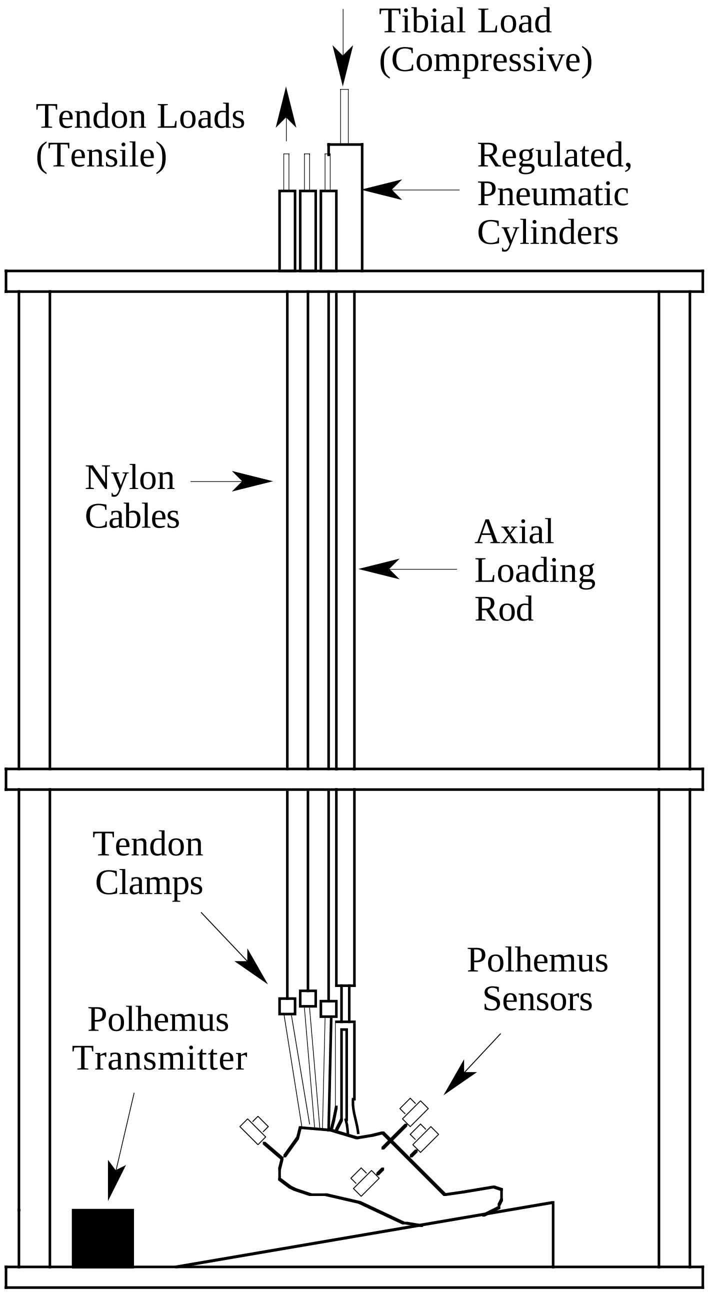


Figure 3: Lateral schematic of experimental loading frame with foot in heel off condition.

anteromedial facet contact area and increases posterior facet pressure. The Seattle method has less effect upon hindfoot joint contact characteristics.

(v) Calcaneo-cuboid fusion with the calcaneus lengthened and the foot in neutral position has no effect on hindfoot kinematics. However, fusing the foot in other orientations limits talocalcaneal and talonavicular joint motion.

(vi) The increases in joint load between heel strike and toeoff are more likely due to differences in total load applied than due to differences in orientation of the talus since differences in joint angle are small (10 deg dorsiflexion for toeoff compared with 6 deg of plantarflexion for heelstrike). High forces in toeoff are due primarily to a combination of higher axial load and larger Achilles force required to create thrust.

Assessing the Value of a Procedure: A Pilot Study Using Total Shoulder Arthroplasty as an Example

JAY L. CRARY, M.D., KEVIN L. SMITH, M.D., AND FREDERICK A. MATSEN, III, M.D.

Because of the large sums of money spent on health care, it is important to assess the value of various therapeutic interventions. Recent attempts to define the value of an intervention have been based on the resources necessary to provide it, such as the Resource Based Relative Value Scale (RBRVS). Although this methodology may be useful for allocating reimbursement, it does not determine the value of the intervention to the patient. For example, the "relative value" can be high if the service is expensive to provide, even if it is ineffective. The authors suggest that 'value' is more typically defined as the benefit divided by the charge, that is with the resource expense in the denominator, rather than in the numerator as it is in the RBRVS. Specifically, we propose that the value of a procedure be determined by measuring the differences the procedure makes in the patient's comfort, function, and quality of life and then dividing these by the charge of the procedure.

Standardized self-assessment tools are now available for documenting patients' health and function before and after treatment. The SF- 36 is one of the most widely used general health status assessments. The Simple Shoulder Test is a commonly used inventory of shoulder functions. Both of these tools have been shown to reflect the health and functional deficits associated with shoulder problems as well as the change in these parameters after treatment. Because they can be used without the patients having to return for follow-up visits, these self-assessment tools are useful for repeated assessments over time. This allows time-dependent changes in the benefit experienced by patients to be incorporated into the analysis. The actual lifetime benefit experienced by the patient will be the summation of benefit measured throughout the patient's life.

In this pilot study, the authors used the SF-36 and the Simple Shoulder Test for patient self-assessment before and sequentially after shoulder arthroplasty. These results were used to predict the "natural history" of a patient's response to the procedure. The value of the procedure relative to the self-assessment parameters is determined by dividing the lifetime benefit experienced by the patient by the total charges for the procedure.

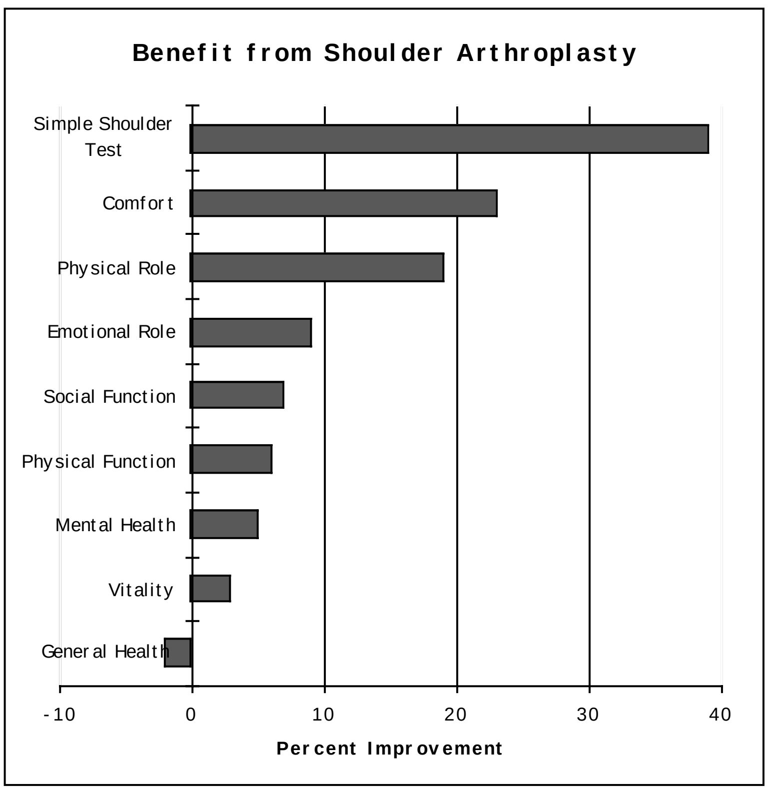


Figure 1: The average change in scores from the pre- to post-operative period was statistically significant for the Simple Shoulder Test and some of the subsections of the SF-36 (p<.05).

METHODS

Patient population. 125 patients who underwent 137 primary total shoulder arthroplasties completed the Short-Form 36 and Simple Shoulder Test self-assessment questionnaires on their initial visit and at 6 month intervals after their procedure. All patients were from the practice of an individual surgeon and the procedures carried out with standardized selection criteria, technique, prostheses and rehabilitation.

Benefit. The benefit of the procedure is defined in this study as the percent change in a parameter, i.e. the difference between the post-operative score and the pre-operative score divided by the maximal possible score on the SST or the SF-36. Thus if a patient could perform 4 of the 12 SST functions pre-operatively and 8 of the 12 post-operatively, the benefit for the SST would be (8-4)/12 or 33%. Similarly if the SF-36 comfort score improved from 32/100 to 76/100, the benefit for SF-36 comfort would be 44%.

If the benefit determined at each follow-up is plotted against number of years after the procedure, the area beneath this curve is the realized

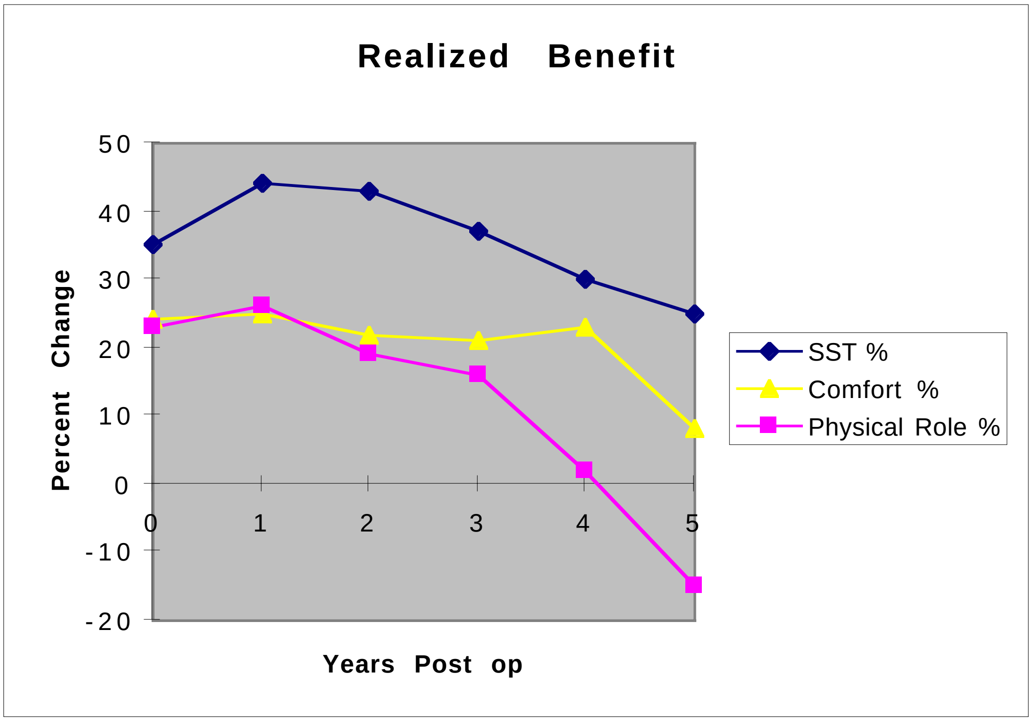


Figure 2: The average percentage change in SST, Comfort and Physical Role for each post-operative year.

benefit, expressed in units of %-years. If this curve is extrapolated out for the life of the patient, the area beneath the curve is the lifetime benefit of the procedure, again in units of %-years. The lifetime value of the procedure is the lifetime benefit divided by the charge of the procedure, expressed in percent-years/$1000.

The sums of hospital and physician charges were normalized to 1992 dollars using the Consumer Price Index for medical care for urban areas.

Results

The average age of our study population was 61 years (range 29-84). 38 shoulder replacements were done in females and 98 in males. Each total shoulder was followed for an average of 2.0 years. 125 patients who underwent 137 total shoulders completed 481 follow-up SF-36 and SST questionnaires during the post-operative period, for an average of 3.5 follow-ups per shoulder.

Benefit of TSA

The average change in scores from the pre- to post-operative period was statistically significant for the Simple Shoulder Test and some of the subsections of the SF-36 ($p<.05$). (Figure 1). The SST showed an average improvement of 38%. In the SF-36, the comfort and the role function physical subsections showed the largest numerical changes, with average improvements of 23% and 19% respectively. We have focused our analysis on the SST and these two sections of the SF-36.

Figure 2 shows the average percent change in SST, Comfort and Physical Role for each post-operative year. As expected, each of these parameters tends to decline with increasing time after surgery.

A linear regression was performed to determine the average percent decrement in the benefit per year after the first post-operative year. The average percent decrements for SST functions, Comfort, and Physical Role function were 4.8%/year, 3.3%/year and 7.9%/year, respectively. The one-year benefit values for each of these parameters were 44%, 25% and 25%, respectively. Using the slopes for the annual decrements, the number of years for each of these parameters to reach the point of zero percent benefit was obtained by dividing the one year value by the slope. The durations of benefit were 9.2, 7.6 and 3.3 yrs for SST functions, comfort and physical role, respectively. The total lifetime benefits for SST functions, comfort and physical role were estimated to be 246 percent-years, 120 percent-years and 69 percent-years, respectively. These data are summarized in Table 1.

Charges. The average medical center and physician charges for total shoulder arthroplasty at our institution was $22,843.

Value. The value of the procedure was estimated by dividing the lifetime benefit by the normalized charges. The average value for SST functions was 10.8 %-yrs/$1000, for comfort 5.3 %-yrs/$1000, and for physical role function 3.0 %-yrs/$1000.

Value can also be expressed in terms of specific functions or symptoms. For example, the Simple Shoulder Test indicated that pre-operatively 92% of patients could not sleep comfortably at night because of shoulder discomfort. At post-operative year one eighty-two percent of patients slept comfortably at

	SST	Comfort	Physical Role
First year benefit	44%	25%	26%
Rate of decrement in benefit	4.8%/yr	3.3%/yr	7.9%/yr
Years of benefit	9.2 yrs	7.6 yrs	3.3 yrs
Total lifetime benefit	246% - yrs	120% - yrs	69% - yrs

Table 1: A summary of first year benefit, rate of decrement in benefit, years of benefit and total lifetime benefit versus SST, Comfort and Physical Role.

night. This effect diminished at a rate of 1.9% per year during the five years of follow-up. Given this slope, the estimated years of benefit with regards to comfortable sleep was 43.2. The average life expectancy of these patients was 20.3 years. Therefore benefit was truncated at that point. Using the methodology described above, the average patient who could not sleep comfortable pre-operatively because of shoulder discomfort could expect 13.9 years (4919 days) of comfortable sleep attributable to this procedure. The charge per night of comfortable sleep ($22,843/4919 days) would be $4.64.

Conclusion

We have illustrated a new methodology for measuring the value of a medical intervention. In this example, we used self-assessment questionnaires—the Short-Form 36 and the Simple Shoulder Test—to quantitate the benefit and value a patient receives from total shoulder arthroplasty. This type of analysis is, to our knowledge, unique in that it attempts to measure the lifetime benefit and value of the procedure.

Our data demonstrate that SF-36 scores and the SST are significantly improved after shoulder arthroplasty. As assessed by the SST and SF-36, the benefit tends to lessen with time after this surgical procedure. The SST and SF-36 percent benefit scores showed a near linear decrease over time. We used these slopes to predict scores in the future. This allowed us to predict the lifetime benefit that a patient will receive. Dividing the lifetime benefit by the expense of the procedure yields an estimate of the value of the procedure, which is comparable to other measures of value in common use, such as miles per gallon.

The purpose of this investigation was to demonstrate an approach to measuring the benefit and value of interventions which could be applied to other procedures and other practices. Because successful orthopedic procedures yield benefits that are apparent to the patient, orthopedic surgeons are fortunate that patient self-assessments can facilitate such an analysis.

Recommended Reading

Bayley KB, London MR, Grunkemeier GL, and et al: Measuring the success of treatment in patient terms. Med Care 33(4 Suppl):AS226-235, 1995.

Beaton DE, and Richards RR: Measuring function of the shoulder. J Bone Joint Surg 78A:882-890, 1996.

Bergner M, Bobbitt RA, Carter WB, and et al: The Sickness Impact Profile: Development and final revision of a health status measure. Med Care 19:787-805, 1981.

Cotton P: Orthopedics research now asks, "does it work?" rather than just, "how is the procedure performed?". JAMA 265:2164-2165, 1991.

Emery DD, and Schneiderman LJ: Cost-effectiveness analysis in health care. Hastings Cent Rep 19(4):8-13, 1989.

Gillespie WJ, and Daellenbach HG: Assessing cost-effectiveness in orthopaedic outcome studies. Orthopaedics 15:1275-1277, 1992.

Levinsohn DG, and Matsen FA, III: Evaluation of nine common mechanical shoulder disorders with the SF-36 health status instrument. Presented at the 64th Annual Meeting of the American Academy of Orthopaedic Surgeons, San Francisco, CA, 1997.

Lippitt SB, Harryman DT, II, and Matsen FA, III: A Practical Tool for Evaluating Function: The Simple Shoulder Test. In The Shoulder: A Balance of Mobility and Stability. Matsen FA, III, Fu FH, and Hawkins RJ, (eds.). American Academy of Orthopaedic Surgeons, Rosemont, Il, pp. 501-518, 1993.

Matsen FA, III: Early effectiveness of shoulder arthroplasty for patients who have primary glenohumeral degenerative joint disease. J Bone Joint Surg 78A:260-264, 1996.

Matsen FA, III, Ziegler DW, and DeBartolo SE: Patient self-assessment of health status in glenohumeral degenerative joint disease. J Shoulder Elbow Surg 4(5):345-351, 1995.

Nerenz DR, Repasky DP, Whitehouse FW, and et al: Ongoing assessment of health status in patients with diabetes mellitus. Med Care 30(5):MS112-124, 1992.

Parker MJ, Myles JW, Anand JK, and et al: Cost-benefit analysis of hip fracture treatment. J Bone Joint Surg 74B:261-264, 1992.

Radosevich DM, Wetzler H, and Wilson SM: Health status questionnaire (HSQ) 2.0: Scoring comparisons and reference data. Health Outcomes Institute, Bloomington, MN, 1994.

Segel MJ, and Heald RB (editors):Medicare RBRVS: The Physician's Guide.Chicago, American Medical Association, 1996.

Vital Statistics of the United States. Life Tables. U.S. Department of Health and Human Services. 1992.

The Simple Knee Test: A Quick and Sensitive Self-Assessment of Knee Function

MICHAEL H. METCALF, M.D., ROGER V. LARSON, M.D., PETER T. SIMONIAN, M.D., AND FREDERICK A. MATSEN, III, M.D.

There is an increasing demand for all orthopaedic surgeons to document the functional status of their patients before and after treatment as well as the efficacy of their treatment approaches to different diagnoses. Existing approaches to this documentation consume substantial time and resources and often do not capture the patients' perception of their comfort and function. Others are not sufficiently sensitive to clinical problems with the anatomic area of interest. The ideal method would be a rapid self-assessment that patients can easily complete within a few minutes without assistance, whether in the office or at home. The tool must discriminate dependably between normal and pathological knee function.

Our goals were (1) to develop a self-assessment questionnaire sensitive to common knee pathologies which would be practical in the context of a busy office practice, (2) to document its results in asymptomatic and symptomatic knees and (3) to demonstrate its sensitivity to a range of knee pathologies.

METHODS

Initial questions

A series of questions was developed from established knee scores. Initial questions were taken from the Lysholm, Revised Hospital for Special Surgery Knee Score, Cincinnati Knee score, and the 1993 International Knee Documentation Committee Knee Ligament Standard Evaluation. Subsequently the questions were reformatted in a "yes/no" format with a "normal" response in the positive sense. All questions were reviewed with six experienced knee surgeons and edited to develop 23 questions (Table 1).

	Question	Result
1	Does your knee allow you to sleep?	kept
2	Will your knee straighten fully?	kept
3	Will your knee bend all the way?	kept
4	Is your knee free from swelling?	kept
5	Does your knee move smoothly without catching or locking?	kept
6	Can you sit comfortably with your knee bent for 1 hour?	kept
7	Does your knee allow you to get up from a chair with out difficulty?	deleted
8	Can you enter and leave a car without difficulty?	kept
9	Can you stand and walk without your knee giving away?	kept
10	Does your knee allow you to walk without a cane or crutch?	deleted
11	Does your knee allow you to walk down the hall without difficulty?	deleted
12	Does your knee allow you to walk two block without difficulty?	kept
13	Will your knee allow you to walk one mile without difficulty?	deleted
14	Does your knee allow you to do your usual work?	kept
15	Will your knee allow you to go down stairs easily?	kept
16	Will your knee allow you to go up stairs easily?	deleted
17	Will your knee allow you to do a deep squat (beyond 90 degrees)?	deleted
18	Will your knee allow you to run?	kept
19	Will your knee allow you to pivot to the outside while running?	deleted
20	Will your knee allow you to pivot to the inside while running?	deleted
21	Will your knee allow you to participate fully in your sport?	kept
22	Will your knee allow you to kneel comfortably?	kept
23	Can you hop on one leg?	kept

Table 1: Initial 23 Questions of the Simple Knee Test and Reduction to the Final 15

Controls

This initial self-assessment was administered to 360 persons who served as controls. This included 200 medical students, residents or orthopaedic staff, as well as 160 patients seen in the orthopaedic clinics for non-knee related symptoms. In addition to the 23 questions, each person was asked their age, gender, activity level, prior history of knee surgery, prior history of seeing a doctor regarding knee symptoms, and to comment about each of the 23 questions. Any individual who had either a previous knee surgery or had visited a doctor regarding a knee problem was excluded from the control group.

Patients

150 consecutive new patients presenting to either the sports medicine or the adult reconstruction clinics for evaluation of a knee problem were asked to respond to the series of 23 questions as well as indicate the importance of each question to them in their daily activities as either important or not important. The age, gender and activity level for each patient was recorded.

Diagnostic groups

Each patient was given a clinical diagnosis based upon their history, physical examination, radiographs, MRI and/or arthroscopy. Patients with similar diagnoses were grouped and the "group response" to each question was calculated as a percentage.

Statistical analysis

A correlation matrix for all patient responses was created (Statview 4.5). Significant intercorrelation was predetermined to be any set of questions with $r > 0.50$. The mean response of each diagnostic related group to each question was compared to the mean response of the control group for the same question using a t-test. Significance was defined as p–value < 0.05.

RESULTS

Controls

From the original set of 360 individuals, 7 persons were excluded based upon having a prior knee surgery and 40 others were excluded because they had seen a doctor regarding a knee problem. This left a total of 313 persons in the control group. Of these, 145 (46%) were female and 168 (52%) were male. The average age was 30. The average Tegner activity level was 5.

Patients

Of the 150 patients, 79 (53%) were female and 71 (47%) were male. The average age was 35 and the average Tegner activity level was 5.

Diagnostic groups

Patients were placed in one of eight diagnostic groups: 1) anterior cruciate ligament insufficiency, 2) degenerative joint diseases, 3) isolated meniscal tears, 4) patellar instability, 5) patellar irritation, 6) tendinitis, 7) other diagnosis, and 8) no diagnosis.

Reduction of questions

Of the original 23 questions, 8 were eliminated because of: 1) significant intercorrelation with other questions ($r \geq 0.50$), 2) lack of differential sensitivity (≥ 95% of patients within a diagnostic group gave the same response to the question), or 3) lack of clarity, based on patient comments. This left a total of 15 questions which comprised the Simple Knee Test.

Question # 11 (Does your knee allow you to walk down the hall without difficulty?) and Question #13 (Will your knee allow you to walk one mile without difficulty?) were both highly correlated with Question #12 and were deleted.

Question #7 (Does your knee allow you to get up from a chair without difficulty?) was highly correlated with four questions (#8, 11, 13 and 16) and was deleted.

Question #16 (Will your knee allow you to go up stairs easily?) was highly correlated with questions #7 and #8 and was deleted.

Question #10 (Does your knee allow you to walk without a cane or a crutch?) was not highly correlated with any other questions; however, it lacked differential sensitivity in that greater than 95% of patients with ACL deficiency, meniscal tears, degenerative joint disease, or patellar irritation responded that they could ambulate without assistive devices. This question was deleted.

Question #17 (Will your knee allow you to do a deep squat?), Question #19 (Will your knee allow you to pivot to the outside while running?) and Question #20 (Will your knee allow you to pivot to the inside while running?) were both highly correlated with other questions and were confusing to a significant portion of the patients and were deleted.

Variance within diagnostic groups

For each question, the mean patients' response was significantly different from the mean controls' response ($p<.0001$). Patient responses also varied significantly among different diagnoses (see Figure 1).

DISCUSSION

The 15 endorsable item Simple Knee Test provides a quick, joint-specific functional self-assessment that is practical for documenting knee function in the context of a busy practice.

Each question in the Simple Knee

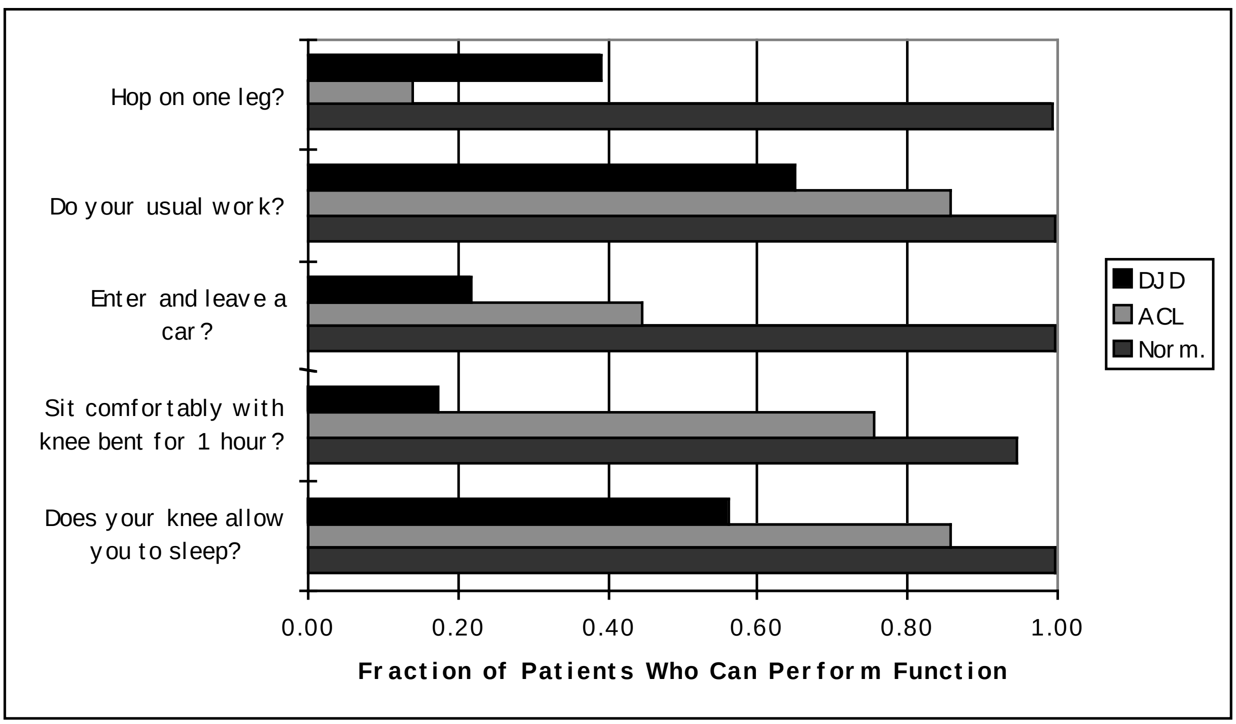


Figure 1: Examples of variance of results by diagnosis

Test is unique. All questions that were found to be highly correlated, lacking differential sensitivity, or unclear have been deleted. The remaining 15 questions measure different aspects of a patient's knee function.

The Simple Knee Test is sensitive to differing knee pathologies. For example, patients with DJD and ACL insufficiency gave significantly different answers to "Does your knee allow you to sleep?," "Can you sit comfortably with your knee bent for one hour?," "Can you enter and leave a car without difficulty?," "Can you stand and walk without your knee giving away?," and "Can you hop on one leg?" (see Figure 1).

The Simple Knee Test provides a convenient method for regular follow-up without having the patients return to the office. The ability to assess patients via the mail allows a substantial savings of both patient and office resources. With a systematic follow-up, surgeons can conduct personal quality control, determining which techniques are most effective in their hands.

The simplicity of the SKT questions facilitates communication of results to patients. The SKT reflects the status of the knee in functional terms rather than in degrees of motion, appearance of radiographs, millimeters of displacement, or scores. Patients can easily compare their responses to those of other patients and, using this comparison, help determine their candidacy for different treatment.

Continuing clinical research will establish the characteristic SKT profiles of patients who are most likely to benefit from treatment as well as the effectiveness of different therapeutic approaches in improving patients' assessment of their knee function. The simplicity and standardization of the Simple Knee Test facilitates comparison of these results among the practices of different surgeons.

Recommended Reading

Kelley, R. B., Rudicel, S. A., and Liang, M. H.: Outcomes research in orthopaedics. J Bone Joint Surg 75A(10):1562-1574, 1993.

Matsen, F. A., III, Lippitt, S. B., Sidles, J. A., and Harryman, D. T., II: Practical evaluation and management of the shoulder. W. B. Saunders Company, Philadelphia, 1994.

Noyes, F. R., Matthews, D. S., Mooar, P. A., and Grood, E. S.: The symptomatic anterior cruciate-deficient knee. Part II: the results of rehabilitation, activity modification, and counseling on functional disability. J Bone Joint Surg Am 65(2):163-74, 1983.

Tegner, Y., and Lysholm, J.: Rating systems in the evaluation of knee ligament injuries. Clin Orthop 198:43-9, 1985.

Windsor, R. E., Insall, J. N., Warren, R. F., and Wickiewicz, T. L.: The hospital for special surgery knee ligament rating form. Am J Knee Surg 1:140-145, 1988.

The Response of Cartilage to Intra-articular Step-off: A Sheep Weight Bearing Model

THOMAS E. TRUMBLE, M.D.

To evaluate the *in vivo* response of cartilage to an intra-articular injury with residual step-off, examining both the biomechanical effects as well as the histomorphologic changes is the objective of this study.

METHODS

An intra-acticular step-off was created in medial tibial plateaus of the knees of 12 adult, domestic sheep. A sagittal osteotomy was made through the middle of the weight-bearing surface, with displacement of the medial fragment distally by one millimeter. After rigid fixation with screws, the animals were allowed activity *ad libitum*. The contralateral knee was used as a control. Four animals were terminated at six weeks; the others at twelve weeks. All animals were labelled with oxytetracyline (50 milligrams/kilogram) three weeks prior and three days prior to termination and well as calcein (12 milligrams/kilogram) two weeks prior to termination.

After termination, the knees were loaded in a materials testing machine using pressure sensitive film to record joint contact pressures. Subsequently, the articular surfaces were sectioned and prepared for both calcified and non-decalcified histology as well as imaging by scanning electron microscopy.

RESULTS

Qualitative analysis of the pressure sensitive film demonstrated a single, broad area of contact in the control knees. The knees with intra-articular step-off had two major contact areas with an intervening zone of reduced load corresponding to the edge of the depressed fragment. Quantitative analysis revealed reduced overall contact area in the knees with step-off.

Histologically, coronal sections through the articular surface demonstrated the presence of thinning and fibrillation on the high side of the step-off. In addition, at the edge of the high side compensatory bending of the normally vertical fibrils towards the low side was observed. Some compensatory hypertrophy of the cartilage at the edge of the low side was seen, but not adequate to level the articular surface. No significant remodelling was seen in the subchondral bone, with the plane of the osteotomy still being readily identified.

Scanning electron microscopy demonstrated partial cartilage remodeling by deformation of the high side cartilage to partially overlap the low side cartilage and by behind the vertical collagen fibrils on the high side cartilage even in the unloaded state (Figure 1).

CONCLUSIONS

In this animal model, a one millimeter intra-articular step-off changed the contact distribution both qualitatively and quantitatively during *in vitro* loading, with a net loss of contact area. Examination by both light and electron microscopy revealed morphologic changes suggesting compensation by the cartilage, although incomplete, to accommodate the height discrepancy.

Significance

Small intra-articular step-offs are encountered frequently in trauma to the hand and wrist. Although the maximum amount of acceptable incongruity has not yet been

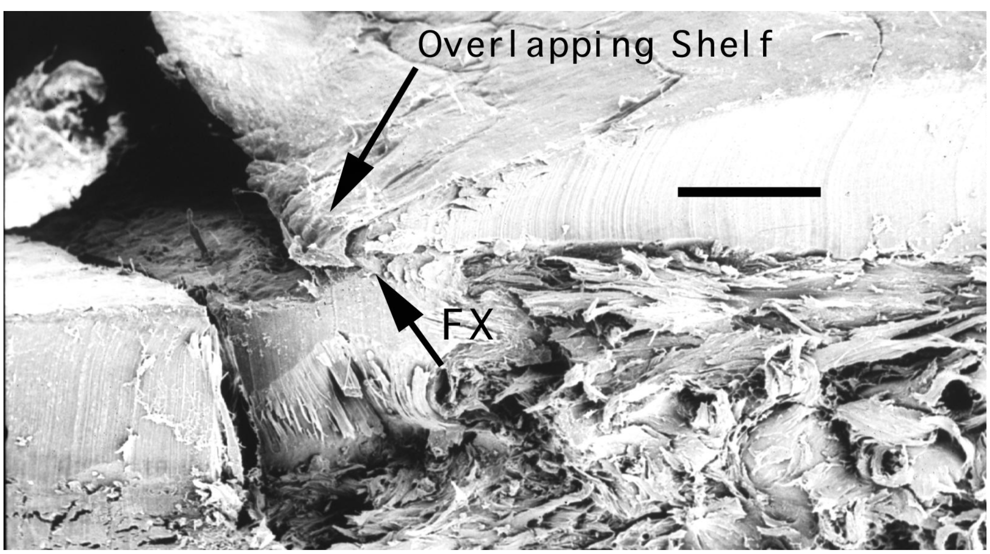


Figure 1: Scanning electron microscopy demonstrated partial cartilage remodeling by deformation of the high side cartilage to partially overlap the low side cartilage and by behind the vertical collagen fibrils on the high side cartilage even in the unloaded state.

Figure 2: Arrow points to location of cartilage in knee as was studied in this evaluation.

established, this study provides a useful model for further evaluation of the effects of an intra-articular injury.

Recommended Reading

Anglen JO, Healy WL: Tibial plateau fractures. Orthopaedics 11: 1527-1534, 1988.

Ausberger S, Necking L, Horton J, Bach AW, Tencer F: A comparison of scaphoid-trapezium-trapezoid fusion and four bone tendon weave for scapholunate dissociation. J Hand Surg 17A: 360-369, 1992.

Baron R: Bone histomorphometry and interpretation. R.R. Backer, ed. CRC Press, Baton Rouge, FL, 1983, pp 14-22.

Brown TD, Pope DF, Hale JE, Buckwalter JA, Brand RA: Effect of osteochondral defect size on cartilage contract stress. J Orthop Res 9: 559-567, 1991.

Fernandez DL, Geissler WB: Treatment of displaced articular fracture of the radius. J Hand Surg 16A: 375-83, 1991.

Kellenger E: The potential of cryofixation and freeze substition: observations and theoretical considerations. J Microsc 161: 183-203, 1991.

Knirk JL, Jupiter JB: Intra-articular fractures of the distal end of the radius in young adults. J Bone Joint Surg 68A: 377-390, 1986.

Lansinger O, Bergman B, Koner L, Andersson GBJ: Tibial condylar fractures. J Bone Joint Surg 68A: 13-19, 1986.

Llinas A, McKellop H, Marshall J, Sharpe F, Mu B, Kirchen M, Sarmiento A: Healing and remodeling of articular incongruities in a rabbit fracture model. J Bone Joint Surg 75A: 1508-1522, 1993.

Contact Pressures at Osteochondral Donor Sites in the Knee

Peter T. Simonian, M.D., Thomas L. Wickiewicz, M.D., and Russell F. Warren, M.D.

Osteochondral autograft techniques are currently receiving increased attention for the treatment of focal cartilage defects in "weight-bearing" areas of the knee. The purposes of this study are to determine if any of the commonly recommended osteochondral donor sites are non-articulating through a functional range of knee motion, and determine the differential contact pressures for these sites through a functional range of knee motion.

Materials & Methods

Ten commonly recommended sites for osteochondral donor harvest were evaluated with pressure-sensitive film (Prescale Low Pressure Type, Fuji Photo Film, C. Itoh & Co. Inc., New York, NY) through a functional range of motion with a model that simulated non-weight-bearing resistive extension of the knee.

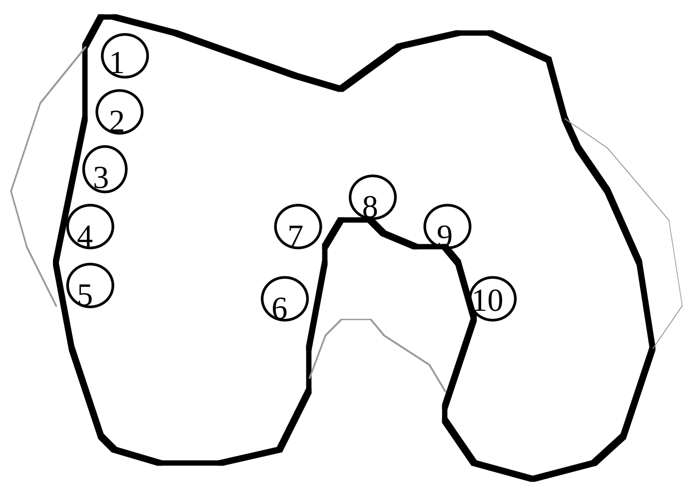


Figure 1: Diagram of Contact Pressures noting the ten commonly recommended sites for osteochondral donor harvest.

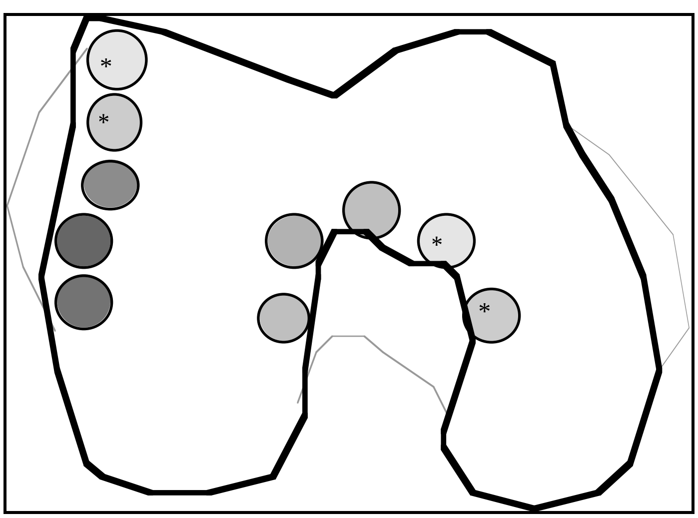


Figure 2: Diagram of Contact Pressures noting different color density measurements between harvest sites.

Results

All 10 harvest sites demonstrated a significant ($p < 0.05$) contact pressure through a functional range (0-110 degrees) of knee motion (Figure 1).

The different color density measurements between harvest sites were also significant ($p < 0.05$) (Figure 2). Harvest sites 1 and 2 demonstrated significantly less pressure than harvest sites 3, 4, and 5. Harvest site 9 demonstrated significantly less pressure than harvest site 3 and 4, and harvest site 10 demonstrated significantly less pressure than harvest site 4. Although donor sites 1, 2, 9, and 10 demonstrated significantly less contact pressure than the sites with the greatest contact pressure, the difference in mean pressures were small; for example, the site of least contact pressure (harvest site 1 at 22.4 kgf/cm2) and maximal contact pressure (harvest site 4 at 28.0 kgf/cm2) was only 5.6 kgf/cm2 (see Table 1).

Conclusion

In conclusion, no osteochondral donor site tested was free from contact pressure. Four sites demonstrated significantly less contact pressure when compared to the sites of maximal pressure. It is currently unknown whether articular contact at these osteochondral donor sites will lead to degenerative changes or any other problems.

Recommended Reading

Ahmed, A. M., Burke, D. L., and Hyder, A.: Force analysis of the patellar mechanism. J Orthop Res, 5: 69-85, 1987.

Brown, T. D., Pope, D. F., Hale, J. E., Buckwalter, J. A., and Brand, R. A.: Effects of osteochondral defect size on cartilage contact stress. J Orthop Res, 9: 559-67, 1991.

	site 1	site 2	site 3	site 4	site 5	site 6	site 7	site 8	site 9	site 10
Mean Color Density	0.36	0.39	0.50	0.52	0.51	0.42	0.43	0.43	0.36	0.41
Standard Deviation	0.07	0.07	0.10	0.13	0.12	0.12	0.10	0.16	0.15	0.09
Pressure (kgf/cm2)	22.4	23.9	26.9	28.0	27.5	24.7	25.1	24.8	22.6	24.3

Table 1: All of the 10 commonly recommended sites for osteochondral donor harvest evaluated versus mean color density, standard deviation, and pressure.

Convery, F. R., Akeson, W. H., and Keown, G. H.: The repair of large osteochondral defects. An experimental study in horses. Clin Orthop, 82: 253-62, 1972.

Eilerman, M., Thomas, J., and Marsalka, D.: The effect of harvesting the central one-third of the patellar tendon on patellofemoral contact pressure. Am J Sports Med, 20: 738-41, 1992.

Goldstein, S. A., Coale, E., Weiss, A. P., Grossnickle, M., Meller, B., and Matthews, L. S.: Patellar surface strain. J Orthop Res, 4: 372-7, 1986.

Goodfellow, J., Hungerford, D. S., and Zindel, M.: Patello-femoral joint mechanics and pathology. 1. Functional anatomy of the patello-femoral joint. J Bone Joint Surg [Br], 58: 287-90, 1976.

Hangody, L., and Karpati, Z.: New possibilities in the management of severe circumscribed cartilage damage in the knee. Magy Traumatol Ortop Kezseb Plasztikai Seb, 37: 237-43, 1994.

Hangody, L., Sukosd, L., Szigeti, I., and Karpati, Z.: Arthroscopic autogenous osteochondral mosaicplasty. Hungarian J. Orthop. Trauma, 39: 49-54, 1996.

Huberti, H. H., and Hayes, W. C.: Patellofemoral contact pressures. The influence of q-angle and tendofemoral contact. J Bone Joint Surg [Am], 66: 715-24, 1984.

Matsusue, Y., Yamamuro, T., and Hama, H.: Arthroscopic multiple osteochondral transplantation to the chondral defect in the knee associated with anterior cruciate ligament disruption. Arthroscopy, 9: 318-21, 1993.

Matthews, L. S., Sonstegard, D. A., and Henke, J. A.: Load bearing characteristics of the patello-femoral joint. Acta Orthop Scand, 48: 511-6, 1977.

Yamashita, F., Sakakida, K., Suzu, F., and Takai, S.: The transplantation of an autogeneic osteochondral fragment for osteochondritis dissecans of the knee. Clin Orthop, 43-50, 1985.

The Enzymatic Preparation of Allograft Bone

DAVID J. BELFIE, M.D. AND JOHN M. CLARK, M.D., PH.D.

The surgical procedure of bone transplantation is very common in orthopedics. With the exception of blood, bone is the most frequently transplanted tissue in humans. More than 200,000 bone grafts or bone implants are performed each year in the United States alone. These types of grafts, which are obtained from cadaver donors, are used to treat many different problems with a variety of surgeries including acetabular and proximal femoral reconstruction and spine fusions. The results of these surgeries are good, but the frequency of associated problems is still high. Horowitz and Freidlander have reported allograft failure rates between ten to fifty percent, depending upon how the allograft was prepared after harvest and prior to implantation.

Musculoskeletal allografts cause a cell mediated immune response. This cellular response is directed at the antigen presenting cells located primarily in the graft marrow. Various attempts have been made to decrease the cellular antigenic response. Since the surrounding soft tissues and bone marrow elicit the greatest immune response, attempts to remove or alter these two tissues have been made. Allograft preparations have attempted to achieve these goals.

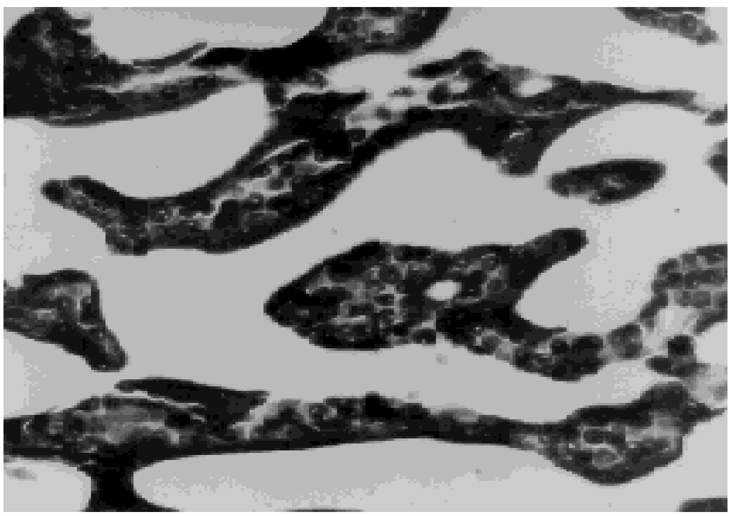


Figure 1A: Bone Micrograph: Treated with Papain to remove non-bone soft tissue.

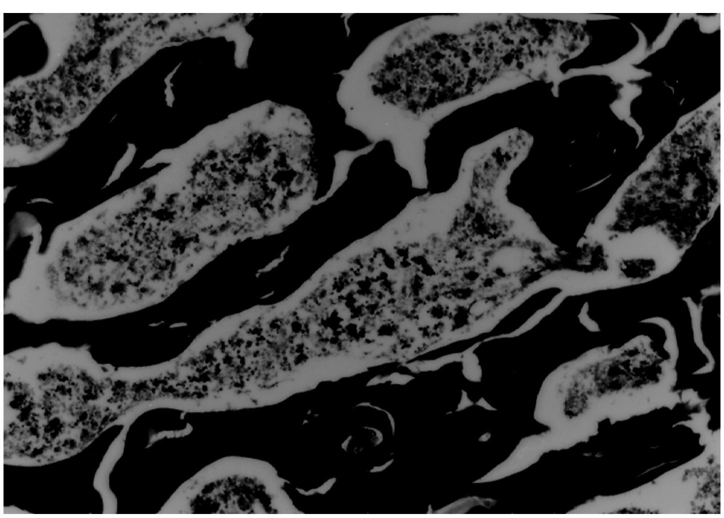


Figure 1B: Bone Micrograph: Untreated.

Of the standard preparation techniques used today, freeze-drying appears to have the most reliable effect; however, these techniques can significantly compromise the structural properties of the bone. Other techniques including detergents, aldehydes and ethylene oxide can result in the generation of potential toxins. Proteolytic enzymes theoretically could achieve these goals without compromising structural integrity or introducing toxins.

The purpose of this study is to evaluate the ability of proteolytic enzymes to remove antigens from allograft bone and determine if there is an affect on structural integrity.

MATERIALS AND METHODS

Specimens

Fresh segments of bilateral proximal femoral metaphyseal bone were harvested from thirty sacrificed Lewis rats (L-450 Toledo, Ohio). The femora were from animals between six months and one year of age and weighed between 400-600 grams. These segments contained cancellous bone, cortical bone, articular cartilage, relatively large vessels and marrow composed of equal amounts of fatty and hemopoietic cells.

Proteolytic Enzyme Treatment

Four different enzymes were chosen based on their well known proteolytic properties. They were Collagenase, Chymopapain, Trypsin and Papain. The activity of each enzyme was observed at standard concentrations of .01, .02, .04, and .08 grams dissolved in 20ml of a calculated buffer solution. Each 1cm segment of bone was sealed in a sterile vial along with the 20ml of activated enzymatic solution and placed in a water bath. A pH of 7.4 for the solution and a temperature of 37 degrees Celsius for the bath were maintained throughout, to ensure physiologic conditions. A control group was maintained under identical conditions without the activated enzyme solution and replaced with sterile normal saline. The bone specimens, each sealed in its enzymatic solution, were treated in the water bath for either 6, 12, 24 or 48 hours. All were handled with sterile technique and a commercial solution of penicillin and streptomycin was added to each solution. Once completed, the specimens were washed with pulsed distilled water, fixed with 2% phosphate buffered glutaraldehyde, decalcified with EDTA and then prepared for light microscopy.

Structural Integrity Testing

To evaluate the effect of our treatment process on the structural integrity of potential grafts, four-point stress testing was performed. Fifty whole bilateral femur samples were harvested in the same manner. Half of the samples were selected randomly and treated as above. The other half were placed in sterile water and refrigerated. These two groups were then evaluated for ultimate stress fracture in lateral bending using a four point bending system with a load cell attached to a materials tester (model 828, Bionix MTS Systems). An analog to digital converter was used and data compiled on a personal computer. The means and standard deviations were calculated. The data was then reduced and tested for significant difference.

Antigenicity Testing

The specimen slides were stained with H&E or Masson's Trichrome. The effectiveness of each enzyme was determined by microscopic observation for any residual marrow tissue.

The treated vs non treated samples were then placed under the skin of the same and different strain of rats. 2cm sections of treated and non-treated metaphyseal and diaphyseal bone were transplanted under the skin of Lewis (White) and Brown Norway (Brown) rats. Sixteen rats were used, performing Brown-Brown, White-Brown, White-White, and Brown-White implantations with treated and non-treated samples. Sterile surgical technique was utilized, with one section of sample being placed subcutaneously between the scapluae of each rat. The treated and non-treated samples remained under the rats skin for twenty-one and thirty-five days. No antibiotics were given and postoperative care was per animal studies protocol at the University of Washington.

The animals were sacrificed by standard protocol and bone samples recovered. These samples were fixed and decalcified as described previously, and placed in paraffin blocks. Histologic staining with Masson's Trichrome was performed to evaluate the inflammatory response along as well as destruction and new vessel formation.

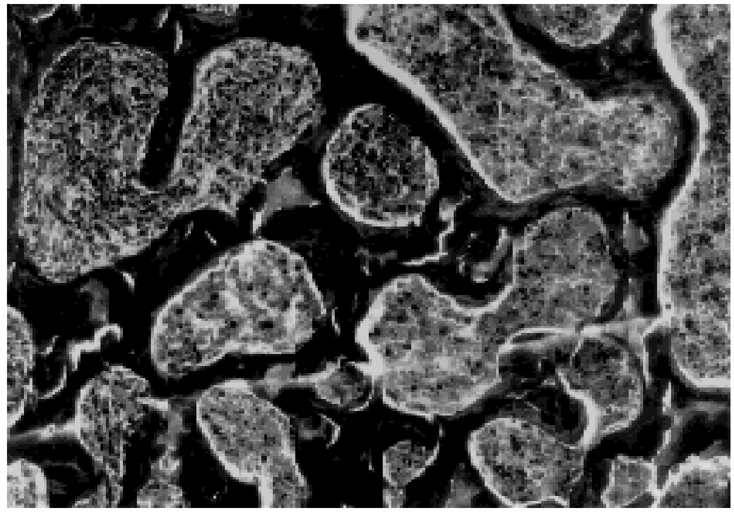


Figure 2A: Bone Micrograph: Untreated, showing inflammatory cell invasion of marrow space.

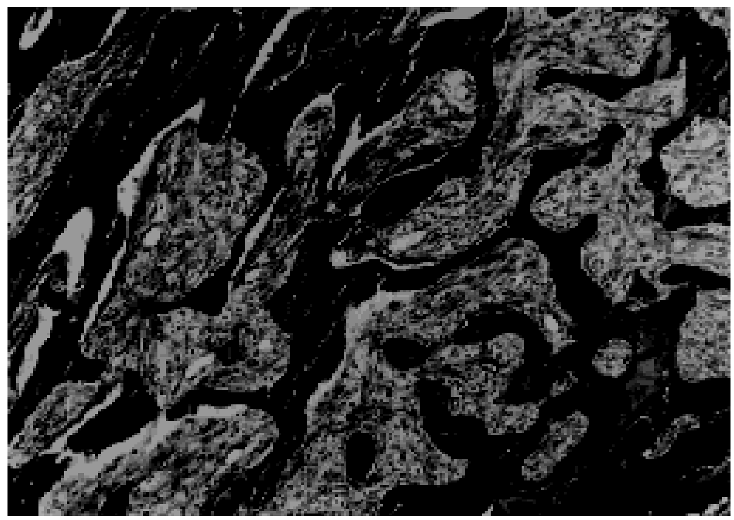


Figure 2B: Bone Micrograph: Treated with Papain prior to implantation showing favorable invasion by vascular and loose connective tissue.

Results

Proteolytic Enzyme Treatment

The histologic evidence from part one of our experiment demonstrated the highly effective proteolytic nature of Papain. This was when compared against the other enzymes and the control group. Of the other enzymes tested none were as complete as Papain in removing the intra and extramedullary non-bone soft tissue (Figure 1A). The untreated control group demonstrated minimal change in the medullary contents (Figure 1B).

Structural Integrity Testing

All of the data from the load cell was collected and a standardized T test was performed to compare sample means between the treated and non-treated groups. Also, a one factor ANOVA test was performed to compare the mean within each group, to the mean between the two groups. In both cases, no significant difference in ultimate strength to failure was detected based on a selected Alpha of .05.

Antigenicity Testing

After three weeks, both the treated and non-treated samples under the cross-strain skin had elicited a moderate inflammatory response. No difference being noted between the two groups. By week five however, the untreated grafts were invaded much more by inflammatory cells, with evidence of necrosis and isolated fibrous encapsulation (Figure 2A). In one case the bone specimen had been completely resorbed. The treated allografts at five weeks, demonstrated a minimal amount of inflammatory cells and no evidence of necrosis or encapsulation. Favorable invasion of marrow space by vascular and loose connective tissue was clearly evident (Figure 2B).

Discussion

Bone allografts, although the most common alternative to autografts, encounter the same immunologic complications as soft tissue allografts. The incorporation of bone grafts is similar to the process of fracture healing. However, the process is slow when allogenic or pretreated bone is used. This may be due to an immune response by the host or a lack of osteoinductive or conductive properties from the graft.

Under the present study conditions, it appears that the proteolytic enzymes selected are capable of removing non-calcified tissue from bone without altering the graft's structural integrity. Of the four enzymes tested, Papain was superior in removal of the marrow cells and surrounding soft tissue. Because bone itself has little immunogenic properties, Papain treatment could reduce the host cellular response to transplanted bone grafts. Our study suggests that enzyme prepared bone evokes only a minimal inflammatory reaction in a rat model.

Enzymes have the theoretical ability to remove much more of the soft tissue within bone when compared to current graft preparation techniques. We found that the open spaces in our treated grafts were rapidly filled with vascular connective tissue which likely signifies an increased ability to incorporate into the host environment. Further, Papain does not change the gross mechanical properties of bone because the enzyme is apparently unable to reach the calcified collagen molecule. Enzymatic treatment avoids extreme alterations of pH and temperature decreasing the likelihood to the structure of the bone. This technique must be tested further. One of the most important questions is whether the bone matrix, devoid of all soft tissues, can effectively induce new bone formation. The next step is to evaluate the enzyme treated bone using a same strain rat model in a heterotopic environment.

Recommended Reading

Bone and Cartilage Allografts. AAOS Symposium. G Friedlander 1990.

Natural History of Allografts. COOR V. Goldberg 1989.

Immunologic Aspects of Bone Transplantation. Orthopaedic Clinics of North America. M. Horowtiz 1989.

The Biology of Bone Grafting. Orthopaedics. T. Gross 1991.

Factors Affecting Bone Graft Incorportation. CORR. S. Stevenson 1996.

Angulated Screw Placement in the Lateral Condylar Buttress Plate for Supracondylar Femur Fractures

Peter T. Simonian, M.D., Greg J. Thomson, Will Emley, Richard M. Harrington, Stephen K. Benirschke, M.D., and Marc F. Swiontkowski, M.D.

A supracondylar femoral fracture with articular involvement is a serious injury and is difficult to treat. Whenever possible a fixed angle device should be used to decrease the chance of malunion or more specifically, the chance of varus deformity before union. Certain fracture patterns do not allow placement of these rigid devices. In these instances a less rigid construct is a necessary alternative, despite the increased risk of malunion or nonunion.

Specifically, the condylar buttress plate is recommended when the distal fragment is too small for the insertion of the condylar blade plate or when the fracture lines are in the frontal plane, as in a C3 fracture, in which the blade of the condylar plate would interfere with the lag screws which must be inserted from front to back. Another construct for these difficult fractures uses both lateral and medial plates; however, this necessitates considerable soft-tissue stripping. Others have augmented fixation with bone cement, especially when bone quality is poor.

In an attempt to resist the potential for varus deformity with the lateral condylar buttress plate, especially when the medial cortical buttress is deficient, screws in the middle of the plate can be angulated toward the dense, subchondral bone of the medial condyle. By this simple means, screw angulation in the plate should strengthen the overall construct to resist the tendency toward varus deformity. The attractive features include the ease of application, and the use of an existing construct. If in fact screw angulation adds significant stability to these unstable fractures, the technique could be used easily with the lateral condylar buttress plate.

The purpose of this study is to compare the biomechanical properties of lateral condylar buttress plate fixation of unstable supracondylar fractures with screws in the standard perpendicular position versus screw angulation toward the medial condyle in a diagonal position.

Materials and Methods

Six fresh-frozen human knee specimens, from mid-femur to mid-tibia, were obtained from the University of Washington Department of Biological Structure. The average age of the patients from whom specimens were taken was 72 years (range 53 - 87), and four were from men and two from women. Segmental defects were created with a bone saw, removing a 10 mm transverse slice of bone 50 mm from the distal end of the femur, to mimic a supracondylar femoral fracture. The fracture was fixed with a lateral condylar buttress plate (Synthes, Paoli, PA) using 4.5 mm screws. The medial cortical gap was maintained at 10mm after fixation. Five cortical screws were placed perpendicular to the plate proximal to the fracture and four screws placed perpendicular to the plate distal to the fracture. Each specimen was tested once with all the screws placed perpendicular to the plate, and alternatively with the most distal screw just proximal to the fracture angled 45 degrees across the fracture into the medial femoral condyle (Figure 1); the sequence of fixation was alternated for testing. This angled screw was not placed in "lag" mode but instead in "push" mode against the subchondral bone of the medial femoral condyle. The order of testing was alternated. The proximal end of the femur and distal end of the tibia were secured in potting compound and attached to loading fixtures on a materials testing machine (Bionix 858, MTS, Minneapolis, MN). Cyclical compression loading was applied for 1000 cycles at 1 Hz. Displacement control of the crosshead was used to adjust the initial loading to 0-500 N. The same cyclical displacement was maintained for the 1000 cycles, and applied loads were recorded.

Displacement across the medial side of the fracture site was monitored with a liquid metal strain gauge (Parks Medical Electronics, Aloha, OR). Each strain gauge was calibrated before application with a micrometer to establish its region of linear output from approximately 10 to 50% strain. The gauge was installed prestrained to the midpoint of its linear region so that it responded to either opening or closing of the fracture gap. Gap closure

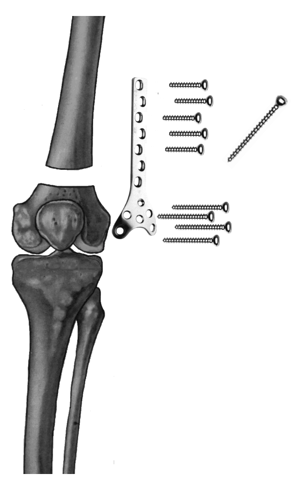


Figure 1: Knee specimens were tested once with all screws perpendicular to plate and again with one screw angled diagonally across fracture. The medial cortical buttress was removed in each specimen to increase varus instability.

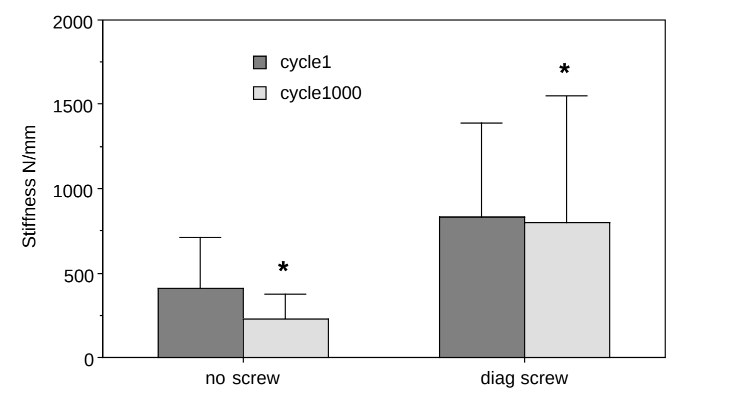


Figure 2: Construct stiffness at the beginning and end of 1,000 loading cycles.
* indicates significant difference p = 0.028

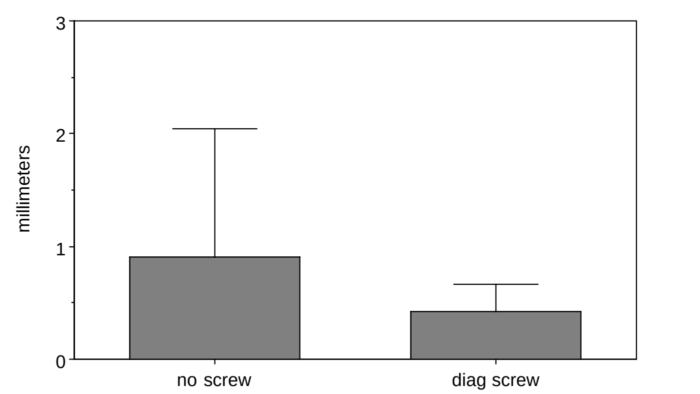


Figure 3: Permanent deformation across the fracture site after 1,000 load cycles.

corresponded to varus deformity of the distal segment.

Applied compression loads and gap displacement were recorded on a personal computer using an analog-to-digital converter at a sampling rate of 25 Hz. Force-vs.-displacement curves were plotted for the 1000 load cycles. A linear regression analysis was used to determine the stiffness (slope) of the initial and final load cycles. The amount of permanent varus/valgus deformity caused by the cyclical loads was determined by calculating the difference in displacement at zero applied load between the first cycle and the 1000th cycle. The Wilcoxon signed rank test (nonparametric paired t-test, StatView, Abacus Concepts, Berkeley, CA) was used to test the hypothesis that there was no difference in stiffness or permanent deformity between the first and last cycles for the two screw configurations. Differences were considered significant for $p < 0.05$.

Results

For the construct with all screws placed perpendicular to the buttress plate, the initial stiffness was 410 ± 302 N/mm (mean plus / minus one standard deviation), and after 1000 cycles was 230 ± 144 N/mm. With a screw placed diagonally across the fracture site, stiffness increased to 833 ± 556 N/mm on the first cycle, and 796 ± 757 N/mm after 1000 cycles. The stiffness after 1000 cycles with the diagonal screw was significantly greater than without, p = 0.028 (Figure 2).

In all specimens with the screws placed perpendicular to the plate, the distal fragment had a permanent varus deformity under no load of 0.91 ± 1.13 mm. For the diagonal screw condition, 5 of 6 specimens had a permanent varus deformity of 0.37 ± 0.22 mm, while one specimen developed a valgus deformity of 0.68 mm. Assuming that neither varus nor valgus deformity is desirable, the average magnitude for all six specimens with the diagonal screw is 0.42 ± 0.24 mm (Figure 3).

All screws that were placed perpendicular to the plate failed by cutting through the bone; while the diagonal screw simply backed out of the plate never penetrating the medial femoral subchondral bone.

Discussion

Certain fracture patterns of the distal femur are not amenable to the placement of a fixed angle device. In these instances, the condylar buttress plate is the recommended alternative; however, it is less rigid. Because of the decreased rigidity and strength of this device there is a tendency toward varus angulation and malunion. In an attempt to solve this problem Sanders and associates use both lateral and medial plates which necessitates considerable soft-tissue stripping. We hypothesized that simple angulation of a screw through the middle hole of the lateral condylar buttress plate towards the medial condyle adds significant strength to varus deformity. The single screw should be placed as close as possible to the dense subchondral bone of the medial femoral condyle without joint violation; in this position, the screw can act as a buttress against varus deformity. The screw would essentially "push" against the medial femoral condyle. In the clinical situation, the significant force of this screw pushing against the subchondral bone will sometimes result in a bending of this screw. Typically because of the confines of the bone, fracture pattern, and plate, only one screw can be angulated across the fracture; therefore only one screw was angulated in this study.

In this study specimens were loaded to a 500N force through 1,000 cycles in an attempt to simulate the clinical situation as accurately as possible. This is not a large enough load to simulate

A Fracture Treated With This Method

Figure 4A: One view of the injury.

Figure 4B: A lateral view of the injury.

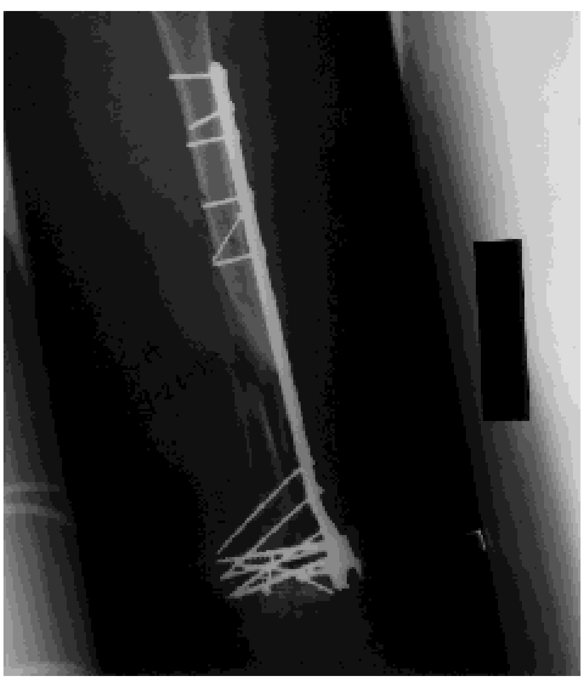


Figure 5: 2 angulated screws placed through lateral condylar buttress plate.

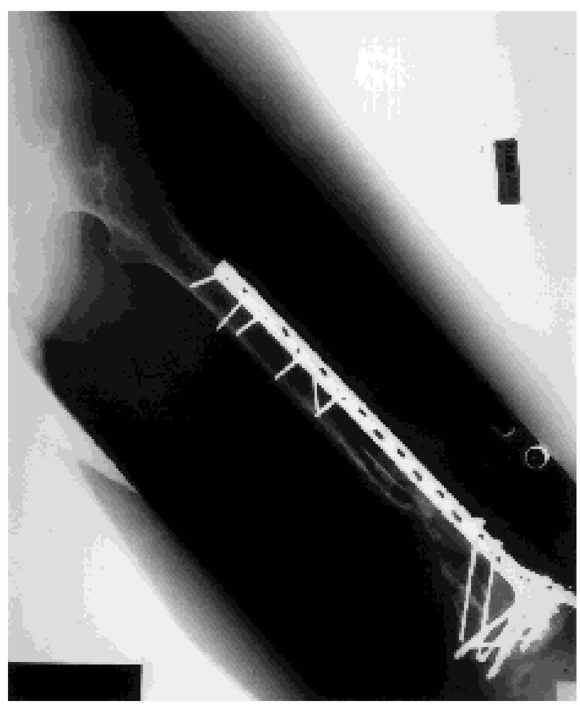


Figure 6: The healed fracture.

full weight bearing because patients with this injury would not be advised to weight bear fully at an early stage. Varus angulation at the medial cortex was monitored with a single strain gauge. We reported the stiffness of each construct at the first and last cycles; the difference was significant after 1000 cycles. By simply angulating the screw just proximal to the fracture, the average stiffness was more than doubled at the first cycle of loading and three times stiffer after 1000 cycles. Also, the amount of permanent deformation after 1000 cycles was more than double for the standard construct with all screws placed perpendicular to the plate.

This simple means of screw angulation in the plate strengthened the overall construct to resist the tendency toward varus deformity. The attractive features include the ease of application, and the use of an existing fixation device and instrumentation.

Recommended Reading

Firoozbakhsh, K., Behzadi, K., DeCoster, T. A., Moneim, M. S., and Naraghi, F. F.: Mechanics of retrograde nail versus plate fixation for supracondylar femur fractures. J Orthop Trauma, 9: 152-7, 1995.

Merchan, E. C., Maestu, P. R., and Blanco, R. P.: Blade-plating of closed displaced supracondylar fractures of the distal femur with the AO system. J Trauma, 32: 174-8, 1992.

Newman, J. H.: Supracondylar fractures of the femur. Injury, 21: 280-2, 1990.

Sanders, R., Swiontkowski, M., Rosen, H., and Helfet, D.: Double-plating of comminuted, unstable fractures of the distal part of the femur. J Bone Joint Surg [Am], 73: 341-6, 1991.

Shahcheraghi, G. H., and Doroodchi, H. R.: Supracondylar fracture of the femur: closed or open reduction? J Trauma, 34: 499-502, 1993.

Struhl, S., Szporn, M. N., Cobelli, N. J., and Sadler, A. H.: Cemented internal fixation for supracondylar femur fractures in osteoporotic patients. J Orthop Trauma, 4: 151-7, 1990.

Yang, R. S., Liu, H. C., and Liu, T. K.: Supracondylar fractures of the femur. J Trauma, 30: 315-9, 1990.

Zehntner, M. K., Marchesi, D. G., Burch, H., and Ganz, R.: Alignment of supracondylar/intercondylar fractures of the femur after internal fixation by AO/ASIF technique. J Orthop Trauma, 6: 318-26, 1992.

Comminuted and Unstable Iliac Fractures

Julie A. Switzer, M.D., Sean E. Nork, M.D. and M.L. Chip Routt, Jr., M.D.

Pelvic ring disruptions are variable. Common anterior pelvic zones of injury are the symphysis pubis and pubic ramus, while posterior pelvic ring disruptions occur through the sacrum and sacroiliac joints. Acetabular and iliac wing fractures also occur in association with pelvic ring injuries. Posterior iliac fractures associated with ipsilateral sacroiliac joint dislocations ("crescent" fracture-dislocations), as well as other "simple" iliac fractures. It is our purpose to characterize an unusual type of injury, the comminuted and unstable iliac fracture which results from direct high energy impact of the iliac crest.

Materials and Methods

Over a sixty-eight month period, 695 patients with pelvic ring disruptions were treated at Harborview Medical Center. Only thirteen (1.9%) of these patients had severely comminuted and unstable iliac fractures. All thirteen were men, ranging in age from 20 to 80 years (mean 38 years). Six patients were injured in automobile accidents, two in motorcycle accidents, two in falls from a height, and another in a jet ski accident. Two other patients were crushed by trees. The pelvic injuries were characterized based on anteroposterior, inlet, outlet, and Judet oblique plain pelvic radiographs. Pelvic computerized tomography scans further evaluated these fractures and the surrounding soft tissues.

These patients were polytraumatized and had a mean Injury Severity Score of 23. Eleven of the thirteen patients had severe iliac and flank degloving injuries. Five patients had open fractures, one with fecal contamination requiring diverting colostomy. Another patient had an intraperitoneal bladder disruption, and a third patient had herniation of his descending colon between the comminuted fracture fragments into the buttock compartment. Six patients with clinical signs of hemodynamic instability had fracture displacement through the greater sciatic notch causing local arterial injuries. All six patients stabilized after angiographic embolizations. One patient had a lumbosacral plexopathy on the fractured side. Four patients had traumatic brain injuries.

All thirteen patients had severe pelvic boney instability, and were treated operatively according to a management protocol for their pelvic fractures by the same surgeon. The five open fractures were treated emergently. The remaining eight patients underwent operative reduction and fixation of their iliac fractures and other pelvic ring injuries ranging from one to four days after injury, depending on the patient's clinical condition. Routine pelvic external fixation was not used because of the iliac comminution. Instead, stable internal fixation was accomplished via an anterior iliac surgical exposure using lag screws with and without plating. The open wounds and degloving injuries were treated with irrigation, debridement, and closure over drains. Broad spectrum cephalosporin antibiotic prophylaxis was used for all patients.

Results

Follow up evaluations were available for all patients at a mean of 18 months after injury. There were no deaths. All of the fractures healed clinically and radiographically. The fecal contamination caused a polymicrobial wound infection, and an associated delayed union. Another patient with an open fracture had an iliac wound infection. Both infections responded to local management and antibiotics. Another patient had a severe skin abrasion/contusion over his iliac crest which healed eight weeks after the injury. There were no complications associated with the degloving injuries. Venous thrombosis occurred preoperatively in one patient and post-operatively in another patient. None of the patients developed meralgia paresthetica. The patient with the lumbosacral plexopathy had residual weakness and numbness. Combative behavior due to head injury caused fixation changes in one patient.

Discussion

Comminuted and unstable iliac

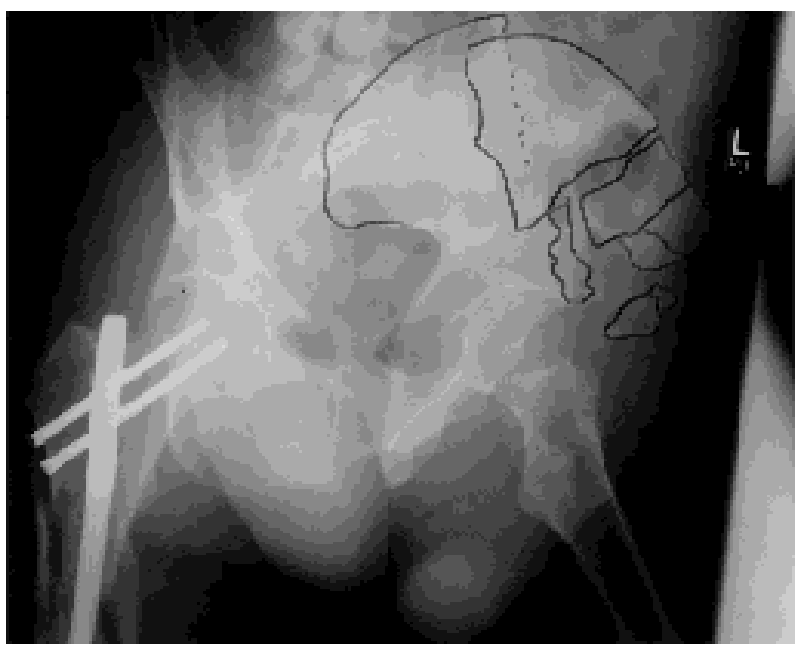


Figure 1A: The iliac oblique plain radiograph demonstrates the comminution and displacements of the iliac fracture fragments.

Figure 1B: The pelvic CT scan further defines the extent of boney and local soft tissue injuries.

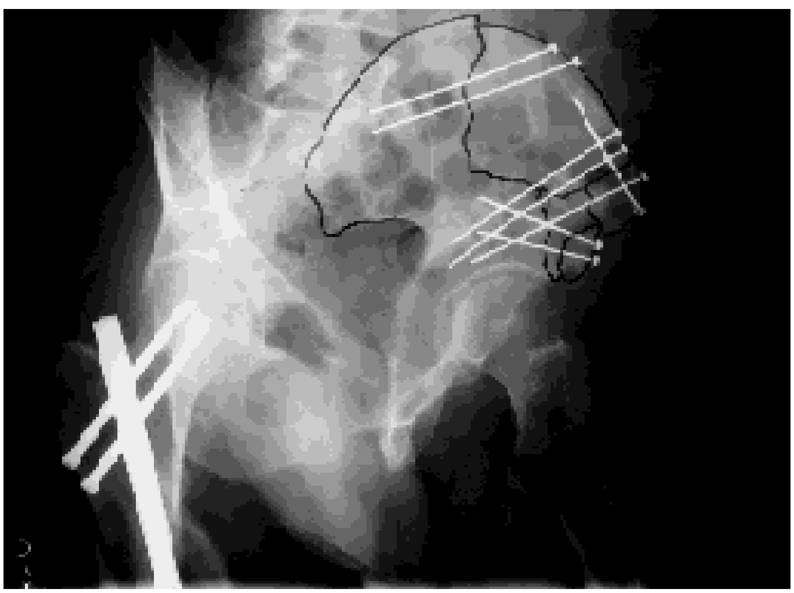


Figure 1C: Lag screws between the iliac cortical tables were used to stabilize the fractures.

fractures are very rare, and quite difficult to treat successfully. Because they are the result of high energy trauma, concomitant soft tissue, vascular, bowel, and genitourologic injuries further complicate their management. Early angiographic evaluations should be performed when the iliac fracture is displaced through the greater sciatic notch, especially when the patient demonstrates hemodynamic instability. Routine anterior pelvic external fixation is not effective due to the iliac comminution and instability. Instead, early open reduction and internal fixation is necessary to achieve fracture and local soft tissue stabilities. Comminuted iliac fractures are associated with a variety of potential complications. Fixation failure was associated with craniocerebral trauma and combative behavior after surgery. Perhaps additional fixation could have avoided this problem. Our open fractures were complicated by a high number of wound infections. Because of this, we recommend that open iliac fractures should not be closed primarily, but treated with open wound management after internal fixation. For closed iliac fractures, aggressive debridement and closed suction drainage of the associated degloving injury is effective. Pelvic fracture classification schemes should include this unusual type of iliac fracture.

Recommended Reading

Burgess AR, Eastridge BJ, Young JWR et al: Pelvic ring disruptions: effective classification system and treatment protocols. Journal of Trauma 30(7): 848-56, 1990.

Kottmeier SA, Wilson SC, Born CT, Hanks GA, Iannacone WM, and WG De Long: Surgical management of soft tissue lesions associated with pelvic ring injury. Clinical Orthopaedics and Related Research 329: 46-53, 1996.

Latenser BA, Gentilello LM, Tarver AA et al: Improved outcome with early fixation of skeletally unstable pelvic fractures. Journal of Trauma 31(1): 28-31, 1991.

Routt MLC, Simonian PT, and Ballmer F: A rational approach to pelvic trauma: resuscitation and early definitive stabilization. Clinical Orthopaedics 318: 61-74, 1995.

Routt MLC, Simonian PT, Defalco AJ, and Clarke T: Internal fixation in pelvic fractures and primary repairs of associated genitourinary disruptions: a team approach. Journal of Trauma 40(5): 784-90.

Early vs Delayed Acetabular Fracture Fixation

ORIENTE DITANO, M.D., WILLIAM J. MILLS, M.D., AND M.L. CHIP ROUTT, JR., M.D.

Acetabular fracture treatment has evolved significantly over the past three decades due to the pioneering work of Letournel and other authors. Operative treatment including stable fixation after accurate open reduction is advocated for most patients with displaced acetabular fractures. The timing of operative intervention for patients with acetabular fractures may be delayed for various reasons. In polytraumatized patients, their associated injuries and overall clinical condition may prevent early operative care. Delayed referrals also account for delayed surgical treatment. Some authors believe that later surgical interventions for displaced acetabular fractures is indicated in order to decrease operative blood losses. Emergent acetabular fracture open reduction and internal fixation is advocated for those patients with irreducible fracture-dislocations, open fractures, and altered sciatic or femoral nerve functions after closed reduction. Some authors have suggested that delayed acetabular fracture fixation decreases operative bleeding and operative times. Our goal was to attempt to define the impact of early acetabular fixation.

MATERIALS AND METHODS

One hundred and eleven displaced acetabular fractures were treated operatively at Harborview Medical Center by the same surgeon over three years. There were 86 male and 25 female patients, ranging in age from 13 to 85 years, mean 34 years. Ninety-seven patients were injured in vehicular accidents, 8 fell from a height, 3 were crushed, and 3 were pedestrians. The average Injury Severity Score(ISS) was 10.8, ranging from 4 to 32. Judet oblique pelvic radiographs and routine two dimensional computerized tomography scans were used to classify the fractures according to Letournel. There were 18 posterior wall, 1 posterior column, 7 anterior column, 1 anterior wall, 15 transverse, 7 associated posterior column/posterior wall, 29 associated transverse/posterior wall, 12 T-type, and 21 associated both column patterns. Surgical exposures were chosen for each patient according to the fracture pattern. We used 70 Kocher-Langenbeck, 29 ilioinguinal, and 3 extended iliofemoral surgical exposures. Four unusual fractures needed sequential anterior and posterior exposures at the same anesthesia, while 5 were reduced and stabilized percutaneously.

The patients were divided into two groups based on their delays from injury until acetabular fixation. The "early" group consisted of 53 patients treated within the initial three days after injury, while the 58 patients in the "delayed" group were treated after four days or more. This arbitrary division allowed divisions of patient number, gender, ISSs, and surgical exposures. The "early" group had 29 elementary and 24 associated fracture patterns, while the "delayed" group had only 13 elementary and 45 associated fracture patterns.

RESULTS

The operative blood losses were estimated by the attending anesthesiologists and surgeon for each operation, and the higher estimate was recorded. In the "early" group of patients, blood losses averaged 935 ml, ranging from only 20 ml for percutaneous procedures to 3600 ml for more extensive exposures. The

	Early group<4 days	**Delayed group 4 days or more**	**P value**
Average blood loss	935 ml (20-3600)	922 ML (50-2000)	.8862
Average operative time	330 minutes (65-705)	320 min (100-660)	.5276
Average number of hospital days	12 (5-28)	16 (7-66)	.008*(stat. different)

Table 1: Acetabular Fracture Fixation Operative Timing.

"delayed" group averaged 922 ml of blood loss, range 20 to 2000 ml. There was no statistical difference noted for operative blood losses between the two patient groups.

Operative times for the acetabular surgical procedures were documented. Polytraumatized patients often had several surgical procedures at the same anesthetic, but only the acetabular portions were examined in this study. The average acetabular operative time for the "early" group was 330 minutes, range 65 to 705 minutes. In the "delayed" group, the mean was 320 minutes, range 100 to 655 minutes. There was no statistical difference for acetabular operative times between these two patient groups. This was surprising since there were more complex, associated fracture patterns in the "delayed" group.

Total hospital days from injury until discharge were documented for these patients. The "early" group of patients had a 12 days average length of stay, range 5 to 28 days; while the "delayed" group averaged 16 hospital days, range 7 to 66 days. This was statistically significant ($p = 0.006$) (Table 1).

Discussion

Early operative intervention is beneficial for patients with other skeletal injuries, especially in polytraumatized patients. For example, urgent reduction and stable medullary fixation of femoral shaft fractures improves clinical outcomes according to several authors, but this may not be the case for acetabular fractures. Displaced acetabular fractures occur infrequently, making it difficult for most orthopedic surgeons to gain sufficient clinical experience; their deep location and surrounding important soft tissue structures further complicate effective management. Until recently, the radiology, classification, and surgical treatment options for acetabular fractures were poorly understood. Because of these complexities, operative fixation of acetabular fractures is often delayed due to the need for patient referrals to a regional acetabular surgeon, and the time for a complete preoperative work-up.

In our patients, we did not identify major disadvantages of delayed fixation. Operative blood losses were equivalent for the two patient groups and correlated with fracture patterns and surgical exposures rather than operative timing. Similarly, there were no notable differences for the two groups regarding the duration of the acetabular surgical procedures. Early operative management of patients with displaced acetabular fractures was associated with a shorter hospital stay, but this may be due to other factors as well. We conclude that treatment of these difficult fractures can be delayed until the optimal team and circumstances are available for the surgical reconstruction.

Recommended Reading

Latenser BA, Gentilello LM, Tarver AA et al: Improved outcome with early fixation of skeletally unstable pelvic fractures. Journal of Trauma 31(1): 28-31, 1991.

Letournel, E: Acetabulum Fractures: Classification and Management. Clin Orthop. 151:81-106, 1980.

Letournel, E, Judet, R: Fractures of the Acetabulum. Publisher: Springer-Verlag, New York, 1981.

Matta, JM: Fractures of the Acetabulum: Accuracy of Reduction and Clinical Results in Patients Managed Operatively with Three Weeks After the Injury. J Bone Joint Surg. 78A:1632-1645, 1996.

Routt, ML Jr, Swiontkowski, MF: Operative treatment of Complex Acetabular Fractures. Combined Anterior and Posterior Exposures During the Same Procedure. J Bone Joint Surg. 72A:897-904, 1990.

A Biomechanical Comparison of Some Bone-Ligament-Bone Autograft Replacements for the Injured Scapho-Lunate Ligament

E.J. Harvey, J.B. Knight, Douglas P. Hanel, M.D., and Allan F. Tencer, Ph.D.

In this study the mechanical properties of 3 candidate autografts for repair of the injured scapho-lunate ligament are compared to those of the intact scapho-lunate ligament.

The most common treatment for chronic scapho-lunate (S-L) dissociation is limited carpal fusion, however fusion has been documented to change both kinematics and articular contact pressures. Methods for restoring the scapho-lunate ligament include (a) replacement with flexor or extensor carpi radialis tendon, (b) allografts, (c) and autografts. In this study, we tested autograft tissues which could be harvested from the same incision and used for S-L ligament reconstruction; these included the 2nd metacarpal-trapezoid ligament, the 3rd metacarpal-capitate ligament, and the dorsal periosteal retinaculum (Figure 1). The mechanical properties of these ligaments were compared to those of the scapho-lunate ligament.

Methods

Specimens: The following bone-tissue-bone grafts were harvested from each of 7 fresh cadaveric wrists (Fig 1); (i) radial tubercle with surrounding retinaculum , (ii) 2nd metacarpal-trapezoid ligament, (iii) 3rd metacarpal-capitate ligament, along with, for comparative purposes, and (iv) the scaphoid-ligament-lunate. Each specimen had 0.054" diameter K wires placed in both bone ends for anchoring, which were then embedded in polymethylmethacrylate in mounting cups. Specimens were kept moist throughout testing.

Mechanical testing: Specimens were tested to failure in uniaxial tensile loading at 10 mm/min in a mechanical tester (Instron, Canton, MA). Because of the short lengths of these tissues, displacement was measured from the crosshead as opposed to locally within the tissue. To check for errors induced by this method of displacement measurement, a rigid aluminum rod was mounted and tested in the same way as the specimens. Load was monitored by the Instron load cell.

Data Analysis: Ligament stiffness and load to failure were derived from the data. To compare means, a Kruskal-Willis non parametric multiple comparison by ranks was performed.

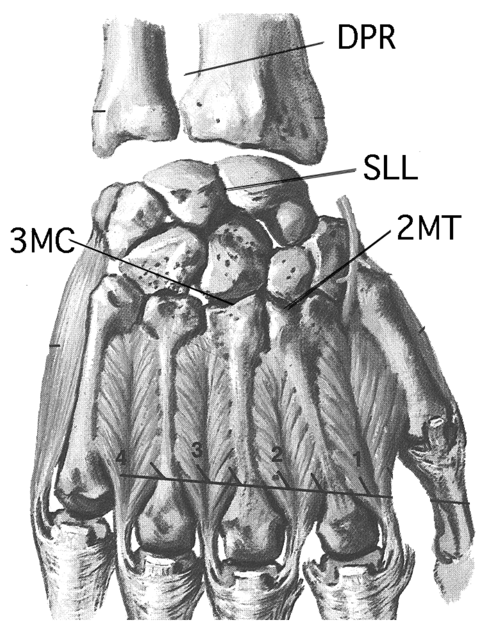


Figure 1: Drawing of the dorsal side of the hand showing the scapholunate ligament (SLL) and three bone-ligament-bone graft replacements, DPR (dorsal periosteal retinaculum), 2MT (2nd metacarpal-trapezoid), and 3MC (3rd metacarpal-capitate) (adapted from Netter FH, Ciba-Geigy, Summit, NJ, Vol 8).

Results

Figure 2 demonstrates that only the dorsal retinaculum was less stiff than the scapho-lunate ligament (SLL) ($p = 0.045$), reaching a mean of 49% of the stiffness of the SLL while the 2nd metatarsal-trapezoid was 118% as stiff, and the 3rd metacarpal-capitate was 97% as stiff. The dorsal retinaculum was also significantly less strong than the SLL (mean 26% as strong), while the others were very similar in strength to the SLL (111% and 101% for the 2nd metacarpal-trapezoid and 3rd metacarpal-capitate respectively).

Conclusions

Both the 2nd metacarpal-trapezoid and the 3rd metacarpal-capitate ligaments have tensile mechanical properties similar to the scapho-lunate. Since they are bone-ligament-bone grafts, are accessible through the same incision used for scapho-lunate ligament repair, and attach to nearly immobile joints, they offer the potential for use in reconstruction of the scapho-lunate ligament without requiring limited carpal fusion or tendon weaves for stabilization.

Clinical Relevance

The reconstruction of intercarpal ligaments with similar tissues, secured with a bone ligament bone interface in the clinical setting is appealing but as yet untested. Having now identified potential tissues for reconstruction, we are now charged with the task of determining how best to secure the transferred tissue before recommending the use of bone-ligament-bone composite grafts in a clinical setting.

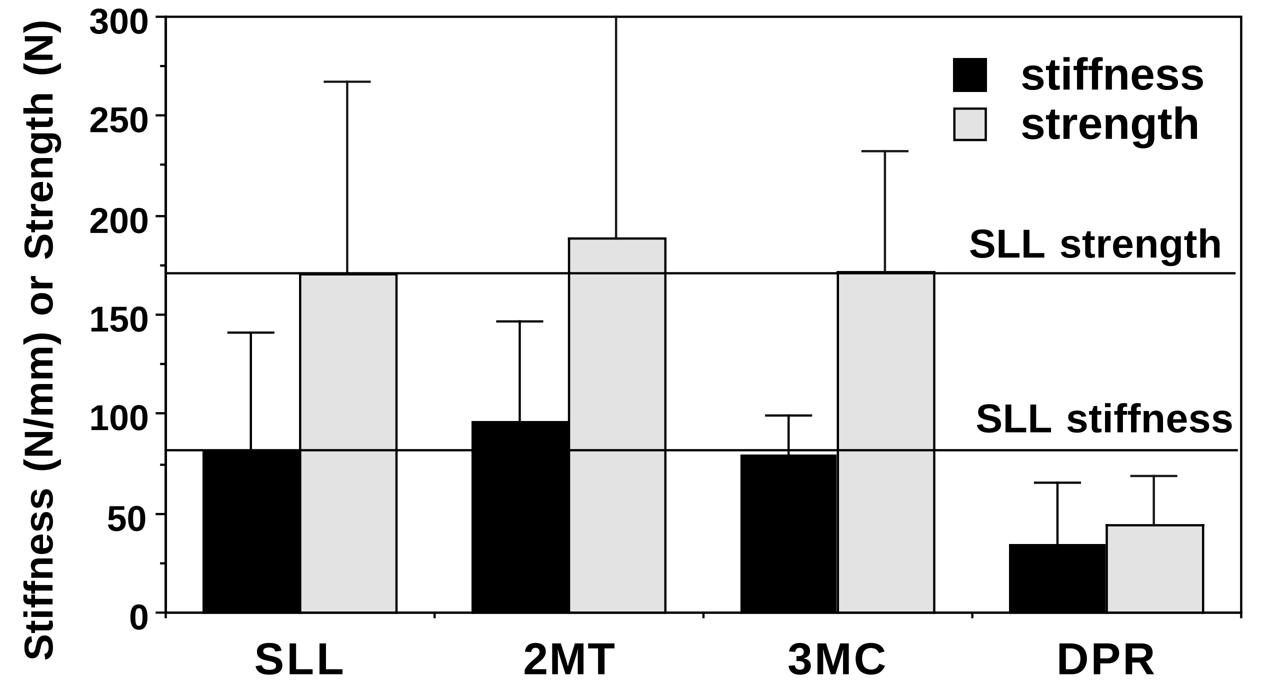


Figure 2: Stiffness and strength of potential bone-ligament-bone substitutes for the scapho-lunate ligament available through the same incision used for the repair (SLL-scapho-lunate ligament, 2MT-2nd metatarsal-trapezoid, 3MC 3rd metacarpal-capitate, DPR-dorsal periosteal retinaculum).

Recommended Reading

Augsberger S, et al, J Hand Surg 17A:360-9, 1992.

Kleinman WB, et al, J Hand Surg, 15A:408-14, 1993.

Weiss A, Trans AAOS 213:169, 1996.

Svoboda SJ, J Hand Surg, 20A:980-5, 1995.

Early "Simple" Release of Post-Traumatic Elbow Contracture Associated with Heterotopic Ossification

Randall W. Viola, M.D. and Douglas P. Hanel, M.D.

Treatment of post-traumatic elbow stiffness secondary to heterotopic ossification (HO) is controversial. This is especially true regarding timing and post operative measures to prevent recurrence. Many surgeons delay treatment until serum alkaline phosphatase and bone scans normalize, processes which may take 2 years post injury to occur. After excision of the HO and release of the contractures, various prophylactic measures have been proposed including radiation and/or non steroidal antiinflammatories (NSAIDS). We wish to present our approach to this problem which includes early surgical release and 5 days of NSAIDS post operatively as a measure to prevent recurrence of HO.

Methods

Sixteen patients (18 elbows) were treated at Harborview Medical Center with early excision of post-traumatic elbow HO in the past 4 years. Each patient was treated with open surgical release alone or with open release and distraction arthroplasty. The criteria for operative release were: (1) function limiting elbow stiffness, (2) fracture union, (3) heterotopic bone on plain radiographs, (4) preserved ulnohumeral articular surfaces and (5) resolved traumatic brain injury. Each elbow was classified according Hastings: class I (0), class IIA (7) , class IIB (1), class IIC (5), and class III (5). Delayed cubital tunnel syndrome was documented in 7 patients. The average time from injury to release was 31 weeks. Alkaline phosphatase and bone scans were not obtained. Postoperatively, CPM was used for five days. A daily program of aggressive active and active-assist motion exercises was continued for six weeks. Radiation was not used. Indomethacin was prescribed for the first five days post operatively. The average duration of follow-up was 26 months.

Results

Preoperatively, the mean flexion/extension and pronation/supination arcs were 33 and 75 degrees, respectively. The corresponding follow-up values were 117 and 155 degrees. Cubital tunnel syndrome resolved in all patients. There were no operative complications. Three post-operative complications occurred in two patients. 3 months after release, the skin over the olecranon in one patient broke down as range of motion and activity improved. This was corrected with free tissue transfer. The other two complications occurred in one patient: a pin tract infection from a hinged fixator which cleared with pin removal and oral antibiotics. In addition this patient went on to develop avascular necrosis of the capitellum. The patient has pain with heavy lifting but continues to work as a carpenter. There were no recurrent contractures or loss of motion resulting from contracture release.

Conclusions

These results suggest that the conventional delay of surgery until normalization of both the patient's bone scan and serum alkaline phosphatase may be unnecessary. Furthermore, this series documents a low complication rate and demonstrates that good results may be achieved without postoperative radiation and with less than one week of Indomethacin.

A Prospective Multicenter Functional Outcome Study of Arthroplasty in Glenohumeral Inflammatory Arthritis

David N. Collins, M.D., Douglas T. Harryman, II, M.D., and Michael T. Wirth, M.D.

Patients with intractable shoulder pain and dysfunction from inflammatory glenohumeral arthritis are often treated with shoulder arthroplasty to improve their shoulder comfort and function. While this procedure yields predictable pain relief, improvements in active motion are less consistent. Persistent functional deficits may be related to rotator cuff pathology, loss of glenohumeral joint architecture and the severity of this systemic disease.

The purpose of this study was to compare and contrast the functional outcomes of hemiarthroplasty (HA) and total shoulder replacement arthroplasty (TSA) for end-stage glenohumeral inflammatory arthritis.

Methods

The study cohort included 59 cases of hemi (35) or total shoulder (24) arthroplasty performed by multiple surgeons using a single prosthesis system (Global™, DePuy). These patients had at least 24 months of post operative follow-up (mean 39 months (range 24 to 73)). Standardized forms were used to record clinical observations as well as pre and post operative self-assessment of comfort (Visual Analogue Scale (VAS)) and functional inventories using the Simple Shoulder Test and a 48-item activity list. Physical examination documented motion, strength and stability before and after treatment. Pre and postoperative anteroposterior and axillary lateral radiographs were also reviewed by the three authors.

The authors reviewed the preoperative radiographs to determine whether they thought the shoulders had adequate bony architecture to support the prosthetic components in anatomic position. Criteria for inadequate bone included:

1) Glenoid erosion to the base of the coracoid (AP view).

2) Head migration to less than 3 mm from the inferior acromion. (AP view).

3) Greater tuberosity inadequate to cover prosthetic template. (AP view).

4) Loss of > 40% of the glenoid.(Axillary view).

5) Missing acromion or clavicle.(Axillary view).

Post-operatively, glenohumeral alignment was determined from the relationship of the humeral head position relative to the glenoid on AP and axillary radiographs. Criteria for inadequate alignment were:

1) Humeral head dislocation or subluxation of $\geq$ 3 mm from glenoid center line on either view.

2) Improper head height relative to tuberosity (<0 or >10 mm).

3) Acromiohumeral interval < 3 mm.

4) Glenoid angulation on AP or axillary view of > 15° from normal glenoid axis orientation.

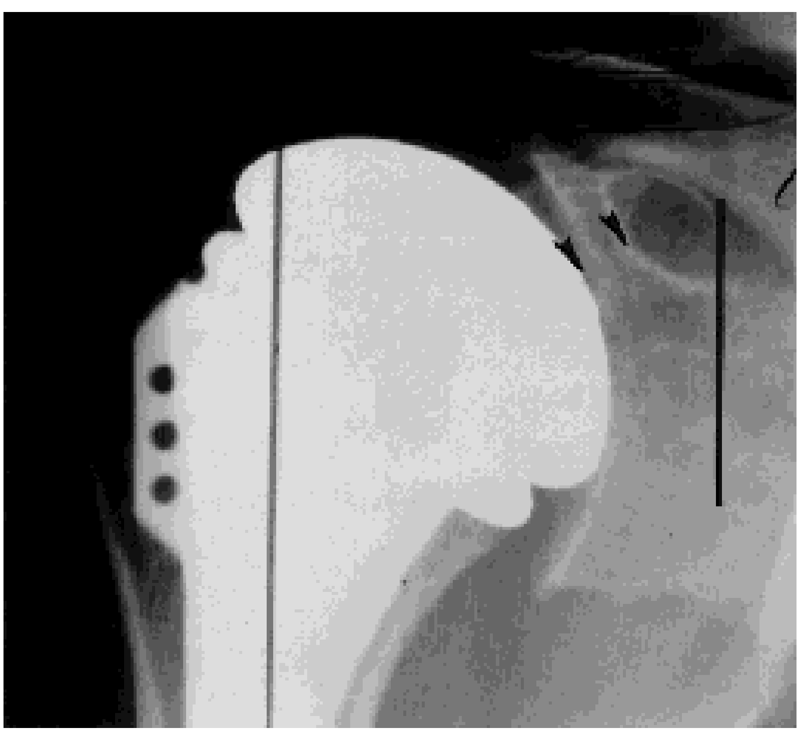


Figure 1A: AP view immediately following prosthetic hemiarthroplasty replacement. Note 15 mm of humeral head offset between the medial coracoid base and humeral head articular surface and 7 mm of gap between the coracoid and the glenoid articular surface.

Results

No statistical differences were identified between the patients treated with HA and those treated with TSA with respect to their pre-operative pain, comfort, extremity related function, quality of life or by total SST score or range of motion (Student's two sample t-test corrected if unequal variances were present between groups using Satterthwaite's adjustment, significance level $p \leq 0.05$).

Full thickness rotator cuff tears were present in 19 (54%) of the 35 HA and 8 (25%) of the 24 TSA cases. In the presence of a full thickness rotator cuff tear, the HA group reported greater pain at rest and during sleep.

An average overall improvement on SST of 4.4 "yes" responses was observed. Range of motion improved for both HA and TSA but much better improvement in active elevation was achieved for those who underwent TSA (50°

Figure 1B: AP view of hemiarthroplasty 36 months following prosthetic hemiarthroplasty replacement. Note medial erosion of approx. 10 mm and the narrow gap between the coracoid and the glenoid articular surface. The humeral head offset is now only 5 mm (medial coracoid base to humeral head articular surface minus magnification).

increase to an average of 118°, $p<0.05$) relative to those after HA (15° increase to an average of 89°).

Anatomic reconstructability was predicted in 53% of cases with HA and achieved in only 22% of those. It was not predicted in 46% of HA but was achieved in 29% of those. Reconstructability was predicted in 70% of TSA and was achieved in 69% of those; whereas it was not predicted for 30% of TSA but was achieved in 27% of those.

Glenohumeral alignment was anatomically restored in 27% of the cases of HA and 51% of the cases of TSA. Significantly better VAS scores were noted when the glenohumeral alignment was achieved as opposed to when alignment was not achieved. This included overall pain, sleep comfort, work and play usage and overall quality of life (all $p=0.05$, two-sample Student's t-test).

For all cases in which alignment had been restored, active total elevation significantly improved by a mean of 21° ($p=0.068$). TSA significantly outperformed HA in this category with post-operative elevation of 131° versus 85° ($p=0.004$). Active external rotation and passive elevation were better for TSA than HA, 48° versus 29° ($p=0.023$) and 144° versus 104° ($p=0.006$), respectively. The presence of a full thickness rotator cuff tear at the time of operation did not influence post operative VAS, SST, ROM, or radiographic alignment.

Progressive glenoid erosion was noted in 12% of HA (Figure 1A and 1B) and there were two TSA cases of glenoid component loosening. VAS, SST, or ROM did not change significantly with time.

Conclusions

In this series of patients with glenohumeral inflammatory arthritis:

1) The most favorable outcomes for implant arthroplasty appear to occur in the presence of an intact rotator cuff and sufficient bony architecture to support humeral and glenoid implants. Factors mitigating against glenoid resurfacing include rotator cuff deficits and glenoid erosions.

2) Both hemi and total shoulder arthroplasty improved the VAS pain scores, SST scores, activities of daily living, and range of motion. Active elevation was significantly better for the TSA group (118° versus 89°).

3) Pain relief and functional parameters were better when glenohumeral alignment was restored.

4) Progressive glenoid erosions can occur following hemiarthroplasty, potentially resulting in pain, instability, and functional loss.

Recommended Reading

Barrett W, Thornhill TS, Thomas WH, Gebhart EM, Sledge Cb. Nonconstrained total shoulder arthroplasty in patients with polyarticular rheumatoid arthritis. J Arthroplasty. 1989; 4:91-96.

Boyd AD Jr, Thomas WH, Scott RD, Sledge CB, Thornhill TS. Total shoulder arthroplasty versus hemiarthroplasty. Indications for glenoid resurfacing. J Arthroplasty. 1990; 5:329-361.

Figgie MP, Inglin AE, Figgie HE III, Sobel M, Burstein AH, Kranny MJ. Custom total shoulder arthroplasty in inflammatory arthritis. Preliminary results. J Arthroplasty. 1992; 7(1):1-6.

Franklin JL, Barrett W, Jackins SE, Matsen FA. Glenoid loosening in total shoulder arthroplasty. J Arthroplasty. 1988; 3:39-46.

Friedmann RJ, Thornhill TS, Thomas WH, Sledge CB. Nonconstrained total shoulder replacement in patients who have rheumatoid arthritis and class IV function. J Bone Joint Surg AM. 1989; 71A:494-498.

Stewart MPM, Kelly IG. Total shoulder replacement in rheumatoid disease: 7 - 13-year follow-up of 37 joints. J Bone Joint Surg. Br. 1997; 79(B):68-72.

Department of Orthopaedics Faculty

Frederick A. Matsen III, M.D.
Professor and Chair

Stephen K. Benirschke, M.D.
Associate Professor

Stanley J. Bigos, M.D.
Professor

James T. Bruckner, M.D.
Assistant Professor

Howard A. Chansky, M.D.
Assistant Professor

Jens R. Chapman, M.D.
Associate Professor

Randal P. Ching, Ph.D.
Assistant Professor

John M. Clark Jr., M.D., Ph.D.
Associate Professor

Ernest U. Conrad III, M.D.
Professor

Mohammad Diab, M.D.
Assistant Professor

David R. Eyre, Ph.D.
Professor

Theodore K. Greenlee, Jr., M.D.
Associate Professor

Douglas P. Hanel, M.D.
Associate Professor

Sigvard T. Hansen, Jr., M.D.
Professor

Douglas T. Harryman II, M.D.
Associate Professor

M. Bradford Henley, M.D.
Associate Professor

Roger V. Larson, M.D.
Associate Professor

William J. Mills, M.D.
Assistant Professor

Sohail K. Mirza, M.D.
Assistant Professor

Vincent S. Mosca, M.D.
Associate Professor

Sean E. Nork, M.D.
Assistant Professor

John O'Kane, M.D.
Assistant Professor

Milton L. Routt Jr., M.D.
Associate Professor

Bruce J. Sangeorzan, M.D.
Professor

John A. Sidles, Ph.D.
Professor

Peter T. Simonian, M.D.
Associate Professor

Douglas G. Smith, M.D.
Associate Professor

Kevin L. Smith, M.D.
Assistant Professor

Kit M. Song, M.D.
Assistant Professor

Lynn T. Staheli, M.D.
Professor Emeritus

Michael D. Strong, Ph.D.
Research Professor

Carol C. Teitz, M.D.
Associate Professor

Allan F. Tencer, Ph.D.
Professor

Thomas E. Trumble, M.D.
Professor

Jiann-Jiu Wu, Ph.D.
Research Associate Professor

Adjunct Faculty

Basia R. Belza, R.N., Ph.D.
Associate Professor, Physiological Nursing

Anne-Marie Bollen, Ph.D.
Assistant Professor, Orthodontics

Charles H. Chesnut, M.D.
Professor, Nuclear Medicine

Gregory C. Gardner, M.D.
Associate Professor, Rheumatology

Thurman Gillespy, M.D.
Associate Professor, Radiology

Daniel O. Graney, Ph.D.
Associate Professor, Biological Structure

John C. Hunter, M.D.
Assistant Professor, Radiology

Frederick A. Mann, M.D.
Professor, Radiology

Susan M. Ott-Ralph, M.D.
Associate Professor, Division of Metabolism

Wendy Raskind, M.D., Ph.D.
Associate Professor, General Internal Medicine

Michael L. Richardson, M.D.
Professor, Radiology

Robert Schoene, M.D.
Professor, Medicine

Peter A. Simkin, M.D.
Professor, Medicine

Tony J. Wilson, M.D.
Professor, Radiology

Joint Faculty

John E. Olerud, M.D.
Professor, Division of Dermatology

Nicholas B. Vedder, M.D.
Assiociate Professor, Plastic Surgery

Affiliate Faculty

David A. Boone, C.P.
Director and Co-Principal Investigator, Prosthetics Research Study

Sarah E. Jackins, R.P.T.
Rehabilitation Medicine

UNIVERSITY OF WASHINGTON SCHOOL OF MEDICINE

Department of Orthopaedics
University of Washington
1959 N.E. Pacific Street
Box 356500
Seattle, Washington 98195-6500

Phone: (206) 543-3690
Fax: (206) 685-3139

Affiliated Institutions

Children's Hospital and Medical Center
4800 Sand Point Way NE
Seattle, WA 98105
(206) 526-2000

Harborview Medical Center
325 Ninth Avenue
Seattle, WA 98104
(206) 731-3462

University of Washington Medical Center
Bone and Joint Center
4245 Roosevelt Way NE
Seattle, WA 98105
(206) 548-4288

VA Puget Sound Health Care System
1660 South Columbian Way
Seattle, WA 98108
(206) 764-2215

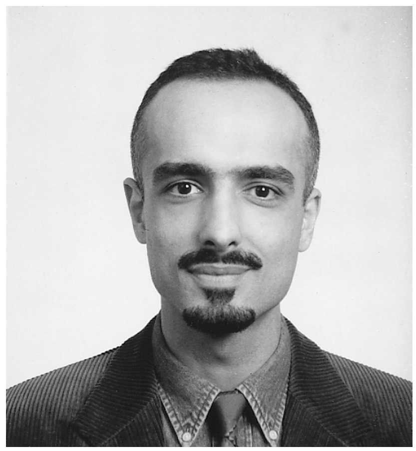
1998 Department of Orthopaedics Incoming Faculty

Randy Ching, Ph.D.

Randy Ching, Ph.D. is an Assistant Professor of Orthopaedics at the University of Washington. Dr. Ching received his research training at the Orthopaedic Biomechanics Laboratory at Harborview Medical Center where he now serves as Assistant Director. He earned both his Masters degree (1988) and Ph.D. (1992) from the Department of Mechanical Engineering at the University of Washington.

Dr. Ching's main area of research is on the biomechanics of the spine. Beyond the more traditional approach to evaluating spinal stability by measuring its load-carrying capacity, he has explored the ability of the spine to protect the neural elements both during and immediately following traumatic events. This paradigm of "neural stability" has had important implications for spinal-injury prevention as well as the post-traumatic management of patients with spinal injury. Current projects with NHTSA (National Highway Traffic Safety Administration) and the U.S. Air Force have allowed Dr. Ching to focus his research towards developing spinal injury threshold criteria for both the pediatric and adult spine subjected to dynamic loading environments.

Outside of his research, Dr. Ching and his wife, Joan, are busy raising their two daughters Megan and Erin (ages 10 and 4). In between the softball practices, swimming lessons, and soccer games, he enjoys trail running and an occasional round of golf.



Mohammad Diab, M.D.

Upon completion of his one year Pediatric Orthopaedic Fellowship at Boston Children's Hospital Mohammad Diab will be rejoining the University of Washington as an Assistant Professor at Children's Hospital and Medical Center. Dr. Diab was a resident here from July 1993 to June 1997.

Dr. Diab was born in Cairo, Egypt. He went to Dollar Academy in Scotland from 1976 to 1979. He received his B.Sc. in Biology as well as a B.A. in Classics from Stanford University, graduating summa cum laude in both fields. He received the Fairclough Scholarship in Classics. Dr. Diab was also elected to Phi Beta Kappa while at Stanford. He stayed at Stanford to attend Medical School.

After working for a number of years as a reasearch and teaching assistant at Stanford, he joined the U.S. Naval Medical Research Unit #3 in Cairo, Egypt as a Guest Investigator. Following this he interrupted his research career to work as a volunteer for the victims of the Afghanistan War in Pakistan for a month. Years later, after beginning his internship at the University of Washington, he worked at Casa de Columbia, Hospital San Jose de Buga in Columbia as a volunteer.

Dr. Diab has also received a number of awards, honors, and recognitions, including the United States Navy Young Investigator Grant in 1987-88, the Victor H. Frankel Award at the University of Washington, the Best Resident Paper (Intermedics Orthopedics) at the American Academy of Orthopaedics Surgeons annual meeting of February 1994, and most recently the Von L. Meyer Fellowship at Children's Hospital in Boston for 1997-1998.

William J. Mills, M.D.

William J. Mills, M.D. joins the University of Washington Department of Orthopaedics as an Assistant Professor. Dr. Mills will be joining the Harborview Medical Center Trauma team. His previous position was as an Orthopaedic Staff Physician at the Naval Medical Center in San Diego, CA.

Bill Mills began his college education at the University of Michigan, where he received his Bachelor's of Science degree. He went on to get his Masters at the University of Minnesota and his Medical Degree at the University of Colorado.

He was an intern here at the University of Washington Department of Surgery and he stayed here for his residency in Surgery from 1990-1991 before his Orthopaedic residency here from 1991-1995.

Dr. Mills was appointed Ensign in the United States Naval Reserve in May of '86. He has been promoted twice since then. He joined the staff at the Naval Hospital in San Diego in July 1995.

In his career he has won numerous

honors and awards such as: Vandenberg Scholar in 1979 at the University of Michigan, the James J. Waring Award of Nu Sigma Nu in 1988 and the George Packard Award for outstanding record in surgery in 1989 at the University of Colorado School of Medicine, the Victor H. Frankel Award for Scientific Paper in 1995 at the University of Washington's Resident Research Days, and the Orthopaedic Residents' Staff Teaching Award in 1995-96 at the Naval Medical Center in San Diego.

Dr. Mills is a member of the American Medical Association, the American Academy of Orthopaedic Surgeons, the Western Orthopedic Association, and the Society of Military Orthopaedic Surgeons. He has given scientific presentations on open tibia fractures , streptococcal infections, as well as other topics. And, he has published work on the effects of the topical use of anesthetic, shivering and other forms of tremor, different approaches to fracture treatment as well as cold injuries and abduction stress.

Sean E. Nork, M.D.

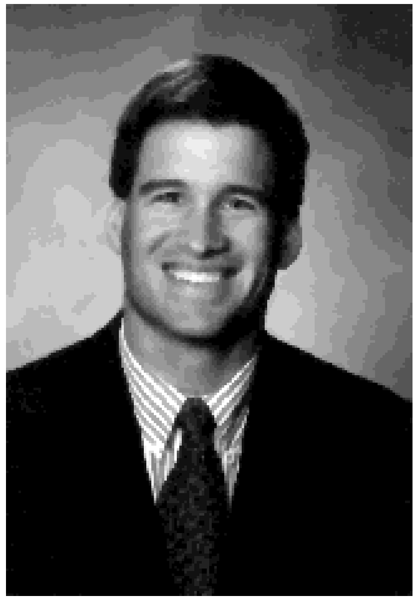
Sean E. Nork, M.D. has been appointed Assistant Professor at Harborview Medical Center. He has previously worked for the Department as an Acting Instructor.

Dr. Nork did his undergraduate studies at the University of California at Berkeley in Bioengineering. He went to medical school at the University of California at San Diego and he was a resident at the University of California at San Francisco.

His major field of interest is orthopaedic traumatology. He has worked in particular on fractures of the pelvis and acetabulum as well as lower extremity periarticular fractures.

His published papers include work on outcomes after instrumented posterior spinal fusions for degenerative spondylolisthesis, the relationship between ligamentous laxity and the site of upper extremity fractures in children, and external fixation versus skeletal traction for pediatric femoral shaft fractures.

Dr. Nork is currently investigating the treatment of U-shaped sacral fractures with iliosacral screws. Other current research topics include: biomechanical evaluation of fixation of fracture dislocations of the sacroiliac joint, results of iliosacral screw fixation without SSEP's, biomechanical evaluation of fixation of U-shaped sacral fractures, and CT evaluation of sacral dysmorphism and safe screw placement.



John O'Kane, M.D.

Dr. John O'Kane is currently an Acting Instructor and will be joining the Sports Medical Center as Assistant Professor, July 1, 1998.

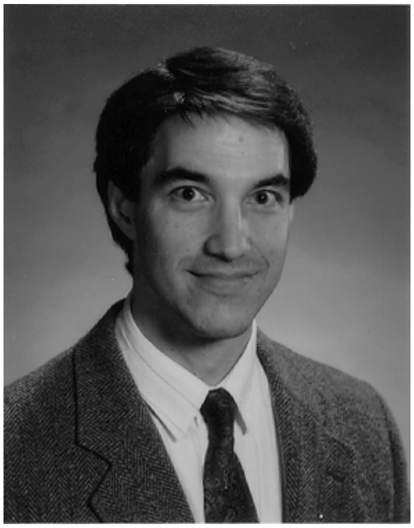
Dr. O'Kane spent his childhood in Vermont enjoying small town life and winter sports. He went to Dartmouth College where he played football and directed the ski school. He met his wife-to-be in college, then they both moved on to University of Vermont Medical School.

Through college and medical school he blended his interests in sports and teaching through coaching and eventually directing summer ski camps in Switzerland. Dr. O'Kane and his wife came to Seattle together as residents in the University of Washington Dept. of Family Practice. She is currently working in the UWP Family Practice clinic in Issaquah.

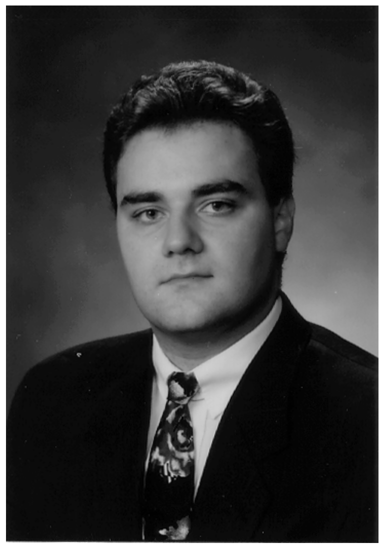
Dr. O'Kane completed an additional year of orthopaedic and sports medicine training with the University of Washington Orthopaedic Department, and he is currently working in Orthopaedics as a member of the Sports Medicine staff. One aspect of his job he especially enjoys is his current role as a Husky team physician, a job combining general medical care and orthopaedics in a unique population of young adults.

In their spare time, he and his wife continue to enjoy skiing, hiking, biking, and other outdoor pursuits. He also enjoys playing guitar.

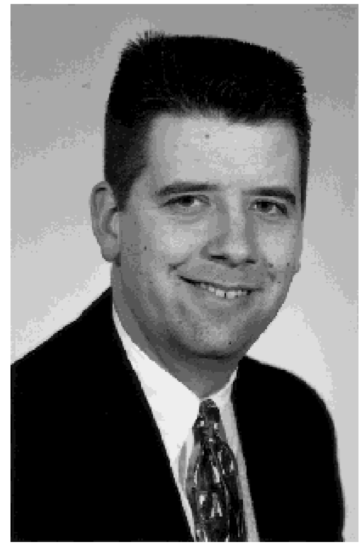
Graduating Residents
Class of 1998



David Belfie, M.D., his wife, Barbara, and their two children will be going to Albuquerque, New Mexico, for four years where David will assume active duty status in the United States Air Force.



Oriente DiTano, M.D., will be returning to the east coast where he will participate in a hand and upper extremity fellowship in Pittsburgh, Pennsylvania.

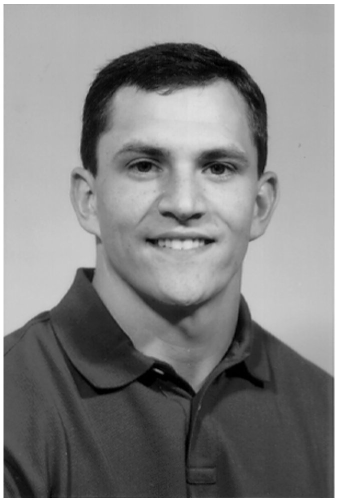


Donald Ericksen, M.D., his wife, Sara, and their children will be staying in Seattle while Don does a six month foot and ankle fellowship at Harborview Medical Center. The family will move to Kalispell, MT where Don will be joining the Flathead Valley Orthopaedics and Sports Medicine Clinic following his fellowship.

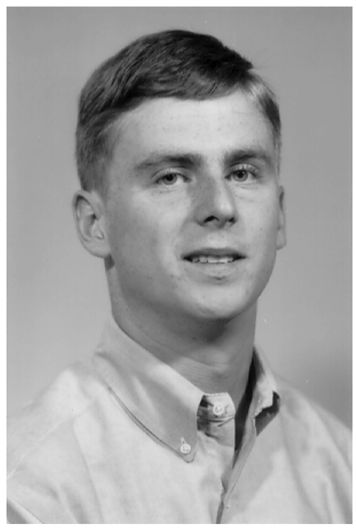
Jay Crary, M.D., his wife, Jennifer, and their two children, will be going to Detroit, Michigan, where Jay will participate in a one year foot surgery fellowship.

Colin Poole, M.D., his wife, Louise, and their two children are going to San Diego, California, where Colin will be partaking in a one year adult reconstruction fellowship at the Scripps Clinic and Research Foundation.

Incoming Residents



Timothy DuMontier: Tim graduated magna cum laude from the University of Southern California in 1993 with a B. A. degree in Biology. Tim went on to attend the University of Washington Medical School where he received his M.D. in 1997. Activities enjoyed outside of medicine include weight lifting, hunting, hiking and horseback riding.



Timothy Rapp: Tim received his B. S. with honors in Biochemistry from the University of Iowa in 1993. Tim went on to attend the University of Iowa where he received his M.D. in 1997. Tim's personal interests are competitive athletics, running, tennis, skiing, travel and cooking.

William Sims: Bill received his B. S. in Zoology from the University of Idaho in 1993. Bill went on to attend the University of Washington Medical School where he received his M. D. in 1997. His extracurricular activities include cycling, weight training and skiing.

Scott Hacker: Scott graduated magna cum laude from the University of California - San Diego in 1990 with a B. S. degree in Bioengineering. This was followed by a M.S. degree in Bioengineering from UCSD in 1991. Scott attended UC-Irvine Medical School where he received his M.D. in 1997. Interests enjoyed outside of medicine include mountain biking, hiking, diving and running.

Carla Smith: Carla received her B. A. magna cum laude in Biochemistry from Rice University in 1989. Carla attended Baylor College of Medicine where she was accepted into a combined M.D./ Ph.D. program in 1989. Carla received her Ph.D. in immunology in 1995 followed by receiving her M.D. in 1997. She enjoys sports which include competitive cycling.

Contributors to Departmental Research and Education

MAY 1997 THROUGH APRIL 1998

We express our appreciation to all who have contributed to the work of the Department of Orthopaedics over the past year. Your assistance makes possible special research activities, educational programs, and other projects that we could not facilitate without this extra support from our alumni, faculty, and friends in the community. We owe a special thanks to the University of Washington Resident Alumni who have made significant contributions to help further the education of our current residents.

Friends of Orthopaedics

Sarah Adler
Jeffrey W. Akeson
Edward Almquist
Franklin and Marilyn Alvine
American Orthopedic Foot & Ankle Society
David and Jean Anderson
Carl A. Andrews
Theresa Antonetti
Craig Arntz
Artro Care
Allan and Carol Bach
Samuel Baker
William Barrett
Timothy Beals
Stephen Benirschke
Carol Benn
Monte L. Benn
Gary Bergman
Bioelectron
David Bishop
John C. Brown
James D. Bruckner
James D. Bruckner (Steven Sitcov)
Ernest Burgess
Susan Cero
Howard Chansky
Herbert Clark (NW Ortho Clinic)
Todd Clarke
Ernest Conrad
Vernon Cooley
James Crutcher
Jerome H. Debbs II
David Deneka
DePuy, Inc.
Catherine Ann Deseranno
Richard Dimond
E. Anne Elliott
Kimberly A. Elliot
David R. Eyre
Edward Farrar
Thomas Fischer
Jim Fletcher (Howmedica)
Jonathan Franklin (Ortho Consultants)
James Friend
Ken Fuji
Joy D. Garner
James Ghiglione
Benjamin H. Gill
Park Gloyd
Jean Goehring
Thomas Green
Theodore and Sandra Greenlee
William A. Guinn
Marian Hampton
Douglas P. Hanel
Sigvard Hansen
Nova Sue Harrison
Doug T. Harryman
Linda S. Hempel
Janet Henry
Scott Hormel
John Hunter
Tom Hutchinson (W.W. Med Group)
Innovasive Devices
Sarah Jackins
Cathy Keating
Carleton Keck
David Kieras
Richard Kirby
Betty E'Drene Killoran
Edith D. Klep

Friends of Orthopaedics

Harvey W. Klep
Jonathan Knight
Philip Kregor
Wally Krengel
Ronald Kristensen
Dennis Kvidera
Albert Larson
Roger Larson
Laurie A. Lee
David Levinsohn
Tim Lovell
Joan Malmassari
Maxine Malmassari
Frederick A. Mann
Rebecca & Steve Marsh
Frederick A. Matsen III
Keith Mayo
Julia C. McCloud
Daniel J. McClure
Joseph Mezistrano
Sohail Mirza
Peter Mitchell
Michael Morris
Vincent S. Mosca
Carol Myers
David Nank
John Neufeld
Wade Alan Newman
Ed North
Northwest Ortho Physicians
Northwest Spine Surgeons
(Bach, Krengel, Dales)
William Oppenheim
John Orr (Zimmer)
Orthopedic Physician Associates
(Knight, R)
Lawrence Page
Arnold Peterson
Eli Powell
Lane Premo
Donna M. Presley
Steve Ratcliffe
Steven Reed
Alberta M. Regan
Reiff (Northwest Biomet)
John Sack, M.D.
(Seattle Hand Surgery)
Michael Sailer
Saint Frances Med Tech
Ronald Sandler
Bruce J. Sangeorzan
Richard Semon
Peter T. Simonian
Cindy Smith
Kevin Smith
Kit M. Song
Lyle Sorensen
Don Striplin
Ilene M. Swanson
James M. Swanson
Marc Swiontkowski
Carol C. Teitz
Steven Thomas
Michael Thorpe
Gayle C. Toney
Thomas E. Trumble
Valley Orthopedic Associates
(Arntz, Barrett, Hendrickson)
Eric Vanderhooft
Nicholas Vedder
Robert Veith
Janet L. Viet
Theodore Wagner
Pamela Walker
Robert Watkins, Jr.
Amy Weisner
John D. West
Richard Williamson
Beverly A. Wilson
Jay Winzenried
Nancy M. Anderson Wires
Brodie Wood
Joseph D. Zuckerman

National Research Grants
Department of Orthopaedics

National Institutes of Health (NIH)

Collagens of Cartilage and the Intervertebral Disk
David R. Eyre, Ph.D.

Imaging of Molecules by Oscillator-Coupled Resonance
John A. Sidles, Ph.D.

Regulation of Gene Expression in Cartilage
Linda J. Sandell, Ph.D.

Pathology of Inborn Skeletal Diseases
David R. Eyre, Ph.D.

Skeletal Dysplasias
David R. Eyre, Ph.D.

Salvage vs. Amputation Following Limb Threatening Injury
Marc F. Swiontkowski, M.D.

Veterans Affairs Medical Center Review Grants

Rehabilitation Research and Development Center for Prosthetics and Amputation
Bruce J. Sangeorzan, M.D.

Biomechanics of Foot Deformities and Alternatives for Surgical Correction
Bruce J. Sangeorzan, M.D.

Synthesis and Function of Cartilage Matrix Molecules
Linda J. Sandell, Ph.D.

Centers for Disease Control

Low Speed Cervical Whiplash Injury
Allan F. Tencer, Ph.D.

Orthopaedic Research and Education Foundation (OREF)

Bristol-Myers Squibb/Zimmer Institutional Grant
Frederick A. Matsen III, M.D.

Randomized Multicentered Clinical Trial of Distal Radius Fracture Treatment
Doug P. Hanel, M.D.

National Research Grants
Department of Orthopaedics

Orthopaedic Research and Education Foundation (OREF)

Predictable Spine and Occupational Health Data
Stanley J. Bigos, M.D.

The Shoulder Function and Health Status of Individuals with Documented Rotator Cuff Tears Before and After Treatment: A Multicentered Prospective Study
Douglas T. Harryman II, M.D.

A Prospective Field Trial to Assess the Reliability, Validity, and Responsiveness of the Short Form Musculoskeletal Function Assessment Instrument (SMFA)
Marc F. Swiontkowski, M.D.