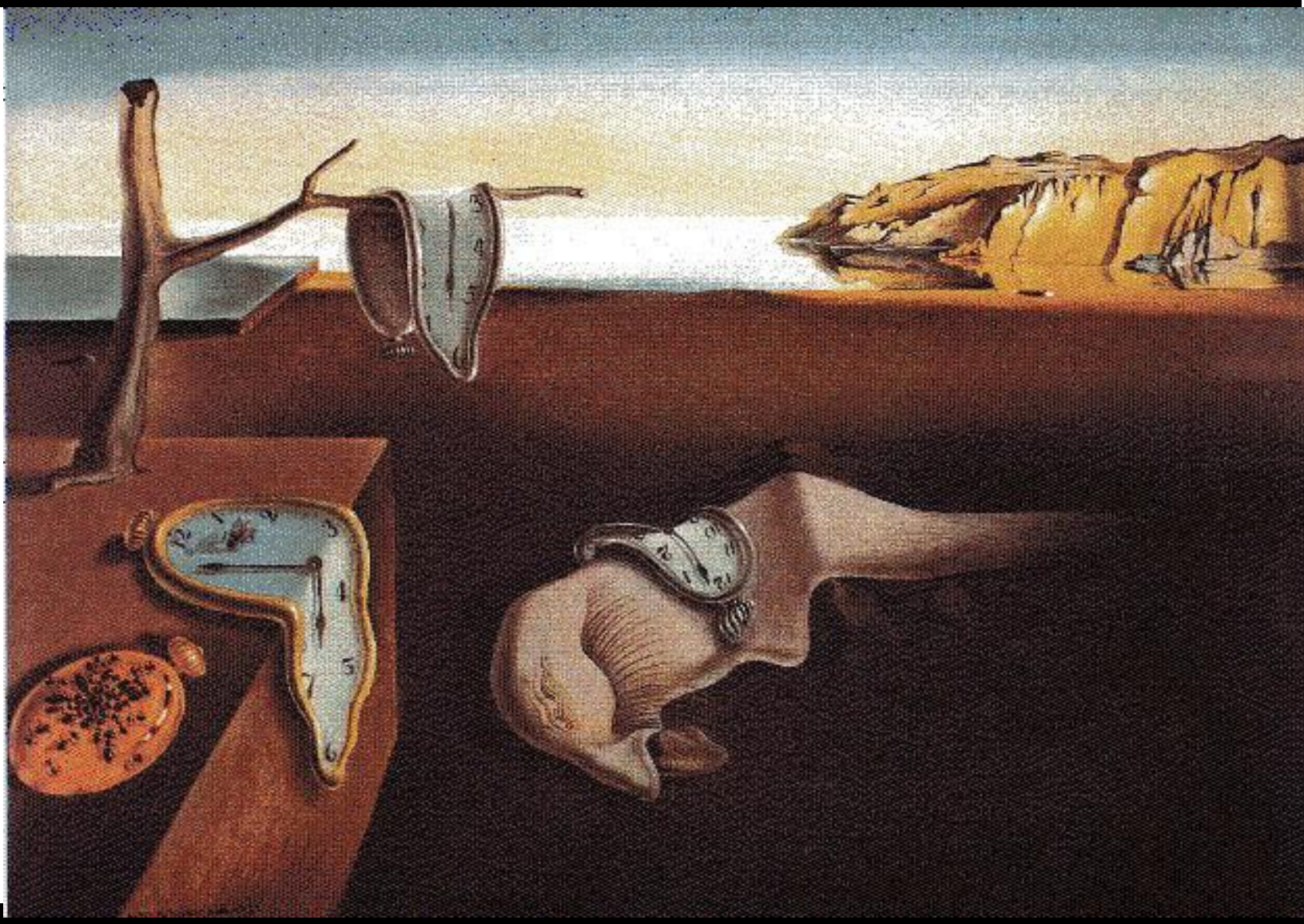
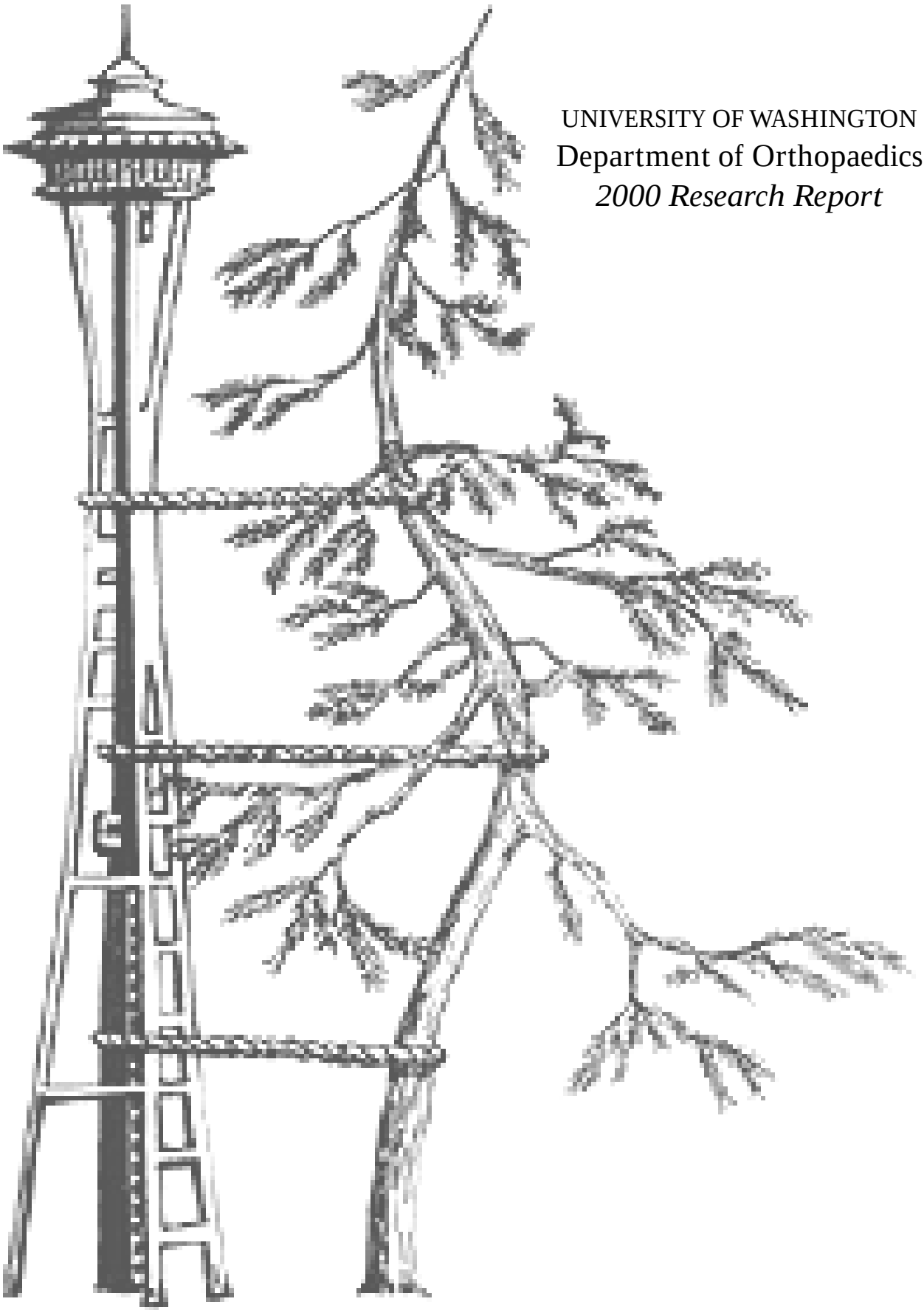
UNIVERSITY OF WASHINGTON

Department of Orthopaedics

2000 Research Report





UNIVERSITY OF WASHINGTON

Department of Orthopaedics

2000 Research Report

UNIVERSITY OF WASHINGTON SCHOOL OF MEDICINE

Department of Orthopaedics
University of Washington
Seattle, WA 98195

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Cover Illustration: "The Persistence of Memory"
by Salvador Dali, 1930
Collection of The Museum of Modern Art, New York

Contents

Foreword

Our cover this year features "The Persistence of Memory" painted by Salvador Dali in 1930. Although Dali said that he got the idea for the limp clocks from watching ripe Camembert slowly deform over the edge of a plate, those of us in Orthopaedics recognize that this picture is a metaphor for what happens to form when the supporting skeleton is lacking. The industrious Orthopaedic worker ants in the lower left corner have figured out a way to restore the structure to a pocket watch, however there is a huge amount of work ahead - as suggested by the three big clocks and the bone-deprived horse-form lying like a jellyfish washed up on the beach. The tree-splint at the left is holding up one clock, but hardly in its 'anatomic' form. The empty OR table at far left suggests the limitations of our current methods. However, the future in the upper right is bright and promising - a future illuminated by Orthopaedic research.

The illustrations on this page each demonstrate a substantial Orthopaedic advance in providing security to the skeletal framework. The upper figure shows the fixation of an unstable cervical spine with an anterior plate and fusion avoiding the need for prolonged neck bracing. The lower figure shows the fixation of a femoral fracture with an interlocking intramedullary nail avoiding the need for long periods of traction and casting. Both are ways that the support function of the skeleton is immediately restored by surgery. Each of these advances has taken place since I completed my Orthopaedic residency; each was pioneered in substantial part by faculty in our Department.

In this Report 2000, we present a broad panorama of the research taking place in our Department, research largely directed at understanding and treating failures of the musculoskeletal system to provide the necessary support. The first two articles demonstrate the use of biological markers developed in our Department to track failure of cartilage in arthritis and in malignant degeneration. The article on metachondromatosis provides example of uncontrolled cartilage growth.

One of the most common failures of the skeletal system is through fracture. The article on motor vehicle crashes demonstrates that contraction of our own muscles can add to the loads from a car crash to produce a force sufficient to break the femur. The next six articles describe the risks associated with major injuries along with some of the advanced methods developed by our faculty for restoring the integrity of the skeletal system following severe injuries. Innovations in the management of thumb arthritis and contractures of the foot demonstrate some of our new approaches to problems located in the joints.

Sports Medicine is a rapidly growing area of Departmental interest. We have enclosed articles representing the breadth of this field - from exercise induced asthma to shoulder stability. The articles conclude with reminders of two factors that can limit the effectiveness of our surgical methods: postoperative inflammation and the limited durability of artificial joint surfaces.

We have a terrific opportunity to make progress in the restoration of skeletal form and function - attacking those limp Dalian forms that remain. One of our major resources are the residents who come to the University of Washington for cutting-edge training in Orthopaedics and another is the faculty who dedicate their lives to excellence in teaching, to research and to the care of individuals with musculoskeletal problems. We dedicate a section of this report to our residents and to our new faculty.

The ability to carry out research depends on funding. We are proud of the level of grant support for our research initiatives, but even more proud of the many individuals who have contributed much needed resources to create a community of Orthopaedic science - a multidisciplinary collaborative that continually innovate new, effective ways to help our patients.

Thanks to all who contribute to the missions of the Department of Orthopaedics.

Stability of the neck restored by anterior plating and fusion.

Stability of the femur restored by a locked intramedullary nail. Rigid fixation is key.

Best wishes,

F. A. Matsen III

Frederick A. Matsen III, M.D.
Chairman

Peter T. Simonian, M.D.
Chief, Sports Medicine Clinic

In Loving Memory of Our Partner and Friend, Douglas T. Harryman II

1953 - 1999

A Collagen II Degradation Marker (CTx) is Generated by Collagenase 3 and in Urine Reflects Disease Burden in Knee Osteoarthritis Patients

LYNNE M. ATLEY, PH.D., LEENA SHARMA, PH.D., J. DANIEL CLEMENS, M.S., KATHY SHAFFER, B.S., TERRI PIETKA, B.S., JEANETTE RIGGINS, B.S., AND DAVID R. EYRE, PH.D.

Matrix metalloproteinases (MMP) are a family of proteases that have been implicated in the proteolytic degradation of cartilage collagen in osteoarthritis (OA). We have developed a monoclonal antibody, 2B4, that recognizes MMP-generated cross-linked C-telopeptide fragments of type II collagen in the joint fluid, serum or urine of OA patients and in animal models of the disease. In this study, we used Western blot analysis to demonstrate collagenase 3 (MMP-13) cleavage of type II collagen and generation of the 2B4 neopitope in vitro.

We also measured 2B4 epitope (col2CTx) by ELISA in the urine of healthy adults and patients with OA to determine if levels differ according to disease subset. Primary generalized OA is a subset of OA involving multiple joints, typically defined by the combined presence of hand and large joint OA. We tested the hypothesis that urine col2CTx levels would be higher in those with evidence of generalized OA than in patients with OA at a single large-joint site.

METHODS

Human articular cartilage was solubilized with pepsin and the type II collagen was precipitated in 0.7M NaCl. An aliquot was digested at 25∞C with recombinant human collagenase 3. Peptides from the digest were resolved by 8% SDS-PAGE, transblotted onto PVDF membrane and screened for mAb 2B4 immunoreactivity (Western blot).

Urine from 26 healthy adults and 50 patients with OA was assayed for col2CTx using a competition ELISA. Patients were grouped as knee OA only or generalized OA first using a common definition (knee OA + Heberden's nodes in > 2 digits in at least one hand), and second using a stricter definition to maximize the likelihood of a pure polyarticular OA group (knee OA + nodes in 5-10 hand digits). Ranked data were analyzed by ANOVA and pairwise multiple comparisons by Dunn's Method.

RESULTS

Collagenase 3 cleaved pepsin-soluble type II collagen yielding the well-characterized 1/4 and 3/4 fragments (Fig. 1A). On the Western blot, 2B4 immunoreactivity was associated with the a1(II) and a1(II) 3/4 chains due to collagenase 3 cleavage of the attached C-telopeptide domains (Fig. 1B). There was no signal from the a1(II) 1/4 peptide or the undigested collagen. Fig. 1C shows the collagenase 3 cleavage sites that generated the 1/4 and 3/4 fragments (helical domain) and the 2B4 neoepitope (C-telopeptide domain).

The mean age of the OA patients was 67 years (± 9, SD, range 45-84). There were 12 men and 38 women. Urinary col2CTx levels were higher in OA patients than controls (42.2 ± 15.2 vs. 30.0 ± 10.4 ng/mg Cr, mean + SD, $p<0.001$), and were higher in those with generalized OA than in those with knee OA alone ($p< 0.05$). Among those with OA, the lowest levels of col2CTx (36.6 ± 8.8 ng/mg Cr) were found in the 23 patients with knee OA alone and the highest levels of col2CTx (51.9 ± 20.7

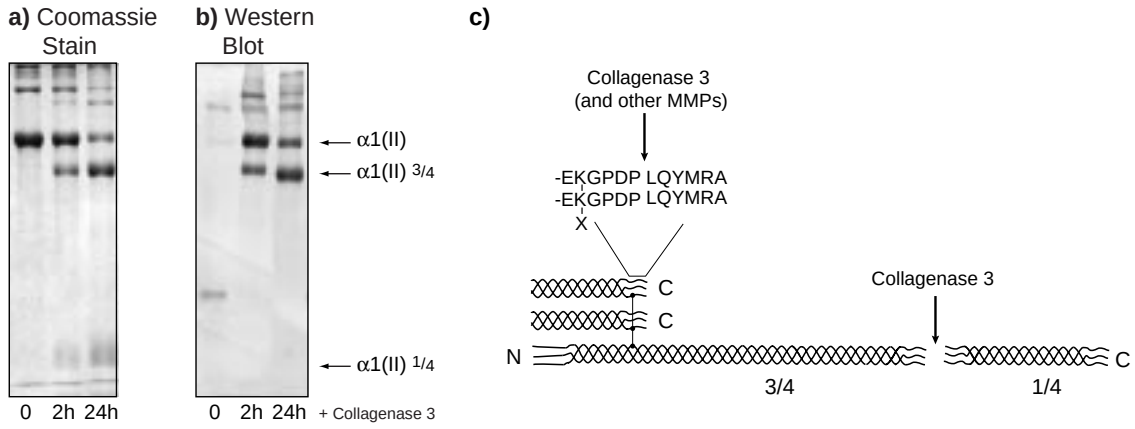

Figure 1: Cleavage of pepsin-soluble type II collagen by collagenase 3 at 25∞C. A: Coomassie-stained gel B: Western blot using mAb 2B4 C: Diagram of the collagenase 3 cleavage sites that generated the 1/4 and 3/4 fragments and the 2B4 epitope.

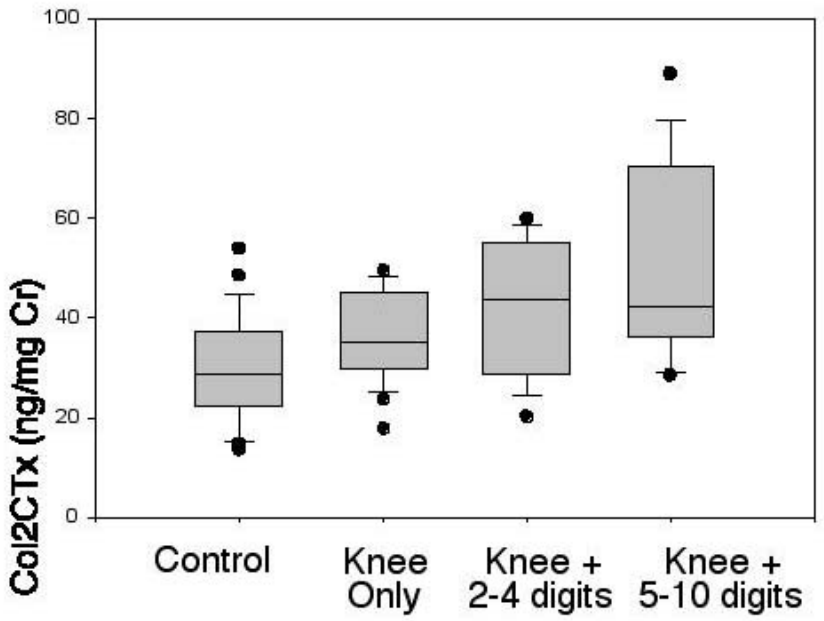

Figure 2: Urinary col2CTx for controls and OA patients. Two values (274 and 148 ng/mg Cr from the 2nd and 4th groups, respectively) were considered high outliers and omitted from the statistical analysis.

ng/mg Cr) were detected in the 13 subjects who fulfilled the stricter definition of generalized OA (knee OA + 5-10 hand digits; Fig. 2). Intermediate levels were found in the 12 subjects with OA in the knee + 2-4 hand digits. These results suggest that urine col2CTx levels may reflect total tissue burden of disease.

Discussion

Collagenase 3, as well as other MMPs (stromelysin and matrilysin) cleave a peptide bond in the C-telopeptide domain of a1(II), generating the 2B4 neoepitope (col2CTx). Monoclonal antibody 2B4 recognizes col2CTx whether as large chain fragments as might be found in cartilage, joint fluids and serum or as small peptides found in urine. This antibody is proving a useful tool for examining MMP-mediated collagen degradation at the molecular level in vitro and by histochemistry in the tissue. The results from healthy and OA subjects suggest that the usefulness of the urinary col2CTx immunoassay may extend beyond identifying those with OA in general to identifying those with a polyarticular subset of disease.

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Atley et al., Trans Orthop Res Soc 1998:23:850

Expression of a Cartilage-Derived Retinoic Acid Sensitive Protein (CD-RAP) by Chondroid Tumors

HOWARD A. CHANSKY, M.D., ANDREW HOWLETT, M.D., ANJA BOSSERHOFF, M.D.,
ERNEST U. CONRAD, M.D., REINHARD BUETTNER, AND LINDA J. SANDELL, PH.D.

Cartilage-derived retinoic acid sensitive protein (CD-RAP) is a secreted protein synthesized under normal conditions by chondrocytes. In cultured articular chondrocytes, expression of CD-RAP is inhibited by retinoic acid in a manner that parallels the inhibition of expression of type II collagen. In embryonic tissue, CD-RAP mRNA is synthesized primarily by cartilage primordia and differentiated cartilage. High levels of MIA have been found in nearly 100 percent of human melanoma specimens from patients with stage III or IV disease, and levels of MIA mRNA are correlated with the degree of malignancy of melanocytic tumors. A sensitive, nonradioactive enzyme-linked immunosorbent assay (ELISA) was recently developed to quantitate MIA protein levels in serum from patients with melanoma.

Attempts to devise histological or biochemical criteria for the classification of benign and malignant cartilage tumors have met with limited success. It remains difficult to distinguish with certainty the different grades of malignancy, or even benign from low- grade malignant lesions. CD-RAP has been previously identified in rat chondrosarcoma and in a human chondrosdarcoma cell line, Ch-1. The goal of this study was to quantitatively assess expression of CD-RAP by chondroid tumors of varying grades. We were also interested in establishing the specificity of CD-RAP expression by chondroid tumors and in the relationship between levels of expression and pathologic grade.

MATERIALS AND METHODS

Thirty-six archived frozen (-700 C) tumors were chosen for analysis. Diagnoses had been previously made based upon clinical, radiographic and histologic criteria. For the chondrosarcomas there were fourteen grade I tumors, ten grade II tumors, one grade III tumor and two grade IV tumors. There were five enchondromas ("grade 0"), five classic osteosarcomas and one chondroblastic osteosarcoma. The specimens were labelled in such a fashion that the investigators performing the extraction and assay were unaware of the diagnosis and grade.

Quantification of CD-RAP: Cores were removed from three different areas of each tumor using a trephine. Extraction of CD-RAP was performed using a technique described by Ayad et al, 1989. The extracts were concentrated by dialysis on an Amicon PM10 membrane and stored at 40 C. The resultant extract was quantified using ELISA with an anti-human CD-RAP antibody (Boehringer-Mannheim, Penzburg, Germany). This one-step ELISA for CD-RAP has been previously validated. To ensure complete extraction, several samples initially underwent a second round of denaturation and extraction by placing the remaining pellet in an additional 750 µl of guanidinium and then repeating the dialysis. This did not result in siginificant levels of additional, detectable levels of CD-RAP and subsequent extractions consisted of one stage. The CD-RAP levels from each of the three cores from each tumor were normalized with respect to the weight of the sample and then averaged.

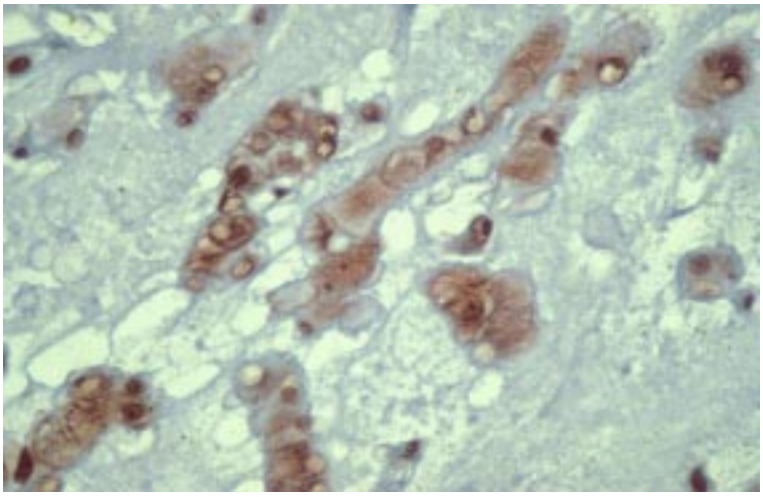

Figure 1: Immunochemistry. High power photomicrograph of a grade II chondrosarcoma stained with an antibody to CD-RAP. The reddish brown areas are chondrosarcoma cells that have synthesized CD-RAP that has reacted with anit-CD-RAP antibody. The intensity of staining is related to the levels of CD-RAP present in the cell. The pale green areas are pericellular matrix.

RESULTS

CD-RAP expression was detected in all grades of chondroid tumors except for the two dedifferentiated (grade IV) chondrosarcomas. Four of five enchondromas, 13 of 14 grade I chondrosarcomas, 9 of 10 grade II, and 1 of 1 grade III chondrosarcoma expressed detectable levels of CD-RAP.

Enchondromas and grades I, II, and III chondrosarcomas expressed an average of 2.8, 6.0, 3.4, and 8.0 ng/ml/mg, respectively. Neither of the two dedifferentiated chondrosarcomas (0.43 ng/ml/mg) produced significant levels of CD-RAP. Of the six osteosarcomas, only supernatant from the chondroblastic variant (7.4 ng/ml/mg) contained detectable levels of CD-RAP.

Discussion

The results of this study confirm that CD-RAP is expressed by varying grades of cartilage tumors but not by classic osteosarcoma. This finding is consistent with CD-RAP expression being limited to developing and mature cartilage in normal embryonic tissue. We identified interesting trends but there was not a statistically significant correlation between chondrosarcoma grade and level of CD-RAP. Chondrosarcomas can be heterogenous tumors composed of varying amounts of acellular matrix and nests of tumor cells. In general, cellularity increases as tumor grade increases but spontaneous necrosis of high-grade tumors or atypical cellularity of low-grade tumors, especially those located in the periphery of the skeleton, complicate this relationship. Our values of CD-RAP have been normalized to the weight of the tissue analyzed but we have not made any formal measurement of cell density. In addition, we grossly inspected the tumors for regions of homogenous appearance but there are certainly heterogeneities on a finer scale. Measurement of serum levels or immunochemistry of mounted slides to evaluate CD-RAP synthesis by individual cells may obviate these potential problems with our assay.

Local and circulating tumor markers have increasing importance in the management of carcinomas but there is a relative dearth of similar markers for tumors of the musculoskeletal system. Circulating levels of markers such as prostate specific antigen are widely used as diagnostic screening tests, to monitor for progression or recurrence of disease, and also to follow the response of a cancer to surgery or chemotherapy. CD-RAP is a small (11 kilodaltons), secreted protein and thus may have potential as circulating marker of carcinogenesis.

Recently, quantitation of serum CD-RAP/MIA has been shown to be a very sensitive and specific marker of malignant melanoma. In addition to being predictive of the existence of metastatic disease, there was a correlation between circulating levels of MIA and the clinical response of the melanoma to chemotherapy. The first stage of establishing the utility of a new tumor marker is to determine tissue levels of the marker within the tumor of interest and in similar or related tumors. CD-RAP appears to a relatively specific marker of chondroid-containing tumors and may help to differentiate various histologically similar sarcomas. Of potential diagnostic interest is the fact that CD-RAP expression was negligible in the single chondroblastic osteogenic sarcoma (OGS) studied. Chondroblastic OGS is often difficult to distinguish from its more common variant, classic OGS, and is thought to have a worse prognosis. CD-RAP may be useful to distinguish between these variants but more specimens will need to be evaluated. Additional specimens and patients will be needed to assess the utuilty of CD-RAP as a circulating marker of chondrosarcoma and whether such levels can be used as surrogate markers for response to treatment and recurrence of disease.

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Metachondromatosis

MOHAMMAD DIAB, M.D.

Metachondromatosis (Mch) is characterized by multiple chondral lesions and exostoses associated with periarticular mineralization. We differentiate this dysplasia clinically from hereditary multiple exostosis (HME). We also exclude linkage of Mch to the genetic loci for HME, including EXT1 (chromosome 8q24.1), EXT2 (chromosome 11p13), EXT3 (chromosome 19q), and EXTL, an EXT-like gene with significant sequence homology but with no known function.

METHODS

Eleven affected members of two families were identified. Two girls and one boy underwent operation. Average age at diagnosis was 1+5 yr. (8 mo.-2+9 yr.). Average age at first operation was 3+4 yr. (16 mo.-5+1 yr.). Average surgical follow-up was 5+6 yr. (21 mo.-12+4 yr.). Linkage studies were performed on 7 affected and 10 unaffected members of one of the two families. We used the following markers: D8S527, D8S547 and D8S592 (within a 3cM region surrounding EXT1); D11S903 (within 1cM of EXT2) and flanking markers D11S905 and D11S4151; D19S221 (shown to be linked to EXT3) and flanking marker D19S406; and D1S234 (within a 3.5 cM region linked to EXL).

RESULTS

Inheritance was autosomal dominant with incomplete penetrance. Stature and intelligence were normal. There was no malignant transformation. All patients underwent excision of lesions from the hands. A lesion of the right fourth toe proximal phalanx producing curly toe and interferring with shoe wear spontaneously regressed. A lesion was excised from the posterolateral soft tissues of the left knee for peroneal neurapraxia. Osteonecrosis of the right femoral capital epiphysis was treated by slotted acetabular augmentation. Excision of a lesion from the metaphysis of the left distal tibia was complicated by recurrence. At repeat operation, the physis was crossed and the epiphyseal component was excised. There was no disturbance of growth, and no recurrence. Histological analysis presented a mixed picture of exostoses and foci of endochondral ossification. There was no linkage to the markers for the EXT1, EXT2 and EXT3 loci, or to the homologous EXTL locus.

DISCUSSION

Enlarging lesions are painful, interfere with clothes wear, limit joint range of motion, and may produce pressure neuropathy. Involvement of the hands is a hallmark. Involvement of the capital femoral epiphysis may present as Legg-Calvé-Perthes disease, and treatment should follow the same principles. The disorder differs clinically from HME, in which lesions point away from adjacent joints, there are no enchondromata, and there is the potential for malignant transformation. In Mch, exostoses are directed toward adjacent joints, there is less deformation, spontaneous regression is possible and there is no malignant potential. While previous reports have pointed to their metaphyseal nature, the exostoses in Mch may cross the growth plate to involve the epiphysis. This dictates traversal of the growth plate at operation, and emphasizes the importance of in toto excision to prevent recurrence. Exclusion of the known loci for HME suggests that Mch and HME are not due to mutations in the same gene. The genetic data support the clinical observation that Mch is a distinct entity from HME.

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The Role of Internal Muscle Loading on Fracture of the Femur in Frontal Motor Vehicle Crashes

ALLAN F. TENCER, PH.D., ROBERT KAUFMAN, KATHY RYAN, DAVID GROSSMAN, M. BRAD HENLEY, M.D., FRED MANN, CHARLES MOCK, FRED RIVARA, STEWART WANG, JEFFERY AUGENSTEIN, DAVID HOYT, AND BRENT EASTMAN

Fractures about the femur due to motor vehicle impacts can result in extensive medical care, and if they include an intra-articular component, may result in permanent disability. Extensive biomechanical testing has shown that the approximate range of axial compressive fracture load for cadaveric femurs is 7500 N- 15000 N, with an accepted threshold load of 8900N (16% probability of fracture). In an ongoing study of motor vehicle crashes we have noticed that a significant proportion of relatively low deceleration frontal crashes resulted in isolated fracture of the occupant's femur, at loads below those expected to cause fracture. The mechanism in each case, based on appearance of the fracture (a transverse fracture line indicating failure by bending combined with comminution indicating compression), was axial compressive loading by impact with the dashboard.

The goal of the study was to explain why these fractures occurred, considering that the estimated loads on the femurs of the occupants in the crashes studied were below those considered to result in femur fracture. The results may have implications in the design of interior surfaces of motor vehicles to help prevent these fractures.

METHODS

The motor vehicle crash information included in this study was collected from CIREN (Crash Injury Research and Engineering Network, National Highway Transportation Safety Administration) Centers. Each crash site had scaled documentation of the roadway, traffic controls, road surface type, conditions, and road grade at both pre- and post- impact locations. Physical evidence such as tire skid marks were located and referenced to establish the heading angle and post impact trajectory of the colliding vehicles. Exterior inspections of the vehicle were performed, which included detailed measurements of the direct and induced damage, an example of which is shown in Figure 1. These measurements were entered into crash analysis software (Win SMASH, U.S. Dept of Transportation) to calculate the change in velocity of the vehicle during impact and the energy dissipated during the crash event. An inspection of the interior of the vehicle from which the injured person had been removed was performed to determine points of contact Figure 2, and restraint system use. A complete medical history, including review of radiographs, Figure 3, was performed after which the bio-mechanical mechanism was determined.

To estimate the femur force in the collisions studied, We used data from the New Car Assessment Program (NCAP, National Highway Traffic Safety Administration, US Dept of Transportation) testing in 35 mph frontal collisions with 2 front seat fully restrained instrumented anthropometric dummies. A set of data was retrieved for each of the specific vehicles of our collision sample, including change of velocity of the vehicle at impact, crush deformation of the vehicle, average deceleration during impact, and load on the femurs, lap belt, and shoulder belt. Based on this experimental data, the femur force acting on the occupants in our crash studies was estimated, considering the effects of (i) single femur contact, (ii) partial or total restraint system use, (iii) weight of the occupant, and (iv) estimated peak deceleration of the vehicle in the crash studied. For example, for the case of a lap and shoulder belt restrained occupant with single femur contact, $F = 388 * (Wo/Wd) * a$, where F = predicted force on the occupant's femur, 338 = constant relating femur force to NCAP crash test acceleration and dummy weight, (Wo/Wd) = correction for weight of occupant to weight of standard crash dummy, a = peak acceleration in crash studied.

Figure 1: Vehicle in which the driver sustained the femur fracture of Figure 3 through contact with the dashboard, shown in Figure 2. This was a direct frontal collision with a speed change about 25 mph. The dashboard and interior surfaces remained intact and were not pushed towards the driver's legs.

RESULTS

A total of 20 crashes were studied. The principal direction of force on the vehicle ranged from +20 deg to -10 deg, with 11 crashes having an estimated direction of 0 deg (directly frontal).

Figure 2: View of dashboard from underside, center console is to the right, looking upwards from underneath dashboard. Arrow and tape on dashboard indicate major area of contact of the occupant's knee (scuff marks and indentations) for the right femur of the driver that was fractured.

Figure 3: Midshaft femur fracture due to axial compression from loading the right knee against dashboard during deceleration of the occupant in the crash shown in Figure1.

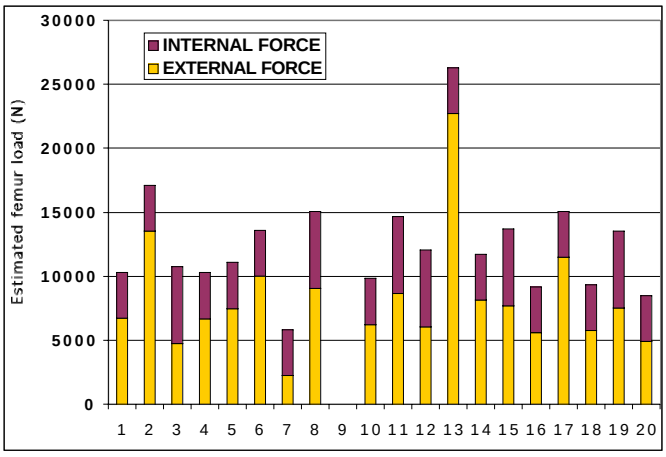

Figure 4: Comparison of the estimated loads acting on the femur of an occupant in the crashes studied due to contact with the dashboard (light bar) with estimated superimposed internal compression caused by contraction of muscles about the knee during braking and bracing for the crash.

The average vehicle speed change during the collisions was 25.3 mph (40.7 kph), with an average deceleration of 13.7g. The victims consisted of 13 females with an average age of 36 years and 7 males, with an average age of 26.7 years. Eighteen of the 20 occupants were drivers and of these, 13 fractured their right femur. The contact of the femurs with the knee bolster systems and the lower instrument panels consisted of only scuffs, small cracks or dents, with minimal observable deformation, although elastic rebound of the padding could have occurred. All occupants sustained at least a midshaft femur fracture, with 5 having additional supracondylar or femoral neck involvement. The mean estimate of the femur load was 8187 N (sd = 4343 N) for the sample, which is below the commonly accepted threshold of 8900N for axial compressive fracture load for the femur, Figure 4. Of the sample, 13 had a probability of fracture less than 10% based on the NHTSA fracture probability curve.

DISCUSSION

Since the great majority of occupants studied were not exposed to sufficient force to create a femur fracture, and yet the femur fractures were characteristic of those due to axial compressive impact, other axial forces must have been present.

Muscle loading, which must occur in living humans, is not accounted for in estimating the compressive loads acting on the occupants' femurs in crash tests. In a frontal crash when the driver forcefully presses on the brake and braces for the impact, the leg muscles (quadriceps and hamstrings) are tensed. Quasistatic measurements of maximum voluntary flexor and extensor muscle torques, show that a mean extensor muscle torque around the knee for 26 year old males (the average age of the male subjects in our study) is 273 Nm. With an approximate moment arm of 5 cm, this results in a compressive force of 5383N acting along the axis of the femur. For 36 year old females (the average age in our study for the female subjects), the extensor force is about 3356N. The knee flexors produce about 3002N for males and 1801N for females.

It is impossible to determine specifically the extent of muscle contraction that the occupants of the vehicles in the crashes that we studied actually exerted, but it is entirely reasonable to assume that forceful braking and anticipatory bracing for the impact produced considerable contraction of the knee flexor and extensor muscles. This appears to be the most reasonable explanation for the discrepancy between the mechanism of the femur fracture, axial loading, and the relatively low load predicted. For comparison, the predicted loads, without and with the contributions of muscles (taken as the force generated by the knee flexors and an equal load from the extensors at maximum contraction), are shown in Figure 4.

This observation, if correct, has

significant implications for the redesign of dashboards and knee bolsters to reduce femur fractures. Knee bolsters are actually designed to transfer load to the femurs, relieving load on the occupant's chest during deceleration. If internal muscle loads add considerably to the external loads experienced by the occupant's femur in the crash, then the dashboard or knee bolster, if designed for an external load criterion of 8900N, and tested using dummy femurs, may be to stiff to prevent femur injury in crashes involving human occupants in frontal crashes to 35 mph.

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Severe Heterotopic Ossification After Knee Dislocation: The Predictive Value of the Injury Severity Score

WILLIAM J. MILLS, M.D. AND NIRMAL TEJWANI, M.D.

Knee dislocation is a relatively rare injury, and is generally the result of high energy trauma. As a result it is frequently associated with other injuries, including closed head injury, thoracic and abdominal trauma, and additional Orthopaedic injuries. Complications are common, and include popliteal artery disruption or occlusion, peroneal nerve injury, compartmental syndrome, arthrofibrosis, chronic pain and early degenerative arthritis. Multiple ligament reconstruction is generally felt to be the optimal treatment for this injury, to allow early stable knee range of motion.

One complication of knee dislocation that receives little attention is heterotopic ossification (HO). This has been reported about the knee, elbow and other joints in patients with closed head injury but has been alluded to only rarely after knee dislocation, and no literature exists relating HO after knee dislocation to the severity of overall injury or concurrent head injury. The formation of significant amounts of heterotopic bone around the knee can produce severe stiffness, or even ankylosis, nullifying the effects of a complex, early multi-ligament reconstruction. Some means of identifying or recognizing those patients at risk for this complication would prove useful in management of this already complicated injury.

In the past year a relationship between Injury Severity Score (ISS) and development of significant peri-articular HO has been recognized. The Injury Severity Score is a system initially designed to predict patient mortality after injury. However, its value in predicting degree of disability has been demonstrated as well.

MATERIALS AND METHODS

All patients with knee dislocation admitted to Harborview Medical Center over a 12 month period were enrolled in a treatment protocol that included examination under anesthesia, plain radiographic and Magnetic Resonance Imaging (MRI) evaluation, multiple ligament reconstruction as soon as the soft tissue envelope safely allowed, post-operative physical therapy emphasizing early range of motion, and protected weight bearing. Injury Severity and Glascow Coma Scores were calculated at the time of admission, and all additional injuries documented at initial presentation and secondary patient examination. Fractures about the knee and ipsilateral lower extremity, as well as additional local soft tissue injuries were carefully documented. Following ligament reconstruction, patients were enrolled in an inpatient physical therapy program; this included an active and passive motion plan. Following hospital discharge they were evaluated at six, twelve and twenty-four weeks and one year for range of motion and stability. The presence of heterotopic bone formation was usually evident within three to six weeks of reconstruction by physical examination findings of gross soft tissue distortion, and marked range of motion limitations.

Twenty-five (25) patients with twenty-six (26) knee dislocations were admitted in this 12 month period. All were the result of high energy trauma:

Figure 1: Classic pattern of medial knee heterotopic ossification in a patient without knee trauma but severe closed head injury.

nine motor vehicle or motorcycle accidents, 10 automobile-pedestrians accidents, 5 falls greater than three stories, and one crush injury after a wall collapse. Six were isolated injuries, while two were open. Four patients had complete peroneal nerve palsy, and six had vascular injury requiring repair. Admission Injury Severity Scores ranged from 9 to 50; Glascow coma scores from 3T (intubated and pharmacologically paralyzed in the Emergency Department) to 15 (no neurological deficit).

Twenty-two (22) patients had open reconstruction of multiple knee ligaments within three weeks of injury; three had arthroscopically assisted reconstruction between 4 and 12 weeks after injury. Local injuries frequently delaying or complicating ligament reconstruction included patellar tendon ruptures, tibial plateau fractures, concurrent patellar dislocations, and soft tissue degloving injuries.

Results

Five of twenty-five patients (20 %) formed significant heterotopic bone about the involved knee. Significant HO was not difficult to define in this setting: in all five cases frank ankylosis of the knee occurred. These five patients had a consistent pattern of HO formation that included predominantly posterior and medial bridging bone, with lesser amounts of lateral HO (Figure 1). This differs from the HO reported to occur in head injured patients without knee trauma, which fairly uniformly involved only the medial aspect of the distal femur, medial collateral ligament and occasionally proximal tibia. Ankylosis is not commonly reported in these patients. Figure 2 demonstrates the radiographic findings in a head injured patient without knee trauma treated at Harborview.

Figure 2: Post-traumatic medial, lateral and posterior heterotopic ossification in a patient with knee dislocation and ISS of 50.

The injury severity scores for the five patients who formed significant HO ranged from 26 to 50 (see table 1). ISS's for the remaining twenty patients ranged from 4 to 26. While no patient who had delayed reconstruction formed HO, their Injury Severity Scores were all less than twenty (9, 17, 18). The HO group had GCS scores ranging from 3T to 15, while all but one of those not forming HO (19 of 20) had a GCS of 15; the remaining patient had a GCS of 12 at admission. The patient in the HO group with an ISS of 26 had a GCS of 9T, and a significant closed head injury, bifrontal contusion and a dural tear; the patient in the HO spared group with an ISS of 26 had a GCS of 15, and a normal head CT.

When significant HO did form in these five patients, it was evident clinically by marked loss of passive knee motion within three weeks of surgery, and radiographically within six weeks of surgery. HO progression was relentless in all five patients, and no means of therapy influenced this progression.

Discussion

An ISS of 26 appears to be a fairly distinct tidemark for determining the patient at risk for HO formation after knee dislocation. The sensitivity of an ISS of ≥ 26 is 100%, the specificity 95% and the positive predictive value 83 %. While this is a relatively small number of patients, it appears that an ISS of 26 represents a fairly well established line above which significant HO formation may be unavoidable, and below which it is very unlikely.

Conversely, while head injury appears to play a role in the formation of HO in these patients as evidenced by the variety of GCS scores in the HO group and the nearly uniform GCS scores of 15 in the HO spared group, the predictive value of the GCS is not as discrete as the ISS. This difference is illustrated best by our fourth patient (#4, Table 1) with a GCS of 15, who formed HO requiring surgical excision. However, in those patients with an ISS on the border (25-27), a GCS of other than 15 may imply significant risk of

Table 1.
Patients with Significant Heterotopic Ossification after Knee Dislocation

Patient	ISS	GCS	Ligaments injured *
1	34	3T	ACL, PCL, MCL, LCL, PLC
2	27	13	ACL, PCL, MCL
3	26	9T	ACL, PCL, LCL, PLC
4	34	15	ACL, PCL, MCL, LCL, PLC
5	50	3T	ACL, PCL, MCL, LCL, PLC

ACL = Anterior Cruciate Ligament
PCL = Posterior Cruciate Ligament
MCL = Medial Collateral Ligament
LCL = Lateral Collateral Ligament
PLC = Posterolateral Corner

HO, while a GCS of 15 may suggest HO sparing. Fortunately, both of these scores are available early in the patient's hospitalization.

These findings have changed our practice management. While knee dislocations are generally treated with open reconstruction as soon as local soft tissue status allows, those multiply injured patients with ISS > 26 are treated with initial immobilization for soft tissue protection, then passive motion if co-existing injuries such as plateau fracture or patellar dislocation are not present. Delayed reconstruction is then planned greater than six weeks from injury, a period after which it is generally apparent whether or not HO will form. Currently radiation therapy (XRT) or other means of HO prevention have not been employed in this group. If future patients with ISS's >26 continue to form HO despite delayed surgical treatment, then a study of the effects of XRT will be useful. While ankylosing HO can be excised, it is a procedure requiring extensive dissection, places the popliteal vessels and tibial and peroneal nerves at risk, can be associated with significant blood loss and increased infection rates. Finally, ultimate range of motion gains are difficult to predict following this procedure. Recognizing the high likelihood of HO formation in these multiply injured patients, especially those with concomitant head injury, allows not only alteration in management of this severe injury, but critical patient education as well.

Morbidity and Mortality After Reamed Intramedullary Nailing of Bilateral Femur Fractures

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Overall, mortality rates associated with isolated, unilateral fractures of the femur are low. Statically locked, intramedullary nailing is currently the recommended treatment for most if not all fractures of the shaft of the femur in adult patients. Early operative treatment of lower extremity long bone fractures is associated with a decrease in patient morbidity and mortality. The effects of reaming on patient survival and morbidity has not been clearly defined despite numerous reports. Bilateral femur fractures, known to have worse overall prognosis compared to a unilateral femur fracture, have been recently associated with a higher mortality rate and a higher risk of adult respiratory distress syndrome. The outcome of stabilization of these bilateral injuries with reamed intramedullary nailing has not been previously investigated.

The Injury Severity Score (ISS) is widely used to predict the morbidity and mortality of polytraumatized patients. One limitation of the ISS is the lack of contribution of multiple injuries within a subcategory (Abbreviated Injury Score, AIS) to the determination of the overall ISS. Bilateral femur fractures, therefore, have no additional contribution to the ISS than a unilateral femur.

The questions this study addresses include:

1. Do patients with bilateral femoral shaft fractures represent a more severely traumatized group than patients with unilateral femur fractures?

2. Do patients with bilateral femoral shaft fractures treated with reamed intramedullary nailing have an increased mortality and longer hospital stay than blunt trauma patients of similar age and ISS with unilateral femur fractures?

3. Does the ISS accurately predict mortality in patients with bilateral femoral fractures due to blunt trauma?

MATERIALS AND METHODS

During a 105 months period between April, 1989 and December, 1997, 825 patients with fractures of the shaft of the femur survived their initial resuscitation and were operatively treated at the same level one trauma center. Patients injured due to ballistic missiles (n=35), those initially treated with external fixation (n=6), those treated with compression plating (n=29), and patients treated with unreamed intramedullary nailing (n=12) were excluded. The remaining 743 patients underwent reamed intramedullary nailing for a femur fracture due to blunt trauma. Unilateral injuries occurred in 689 patients (Group I) and bilateral injuries occurred in 54 patients (Group II).

DATA ANALYSIS

For each patient, the following parameters were reviewed: age, ISS, AIS, mechanism of injury, and treatment. The outcomes measures were length of stay in the intensive care unit (days), length of stay in the hospital (days), and mortality. The differences between age, ISS and the outcome variables of Groups I and II were evaluated. To compare age, ISS, length of stay in the intensive care unit, and length of stay in the hospital, a student's t-test assuming unequal variance was used. Fischer's exact test was used to compare mortality given the small sample size of Group II. To account for

	Group I (range)		Group II (range)		p-value
N	689		54		
Age	31.2	(16-88)	29.3	(16-70)	0.30 *
ISS	16.5	(9-50)	20.2	(9-43)	.006 *
ICU length of stay	2.6	(0-87)	5.8	(0-24)	.002 *
Hospital length of stay	12.7	(1-116)	18.0	(4-45)	.001 *
Mortality	1.5%		5.6%		.06 **

Table 1: Comparison of Groups I and II.

age and ISS in a given outcome, two sets of analysis were performed. Multiple regression was used to assess the length of stay in the intensive care unit and the length of stay in the hospital. Logistic regression with calculation of the odds ratio was used to assess differences in mortality. The covariants selected were age and ISS in an attempt to compare similar patients with a similar overall injury pattern.

Results

Thirteen patients died including ten with unilateral femur fractures (1.5%) and three with bilateral femur fractures (5.6%). The average ISS in the patients that died was 33.2 (range: 9-50) compared to 16.5 (range: 9-50) in the patients that survived ($p = 0.001$).

The raw data in Group I and Group II was compared (Table 1). As expected, those patients with bilateral femur fractures had significantly higher Injury Severity Scores ($p = .006$), a longer length of stay in the intensive care unit ($p = .002$), and a longer length of stay in the hospital ($p = .001$). The odds of dying in patients with bilateral femoral shaft fractures was 3.8 times higher than in patients with a unilateral femur fracture ($p = 0.06$). The age of the patients in the two groups was not significantly different.

In order to compare similar groups of patients with a similar degree of trauma, the age and ISS were then analyzed as covariants in the two groups. Multiple regression analysis with age and ISS as covariants showed there was a significantly longer length of stay in the intensive care unit ($p = .026$) and a longer length of stay in the hospital ($p = .015$) in patients in Group II. Logistical regression of mortality revealed an odds ratio of 3.3 (95% confidence interval: 0.8 – 13.9) between Groups I and II.

Figure 1: A 28 year old male sustained bilateral femur fractures, bilateral tibia fractures, and a left humerus fracture as the result of high speed motorcycle accident. Treatment of the femur fractures consisted of reamed, antegrade, statically locked, medullary femoral nailing bilaterally.

Discussion

Early stabilization of femur fractures has been shown to be associated with decreased mortality and pulmonary morbidity in polytraumatized patients. Although several clinical and basic science publications implicate reamed intramedullary nailing as a cause of pulmonary dysfunction, this has been recently refuted. At our institution, reamed intramedullary nailing is used almost exclusively in the treatment of fractures of the femoral shaft in adult patients. Of 790 patients with a unilateral or bilateral femur fractures due to blunt trauma, 755 (95.6%) were treated with intramedullary nailing and 743 (94.1%) were treated with reamed intramedullary nailing.

In this study, an attempt was made to control for differences in overall injury between groups I and II by analyzing the data with the ISS and age as covariants. This allows for correction of the known increased number of associated injuries noted in patients with bilateral femur fractures. The contribution of the second femur fracture to mortality cannot be determined from these data. By accounting for age and ISS in the statistical analysis, similarly injured patients can be compared to determine the contribution of bilaterality of femur fractures to the mortality rate. This however, assumes that a similar ISS implies a similar degree of trauma. It has been suggested that the ISS underestimates the contribution of multiple major long bone injuries to morbidity and mortality. In scoring the AIS of the ISS, unilateral and bilateral femur fractures both give a contribution of 3 squared or 9. The significantly higher mortality rate in patients with bilateral femur fractures treated with reamed intramedullary nailing observed in this study may be due solely to this inadequacy of the ISS.

Conclusions

Patients with bilateral femur fractures are more severely polytraumatized than patients with unilateral femur fractures. Patients with bilateral femur fractures treated with reamed intramedullary nailing had significantly higher Injury Severity Scores ($p = .006$), longer length of stay in the intensive care unit ($p = .002$), and a longer length of stay in the hospital

(p = .001). Mortality in patients with bilateral femur fractures was 5.6% compared to 1.5% in patients with unilateral femur fractures. After accounting for age and ISS of the two groups using multiple logistical regression, bilateral femur fractures were still associated with a significantly higher mortality (odds ratio = 3.3), longer length of stay in the hospital (p = 0.015), and longer length of stay in the intensive care unit (p = 0.026). The ISS does not accurately account for the difference in outcome in patients with bilateral femur fractures when compared to unilateral femur fractures, and may underestimate the risk of mortality in these patients.

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New Trauma Techniques: Submuscular Plating and Less Invasive Fracture Stabilization

DOUGLAS G. SMITH, M.D.

Fracture stabilization has evolved and improved over the past several decades. Various techniques such as strategic surgical exposures which limit tissue devascularization, diminished periosteal stripping, and indirect reduction methods demonstrate the orthopedic trauma surgeon's increased respect for the local soft tissue envelope. Fracture fixation implants also continue to improve. Low contact dynamic compression plates (LCDCP) minimize bone necrosis beneath the implant by design. Special periarticular plates optimize implant fit and screw placement for difficult articular fractures. Improved medullary nails are available as reamed, unreamed, flexible, rigid, and also are designed to accomadate various insertion sites. The principles of fracture fixation remain as: (1)accurate reduction, (2)stable fixation, (3)preservation of local vascularity, and (4)early active mobilization.

Surgical exposures and their impact on traumatized soft tissues are very important factors in operative fracture management. For this reason, medullary nailing became the treatment of choice in most adult diaphyseal femoral and tibial fractures. Similarly, improved surgical techniques for plate fixation of fractures are evolving. Traditional plates and newly designed analogous implants termed "internal fixators" are now applied to bone using minimally invasive, submuscular surgical techniques.

The limited surgical exposures, improved reduction and fixation techniques, newly designed implants, and early results of "less invasive surgical stabilization" are presented.

HARBORVIEW EXPERIENCE

Percutaneous fracture fixation has been used for many decades, usually for fractures of smaller bones stabilized using smaller implants. Percutaneous internal fixation was often combined with other fracture stabilization methods, such as external fixators or casts, to support the internal fixation. Kuntscher introduced various medullary nailing techniques for diaphyseal fractures. His implant insertion methods became percutaneous techniques, using limited or no exposure of the fracture site, as intraoperative fluoroscopic imaging techniques advanced. Using these newer techniques, surgical injury to the local soft tissue envelope was avoided, and results improved.

Unfortunately, plate fixation techniques still required extensive surgical approaches of the entire fracture for debridement, reduction, and fixation. Contouring straight plates to accomadate complex osseus topography was also an intraoperative challenge. Infection, delayed union, nonunion, and implant prominence were but a few of the problems associated with such open plating techniques. Some surgeons would occasionally limit the operative exposure slightly by inserting the end of the plate beneath the soft tissues without subperiosteal stripping. Theoretically, limited operative exposures without extensive periosteal stripping should preserve the fracture fragment soft tissue attachments and vascularity. Improved implant designs similarly should allow accurate fracture reduction and stable fixation through these limited exposures. Less invasive, submuscular plating is a more radical extension of these standard open plating techniques which should preserve fracture vascularity and facilitate fixation. Associated complications should decrease significantly.

Figure 1: Femoral shaft fracture in an eight year old girl who was a pedestrian hit by a car.

DISTAL TIBIA

The initial Harborview experiences using limited plating techniques were similar to those of other authors. They began with the placement of standard implants beneath the skin or muscle in the distal tibia. The soft tissue envelope of the leg and ankle region is compromised after trauma. For this

Figure 2: Skin incisions marked out at thinnest portion of vastus lateralis, also planned to avoid the proximal and distal femoral physis.

Figure 3: The Cobb elevator is used to gently develop the plane between the vastus lateralis and the periosteum.

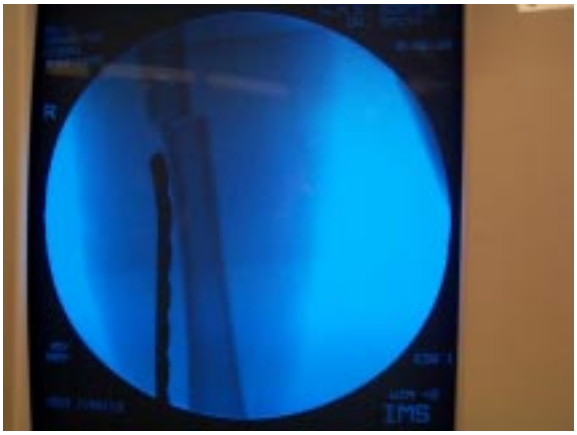

Figure 4: C-arm image of the pre-contoured 4.5 mm Narrow Low Contact Dynamic Compress Plate being gently passed up the interval created by the Cobb elevator.

reason, staged operative approaches are used for distal tibial articular (pilon) fractures. Initial fibular stabilization is advocated to obtain length and alignment. An external fixator or splint supports the fibular fixation. The tibial reduction and fixation is then delayed until the soft tissue envelope recovers sufficiently and allows a second operative exposure. Even this two-staged approach can be complicated by incisional healing problems, which are quite problematic in this area.

Less extensile periarticular tibial exposures were attempted to avoid potential wound problems. After routine fibular reduction and fixation, these limited tibial exposures facilitated the articular tibial reduction. They also accomadated the insertion of a precontoured plate onto the lateral or medial aspect of the tibia subcutaneously. The plate spanned the tibial comminution and was secured to the stable tibial component using a proximal tibial incision, or small incisions for screw placements through the plate. These early patients treated with subcutaneous plating achieved rapid union. These results emphasized the concepts of indirect reduction, and minimal soft tissue stripping of bone fragments popularized by Mast and other authors.

Dynamic Condylar Screw

Fixation of proximal and distal femoral fractures is difficult. Various implants have been advocated. Angled blade plates(ABP) provide rigid fixation for many of these peripheral femoral fractures, but these implants are technically demanding if used infrequently. Due to its design, an angled blade plate requires a wide surgical exposure for insertion. The dynamic condylar screw (DCS) was designed similarly to the more familiar dynamic hip screw (DHS).

The DCS can be inserted using less invasive submuscular techniques. For proximal femoral fractures, the lag screw is inserted into the proximal fracture fragment after a closed reduction is achieved. Using a small exposure, the 95 degree drill guide directs the pin insertion. The tract is prepared and the appropriate length lag screw is placed. Without engaging the barrel, the DCS side plate component is inserted submuscularly between the vastus lateralis and the periosteum. The

Figure 5: Clinical photograph of the plate being passed up the submuscular interval from distal to proximal in the thigh.

Figure 6: Clinical photograph of the leg and the incisions used for submuscualr fixation of the femur proximally and distally.

side plate component and barrel are then manipulated over the lag screw, the plate is aligned with the diaphysis, and the comminuted fragments are spanned by the side plate. The construct is then stabilized, according to the preoperative plan, with plate screws inserted through small incisions. Similar techniques using the DCS are available for distal femoral fractures also. Optimal implant placement and accurate closed reduction techniques depend on good quality intraoperative fluoroscopy, among other factors. This technique provides stable fracture fixation using diminished surgical exposure with less associated periosteal stripping of fracture fragments. Intraoperative blood losses and surgical duration are decreased with experience.

The DCS fixation construct applied after closed reduction using this submuscular technique stabilized difficult peripheral femoral fractures in six patients: three proximal subtrochanteric/intertrochanteric fractures, and three distal supracondylar/intercondylar. Early unions without implant failures were attained in these patients.

Pediatric Femoral Shaft

Pediatric patients with numerous and/or high-energy injuries benefit from secure stabilization of their fractured femoral shaft. Several methods of operative fixation are effective, each with unique advantages and disadvantages. External femoral fixation is complicated by pin tract/bone infection and refracture. Flexible medullary nails often require supplemental spica cast immobilization. Plating techniques are complicated by infection and scarring. Implant removal regardless of the chosen technique, is also advocated by many authors for these young patients.

Using less invasive, submuscular techniques a precontoured LCDC plate is inserted through small incisions at the proximal and distal thigh. The implant avoids both the proximal and distal physes. The incisions are located in the thinnest portions of the vastus lateralis, its origin and insertion, similar to those used for flexible medullary nailing, The plate is secured at one end with a screw, and temporarily at the other end with a K-wire through a chosen screw hole. This reduction and implant are adjusted until length and rotation are correct. A second plate screw is then placed into the other fragment to stabilize length and rotation. Flexion/extension and varus/valgus residual deformities are corrected with closed and percutaneous manipulations, then secured with additional plate screws according to the preoperative plan. The patients are mobilized depending on their other injuries.

Four pediatric femuoral shaft fractures were stabilized using less invasive submuscular plating techniques. Operative blood losses averaged 50 ml. Two patients could perform straight leg raises one day after surgery, the others by the third postoperative day. Stable plate fixation provided comfort and facilitates early mobility. One patient returned to school only six days after injury. All four fractures healed clinically and radiographically, demonstrating anterior, posterior, and medial callus formation. Bone overgrowth of the plate did not occur. Perhaps the extraperiosteal plate location avoids this potential problem. Two implants were removed without complications.

Improved Implants

Submuscular placement of standard plate implants is demanding and requires excellent intraoperative fluoroscopy. These techniques require the orthopedic surgeon to learn new skills of closed and percutaneous

Figure 7: Radiograph of the final fixation of the femur with the submuscular plate technique.

reductions of certain fractures. Screw placement is easy along the subcutaneous tibia, and challenging in the thigh. New surgical instruments and implants are available on a limited basis, while others are being further refined.

The recently introduced LISS (Less Invasive Skeletal Stabilization) implants provide fixed angle fixation of complex fractures. Using threaded screw holes through the plate, each screw is firmly attached to the plate and then the bone. Reduction tools aid in percutaneous manipulations, and maintain the reduction during screw placement. Screw innovations include self-drilling, self-tapping, and unicortical, which simplify percutaneous placement using a guide.

Future and Research Ideas

The evolution of surgical techniques which allow implant placement using less invasive procedures will continue. Clinical investigations comparing less invasive plating techniques with standard femoral nailing, especially in polytraumatized adult patients will be revealing. Similarly, controlled evaluations of pediatric femoral shaft stabilization comparing external fixation, flexible medullary nailing, and submuscular plating techniques are needed. Comparisons of proximal and distal femur fracture fixation using routine angled blade plate and less invasive submuscular placement of the DCS should evaluate union, operative blood losses and times, as well as outcome.

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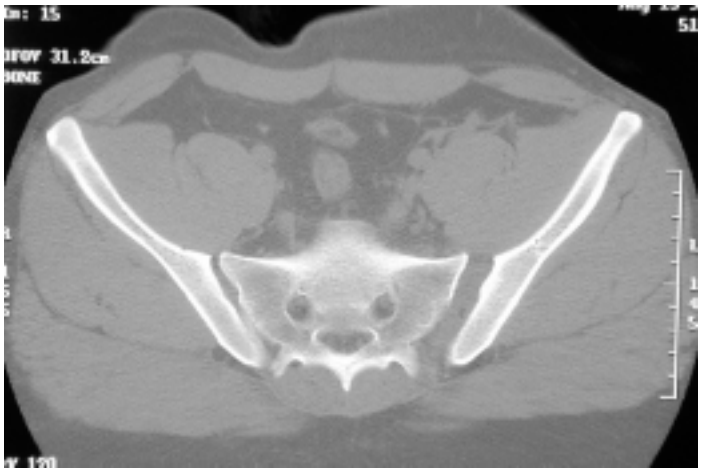
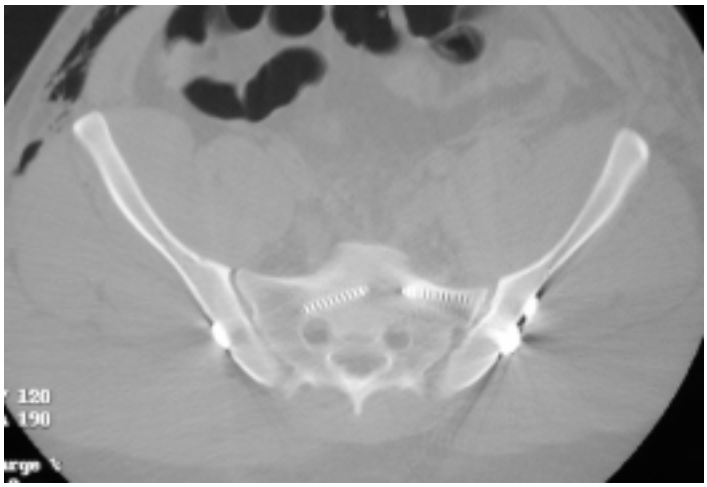
Percutaneous Placement of Iliosacral Screws Without Electrodiagnostic Monitoring

SEAN E. NORK, M.D., DANIEL N. SEGINA, M.D., WILLIAM J. MILLS, M.D., AND M.L. CHIP ROUTT, JR., M.D.

Surgical management of pelvic ring disruptions decreases hemorrhage, provides pelvic stability, and facilitates patient mobilization. Iliosacral screws inserted percutaneously or though a surgical incision have gained popularity as a method for stabilization of posterior pelvic ring disruptions. However, the local anatomy of the posterior pelvis and the upper sacral segments often makes the safe placement of these implants difficult. Iatrogenic nerve injuries from iliosacral screw placement has been reported as high as 10%. Not surprising, several neurological monitoring methods have emerged including somatosensory evoked potentials, spontaneous electromyography, and stimulus evoked electromyography. These methods are expensive and their efficacy has never been proven. The purpose of this study is to evaluate the neurologic complications after percutaneous stabilization of posterior pelvic ring injuries using iliosacral screws inserted without neurodiagnostic monitoring.



(A)



(B)

Figure 1: This patient sustained a complete left sacroiliac joint disruption, a right anterior incomplete sacroiliac joint disruption, and a pubic symphysis diastasis (A). Stabilization consisted of pubic symphyseal plating and percutaneous posterior pelvic ring stabilization with safely placed iliosacral screws (B).

METHODS

Over a 21 months period, 326 patients with pelvic ring injuries were treated at a level one trauma center. One hundred and seventy-four patients underwent operative stabilization of their unstable pelvic ring disruptions. Patients who underwent an open reduction (n = 66), those intubated prior to evaluation (n = 24), and those with preoperative neurologic deficits (n = 16) were excluded. In the remaining 68 patients, posterior pelvic stabilizations were accomplished using fluoroscopically guided iliosacral screws inserted percutaneously with the patient positioned supine. Prior to operative treatment, all patients had inlet and outlet views of the pelvis as well as pelvic computed tomography (CT) scans according to a specific protocol. There were 38 sacral fractures, 31 sacroiliac joint disruptions, and 14 sacroiliac joint fracture-dislocations (Table 1). 7.0mm cannulated screws were used for fixation. Neurodiagnostic monitoring was not used during screw insertions on any patient. A detailed neurologic examination was performed preoperatively and postoperatively in alert patients. Plain pelvic radiographs and CT scans were evaluated postoperatively by an independent observer not involved with the surgical procedure to assess screw position relative to the adjacent neurologic structures. Screw position were categorized as intraosseus, juxtaforaminal, or extraosseus (Figure 1). Intraosseus was defined by the clear presence of cancellous bone completely surrounding the screw on all CT cuts. Juxtaforaminal location was defined by a lack of cancellous bone surrounding the screw but an intact cortical rim at the ala, S1 neuroforaminal tunnel and

Table 1

Posterior Ring Injuries		
Sacral Fractures (38)	Zone I	12
	Zone II	22
	Zone III	4
SI Joint Injuries (31)	Unilateral	27
	Bilateral	2
SI Joint Fx-Dislocation (14)		14

***Some patients with multiple posterior pelvic ring disruptions**

Table 2

Screw Location	
Intraosseus	75
Juxtaforaminal	31

All Screws are 7.0 Cannulated inserted into the body of S-1.

the spinal canal.

Results

One hundred and six 7.0 millimeter cannulated screws were placed in the 68 patients. CT scans demonstrated screw placement as intraosseus in 75 and juxtaforaminal in 31 (Table 2, Figure 2). No screws violated the anterior cortex of the sacrum, the neuroforaminal tunnel of the first sacral nerve root, or the spinal canal. In these 68 patients with normal preoperative neurologic examinations, there were no neurologic injuries as a result of iliosacral screw stabilization of their pelvic injuries.

Discussion

Iliosacral screws are recommended for the treatment of unstable disruptions of the posterior pelvic ring. The local anatomy of the upper sacral segments may make safe placement of screws difficult. In order to minimize the risk of this procedure, several monitoring techniques have been advocated including somatosensory evoked potentials, continuous electromyography, and stimulus evoked electromyography. Some of these methods are limited by their ability to provide accurate, reversible, and timely information. The cost effectiveness of these techniques has never been evaluated.

Conclusions

Percutaneous iliosacral screw fixation of unstable posterior pelvic ring injuries can be performed safely while avoiding neurologic injury, even without the use of neurodiagnostic monitoring. Preoperative CT scans and quality intraoperative triplanar fluoroscopy are mandatory for the safe placement of iliosacral screws.

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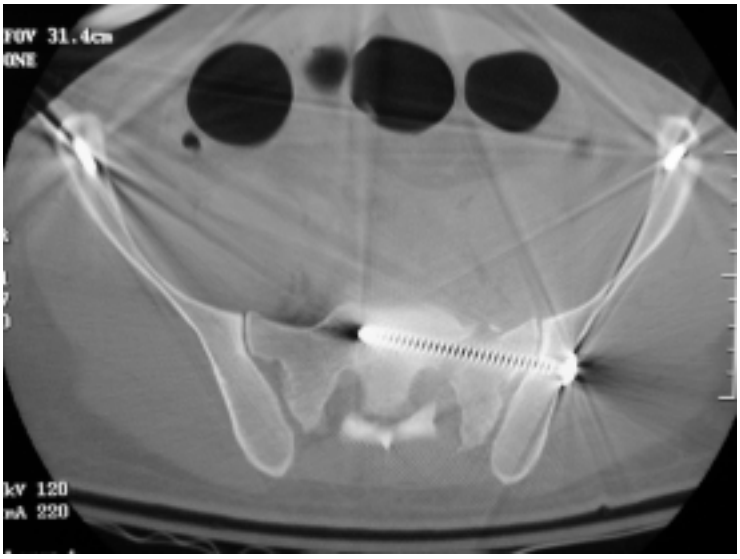
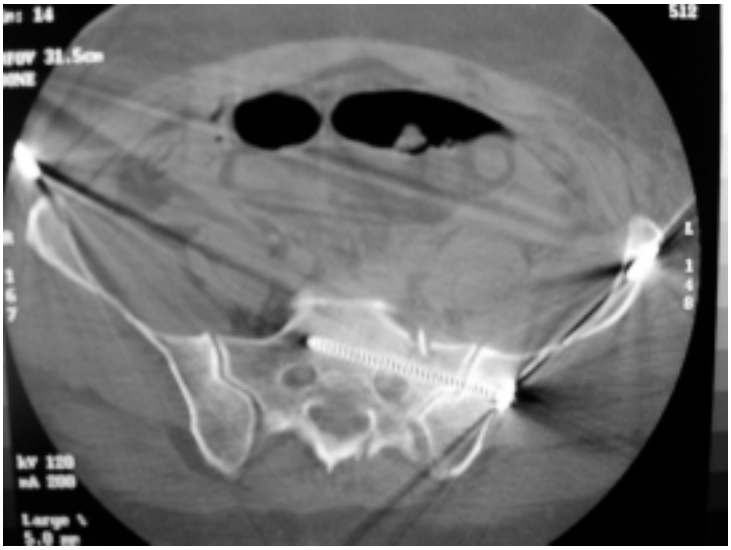


(A)



(B)

Figure 2: Example of an intraosseus screw (A) and a juxtaforaminal screw (B).

Plate Fixation of Pubic Symphyseal Disruptions: 2-hole DC Plates Versus 3.5 mm Reconstruction Plates

SEAN E. NORK, M.D., DAVID F. HUBBARD, M.D., PETER T. SIMONIAN, M.D., AND M.L. CHIP ROUTT, JR., M.D.

Treatment of pelvic ring disruptions remains controversial, especially in the polytraumatized patient. Early operative fixation of the disrupted pelvic ring injury provides stability which decreases bleeding and pain. A stable pelvis allows patient mobilization from the recumbent position, diminishing associated complications. Displaced pubic symphyseal disruptions have been successfully treated using both operative and non-operative methods. Nonoperative treatment options have included slings, spica casting, and traction. Operative techniques include external fixation as well as open reduction and internal fixation under direct visualization. Recent techniques of internal fixation include plate and screw fixation of the pubic symphysis after open reduction using either a Pfannenstiel or a midline laparotomy exposure.

Controversies arise regarding the optimal plate size and number of screws necessary to stabilize the disrupted symphysis. Several authors have advocated a two-hole 4.5 millimeter dynamic compression plate with 6.5 millimeter cancelleous screws placed through the plate. Four and six-hole 3.5 millimeter reconstruction plates have also been described for symphyseal fixation. Tile, however, recommended two anterior plates oriented at right angles to stabilize a pubic symphyseal disruption associated with a posterior pelvic ring injury, especially if the posterior injury could not be surgically stabilized.

The purposes of this study are: 1) to compare two different methods of symphyseal fixation and 2) to assess the complications associated with each method of symphyseal fixation.

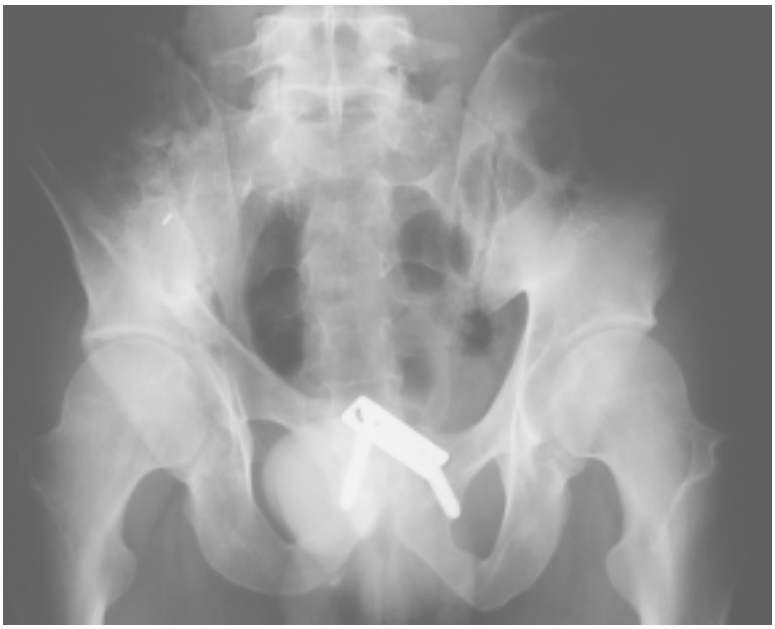
MATERIALS AND METHODS

During a fifty-two months period from July 1990 through October 1994, 478 patients with pelvic ring disruptions survived their initial resuscitations and were treated at the same level one trauma center. Forty-five patients with pubic symphyseal disruptions were identified from a prospectively collected orthopaedic trauma database and retrospectively reviewed. All patients underwent operative stabilization of the pubic symphysis. The patients ranged in age from six to sixty-five years of age with an average age of 33.8 years. There were thirty-eight male and seven female patients. These patients were polytraumatized with an average Injury Severity Score (ISS) of 22 (range, 8 - 43). Five patients had open pelvic fractures. All pubic symphyseal disruptions were associated with either a sacral fracture or a sacroiliac joint

	2-Hole DC Plate	3.5 mm Recon Plate	p-value
N	18	27	
Diastasis	2	4	0.33
Malrotation	9	0	< .001
Loss of Reduction	11	4	< .01
Hardware Failure	0	11	< .01
Revision Surgery	1	2	0.45

Table 1: Comparison of the Two Plating Techniques.

(A)



(B)

Figure 1: (A) This patient had a symphyseal disruption and right sided posterior pelvic disruption after a motor vehicle accident. (B) The anterior pelvic ring injury was initially stabilized with a 2-hole DC plate. Three months after surgery, flexion and internal rotation of the right hemipelvis is noted.

injury. Twenty-four patients had associated rami fractures (six bilateral and eighteen unilateral). There were six associated acetabular fractures. Eleven patients (24%) had associated lower genitourinary disruptions, including eight bladder and five urethral tears (two patients had combination lesions).

Surgery was performed at an average of 3.4 days after injury (range, 0 - 13 days). The symphyseal disruptions were visualized using an anterior exposure, reduced with clamps, and stabilized with plates and screws. Twenty-seven patients were stabilized with a single 3.5mm pelvic reconstruction plate secured to the bone with 3.5mm cortical screws, while 18 patients were stabilized with a single 2-hole, 4.5mm narrow dynamic compression (DC) plate secured with fully threaded 6.5mm cancellous screws. The posterior pelvic ring was stabilized in thirty-nine patients (87%). Healing and stability of fixation were assessed clincally and using inlet and outlet pelvic plain radiographs. Loss of reduction was defined as patients who developed either a diastasis or a malrotation deformity. Diastasis was defined as greater than a three millimeter increase in widening at the symphysis on the pelvic outlet film. Malrotation was defined as greater than a three millimeter increase in translation on the pelvic inlet film.

RESULTS

The average preoperative diastasis was thirty-five millimeters (range, 10 mm of overlap to 180 mm of diastasis). The average postoperative diastasis in the forty-five patients was 5.5 millimeters (range, 2 - 12 mm), with no significant difference found between the two groups. For the patients treated with a two-hole DC plate, the average preoperative diastasis was 30 mm and the average postoperative diastasis was 5.7 mm (range, 3 - 12 mm). For the patients treated with a 3.5 mm reconstruction plate, the average preoperative diastasis was 37.0 mm and the average postoperative diastasis was 5.2 mm (range, 2 - 12 mm). A total of six patients had an increase in diastasis at the pubic symphysis when compared to the immediate postoperative radiographs. Two patients (11%) were in the two hole DC plate group and four patients (14.8%) were in the 3.5 mm reconstruction plate group.

Two patients treated with reconstruction plates (7.4%), and one patient stabilized with a DC plate (5.5%), experienced early fixation failures which required revision surgeries. Symphyseal malrotations developed postoperatively in nine of eighteen patients (50%) treated with a 2-hole, DC plate. The 2-hole plate was associated with malrotation ($p < .0001$) and a loss of reduction ($p < .01$) when compared to the reconstruction plate

(A)

(B)

Figure 2: (A) This patient had a pubic symphyseal disruption and right incomplete sacroiliac joint injury after a crush injury during an equestrian accident. The symphyseal disruption was stabilized with a 6-hole, 3.5 mm reconstruction plate. (B) At twelve weeks, the patient had a broken plate, but remained asymptomatic without loss of reduction.

(Figure 1). However, fixation with a reconstruction plate was associated with an increased rate of plate or screw breakage ($p < .001$) (Figure 2). No differences were found with respect to diastasis ($p = 0.33$), need for revision surgery ($p = 0.45$), or infection rate ($p = 0.49$). Similarly, fracture classification did not correlate with loss of reduction ($p = 0.31$) (Table 1).

Discussion

Appropriate treatment of pelvic ring disruption is an important step in the care of the polytraumatized patient. The primary indication for open reduction and internal fixation of the pubic symphysis is the presence of a displaced, unstable anterior disruption which is part of an unstable pelvic ring injury. Open reduction and internal fixation is also indicated for certain patients with open pelvic fractures, as well as symphyseal disruptions associated with bladder and urethral injuries. Plate fixation of displaced, unstable symphysis pubis disruptions diminishes pelvic volume, bleeding, and provides comfort. Biomechanically, two-hole plates and 3.5 mm reconstruction plates have been shown to be similar in their ability to stabilize the disrupted pubic symphysis. No clinical series has compared these implants.

The major disadvantage associated with the use of a two-hole plate is the possibility of displacement around one or both of the screws, causing healing in a malreduced position. This was seen in nine of eighteen of our patients treated with a two-hole plate. Reconstruction plate fixation provides a more rigid construct and prevents malrotation. The plates utilized in our patient population were 3.5mm pelvic reconstruction plates. However, these failed by screw disengagement, screw breakage or plate fracture, usually noted after clinical union. This was seen in eleven of twenty-seven patients (40.7%) treated by this method in our series. However, there was minimal loss of reduction (average 4.5 millimeters) and minimal clinical symptoms when this occurred. No anterior hardware became symptomatic in either group.

Conclusions

Internal fixation of pubic symphyseal disruptions provides early stability which increases mobility and decreases pain. Damaged soft tissues are protected from further injury. There is however, a high rate of predictable complications associated with the implants. Two hole DC plates allow rotation and subsequent malreduction to occur. In contrast, 3.5 mm reconstruction plates demonstrate fatigue failure and screw disengagement. Healing is unaffected by these radiologic findings.

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Outcome After Open Reduction and Internal Fixation of Lisfranc's Tarsometatarsal Joint Injuries

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Injuries to the tarsometatarsal joints are uncommon and challenging. Most authors agree that early, accurate diagnosis and prompt treatment of these injuries are important. Anatomical reduction with stable internal fixation is suggested for optimal results. There is controversy regarding how this is best achieved. While closed reduction and percutaneous Kirschner wire fixation is advocated by some the trend is towards open reduction and screw fixation. Furthermore, it has been observed that injury to the ligaments without fracture to the Lisfranc complex may have a poorer outcome despite open reduction and internal fixation.

The aims of the study were to determine if open reduction and internal fixation provided satisfactory results, particularly in the case of pure ligament injuries.

Figure 1: This is an ap view of the foot of a patient who was treated ORIF after a lisfranc injury. The implants were removed at 8 weeks and the foot drifted into this position. Note the displacement of the base of the second metatarsal relative to the intermediate cuneiform. There is no fracture. This is a pure dislocation.

MATERIALS AND METHODS

We performed a retrospective study of all patients treated with a tarsometatarsal joint injury at Harborview between 1990 and 1997. Inclusion criteria were skeletally mature patients who had open reduction and internal fixation of an unstable Lisfranc injury. Ninety-two adult patients were identified from the trauma registry database. Patients were contacted and then presented for clinical review. All patients gave informed consent. Forty-four patients were excluded because they could not be contacted (23), had inadequate medical records (8), lived out of state (7), were not willing to participate (4) or were incarcerated (2). This left forty-eight patients with forty-eight Lisfranc injuries.

There were thirty-two males and sixteen females. The age range was from fifteen to seventy-seven years, with a mean of 38.8 years. The left foot was involved in thirty-one cases and the right foot in seventeen. Twenty patients were injured in a motor vehicle crash, six in crush injuries, seven falling from a height, three falling from ground level, three with sports injuries and nine from some other accident. Eight patients were injured at work. There were twenty-three isolated Lisfranc's and twenty-five patients with multiple injuries. The average Injury Severity Score (ISS) was ten (range, four to thirty-four). Five patients were multi-trauma patients (ISS greater than or equal to eighteen), ten patients sustained a fracture or fractures of the ipsilateral lower extremity and eight of the contralateral lower extremity.

Figure 2: This is an ap view of the same patient after open reduction and arthrodesis of the tarso metatarsal joints. Note that the base of the 2nd metatarsal is now aligned with the intermediate cuneiform.

There were forty-two closed and six open fractures. The open fractures were classified according to Gustilo and there were no type I, one type II, two type IIIA and three type IIIB. Thirty-five patients had all five tarsometatarsal joints involved, one had four, three had three and nine had two. There were seven injuries involving the medial column (first and second tarsometatarsal joints) alone, and two the lateral column alone (fourth and fifth tarsometatarsal joints).

There were thirty patients whose injuries included fractures of the base of the metatarsals, eighteen with associated cuneiform fractures or disruptions, and nine with associated cuboid fractures. In total there were thirty-three patients with bony injuries and fifteen with injuries to the ligaments only (no fracture). Patients with a 'fleck' sign (avulsion fracture of Lisfranc's ligament) were included in the pure ligament group. The direction of displacement was lateral in thirty-nine, medial in two and divergent in seven. In three referred patients the diagnosis was delayed greater than one month.

Final radiographs were reviewed for any evidence of fracture nonunion, malalignment, post-traumatic osteoarthritis or implant failure. The alignment of the second, third and fourth metatarsal with respect to the tarsals on the AP and oblique views was used to evaluate coronal deformity. The lateral talometatarsal angle was used to evaluate sagittal deformity. The

reduction was considered anatomic, if these relationships were intact; near-anatomic, if within two millimeters; or non-anatomic, if greater than or equal to two millimeters. Post-traumatic osteoarthritis was assessed clinically and on radiographs and was recorded as normal-mild (absent) or moderate-severe (present).

At follow-up patients underwent a physical exam and were asked about pain, deformity, limp, level of function and shoe wear problems. Patient outcome was assessed using the American Orthopedic Foot and Ankle Society (AOFAS) score for the midfoot and the long form Musculoskeletal Function Assessment (MFA) score. The AOFAS score has a scale of 0-100 with 100 points being an excellent or maximum outcome. The MFA score also has a scale of 0-100 but 0 indicates an excellent outcome.

The following were compared to assess impact on outcome: bony versus ligamentous injuries, open versus closed wounds, involvement of five versus less than five tarsometatarsal joints, presence versus absence of associated cuneiform and/or cuboid injury, isolated versus multiple injuries injuries, multi-trauma versus non multi-trauma patients, presence versus absence of ipsilateral lower limb injuries, anatomical versus non-anatomical (includes near- and non-anatomical) reductions, acute versus delayed diagnosis, and work related versus non work related injury. For the AOFAS and MFA outcomes a students t-test was used for comparison. For evidence of post-traumatic osteoarthritis a chi-square test was used to compare groupings.

Results

The average AOFAS score was 77 points (range, 40 to 100 points) with patients losing points for mild pain, decreased recreational function and shoe wear orthotic requirements. The average MFA score was 19 points (range, 0 to 55 points) with patients losing points for problems with leisure activities and difficulties with life changes and feelings due to the injury. Of the forty-eight patients, six had secondary fusions (Group 2) leaving forty-two patients with outcome measurements reflecting open reduction and internal fixation (Group 1)

There was a trend to worse outcome in those with pure ligament injury, open injury, injury involving all five rays, associated cuneiform or cuboid fractures, and ipsilateral lower extremity fracture. However, with the numbers available, no significant difference could be detected. There was significant difference in factors leading to the development of osteoarthritis. Comparison within subgroups showed that the non-anatomical reduction group had significantly more post-traumatic osteoarthritis than the anatomic reduction group (60 versus 16 per cent, $p=0.004$). More osteoarthritic change was seen in the pure ligament injury group (40 versus 18 per cent, $p=0.11$) but not enough to establish statistical significance.

In summary, statistical differences among selected groups were few, though the populations were small enough to hide many type 2 errors. The trends seem to indicate a few things. The overall outcome is good. The average scores reflect people with few limitations. In the AOFAS scores, points were lost for mild pain, decreased recreational function and shoe wear/ orthotic requirements. In the MFA scores points were lost for problems with leisure activities and difficulties with life changes and feelings due to the injury. Secondly, while foot injuries are a source of long term morbidity in people with multiple injuries, in this study, multiply injured patients did not fair worse than those with isolated foot injuries. This may reflect the fact that the foot injury is the limiting factor to recovery of full activities. Thirdly, anatomic reduction remains important to long term outcome. Finally, anatomic reduction is not as reliable in patients who have dislocation without fractures. It may be that those patients who damage the ligament-bone interface cannot heal with sufficient strength to return to stable long term function. However this question would best be answered by a prospective study.

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Thumb Trapeziometacarpal Joint Arthritis: Partial Trapeziectomy with Ligament Reconstruction and Interposition Costochondral Allograft

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Although a number of previous reports have indicated that excision arthroplasty has been effective in the treatment of basal joint arthritis of the thumb by relieving pain and preserving motion other reports have indicated that arthroplasty of the thumb by excision of the trapezium alone causes a substantial loss of thumb strength and stability. In an effort to improve thumb function and prevent proximal metacarpal migration, a number of studies have recommended ligament reconstruction.

In 1984 J.W. Littler, M.D. developed a technique using an interposition material shaped like a lifesaver between the partially resected trapezium and the base of the thumb metacarpal for patients with arthritis limited to the trapeziometacarpal joint. He coined the term, the lifesaver technique, and the original interposition material in the design was a silicone rubber implant. Because of the problems noted with silicone rubber, the interposition material was changed to allograft costochondral cartilage. The allograft cartilage was carved into a shape resembling a lifesaver and stabilized by weaving the flexor carpi radialis (FCR) tendon through the trapezium, allograft cartilage and the base of the thumb metacarpal. A preliminary report of this technique was presented at the 44th Annual Meeting of the American Society for Surgery of the Hand by Vincent R. Hentz, M.D. By replacing the interposition tendon graft with a carved piece of allograft rib cartilage, the authors noted greater stability of the reconstructed thumb especially when a strip of the flexor carpi radialis tendon was woven through the allograft cartilage. With this technique they were able to avoid the need for temporary pin fixation. We hypothesized that this procedure would relieve patient's thumb basal joint pain, allow them to have enough function to perform many important activities of daily life (as measured by The Disability of Arm, Shoulder and Hand (DASH) questionnaire) and improve their objective measurements of grip and pinch strength as well as improving their thumb abduction.

METHODS

At average follow-up of 44 months (range 24-81 months), we retrospectively reviewed the results of 38 thumb reconstructions in 33 (5 bilateral surgeries) patients with an average age of 64 years (range 40-80). A carved costochondral allograft lifesaver spacer was stabilized using and FCR tendon weave through the trapezium, allograft and thumb metacarpal base. Exclusion criteria included the presence of inflammatory arthritis, prior CMC trauma, infection or surgery and pantrapezial thumb arthritis. 28 patients were female and the dominant hand was involved in 25 cases. At follow-up, we evaluated the postoperative pain relief with work and ADL's as well as thumb and wrist ROM and grip and pinch strength relative to the opposite hand. The height of the graft at surgery and at follow up as well as the percent subluxation pre- and post-operatively were measured on x-rays.

RESULTS

All the patients had relief of pain with ADL's and 5 patients noted mild pain with heavy work activities. Range of motion and grip and pinch strength was determined and calculated as the percentage of the unoperated side in patients without bilateral surgery in Table 1. The thumb stability was significantly improved postoperative ($p<.05$, Figure 1). Postoperative pinch strength and pain correlated with postoperative subluxation and the height of the graft (Figure 2, 3). All patients were satisfied that their pain was decreased and the function was improved but 15 still noted symptoms of soreness in cold weather and fatigue with pinching activities.

CONCLUSIONS

This arthroplasty technique provides reliable relief of symptoms for patients with CMC arthritis and maintains the stability of the reconstructed CMC joint. Cartilage allograft arthroplasty provides an alternative to silicone rubber arthroplasty without the risk of silicone synovitis. Because graft height coorelated with improved results, cartilage implants may offer an advantage over tendon interpostion arthroplasty.

TABLE I	Wrist Flex/Ext	Wrist RD/UP	Thumb MCP	Thumb IP	Thumb ABD	Grip (lb.)	Pinch (lb.)
Measured	132°± 12°	57° ± 8°	54° ± 18°	73 ± 18°	50° ± 10°	46 ± 14	10 ± 3
% Unoperated	97%	94%	92%	93	93%	98	82%

Table 1: Range of motion, grip and pinch strength as a percentage of the unoperated contralateral side.

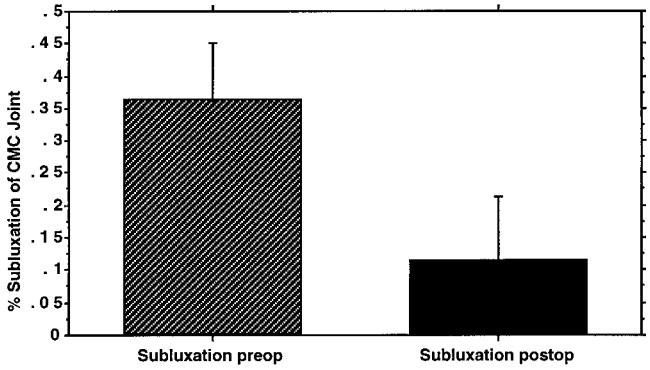
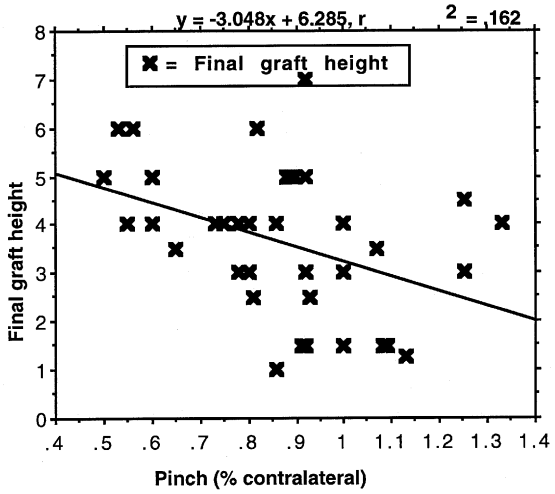
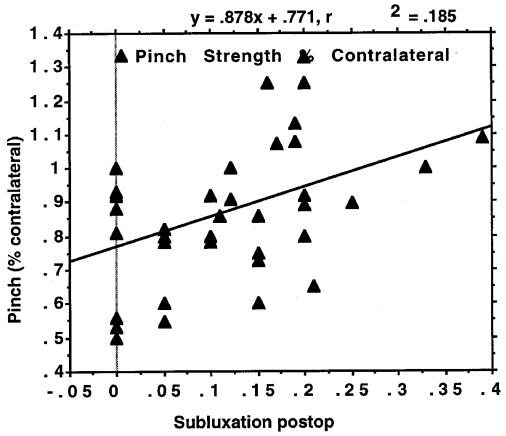


Figure 1: Improvement in thumb stability post-operatively ($p<0.05$).





Figures 2 and 3: Post-operative pinch strength and pain correlated with post-operative subluxation and the height of the graft ($p<0.05$).

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Clinical and Instrumented Assessment of Equinus Contracture in Patients Without Neurological Impairment

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Equinus contracture is the inability of the foot to adequately dorsiflex through the tibio talar joint. It results form inextensibility of the gastrocnemius and/or soleus. Theoretically, contracture of the gastro-soleus complex results in increased loading through the midfoot and forefoot (Figure 1). Though it may play a role in clinical problems such as cavus deformity, pes planus, metatarsalgia or in plantar ulcer formation in patients with diabetes mellitus, it's contribution is rarely documented in clinical or epidemiologic studies. Reasons for that may be inadequate training in physical exam, a lack of a clear definition of equinus and the uncertainty of clinical measurement. In this study we assessed maximum ankle dorsiflexion in a group of patients with metatarsalgia and midfoot pain as well as in a group of controls. We compared results of clinical exam to measurements made using an instrumented goniometer (Figure 2) to assess whether clinical exam can accurately predict whether equinus is present. The hypotheses tested were 1) that there is a difference in maximal ankle dorsiflexion in patients with forefoot pain compared to controls and 2) a clinician is able to reliably assess maximum dorsiflexion by clinical exam alone

METHODS

This investigation prospectively evaluated the maximum ankle dorsiflexion in 34 healthy adults with isolated fore- or midfoot pain and 34 control subjects. Patients were excluded if they had neurological disease, systemic disease affecting the foot or ankle, previous surgery or trauma, or bony block to ankle extension. Participants underwent a history and physical exam including clinical assessment of maximal ankle dorsiflexion. They were then examined using a validated 'equinometer', which measures maximal ankle dorsiflexion. The device consists of a footplate with a force transducer connected to a lateral leg attachment. The force transducer allows the examiner to apply a controlled force (10 N-m) to the underside of the foot. An electrogoniometer connected to the footplate and a lateral leg attachment measures the angular relationship between the leg and the foot. The software displays and records ankle position in the sagittal plane on a Macintosh G3 laptop computer. The testing instrument has been previously validated and is accurate to within 1.31 degrees (0.45 ± 0.43˚). The average variation in individual subject on a day to day basis has been documented as less than 0.5˚. Data were collected both with the knee in full extension (to assess the contribution of the gastrocnemius) and 90 degrees of flexion. The gastrocnemius crosses both the knee and ankle joints. With the knee in full extension, ankle dorsiflexion is dependent upon both the gastrocnemius and Soleus muscles. When the knee is flexed, the gastrocnemius is relaxed. Therefore if there is a contracture with the knee fully extended that is not present with the knee flexed, it is the result of tightness in the gastrocnemius. If the contracture exists both with the knee flexed and extended, both muscles are tight and there is a secondary constraint. Age matched controls without foot pain were selected from hospital staff, physician staff and family members who had accompanied patients to the out patient department.

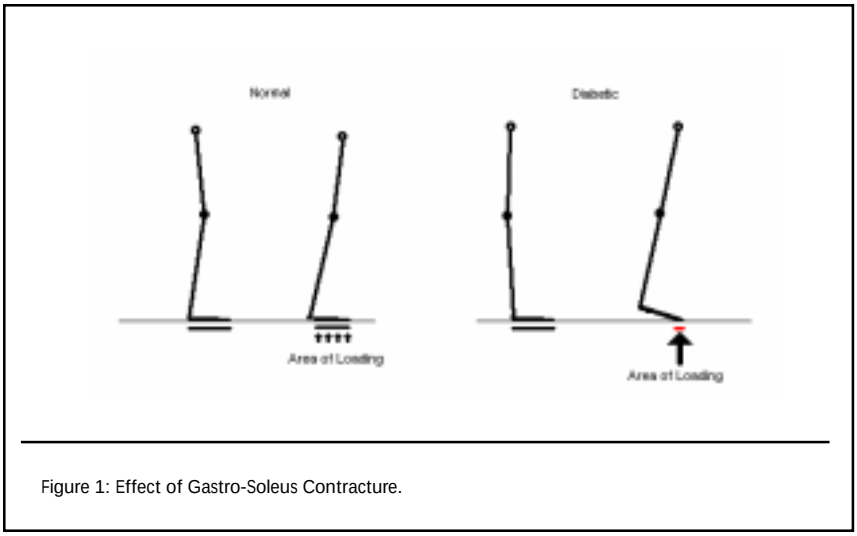

Figure 1: Effect of Gastro-Soleus Contracture.

RESULTS

With the knee fully extended, average maximal ankle dorsiflexion was 4.5 ± 4.5˚ (range -1.1 to 14.3˚) in the study subjects and 13.1 ± 8.2˚ (range 1.1 to 30.7˚) in the control group ($p < 0.001$, power = 0.99). With the knee flexed 90˚, the results were 17.9 ± 9.0˚ (range 6.1 to 37.0˚) for the study subjects and 22.3 ± 10.9˚ (range 7.6 to 51.1˚) for the control population ($p = 0.09$, power 0.40). If gastrocnemius contracture is defined as dorsiflexion £ 5˚ with knee extended, it was present in 65% of the study subjects and 24% of the control populations. We made the correct clinical diagnosis in 76% (ppv 95%, npv 42%) of the study and 94% (ppv 88%, npv 96%) of the control groups. In other words, if clinical exam does not indicate equinus contracture, it is very likely not present. If gastrocnemius-soleus contracture is defined as dorsiflexion < 10˚ during knee extension and 90˚ flexion, it was present in 29% of the study and 15% of the control groups (Table 1).

CONCLUSIONS

Patients with metatarsalgia or related fore/midfoot complaints have

Figure 2: Equinometer.

Group	GE (≤ 5°)	GE (≤10°)	Correct Dx (≤ 5°)	Correct Dx (≤10°)
Study	65% (22/34)	88% (30/34)	76% (26/34)	88% (30/34)
			PPV 95%	PPV 90%
			NPV 42%	NPV 75%
Control	24% (8/34)	44% (15/34)	94% (32/34)	79% (27/34)
			PPV 88%	PPV 53%
			NPV 96%	NPV 100%

Table 1: Comparison of the number of subjects in each group who exhibit gastrocnemius contracture (GE) as identified by the equinometer and whose clinical diagnoses correlate to the equinometer findings. Correct Dx refers to correctly identifying either the presence or absence of GE. Results are listed for two common, potential definitions of equinus contracture as found in the literature: < 5° or <10°.

less average maximum ankle dorsiflexion with the knee extended than a control population without foot or ankle complaints. This suggests an association between gastrocnemius contracture and forefoot pain. When the knee is flexed 90° to relax the gastrocnemius, this difference is no longer present. Clinicians can correctly assess the presence of contracture 76% to 94% of the time by physical exam alone.

Recommended Reading

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Exercise Induced Asthma

JOHN O'KANE M.D.

Asthma is characterized by reversible airway obstruction measured by a reversible decrease in FEV1 of >15% in response to a trigger such as an allergen, respiratory irritant, or exercise. While the airway obstruction occurs intermittently, in patients with persistent symptoms the underlying inflammatory process is ongoing. This may result in chronic irreversible lung parenchymal damage over time and as a result, early identification and treatment of athletes with asthma is essential. In most cases, airway obstruction induced only by exercise represents a mild form of asthma, while airway obstruction secondary to multiple triggers with more persistent symptoms indicates more severe disease. The risk of chronic inflammatory changes increases with the severity and persistence of symptoms.

INCIDENCE

Overall, asthma is increasing in prevalence and athletes are not immune to this trend. Studies comparing the athletes of the 1984 Summer Olympics to those in the 1996 Summer Olympics found asthma increased in prevalence from 11-20%. Sports with the highest prevalence were swimming, cycling, kayaking, and yachting. It is important to note that with appropriate treatment the asthmatic athletes performed as well in the medal counts as non-asthmatic athletes. Winter Olympians may be even more susceptible possibly due to exertion breathing cold, dry air. One study of cross country skiers in Sweden demonstrated a 70% prevalence of EIA.

Asthma is more common in patients with allergies and allergies are a significant trigger in 50% of adults with asthma. Furthermore, exercise-induced asthma (EIA), which affects 10 to 20% of all athletes, may affect up to 40% of athletes with allergies. Many athletes with exercise-induced asthma only complain of symptoms with exercise while 50-80% of patients with persistent asthma have exercise-induced bronchospasm.

Figure 1: Athlete with Asthma Doing the Most Asthmagenic Sport -- Cross Country Skiing.

SYMPTOMS

Typical symptoms include coughing that is minimally or non-productive, wheezing, shortness of breath, chest pain or tightness, inability to take a full breath, or difficulty with exhalation. Asthma is more likely if individuals have a family or personal history of allergic disease. EIA symptoms tend to occur after 5-8 minutes of intense exercise (80% of VO2 max) and are most appreciated over the next 7-10 minutes with improvement over the next 20 minutes. Symptoms are often most exaggerated in the rest period after the completion of exercise. Despite similar levels of exertion, certain activities seem to be more asthmogenic than others. Outdoor running is the most asthmogenic followed by indoor running, cycling, swimming, then walking. Cold, dry air is also more asthmogenic and not surprisingly, environmental airborne pollutants will aggravate bronchoconstriction in susceptible individuals. The clinician must attempt to differentiate athletes with persistent asthma from those with exercise exacerbation only, as the former group requires chronic antiinflammatory treatment.

EXAMINATION

Lung auscultation in an athlete with persistent asthma and active bronchoconstriction is generally abnormal, while the office exam in EIA is usually normal. Typical pulmonary findings in acute asthma include wheezing, rhonchi, prolonged expiratory phase, hyperinflation, and decreased breath sounds. A lack of wheezing during an acute attack should not be reassuring, but may be a potentially ominous sign as airflow becomes sufficiently diminished to no longer generate sound. Signs of upper or lower respiratory tract infection or physical findings of other allergic disease should be noted.

DIAGNOSIS

Asthma is diagnosed by demonstrating a 15% increase over baseline in forced expiratory volume in

one second (FEV1) after administration of an inhaled beta-adrenergic agonist. If a patient has normal baseline spirometry, the diagnosis can be made by demonstrating a drop in FEV1 following inhalation of a bronchial irritant such as methacholine or following an exercise challenge in the case of EIA. In patients with EIA, a typical history with exercise followed by resolution of symptoms after pre-exercise treatment with an inhaled beta-adrenergic agonist can be sufficient to make the diagnosis. Airway obstruction can also be quantified by peak flow testing but because it is more effort dependent, peak flow testing is not as reliable a diagnostic tool as FEV1. Peak flow can be very useful though for patients with chronic symptoms to monitor their response to therapy. In athletes with suspected allergic triggers and difficult to control asthma, skin prick testing to identify allergens is indicated to facilitate avoidance and consider desensitization.

TREATMENT

Non-pharmacologic treatment includes avoiding allergens, respiratory irritants, and other triggers to the extent possible. In patients with EIA, nose rather than mouth breathing should be emphasized as should avoidance of exertion in excessively cold, dry, or polluted air. In addition, many athletes with EIA have a refractory period where following an initial bout of bronchospasm and recovery, they are refractory to further bronchospasm for up to an hour. By eliciting symptoms through exertion then recovering prior to competition, some athletes are able to minimize symptoms during competition.

Long-term-control asthma medications are taken daily to achieve and maintain control of persistent asthma. The most effective long-term-control medications are those that reduce inflammation. Inhaled steroids are the most potent inhaled antiinflammatory medication currently available. Quick relief medications, on the other hand, are used to provide prompt treatment of acute airflow obstruction and its accompanying symptoms of cough, chest tightness, shortness of breath, and wheezing. These medications include short-acting inhaled beta-2-agonists and in some instances anticholinergics. All patients must have a short-acting inhaled beta-2-agonist to take as needed for symptoms. Patients with mild, moderate or severe persistent asthma require daily long-term-control antiinflammatory medication to control their disease.

Relatively recently a new group of medications which inhibit the bronchospastic and pro-inflammatory effects of the leukotrienes, the leukotriene antagonists, have been approved for the treatment of asthma. Leukotrienes have been shown to play a significant role in asthma induced by exercise, aspirin, and allergens. While the specific indications for these drugs in the treatment of asthma are still being established, patients with aspirin and exercise-induced asthma have been shown to respond very well. Currently these medications are recommended as add-on therapy.

For patients with exercise-induced asthma, the following are recommended control measures. 1) Two to four puffs of short-acting beta-2-agonist 5 to 60 minutes prior to exercise. The effects of this treatment should last about 2-3 hours. A long-acting beta-2-agonist taken at least 30 minutes before exercise will last 10-12 hours although recent evidence suggests that the length of time that the drug remains active following a single dose may decrease with time. Cromolyn or nedocromil may also be used prior to exertion with a duration of effect of 1-2 hours. The combination of cromolyn and albuterol has been shown to be more effective than either medication used alone. 2) If symptoms persist despite the above treatment or occur with usual activity or exercise, a step up in long-term control therapy such as use of inhaled steroids and/or leukotriene antagonists may be warranted. Concomitant allergic rhinitis or sinusitis should also always be addressed so as to optimize control of symptoms.

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The 20th Century with the ACL and Meniscus

PETER T. SIMONIAN, M.D.

The 20th Century has seen a tremendous change in the understanding and treatment of injuries to the anterior cruciate ligament (ACL) and the meniscus. Interestingly, a consensus on many of the fundamental issues surrounding the ACL and meniscus had not been reached until this last decade of the 20th Century. Despite this current consensus, new ideas, research, and technology will challenge our current thought, just as it did throughout the 20th Century. The 21st Century is certain to bring exciting technology, understanding, and treatment options never before considered for injuries to these two critical knee structures.

ANTERIOR CRUCIATE LIGAMENT

The presence of the ACL has been known since the time of Galen. Injuries to the ACL have been recognized for more than 100 years. The first operations to repair or reconstruct the ACL were performed just prior to the 20th century.

The importance of the ACL has been debated throughout most of the 20th century. As early as 1850, Stark commented that the loss of the ACL was insignificant. Bennett in 1926 came to a similar conclusion, that disruption of the ACL when the remainder of the knee ligaments are intact did not lead to significant instability. In 1930 Milch came to a similar conclusion. In 1938 Herzmark went as far as stating that the ACL was actually a "vestigial structure". The opposite conclusion was voiced by others at the same time including Hey Groves in 1917 who felt that disruption of the ACL resulted in permanent disability. In the 1930's Krida and Campbell came to similar conclusions on the disability associated with ACL disruption. Similar arguments continued into the 1970's. The natural history of ACL disruption has been considered to have no significant consequences by Chick and Jackson in 1978 while Fetto and Marshall as well as Allman felt that dysfunction and deterioration would result. There is now some consensus that the ACL is critical in providing stability to protect the cartilage of the knee in cutting sports and other high-risk activities.

Operative verses non-operative treatment of ACL injuries has been debated throughout the 20th century. In 1907, Pringle thought exploratory surgery was indicated for knee instability. Jones and Smith in 1913, as well as Albee in in 1919, recommended nonoperative treatment for ACL ruptures. Corner in 1914 thought that surgery yielded unsatisfactory results. In 1933 Jones and Lovett stated that ACL reconstruction is "unusually grave and requires the highest craftsmanship and the strictest technique and should never be undertaken without a sense of grave responsibility". During this same time period, Campbell as well as Palmer recommended surgery for ACL rupture. In 1950 O'Donoghue recommended repair of all damaged structures. Later in the century the debate continued. In 1984 Jokl reported the good results obtained with nonoperative treatment of ACL injuries while at the same time Clancy argued for the surgical treatment of nearly all acute ACL injuries. By the end of the 20th Century, a fundamental consensus for surgical indications has been agreed.

Further, the type of surgical treatment has been argued throughout the majority of the 20th Century. Primary repair of ACL disruptions was done as early as 1885 by Mayo Robson. Langer and Herz both used silk threads to repair the ruptured ACL in the first decade on the 20th Century. Jones in 1916 described primary repair of the ACL as being completely futile. This treatment was advocated by Marshall while others in the 1970's including Cabaud, Feagin, and Curl rediscovered the limitations of primary repair. The majority of surgeons now agree that primary repair is no longer considered a viable treatment option.

One of the few points of consensus throughout the history of ACL surgery is that successful ACL reconstruction is dependent on meticulous technique. The importance of removing sharp edges from the tunnel aperture was stressed by Hey Groves in the early 1920's. The accurate placement of tunnel position was recognized by Palmer in 1944. The concept of isometry was also recognized as early as 1942 by Blair. These same points as

Figure 1: Example of a modern ACL reconstruction.

Figure 2: Cadaveric medial meniscus prior to transplantation.

well as other technical details have been reiterated and stressed throughout the second half of the 20th Century.

The evolution of surgical ACL reconstruction began with Hey Groves in 1917 with a strip of iliotibial band through femoral and tibial drill holes. In 1918 Smith described a series of techniques including reconstruction of the ACL. Around the 1930's Cubbins, Campbell, and Macey all described types of intra-articular, anatomic ACL reconstruction. During this same time period, another group of surgeons felt that the instability resulting from ACL injury was more attributed to the collateral ligaments and recommended different types of collateral ligament reconstruction. Many of these procedures initially focused on medial sided reconstruction with advocates including, Bosworth, and Horwitz. Later in the 1960's and 70's the lateral side extraarticular reconstruction was popularized by MacIntosh, Losee, Arnold, Ellison, and Lemaire.

More recently, the argument for reconstruction of the ACL deficient knee focused on intraarticular verses extraarticular reconstruction or combinations. Today most surgeons agree that an anatomic, intraarticular reconstruction alone is the preferred treatment. This was initially done in an open fashion. With increased skill and technology with the arthroscope, ACL reconstruction is now primarily done in an arthroscopic fashion. Initially this was done with two incisions, with direct access to the tibia and the femur for drilling and fixation, but is now being done more frequently with one incision endoscopic techniques. Once ACL reconstruction was popularized, the procedure became progressively less morbid and invasive. Although not the focus of this review, significant advances in rehabilitation before and after ACL reconstruction has led to a significant improvement on the outcome of modern ACL reconstruction.

The source for the ACL graft remains controversial. Many graft sources had been used throughout the 20th Century. The main sources today include autologous patella tendon and quadrupled hamstrings. Less frequently used is the quadriceps tendon. Allograft sources are another popular alternative with patella tendon being most popular; recently shortages have forced the exploration of other allograft sources. The apparent advantage of synthetic materials for ACL reconstruction was short lived with the failures and synovitis associated with the polytetrafluorethylene prosthesis; other synthetic materials may prove to be more viable.

The near future will include biologic fixation implants which will accelerate healing. Also biologically engineered ACL grafts may be realized. New ways to simulate healing of the ACL after acute injury my be pioneered. There is also bound to be greater insights into the gender differences seen with injury to the ACL.

MENISCUS

The 20th Century has seen great changes and advances in the understanding and treatment of meniscal injuries. This dynamic treatment has been based in thought ranging from the meniscus being a useless vestigial structure to a current understanding that the meniscus serves critical functions of weight-bearing and stability.

The importance of the meniscus was argued through much of the 20th Century. About 100 years ago, Sutton considered the meniscus to be functionless remnants of leg muscles. Despite this thought, the first repair of a torn meniscus was done by Annadale in 1883. At the beginning of 20th Century the usual treatment for symptomatic meniscal injuries was closed reduction followed by immobilization. If this treatment failed, excision of the non-united meniscus was the recommendation. King in 1936 performed a series of enlightening animal experiments and discovered the regional variation in meniscal healing potential. He also noted that articular cartilage seemed to degenerate in proportion to the amount of meniscus tissue removed. In 1944, Smillie reported that meniscus tissue regenerates after complete menisectomy and is no longer symptomatic because of the smaller dimension and firm attachments of the re-grown structure. In 1948, Fairbank compared pre and postoperative radiographs ranging from 7 months to 14 years after menisectomy. He noted the concerning changes following menisectomy including; osteophyte formation, joint space narrowing, and flattening of the femoral condyle.

The debate continued into the second half of the Century. In 1968, Jackson confirmed a higher incidence of degenerative changes after menisectomy when compared to the uninvolved knee. In 1969 Tapper and Hoover found no difference in good and excellent results when comparing partial and total menisectomy. In 1975, Cox in a canine model confirmed the

findings of King nearly 40 years earlier that partial menisectomy led to fewer degenerative changes than total menisectomy. In the later half of the 20th Century, biomechanical studies demonstrated that the meniscus played a critical role in conferring load bearing and stabiltiy to the knee.

In 1962 Watanabe's arthroscope provided the opportunity to treat meniscal lesions with less morbidity than afforded by open procedures. McGinty reported greater patient satisfaction, fewer Fairbank changes, decreased morbidity and hospital stay with arthroscopic partial menisectomy. In the early and mid 1980's a series of studies demonstrated that arthroscopic partial menisectomy produced superior results to open menisectomy. The development of arthroscopic treatment of meniscal injuries has been one of the great advances of orthopaedic surgery in the 20th Century.

The peripheral healing potential of the meniscus as seen by King in 1936 was clearly elucidated with Arnoczky and Warren's vascular studies of the meniscus in 1982. Meniscal repair although reported more than 100 years earlier did not become an accepted form of treatment until DeHaven in 1989 demonstrated an 85% clinical healing rate after open meniscal repair. During this period, arthroscopic techniques were developed by Henning, Cannon, Warren, Morgan and others to repair the meniscus including: inside-out, outsiden-in, and all- inside suture techniques. Each of these methods has specific advantages and disadvantages.

Despite these advances in arthroscopic techniques for meniscal repair, many surgeons opted to continue performing partial menisectomy instead of repair. Most recently the rate of meniscal repair among orthopaedic surgeons has vastly increased with the advent of biodegradable fixation devices. The rationale for this large increase in meniscal repair is likely related to the ease, speed, and lack of immediate morbidity associated with these new devices. However, the popularity of these devices decrease as long-term results are reported. Early reports of articular cartilage damage, device migration, neurovascular injury, synovitis and ganglion related to these fixation devices are being reported with increasing frequency.

Meniscal allografts are being used with some limited success after total menisectomy. Whether meniscal allografts decrease the rate of articular cartilage degeneration is not clear. Experiments with meniscal collagen scaffolds are being used to encourage regeneration of the meniscus. Meniscal tissue is also being grown in the laboratory but the practical application of this technology needs further development.

The future for the 21st Century will include successful application of meniscal regeneration techniques that can be done with reproducible and standard surgical techniques.

Conclusion

If the 20th Century was any indication of the advances surrounding treatment of the ACL and meniscus, then the 21st Century is certain to provide a new and better way of restoring normal function and minimizing morbidity. Based on our 20th Century experience, however, these exciting advances will be accepted only after extensive research and healthy debate.

The Utility of the Knee Arthrometer: Measurements in a Normal Population

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The KT 1000 knee ligament arthrometer (MED-metric Corp., San Diego, CA) is used clinically to quantitatively measure the anterior tibial displacement (translation) of the knee. This information can then be used to determine the integrity of the anterior cruciate ligament (ACL). Reproducibility with this device has been questioned due to tester bias when reading and performing the KT 1000 test. Both the inter-rater and intra-rater reproducibility has been studied. Inter-rater reliability within 5mm of anterior tibial displacement has been shown 95% of the time on ACL reconstructed knees. 90% confidence for intra-rater reliability between expert and novice raters using the KT 1000. The purpose of this study was to determine both the inter-rater and intra-rater reliability of the KT 1000 on a normal population with the examiners being blinded to the results.

MATERIALS AND METHODS

KT-1000 measurements were performed on 10 volunteers, 5 male and 5 female. The volunteers have no history of knee surgery and are painfree. The subjects ranged in age from 21-44.

EXAMINERS

The four examiners are licensed physical therapists with minimum six months – 3 years experience using the KT-1000. Prior to the research, the examiners each reviewed the video provided by the manufacturer of the KT-1000. The physical therapists also met three times to establish consistency in technique prior to the data collection.

Figure 1: The KT-1000 measuring anterior knee translation.

PROCEDURE

Four examiners tested two subjects per session. There were five separate testing sessions. The testing sequence was randomized. The examiner was the therapist performing the KT-1000 and the reader was another therapist reading the numbers on the KT-1000 dial. Subjects alternated with each new examiner. The examiner and reader were randomly selected, until all the physical therapists had performed two KT 1000 tests, and had read and recorded two KT 1000 on each subject. The subjects knees were positioned on the KT 1000 bolster and measured to 30 degrees of knee flexion prior to testing. The examiner zeroed the KT-1000, the dial was shielded from the examiners view by the reader. Verbal feedback from the reader was given the examiner when the dial was zero'ed to baseline, and when the test was performed. The reader would see and record the results from the KT 1000 dial. The KT-1000 measurements were taken until the same numbers occurred three times consecutively and the KT-1000 dial was zeroed to baseline after each test. The reader would then record the numbers. A 15 lb., 20 lb., 30lb. and manual maximum measurements were recorded along with the knee angle. The manual maximum represented the examiner pulling from behind the calf, at the level of the proximal calf strap to their maximum ability without displacing the foot from the stabilizing platform. A total of sixteen KT-1000 readings taken per session in five separate sessions. The subjects, examiners / readers were blinded by assigning a number to individual subjects and examiners.

RESULTS

The KT 1000 measurements did not reveal trends in left:right knee laxity. In reporting the combined left and right normal knee measurements of the10 subjects, each knee was tested twice by four examiners, N = 160. Absolute left right differences were also recorded, N = 80. Intrarater reliability is reported

Table A

		15 Lb	20 Lb	30 Lb	MM
INTERRATER	Mean	0.96	1.19	1.31	1.92
	SD	0.83	0.98	1.15	1.46
INTRARATER	Mean	0.79	0.92	1.06	1.43
	SD	0.67	0.76	0.97	1.18
L:R DIFFERENCES	Mean	1.47	1.84	1.99	2.16
	SD	1.18	1.26	1.42	1.70
NORMS	Mean	4.12	5.60	6.85	8.71
	SD	1.86	2.12	0.19	0.20

Table A: The interrater, intrarater, and left vs right, mean differences in millimeters of anterior translation at 15, 20, and 30 lbs of force and a manual maximum force.

as differences between the first and second tests of each leg for individual examiners, N = 80. Interrater reliability is reported as the differences between all the different pairs of examiners, N = 480. There was no single examiner who stood out as differing especially from the others. The means and standard deviations at 15 lbs, 20 lbs, 30 lbs. and manual maximum are recorded for all these measurements in Table A. It is noted that the averages of the measurements are greater than the means. Therefore, standard deviations are skewed to the right, and the curve of these measurements is not bell shaped. This is true for the differences (intrarater, interrater, and left to right differences), but the curves are bell shaped with the absolute measurements (norms).

The percent of time the differences were > 2 mm on Manual Max testing for intrarater differences were 15%, for interrater differences 30 %, and for left-right differences 39%. Differences of > 5 mm with manual max testing occurred 2.5% with L:R differences.

Discussion

The literature reports differences > 2mm to be significant in identifying ACL laxity. Our results in normal knees suggest that the percent of time the differences were > 2 mm on Manual Max testing for intrarater differences were 15%, for interrater differences 30 %, and for left-right differences 39%. This raises serious concerns regarding the utility of such a tool.

There are a variety of factors that may account for errors in KT 1000 measurements. Proper identification of the tibia femoral joint line is essential for placement of the KT 1000 instrument. It has been demonstrated that positioning the instrument 1 cm proximal to the joint line yielded larger anterior translation than those measurements taken at the joint line. In addition placing the instrument 1 cm distal to the joint line produced smaller values for anterior translation. Tibial translation also varies depending on whether the lower extremity was in neutral, externally rotated or internally rotated. Greatest anterior translation occurs at 30 degrees of knee flexion. Inter-rater error associated with the KT 1000 measurements is greater for novice than experienced examiners. Subject apprehension or discomfort can directly effect a subject's ability to relax. The manufacturers for the KT 1000 recommend avoiding over tightening the proximal Velcro strap, which would decrease discomfort and lead to greater relaxation of the muscles. The amount of soft tissue compliance when pulling on the instrument may also affect the amount of translation measured. The hamstrings limit the amount of tibial anterior translation, which would affect the validity of a KT 1000 measurement. It has been shown that KT 1000 measurements taken with unconscious subjects were significantly higher than KT 1000 measurements taken with conscious subjects. This study suggests that subject apprehension may result in muscle activity, which may inhibit tibial anterior translation. For future studies, the use of surface EMG electrodes for the lower extremity, specifically to the quadriceps and hamstring muscle groups, may be useful to monitor muscle activity. This data also begins to identify normative values for anterior displacement and R:L leg differences in a normal population. Future studies could examine these differences in larger populations, or compare the KT 1000 results of the uninvolved side of a unilateral ACL deficient patient. The data shows interrater mean differences were greater than two times that of intrarater differences. Therefore, whenever possible testing should be collected by the same examiner.

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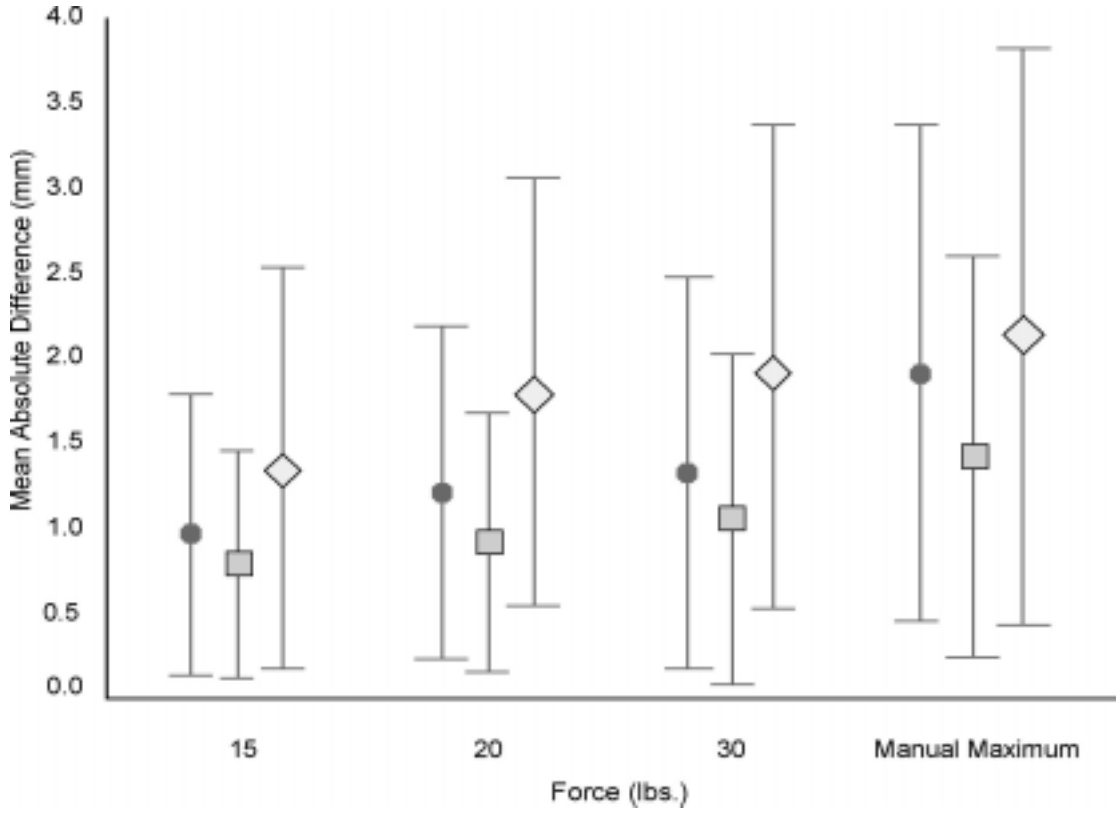

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Centering of the Humeral Head in the Glenoid In Vivo

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Investigations of the mechanisms of glenohumeral centering are important to the understanding of normal shoulder function and to the evaluation and management of the unstable shoulder. The humeral head appears to remain well centered in the glenoid fossa through a wide range of in vivo activities, enabling the upper extremity to be used with both precision and force.

While the role of ligaments in stabilizing the glenohumeral joint is unquestioned, the majority of the range of joint motion, including that in which most activities of daily living are performed, consists of positions in which the glenohumeral joint capsule and ligaments are unloaded. In spite of its substantial functional importance, remarkably few studies have investigated the degree to which the humeral head of the living shoulder remains centered in the glenoid while the shoulder is in these important mid-range positions.

Against this background, the authors carried out an investigation to test the hypotheses that in vivo (1) the humeral head is precisely centered in the glenoid, even when the deltoid and rotator cuff muscles are relaxed, and (2) the concavity of the glenoid cartilage and labrum conforms to the convexity of the humeral head as it is rotated so that a stabilizing concave-convex match is achieved in different positions.

MATERIALS AND METHODS

Six males, ages twenty-five to fifty-four, volunteered for this study. Three of the shoulders had been previously injured and were therefore excluded, leaving nine shoulders which were previously uninjured and asymptomatic. Because of the high degree of consistency of the results, additional subjects were not recruited for this study.

The subject was positioned with the scapular plane parallel to the MRI table. The glenohumeral joint was abducted 35 degrees in the scapular plane, the position our previous cadaver studies had shown to be the position of maximal capsular laxity. While the subject allowed the arm to relax, one of the investigators placed it sequentially in six different positions of rotation, starting with 15 degrees of internal rotation and progressing in 15 degree increments of external rotation to a maximum of 60 degrees of external rotation (Figure 1). MRI scans were obtained while the arm was stabilized by the investigator in each of the six desired positions.

Three separate MRI prints were made for each shoulder to allow measurements to be made by three independent observers who were blinded to the results obtained by the others. Each observer identified the humeral head center by marking the circumference of the humeral head on the MRI prints and aligning a translucent template marked with concentric circles to these marks. The center point was then marked through a hole in the center of the template. The observer then identified the anterior and posterior margins of the glenoid cavity and drew a line connecting these points. A perpendicular line bisecting this line was drawn and extended over the humeral head (Figure 2). The distance from the center of the humeral head to this line was measured and recorded in 0.1 mm increments as either a positive (anterior translation) or negative (posterior translation) number. The average of the measurements of the three observers was recorded.

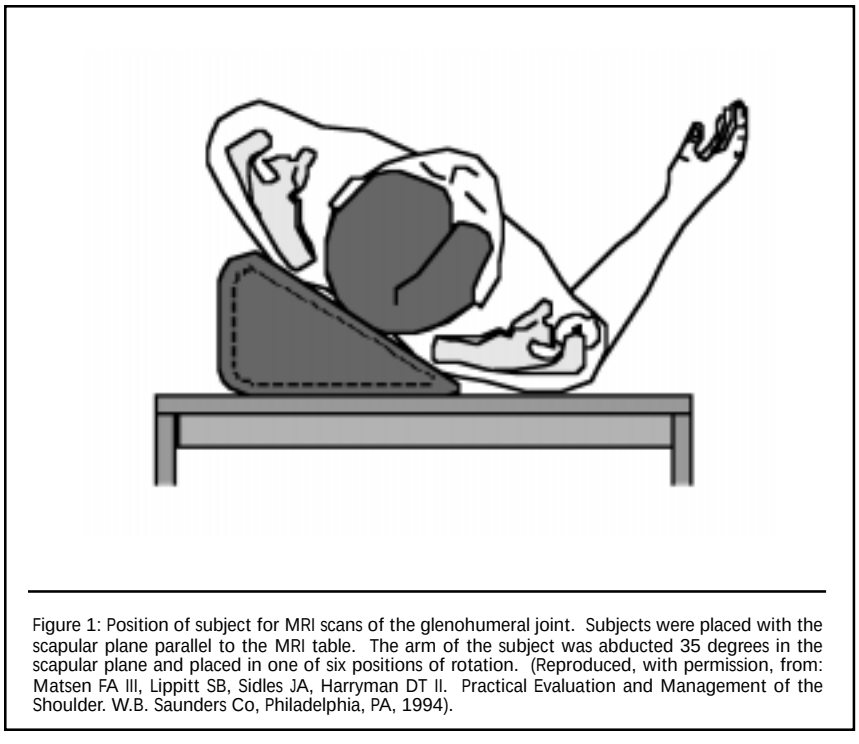

Figure 1: Position of subject for MRI scans of the glenohumeral joint. Subjects were placed with the scapular plane parallel to the MRI table. The arm of the subject was abducted 35 degrees in the scapular plane and placed in one of six positions of rotation. (Reproduced, with permission, from: Matsen FA III, Lippitt SB, Sidles JA, Harryman DT II. Practical Evaluation and Management of the Shoulder. W.B. Saunders Co, Philadelphia, PA, 1994).

RESULTS

The centering of the humeral head for the different positions of the shoulder is shown in Figure 3. In each of the nine asymptomatic shoulders examined, the humeral head remained centered within the glenoid, especially in the mid-range positions of passive rotation where the glenohumeral ligaments and capsule are known to be lax (from 0 to 45 degrees of external rotation, 35 degrees of glenohumeral abduction). Within this mid-range of rotation, none of the humeral heads tested were translated more than 2.2

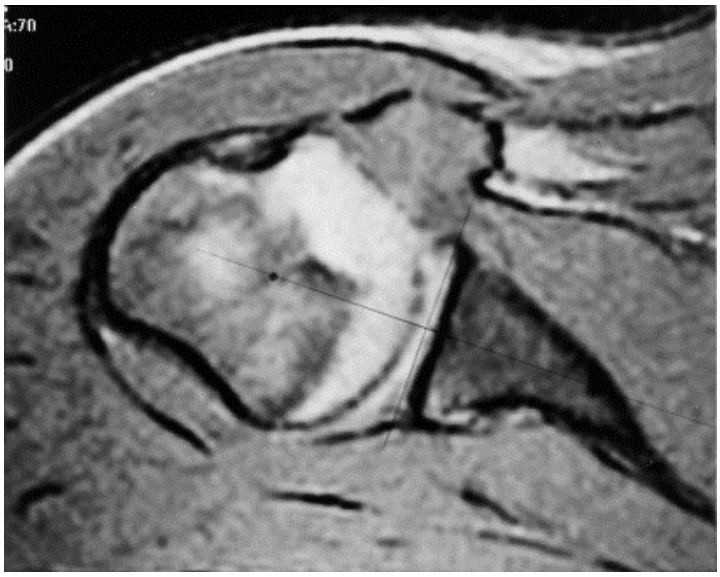

Figure 2: MRI scan showing markings for the humeral head center and perpendicular bisector of the glenoid used to measure anterior or posterior translation of the humeral head from the glenoid center. In this position, the humeral head is precisely centered.

mm either anteriorly or posteriorly in relation to the glenoid center. Mean translation for all shoulders in the mid-range positions was +0.103 +/- 1.2 mm.

At the extremes of rotation, five shoulders demonstrated translation of over 2.2 mm. In the position of maximal internal rotation, one of the shoulders demonstrated anterior translation of 4.4 mm. In the position of maximal external rotation, four of the shoulders demonstrated posterior translations of –3.8 mm, -5.7 mm, -5.0 mm, and –5.0 mm, respectively.

The MRI scans showed close conformity between the glenoid cartilage and labrum to the humeral head at each position of rotation (Figure 4).

Discussion

Our previous studies of in vivo shoulder motion indicate that many important activities of daily living are performed with the glenohumeral joint in mid-range positions in which the capsuloligamentous structures are lax. In these positions, centering of the humeral head must depend on mechanisms other than ligamentous stabilization.

This study has demonstrated that the humeral head of the relaxed shoulder is precisely centered in the glenoid when the shoulder is placed in these functionally important mid-range positions, even in the absence of vigorous muscle contraction. An explanation for this accurate centering may well lie in the observation that the stability ratio (the ratio of force necessary to translate the humeral head to the load compressing the humeral head into the glenoid) is maximal when the humeral head is centered in the glenoid. In such a system, the stabilizing effect of a given compressive load is greatest when the head is centered in the glenoid concavity. In order to demonstrate that only very small compressive loads were required to center the humeral head, the subjects were positioned in a comfortable supine position and asked to relax their shoulder muscles while an investigator passively positioned the arm. Thus, the compressive load in effect during these observations was only that provided by the resting tone in the deltoid and cuff muscles, rather than a major compressive load from vigorous dynamic stabilization. It is of importance that a minimal compressive load is sufficient for accurate humeral centering in the glenoid.

The high degree of conformation of the glenoid concavity to the humeral head observed on our MRI scans provides an anatomic situation that optimizes the centering effect of concavity compression. Recalling the substantial variation in the conformity of the glenoid to the humerus when only cadaveric specimens are considered emphasizes the importance of using MRI of living shoulders to demonstrate the functional glenoid concavity. Although the subchondral bone of the glenoid is relatively flat, the cartilage surface is thicker peripherally than in the center, producing a radius of curvature that closely matches the humeral head. The size of the glenoid cavity is also enhanced by the thick labrum. The labrum serves as a fibrous rim that contributes up to 50 percent to the depth of the glenoid fossa. A defect in the labrum lessens the effective depth of the fossa and reduces the effectiveness of concavity compression.

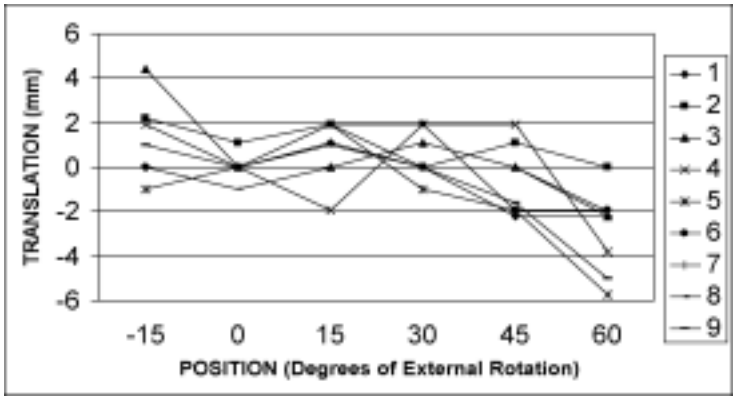

Figure 3: Graph of the humeral head translation from the glenoid center at each of the six positions of rotation for the nine normal shoulders examined, labeled #1-9. Anterior (+) and posterior (-) translation are plotted on the y-axis vs. rotational position on the x-axis.

Figure 4: Typical MRI scan demonstrating conformity of the concavity of the glenoid cartilage and labrum to the convex surface of the humeral head. Glenoid cartilage and labrum appear to mold very closely to the surface of the humeral head, without obvious interruption of contact.

Our study shows in vivo that, throughout the mid-range of motion, the glenoid cartilage and labrum conform closely to the convexity of the humeral head, hence providing a socket for centering through concavity compression.

The observation of anterior translation in one of the shoulders at an internally rotated position, and posterior translation in four shoulders at an externally rotated position demonstrates that the glenohumeral joint can become uncentered in positions where one aspect of the capsule is tightened by rotation to the limit of the range of motion. The tightened capsule on one side of the joint exerts an unopposed translatory load on the concave humeral head, forcing it from its centered position.

By demonstrating precise centering of the glenohumeral joint throughout the mid-ranges of passive motion in vivo, these observations point to the importance of non-ligamentous mechanisms for stabilizing the humeral head in the glenoid. Further study of the properties of the living glenohumeral joint will increase our understanding of these mechanisms and lead to a more effective understanding of the factors contributing to shoulder stability.

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Infection verses Inflammatory Reaction after Hamstring ACL Reconstruction with Two Different Techniques

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Anterior cruciate ligament reconstruction (ACL) a is frequently performed and an effective procedure to treat problems of knee instability after traumatic disruption. Approximately 250,000 ACL tears are diagnosed each year with a significant portion requiring surgical intervention. Infection following arthroscopic ACL reconstructions is of serious concern and consequence. Septic arthritis can be a serious problem, leading to osteomyelitis, graft damage, cartilage damage, and significant morbidity. The reported incidence of infection following any kind of arthroscopic surgery of the knee ranges from 0.1% to 4.0%. It appears that the risk of infection is greater in patients undergoing a procedure using a synthetic as opposed to biological ACL substitutes.

The distinction between an infected knee and sterile significant inflammatory event (SIE) is difficult. Short of positive synovial culture results, which often takes several days for confirmation, there seem to be few pathognomonic indicators to differentiate an infection from a sterile SIE.

The incidence, presentation, and management of post-operative infection after autologous hamstring ACL reconstruction with two-incision or one-incision, endoscopic technique has not been studied. Some endoscopic fixation systems leave more synthetic material in contact with the knee joint which may increase the potential for infection. We hypothesize that the signs of inflammation may not always be bacterial in origin but may be the result of an SIE. This distinction, if possible, has important implications for treatment. Infection rates may also have some relationship to the amount of synthetic material left in the joint.

The purpose of this series was to review patients who had either an intra-articular knee infection or an SIE following arthroscopic ACL reconstructions which employed the use of autologous hamstring tendons with two different surgical techniques.

MATERIALS AND METHODS

This series reviews primary arthroscopic ACL reconstructions done at the University of Washington Medical Center over a 4 year period between July 1994 and June 1998. Patients were identified as subjects if their postoperative progress was significantly altered from the typical postoperative course.

In the four years reviewed, a total of 472 primary arthroscopically assisted ACL reconstructions were done with autologous hamstring tendons, a double loops of semitendinosus and gracilis tendons. Of that total number, 10 patients fit the inclusion criteria. Previous surgeries, including ACL reconstruction, on the opposite knee were noted.

In the period prior to January of 1996, 226 ACL reconstructions were performed with a two-incision arthroscopically assisted technique. Femoral fixation consisted of a 6.5mm titanium cancellous screw with a titanium spiked washer (Linvatec; Largo, FL) around the looped end of the semitendinosus and gracilis tendons. This was done through a second incision on the lateral thigh. In the second half of the time period studied, 246 ACL reconstructions were performed with a one-incision, endoscopic technique. Femoral fixation consisted of an EndoButton (Acufex, Smith & Nephew; Mansfield,

Table 1. Demographics

Patient	Age (sex)	Graft type	Presentation	Previous ACL reconstruction	2° procedure
Infected Group					
1	38 (M)	STG with endo	subacute	Yes, STG on opposite knee with 2-incision	lateral meniscectomy and medial repair
2	38 (M)	STG with endo	subacute	No	lateral meniscectomy
3	20 (M)	STG with endo	acute	No	none
4	36 (M)	STG with endo	subacute	No	medial meniscectomy
5	63 (F)	STG with endo	subacute	Yes, STG on opposite knee with endo	lateral meniscectomy
6	32 (M)	STG with endo	subacute	Yes, STG on opposite knee with endo	lateral meniscectomy
7	28 (F)	STG with endo	subacute	No	none
Significant Inflammatory Event Group					
1	40 (F)	STG with endo	subacute	No	lateral meniscal repair
2	34 (M)	STG with 2 incis	subacute	No	medial meniscectomy
3	30 (M)	STG with endo	subacute	No	none

****STG**=semitendinosus and gracilis, **endo**=EndoButton

Table 2. Summary of presenting signs, lab results, and interventions

Patient	Time to present	Signs	synovial (WBC/µl)	peripheral (WBC/µl)	Gram stain WBC	ESR (mm/hr)	CRP (mg/dl)	Culture	1st procedure	2nd procedure
Infected Group										
1	34 days	Pur/E	n/a	12,300	few	98	n/a	Staph aureus	I & D	none
2	18 days	F/D/E/W/G	31,750	6,000	many	37	7.4	Staph (coag neg)	I & D	I & D
3	13 days	G/F	60,900	13,800	many	98	20.2	Peptostrep	I & D	I & D
4	17 days	P/E/F	58,900	7,900	many	n/a	n/a	Staph (coag neg)	I & D	none
5	35 days	W/E	30,250	7,400	many	82	n/a	Micrococcus	I & D	none
6	21 days	F/R/E/W	n/a	10,000	many	58	n/a	Staph (coag neg)	I & D	none
7	17 days	F/R/E/G	40,850	12,600	many	44	7.3	Staph (coag neg)	I & D	none
Significant Inflammatory Event Group										
1	35 days	R/P/E	n/a	n/a	few	58	2.5	no growth	none	none
2	17 days	R/E	49,800	5,400	few	70	n/a	no growth	I & D	none
3	27 days	R/E/F/P	20,000	n/a	moderate	n/a	n/a	no growth	none	none

****F**=fever, **R**=decreased ROM, **P**=pain, **W**=warmth, **E**=effusion,, **Lym**=lymphadenopathy, **Ery**=erythema, **D**=drainage, **G**=generalized malaise and lethargy, **Pur**=purulent drainage, **I & D**=irrigation and debridement

MA) with an interposed double loop of 5mm wide polyester tape around the looped end of the semitendinosus and gracilis tendons.

RESULTS

Ten subjects had significantly altered postoperative courses (Table 1). Seven of these patients had positive bacterial culture results and 3 had negative bacterial culture results. The incidence of culture positive infection following an arthroscopic ACL reconstruction using hamstring tendons was 7 per 472 operations (1.48%). Four of our 7 positive cultures grew only from enriched media.

Of these 10 cases, 9 had the one-incision, endoscopic technique with EndoButton and polyester tape femoral fixation. One of the 10 cases occurred in the early group using the two-incision technique; this patient had a negative culture and was placed in the SIE group.

Three of the 7 infected patients, or 43%, had undergone a previous ACL reconstruction on the opposite knee. All three of these previous ACL reconstructions on the opposite knee utilized autologous hamstring grafts; one with the two-incision technique and two with the one-incision endoscopic technique.

No patients in the SIE group, had a previous ACL reconstruction.

The presenting signs, lab results, and interventions are summarized in Table 2.

The mean follow-up time was 10 months with a range from 4 to 14 months in the infected group. As of the most recent visit by each subject, the mean range of motion in the knee joint was 0-136º in the infected group. Of the infected group, 2 patients were pain free, 1 had minimal pain, and 4 had moderate pain. In the infected group 6 subjects demonstrated a grade 1 Lachman, and 1 patient had a grade 1 to 2 Lachman. Follow-up radiographs demonstrated 5 of 7 infected subjects with no evidence of progressive arthritic changes or any findings consistent with osteomyelitis. The remaining 2 subjects were found to have an enlargement of the femoral tunnel.

The mean follow-up was 9 months for the SIE group, ranging from 6 to 12 months. Mean range of knee motion was 0-142º. The SIE group revealed 1 patient with no pain, 1 with a minimal amount, and 1 with a moderate amount. The SIE group demonstrated 2 patients with a grade 1 Lachman, and 1 patient with a negative Lachman. None of the radiographs of patients in the SIE group demonstrated evidence of progressive arthritic changes or any findings consistent with osteomyelitis.

CONCLUSION

1) All infected ACL reconstructions were salvaged with early arthroscopic I&D followed by a variable course of IV and oral antibiotics.

2) Infection was higher in patients undergoing one-incision, endoscopic, ACL reconstruction utilizing more synthetic materials to afford femoral fixation.

3) Infection was higher in patients who had a previous ACL reconstruction on the opposite knee.

4) Differentiation of an infection from an SIE is based on a constellation of factors. Presenting symptoms of generalized lethargy and malaise with a fever seemed most important to the infection group. The mean synovial WBC, peripheral WBC, and CRP were higher in the infected group. Gram stains were not helpful; they were negative in all patients. If there is an unclear distinction between an infection and a SIE, the clinician should treat the patient aggressively as if they are infected.

5) With early recognition and treatment, the outcome of the ACL reconstruction was not significantly altered in any of these patients.

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Intrinsic Stability of Unused and Retrieved Polyethylene Glenoid Components

EDWARD J. WELDON III, M.D., MARIUS M. SCARLAT, M.D., SEUK-BEOM LEE, M.D., AND FREDERICK A. MATSEN III, M.D.

Glenohumeral instability is one of the most common complications reported following total shoulder arthroplasty with an overall incidence of approximately 4 percent and a range of 0 percent to 35 percent. Glenohumeral instability was the cause of re-operation in 43 percent of thirty-eight failed total shoulder arthroplasties. This high rate of problems with instability after shoulder arthroplasty suggests the need for a better understanding of the factors contributing to arthroplasty stability. While attention has been devoted to the roles of humeral component version and musculoligamentous factors, relatively little information is available concerning the contribution of glenoid geometry to the stability of a total shoulder arthroplasty.

The stability of a glenohumeral arthroplasty is related in part to the geometry of its glenoid component: flat, narrow glenoids offer less stability than wide, deep ones. The investigation reported here explores the relationship of geometry to intrinsic stability and tests the hypothesis that the intrinsic stability provided by glenoid components can be substantially altered after a period of in vivo use. In spite of the importance of glenohumeral stability in shoulder arthroplasty and the recognition that glenoid components become deformed in vivo, this is one of the first studies of the effect of glenoid deformation to glenohumeral stability. In this investigation, we use the term "intrinsic stability" to refer to the stability resulting from the geometry of the glenoid surface alone, recognizing that this is but one of several factors which contribute to the stability of an arthroplasty in vivo.

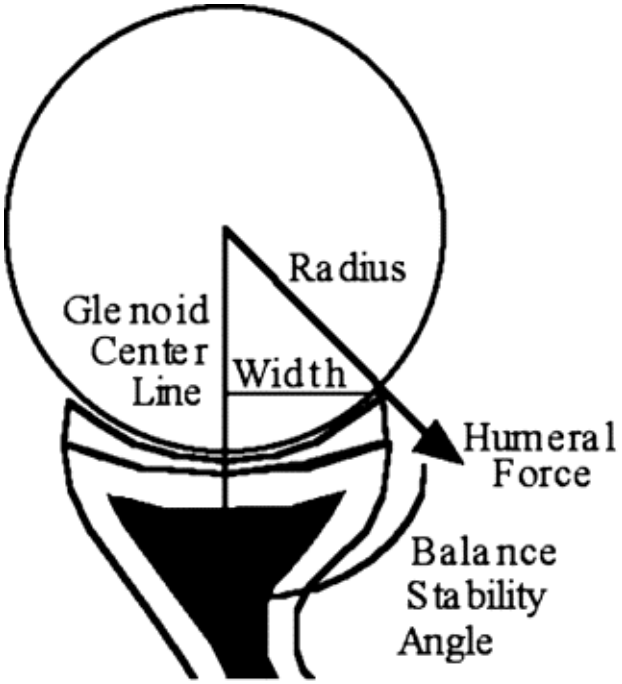

Figure 1: The balance stability angle is the maximal angle that the net humeral joint reaction force vector can make with the glenoid centerline before the humeral head slips over the glenoid lip.

A convenient measure of the intrinsic stability of a component in a given direction is the maximal angle the humeral joint reaction force can make with the glenoid centerline before dislocation occurs; this quantity is referred to as the balance stability angle in the specified direction (Figure 1). If the effects of friction are minimized, the balance stability angle can be predicted from the known geometry of the glenoid surface using basic trigonometry: the balance stability angle is the arc sin of the ratio of the width from the glenoid centerline to the glenoid edge divided by the radius of curvature of the glenoid. We measured the balance stability angle by placing an appropriately sized unconstrained prosthetic modular humeral head in the glenoid component which had been positioned so that its centerline was vertical. The glenoid was then tipped until the humeral head dislocated from the glenoid: the angle of tip at which this occurred was the measured balance stability angle. We compared the predicted and measured balance stability angles and found a very high degree of correlation (Figure 2).

The balance stability angles in eight different directions of displacement were then measured in twenty-four retrieved glenoids and compared to the analogous balance stability angles in identical, but unused glenoid components (Figure 3). The balance stability angles of the retrieved glenoids were often less than the corresponding balance stability angles of the corresponding unused glenoids (Figure 4). In fact, eleven out of twenty-four retrieved glenoids had diminished balance stability angles of at least 30 percent in at least one direction. The average balance stability angle decrement in the most affected direction was 13.1 degrees (29.4 percent) and ranged from 2.5 degrees

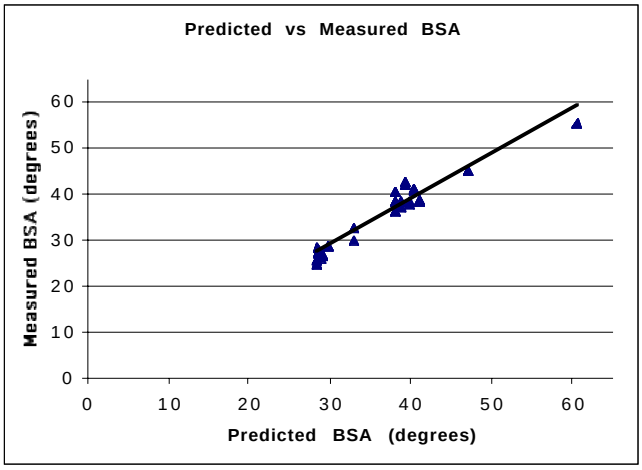

Figure 2: Predicted vs. Measured Balance Stability Angles: Ninety-six measurements in eight unused glenoids. The dark line represents the linear regression with an intercept of -.345 and a slope of .988. R squared for this correlation was .932.

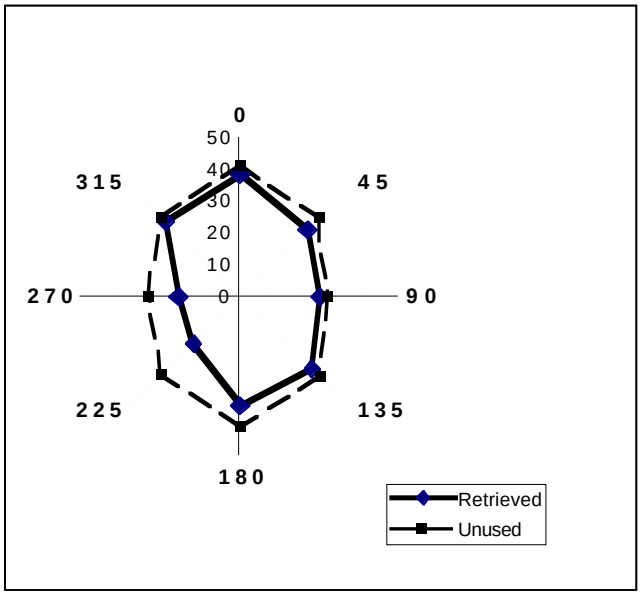

Figure 3: Example data from measurement of balance stability angles in each of eight directions for (1) a retrieved glenoid and (2) a matched unused glenoid component. Note that the retrieved glenoid has compromised balance stability angles in the 180, 225 and 270-degree directions.

to 21.7 degrees (6.8 percent to 57.7 percent). In two-thirds of the retrieved components, the maximal decrement occurred along an oblique axis.

We conclude that the surface geometry of glenoid components can be altered by in vivo use in a manner that may compromise its contribution to glenohumeral stability.

These results are of relevance to the clinical practice of shoulder arthroplasty because (1) they help define the role of glenoid surface geometry as one of the factors contributing to the stability of a total shoulder replacement, and (2) they point out that the functional surface geometry of the glenoid does not necessarily remain unchanged with in vivo use. This knowledge may be of help to surgeons in the prevention and management of one of the major complications of total shoulder arthroplasty: glenohumeral instability.

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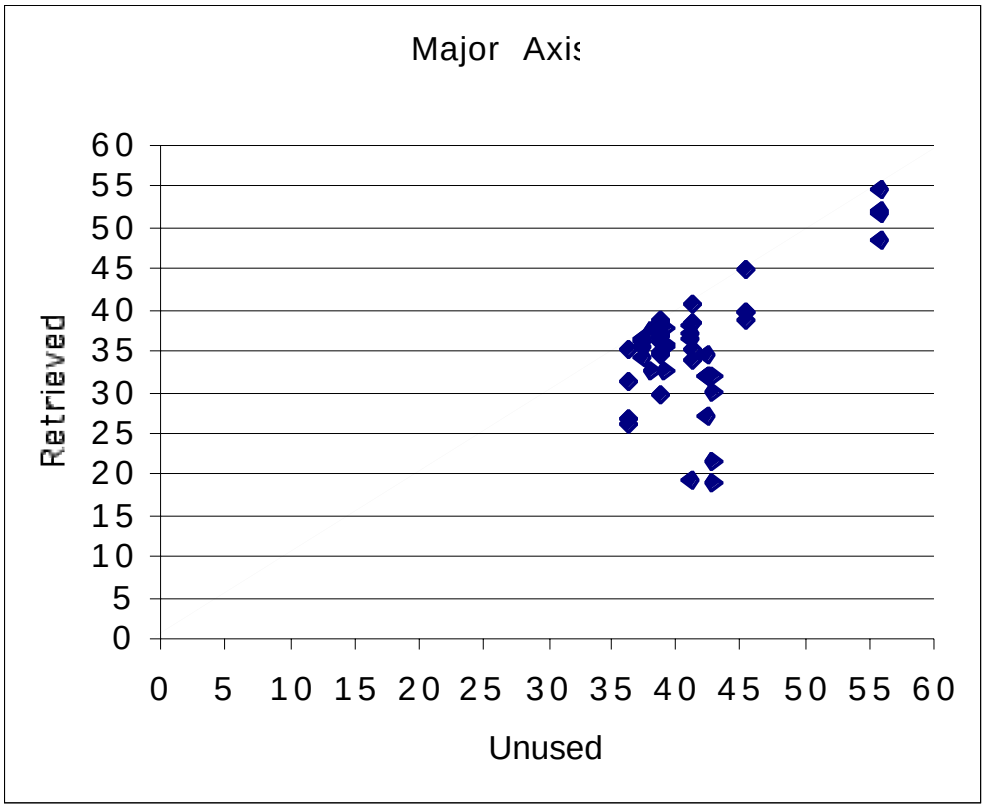

Figure 4: Comparison of the balance stability angles for retrieved and unused glenoids along the 0 and 180 degree axes. Note that the preponderance of the values for the retrieved glenoids fall below the corresponding values for the unused glenoids.

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Seattle, Washington 98195-6500

Phone: (206) 543-3690
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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) 598-4288

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

Incoming Residents

Jonathan Braman: Jon attended Princeton University where he received a B.A. degree in English. He received his medical degree from the University of Washington. He is completing his surgical internship here at the University of Washington. His interests outside of medicine include creative writing, gardening, and International Rules Squash Racquetball.

Michael McAdam: Mike attended Texas Chrisian University in Fort Worth, Texas, where he obtained his B.A. degree in three majors: Chemistry, Biology, and Spanish. He earned his M.D. from the University of Texas-San Antonio. He is currently a surgical intern at the University of Washington.

Jason Thompson: Jason received his B.S. degree in Biology from Wake Forest University. He earned his M.D. from the University of Miami. He is currently completing his internship at the University of Washington. Personal interests include water skiing, pipe carving, and mountain biking.

Alexis Falicov: Alexis attended the University of California at Berkeley where he received a B.A. in Physics and Mathematics. He attended MIT where he was awarded his Ph.D. in Physics. He received his M.D. from Harvard. He is finishing his surgical internship at the University of Washington. Alexis enjoys sports and playing the piano in his spare time.

Thea Wojtkowski: Thea attended Stanford University where she received her B.S. degree in Biology with interdepartmental honors in Humanities. She received her M.D. from the University of Washington, where she is currently a surgical intern. Her interests include skiing, mountain biking, and swimming.

Graduating Residents
Class of 2000

Joel Hoekema, M.D., following his residency he will be doing a spine fellowship in Vancouver, B.C. In the future, he hopes to practice medicine in the Northwest.

Cara Beth Lee, M.D., will participate in a fellowship in Sports Medicine at the University of Washington. She hopes to continue to practice in the Northwest in the future.

Patrick McNair, M.D., will moving to Palo Alto, California to participate in a Sports Medicine fellowship and hopes to begin private practice on the west coast following his fellowship.

Dan Jones, M.D. will be doing a sports medicine fellowship at the Minnesota Sports Medicine Center. He plans to return to the Northwest to pursue private practice.

Brett Quigley, M.D., will be part of a spine fellowship at Case Western Reserve University in Cleveland, Ohio..

2000 Department of Orthopaedics New Faculty

Nancy J. Kadel, M.D.

Nancy Kadel recently joined the University of Washington Department of Orthopaedics as an Assistant Professor specializing in foot and ankle surgery.

Dr. Kadel received her education from Whitman College in Walla Walla, Washington, Sarah Lawrence College in Bronxville, New York, and the University of Washington School of Medicine, where she attended medical school. Her internship was spent at Mount Sinai Hospital in New York City. She completed her residency at the Harvard Combined Orthopaedic Residency Program.

As well, she has completed a fellowship with the Boston Foot and Ankle Center of New England Baptist Medical Center in Boston.

Dr. Kadel sees patients at the University of Washington Medical Center.

NATIONAL RESEARCH GRANTS
DEPARTMENT OF ORTHOPAEDICS

National Institutes of Health (NIH)

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

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

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

Skeletal Dysplasias
David R. Eyre, Ph.D.

Veterans Affairs Medical Center Review Grants

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

Rehabilitation Research and Development Center of Excellence for Limb Loss Prevention and Prosthetic Engineering
Bruce J. Sangeorzan, M.D.

Centers for Disease Control

Age-Related Cervical Spine Mechanics and Injury Tolerence
Randal P. Ching, M.D.

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

Orthopaedic Research and Education Foundation (OREF)

Collaborative Opportunities in Orthopaedic Traumatology Research
Frederick A. Matsen III, M.D.

The Shoulder Function and Health Status of Individuals with Documented Rotator Cuff Tears Before and After Treatment: A Multicentered Prospective Study
Frederick A. Matsen II, 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.

Neural Instability of the Cervical Spine
Sohail K. Mirza, M.D.

American Society for Surgery of the Hand

Prospective Randomized Clinical Trial of Hand Therapy Following Carpal Tunnel Surgery
Thomas E. Trumble, M.D.

Axonal Sprouting from Intact Peripheral Nerves
Thomas E. Trumble, M.D

Using Intact Nerve to Bridge Peripheral Nerve Defects: An Alternative to the Use of Nerve Grafts
Thomas E. Trumble, M.D.

Cervical Spine Research Society

Cervical Spine Instability as Measured by Neural Space Occlusion
Sohail K. Mirza, M.D.

Genetics Institute

A Quality of Life Assessment in Patients with Open Tibial Fractures
Sohail K. Mirza, M.D.

National Highway Traffic Safety Administration

Age-Dependent Properties of the Spine
Randal P. Ching, Ph.D.

Neck Mechanics and Injury Tolerance as a Function of Developmental Age
Randal P. Ching, Ph.D.

NATIONAL RESEARCH GRANTS
DEPARTMENT OF ORTHOPAEDICS

Pfizer, Inc.

Pfizer Study
David R. Eyre, Ph.D.

Spinal Dynamics Corp.

Spinal Dynamics Baboon Testing
Randal P. Ching, Ph.D.

BRD Functional Disc Space Prosthesis Development Project
Randal P. Ching, Ph.D.

Arthroscopy Association of North America

The Effect of Total Meniscectomy on Articular Cartialge Deformation
Peter T. Simonian, M.D.

National Childhood Cancer Foundation

Childrens Cancer Group
Ernest U. Conrad, M.D.

Boeing

Randomized Clinical Trial of Open versus Endoscopic Carpal Tunnel Release and Hand Therapy Comparing Patient Satisfaction: Functional Outcome and Cost Effectiveness
Thomas E. Trumble, M.D.

Wyeth-Ayerst Clinical Research

Safety and Efficacy of Two Intravenous Dosages of GAR-936 for Complicated Skin Infections: A Prospective Randomized Trial
William J. Mills, M.D.

Ostex International, Inc.

Molecular Markers of Connective Tissue Degradation
David R. Eyre, Ph.D.

Contributors to Departmental Research and Education

APRIL 1999 THROUGH MARCH 2000

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 offer 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.

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