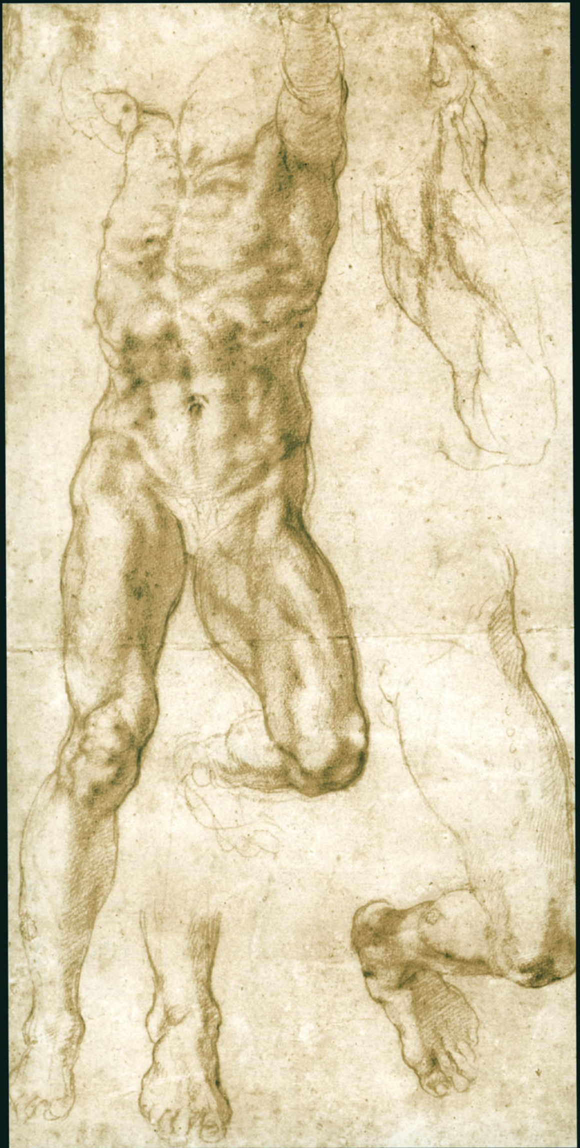
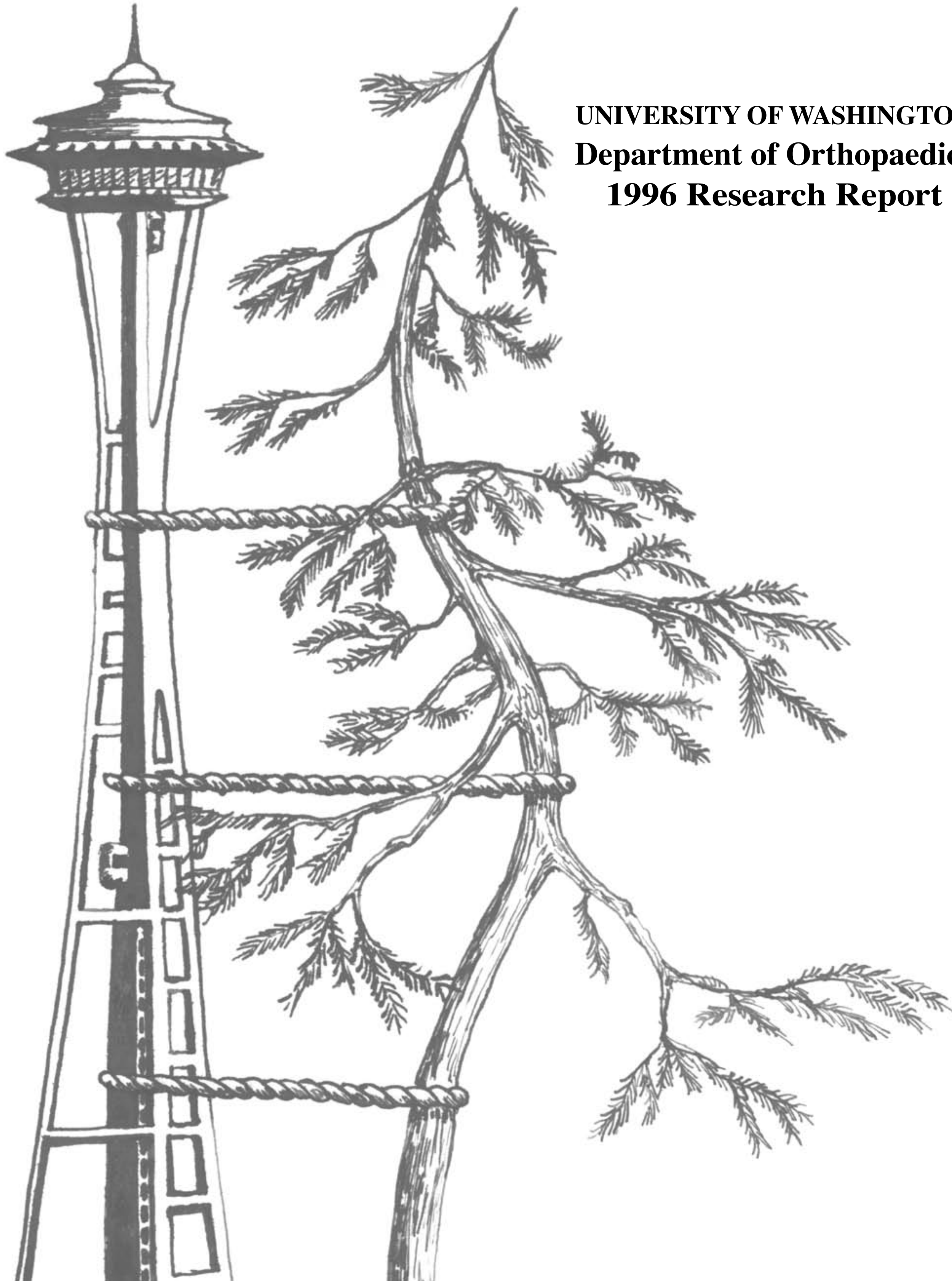
UNIVERSITY OF WASHINGTON
Department of Orthopaedics
1996 Research Report





UNIVERSITY OF WASHINGTON
Department of Orthopaedics
1996 Research Report

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Cover Illustration: "Four Studies for the Sistine Haman" by Michelangelo is reprinted with permission of the Trustees of the British Museum, London, England.

Contents

Foreword

This year's Research Report recognizes the excellence of our Sports Medicine and Fitness program. The members of this broad-based interdisciplinary team provide an outstanding resource to all active individuals, including the high performance varsity athlete, the skier with an anterior cruciate ligament tear, and the mother who wants to get back to playing soccer. We recognize that such individuals not only have unique talents and abilities, but also particular challenges and problems which require specialized expertise. At our April 1996 annual retreat, the faculty of the Department designated Sports Medicine as one of our most important growth areas for the next year. We have launched the recruitment of a new faculty member to help us realize the marvelous opportunities that exist at the University of Washington to develop a premier Sports Medicine Program in the Northwest.

The cover of this year's Research Report is Michelangelo's "Four Studies for the Sistine Haman". Michelangelo Buonarroti (1475-1564) is best known for his treatment of the human body in his paintings and sculpture; his figures convey a sense of strength and energy, the very essences of sports medicine and fitness. The Sistine Haman shows the knee, one of the athlete's greatest assets, but also a source of vulnerability which is of primary concern in Sports Medicine. The 1996 Research Report contains a representation of investigations by our faculty and residents which are of major relevance to the active person, including the effect of medication on cartilage repair, arthritis in ballet dancers, amputee athletes, broken necks, unstable shoulders, torn knee ligaments, wrist injuries and much more. Our hope is that these articles give the reader a flavor of the breadth and depth of our Sports Medicine and Fitness program.

This year marks the thirtieth anniversary of the establishment of the Department of Orthopaedics by D.K. Clawson, who recognized that in order to achieve excellence, Orthopaedics must become a department in its own right. Since its founding in 1966, our Department has been nationally recognized for excellence in research, teaching and clinical care. UW Orthopaedics research continues to be among the top recipients of national funding for research - one of the most rigorous tests of investigator quality. Many of our faculty and resident research programs are supported by grants from the National Institutes of Health, the National Science Foundation, the Centers for Disease Control, the Veterans' Affairs, the Orthopaedic Research and Education Foundation, and the Arthritis Foundation.

The quality and relevance of Departmental research is also being recognized by our patients and the community. This year we have received major donations initiating endowed funds for research in sports medicine, spine, and shoulder. The Don and Carol James Research Endowment in Sports Medicine, the Spine Research Endowment, and the E.A. Codman Endowment for Shoulder Research continue to attract donations while the interest on these endowments is already at work supporting excellence in research in their respective areas. The appointment of Sigvard T. Hansen, Jr. as the first holder the Endowed Chair of Orthopaedic Traumatology which bears his name enables the interest on this endowment to go to work supporting excellence in research related to major musculoskeletal injuries.

The beneficiaries of this research excellence are our patients who receive better evaluation and management as a direct result of the Department's commitment to investigation. As examples, Douglas Harryman's receipt of the Richard O'Connor Award of the Arthroscopy Association of North America recognizes his innovative approach to the management of stiff shoulders. Allan Tencer developed the Joint Machine for visualizing the complex three-dimensional motions of normal and injured joints. David Eyre developed the assay which enables clinicians to measure bone loss, whether in the athlete or the elderly individual. Linda Sandell identified a new marker, CD-RAP, which opens vast opportunities to learn how cartilage repairs itself. John Sidles is making rapid strides to build a magnetic resonance force microscope which would enable us to see biologically active molecules and understand how they function. Marc Swiontkowski has developed and validated an instrument for measuring the effectiveness of treatment for musculoskeletal injuries and diseases. The importance of this research to active individuals is clear.

A primary mission of the Department of Orthopaedics is education. As a new millennium dawns we recognize that in addition to our dedication to the best orthopaedic education for our medical students and residents, we must add commitments to the education of primary care physicians and public. As an example, we are proud that Lynn Staheli was selected as the first recipient of the Distinguished Service Lectureship Award by the American Academy of Pediatrics. Our educational program takes many forms, including clinical rotations and public seminars. Recently, we have begun to make quality bone and joint information available world wide through our site on the World Wide Web (http://www.orthop.washington.edu/). Please visit our web site where you will see the familiar glass skeleton which covered our 1993 Research Report. The American Academy of Orthopaedic Surgeons recognized our home page as an example of the effective use of the Internet in orthopaedic education.

May I take this opportunity to recognize all the faculty, staff, residents, and friends who have made the essential contributions to the continued excellence of the Department of Orthpaedics. Special appreciation goes to Peter Simonian and Robbi Kearns for their partnership in the editing and production of this year's report.

Best wishes,

Frederick A. Matsen III, M.D.

Chairman

Anti-inflammatory Medications: Effect on Cartilage Synthesis

LINDA J. SANDELL, PH.D.

There are drugs now available that can, for example, improve cardiovascular function and delay the onset of cardiac decompensation. It is likely that chondroprotective medicinal agents and other therapies should become available to retard joint degeneration, and not simply to relieve pain. The most commonly prescribed drugs for treatment of the symptoms of joint degeneration are the nonsteroidal anti-inflammatory drugs (NSAIDs). In this article I will address the effects of these drugs on the joint, primarily cartilage, and what is known about the potential for drugs presently available to retard joint disease.

DEGENERATION OF CARTILAGE

The major constituents of the extracellular matrix of mature hyaline cartilage found in diarthrodial joints are type II collagen (with small amounts of types IX and XI) and the cartilage-specific, large aggregating proteoglycan called aggrecan. Collagen, a structural protein, provides strength to the tissue, while the highly negatively charged proteoglycan provides resiliency. The chondrocyte, a terminally differentiated cell, is the single cell type of hyaline cartilage responsible for the maintenance of the cartilage-specific matrix phenotype under normal conditions. Under pathological conditions, such as inflammatory joint disorders or osteoarthritis, (OA), chondrocyte function is altered and there are changes in the composition of the extracellular cartilage matrix. The factors responsible for the altered function of chondrocytes in conditions such as rheumatoid arthritis or OA have not been fully identified. There is evidence, however, that the increased production of "inappropriate" cytokines or alterations in the temporal sequence of their release contributes to the abnormalities in connective tissue that characterize these conditions. Several cytokines originally defined as immu-nomodulators or growth factors are expressed at the level of mRNA or protein in the synovial fluid or tissue of joints affected by arthritis. Among these cytokines, interleukin-1 (IL-1, previously called catabolin) may play a particularly important role as it has been shown to stimulate synovial cells and chondrocytes to produce prostaglandin E_2 (PGE_2) and a variety of proteinases implicated in the breakdown of connective tissues. Because IL-1 increases the synthesis of non-cartilage types I and III collagens by synovial fibroblasts and chondrocytes, it can also contribute to ineffective repair of the damaged cartilage matrix and the fibrosis observed in later stages of these disorders.

Cartilage destruction results from an imbalance between degradation of the extracellular matrix (ECM) by enzymes and attempts at repair, both controlled by the chondrocyte. It is believed that this imbalance between synthesis of matrix components and their destruction causes the erosion of the joint surface. However, in OA and various models of joint degeneration, the synthesis of these ECM molecules increases dramatically during an attempt to repair the eroded cartilage. Figure 1 shows the basic steps in the synthesis of extracellular matrix components. In early stages of joint disease, the enzymes that can degrade the extracellular matrix, primarily collagenase (specific for collagen) and stromelysin (capable of degrading many matrix components), are not very active and are synthesized by the cell at a low rate. During more advanced joint disease, however, these enzymes may be activated and synthesized at a greater rate or inhibitors may be removed, perpetuating the destruction of the joint cartilage.

NONSTEROIDAL ANTI-INFLAMMATORY DRUGS

The pain-relieving effects of NSAIDs have been compared and found to be approximately equivalent when taken in the recommended dosages; however, the effects of NSAIDs on joint destruction may be quite different. Some NSAIDs have even been implicated in the acceleration of joint destruction. The NSAIDs are thought to act primarily through the inhibition of prostaglandin synthesis; however, some effects appear to be unrelated to prostaglandin

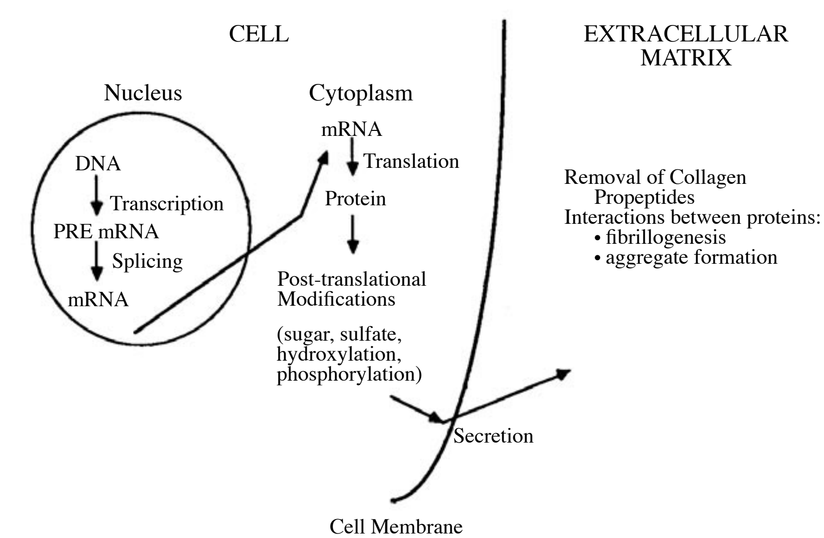

Figure 1: Diagram of the biosynthesis of extracellular matrix proteins. Information necessary to make proteins resides in the DNA. DNA is transcribed into PRE mRNA. Exons of the PRE mRNA are spliced together to produce the mature mRNA, which is transported into the cytoplasm of the cell. The mRNA is translated into protein and posttranslational processing occurs, including hydroxylation of prolines in collagen, addition of carbohydrate chains to collagens and proteoglycan, sulfation and phosphorylation of amino acids and sugars, and the addition of glycosaminoglycan chains to proteoglycans. The macromolecules then are secreted into the extracellular environment, where collagens form fibers and proteoglycans form large aggregates.

production. Results reported recently comparing two NSAIDs with different effects on inflammation and cartilage matrix synthesis showed that both drugs enhanced degeneration of both the affected hip and the contralateral hip (Rashad et al, 1989). In fact, in both areas there was a significant reduction in articular surface cartilage, concentrations of proteoglycans, synovial tissue prostaglandin and related intermediates. In contrast, other studies, primarily in vitro, indicate that many NSAIDs do not interfere with certain chondrocyte functions and consequently have been thought by some to be "chondroprotective." Strategies used to investigative the effect of NSAIDs on cartilage destruction range from looking at the effects of drugs on cartilage in vivo to the use of isolated cell cultures in vitro.

In vitro Studies of the Effects of Anti-inflammatory Drugs on Cartilage

Almost all of the studies to date have been performed on isolated articular chondrocytes from weightbearing joints, such as the human knee, the metacarpal-phalangeal joint of adult bovines, or the human costal chondrocytes. Factors that appear to effect results are the age and tissue origin of the chondrocytes and the conditions under which the cells are grown.

The majority of reported investigations of the effects of NSAIDs on cartilage matrix repair have focused on synthesis of proteoglycans which, together with type II collagen, constitute greater than 95% of hyaline cartilage matrix. The cytokine IL-1 suppresses synthesis of certain components of proteoglycans, as well as type II collagen synthesis, and inhibits chondrocyte proliferation. In addition, IL-1 stimulates proteases synthesis. One of the primary effects of the NSAIDs is to block the production of prostaglandins stimulated by IL-1. This is likely the mechanism by which NSAIDs could lower production of the degradative enzymes stromelysin and collagenase. The effect on matrix molecules is more complicated.

The effects of IL-1 on chondrocytes have been studied in detail. IL-1 increases prostaglandin E_2 (PGE_2) and synthesis of the degradative enzymes, collagenase, and stromelysin, and decreases type II collagen synthesis (Goldring and Goldring, 1990). Because one effect of NSAIDs is known to be inhibition of prostaglandin synthesis, a study was undertaken to determine whether various NSAIDs such as indomethacin, etodolac, or ketoprofen could alter the effects of IL-1 on matrix synthesis. To determine the effect of NSAIDs on IL-1-induced modulation of chondrocyte phenotype, juvenile human costal chondrocytes or adult articular chondrocytes in primary culture were incubated with etodolac, indomethacin, or ketoprofen in the absence or presence of IL-1ß (Goldring et al, 1990). After treatment, $[^3H]$ proline-labeled collagens were analyzed by the SDS-PAGE technique and types I and II collagen mRNAs were analyzed by Northern or dot hybridization (Figure 2A,B). In this experiment, the inhibition of type II collagen synthesis is actually potentiated by agents that block IL-1-stimulated PGE_2. In contrast, the synthesis of types I and III collagens and fibronectin (matrix components that are produced by chondrocytes which have lost the cartilage-specific phenotype) is increased by IL-1 in the presence of NSAIDs. Etodolac or ketoprofen produced a dose-dependent suppression of type II collagen synthesis associated with decreased levels of type II collagen mRNA in the absence of IL-1, while they potentiated the inhibitory effects of IL-1 (Figure 2A). In contrast, etodolac (2 to 2,000 nM) maintained expression of type II collagen protein and mRNA (Figure 2B). All three NSAIDs unmasked the stimulatory effect IL-1 had on the synthesis of type I collagen and fibronectin and on the levels of type I collagen mRNA. These results suggest that even though the capacity of these NSAIDs to reduce PGE_2 synthesis is similar, only etodolac was capable of maintaining type II collagen expression by chondrocytes (Goldring et al, 1990).

In similar studies we have examined the effects of naproxen on a variety of cell parameters. At concentrations present in the joint (less than 30 mg/ml), naproxen had no effect on collagen synthesis, DNA synthesis, or overall protein synthesis (Figure 3).

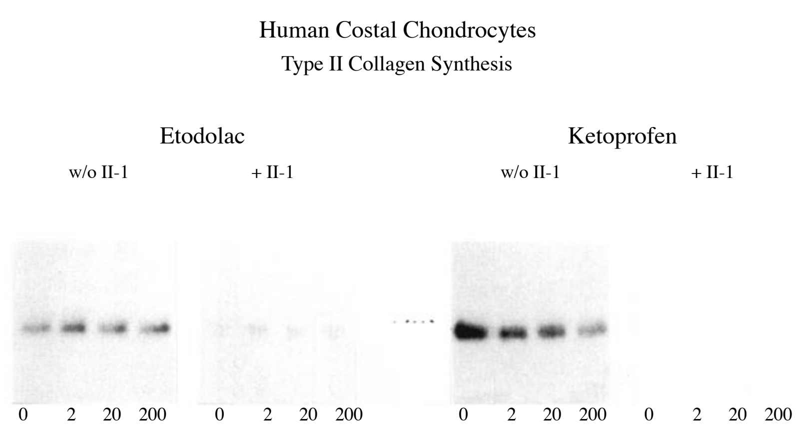

Figure 2A: Effects of etodolac and ketoprofen on synthesis of type II collagen by early cultures of human costal chondrocytes. Chondrocytes (from a 3-year-old boy) at day 8 of primary culture were incubated in the absence or presence of hIL-1b with increasing concentrations of etodolac or ketoprofen $[^3H]$. Proline then was added for a further 24 hours in fresh serum-free culture medium containing ascorbate. The pepsin-resistant collagen chains were analyzed by SDS-polyacrylamide gel electrophoresis and exposed to X-ray film. (Reproduced with permission from Goldring MB, Sohbat E, Elwell JM, et al: Etodolac preserves cartilage-specific phenotype in human, chondrocytes: Effects on type II collagen synthesis and associated mRNA levels. Eur J Rheum Infl, 10:10-21, 1990).

Studies with NSAID in vivo

NSAIDs relieve the symptoms of many patients with OA. Several in vivo studies using experimental models have shown that the effects of NSAID on OA cartilage lesions are quite different. For example, in the spontaneous OA model (C57 black mice), diclofenca and priprofen were found to be very effective in reducing the incidence and severity of OA lesions, while sodium salicylate and other NSAIDs increased the incidence and severity of these lesions. In the rabbit meniscectomy model, pirprofen was again found to be the only NSAID to reduce OA lesions effectively (for review, see Sandell,

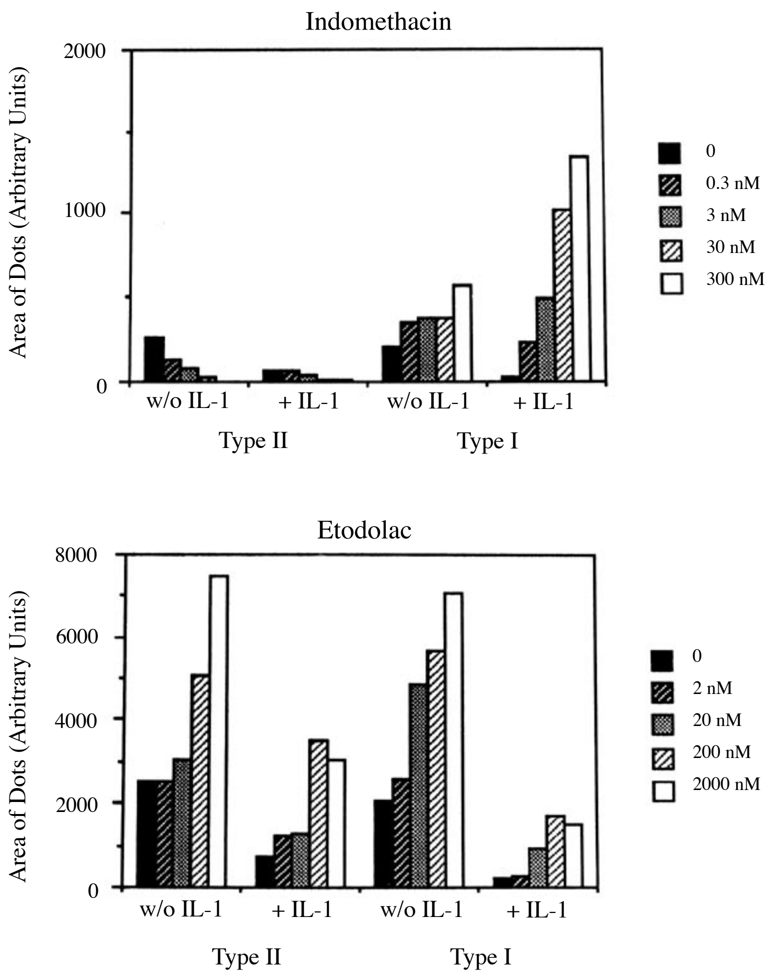

Figure 2B: Dot blot analysis of type II and type I collagen mRNAs in human costal chondrocytes: Effects of etodolac and indomethacin. Chondrocytes were incubated for 24 hours in the absence (w/o IL-1) or presence (+IL-1) of hIL-1b with increasing concentrations of (top) etodolac or (bottom) indomethacin in parallel with the cultures in 2A. Total RNA then was extracted from the cell layers, blotted on nitrocellulose, and hybridized against [32P]-labeled cDNA probes for type II or type I collagen. Values are plotted as the areas of the dots in arbitrary units obtained after densitometric scanning of autoradiographs. (Reproduced with permission from Goldring MB, Sohbat E, Elwell JM, et al: Etodolac preserves cartilage-specific phenotype in human chondrocytes: Effects on type II collagen synthesis and associated mRNA levels. Eur J Rheum Infl, 1990:10:10-21).

The Shoulder: A Balance of Mobility and Stability).

Although some NSAIDs have been reported to inhibit cartilage degradation in animal models of OA, it is generally accepted that NSAIDs do not slow the natural progression of joint degeneration in human OA. Salicylate treatment has been shown to accelerate cartilage breakdown in vivo. This may be related to its suppressive effect on proteoglycan synthesis demonstrated in normal articular cartilage in vitro. They found that this effect of salicylates was independent of effects on PGE_2 biosynthesis. Salicylates and ibuprofen inhibited proteoglycan synthesis by cartilage slices in vitro, but indomethacin, as well as peroxicam, had no effect . The effects of salicylates and peroxicam were consistent with those found in vivo. Goldring and associates (Goldring et al, 1990) also found that ibuprofen suppressed type II collagen synthesis by human chondrocytes but peroxicam had no effect . The failure of indomethacin to have an effect on matrix synthesis in the models of Palmoski and Brandt may indicate that direct exposure of chondrocytes denuded of their matrix in damaged cartilage may be required for these effects but not for the effects of PGE_2 biosynthesis. Indeed, it was found that indomethacin could inhibit proteoglycan synthesis after the cartilage proteoglycan had been depleted by hyaluronidase treatment.

Conclusion

Chondroprotection by Other Compounds: A major contribution to the field of "chondroprotection" has been made by the investigations on glycosaminoglycans (GAGs), which play a crucial role in the physiology of joint cartilage. Several other non-steroidal medications are being examined for potential "chondro-protective" characteristics. Some of these agents are oversulfated glycosaminoglycans (Arteparon) and glycosaminoglycan peptides (Rumalon). These agents are believed to have anti-inflammatory action, to increase proteoglycan synthesis (Collier and Ghosh, 1989), to inhibit certain enzymes present in the synovial fluid (such as elastase and hyaluronidase), and to be tolerated well by the patient. Based on the hypothesis that proper supplementation with GAGs might enable chondrocytes to replace the proteoglycans, galactosamino-glucuronoglycan sulfate (GAGG) has been used in a study that showed apparent clinical improvement (Pipitone, 1991).

Studies on the "chondroprotective" effects of any drug are hampered by incomplete knowledge of the pathogenesis of OA. Fundamentally, we do not know whether it is better to inhibit or increase cell activity, much less which specific molecular species to alter. Recent experimental applications of molecular biologic techniques in situ will reveal the synthetic state of each cell. It is hoped that a strategy will be developed to encourage proper cartilage repair without increased destruction.

Recommended Reading

Collier S, Ghosh P: Evaluation of the effect of antiarthritic drugs on the secretion of proteoglycans by lapine chondrocytes using a novel assay

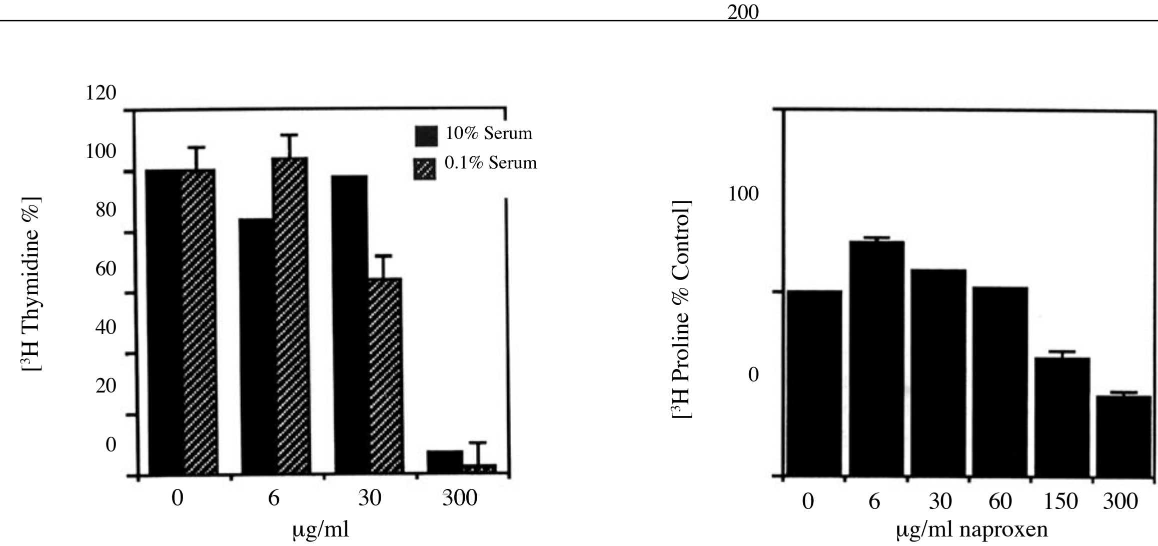

Figure 3: Left: Effects of naproxen on [^{3}H] thymidine incorporation by bovine articular chondrocytes. Cells in either 0.1% or 10% serum were incubated with increasing concentrations of naproxen, [^{3}H] thymidine was added to label DNA, and cells were harvested after four hours. The amount of radioactivity incorporated into protein was determined. Right: Effects of naproxen on collagen synthesis as measured by incorporation of [^{3}H]] proline into protein.

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A Molecular Defect in Type II Collagen Causing Kniest Chondrodysplasia

MaryAnn E. Weis, B.S., and David R. Eyre, Ph.D.

The osteochondrodysplasias are a heterogeneous group of skeletal disorders characterized by abnormal growth or development of osteochondral tissues. A sub-group is emerging based on mutations in the gene encoding type II collagen (COL2A1). Severity ranges from lethal in utero to essentially no overt defect in skeletal growth. The spectrum includes achondrogenesis, hypochondrogenesis, Kniest dysplasia, spondyloepiphyseal dysplasia (SEDc), spondyloepi-metaphyseal dysplasia (SEMD), familial osteoarthritis/ late-onset SED, Stickler syndrome and Wagner syndrome. Most of the reported mutations in type II collagen are being detected at the gene level, and often little or nothing is known of the molecular consequences in the expressed protein and tissue. In this study we report the identification of a novel mutation in a neonatal lethal case of Kniest dysplasia and present findings that relate the underlying mutation to altered structural protein in cartilage.

Methods

Cartilage tissue was obtained from a neonatal lethal case of Kniest chondrodysplasia that was diagnosed by characteristic skeletal radiographs and cartilage histology at The Skeletal Dysplasias Registry of Cedars-Sinai Medical Center in Los Angeles. Pepsin-solubilized collagen and cyanogen bromide (CB) peptides were prepared from the Kniest sternal cartilage and neonatal control cartilage. The collagen chains and CB-peptides were analyzed by sodium dodecyl sulfate-polyacrylamide gel electrophoresis (SDS-PAGE). Peptide α1(II)CB11 was purified by sequential cation-exchange and reverse-phase high-performance liquid chromatography (RP-HPLC). Pooled fractions containing pure CB11 were then digested with either trypsin or endoproteinase Asp-N and fractionated on RP-HPLC. Individual peptides were sequenced on a Porton 2090E protein microsequencer. Native collagen molecules extracted by pepsin were incubated with trypsin for 18 hours at various temperatures. The trypsin digest was electrophoresed on 6% polyacrylamide gels and blotted onto PVDF membrane for micro-sequencing of the major degradation

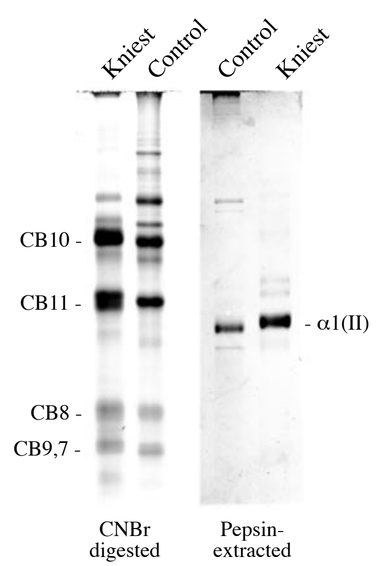

Figure 1: Electrophoresis (SDS-PAGE) of pepsin-extracted collagen and CNBr digested peptides from Kniest and control cartilages. The CB-peptide, α1(II)CB11, from Kniest cartilage runs as a doublet (12.5% gel, left lanes). The α1(II) chains from Kniest cartilage are slower and broader than controls indicating over-modification at synthesis (6% gel, right lanes).

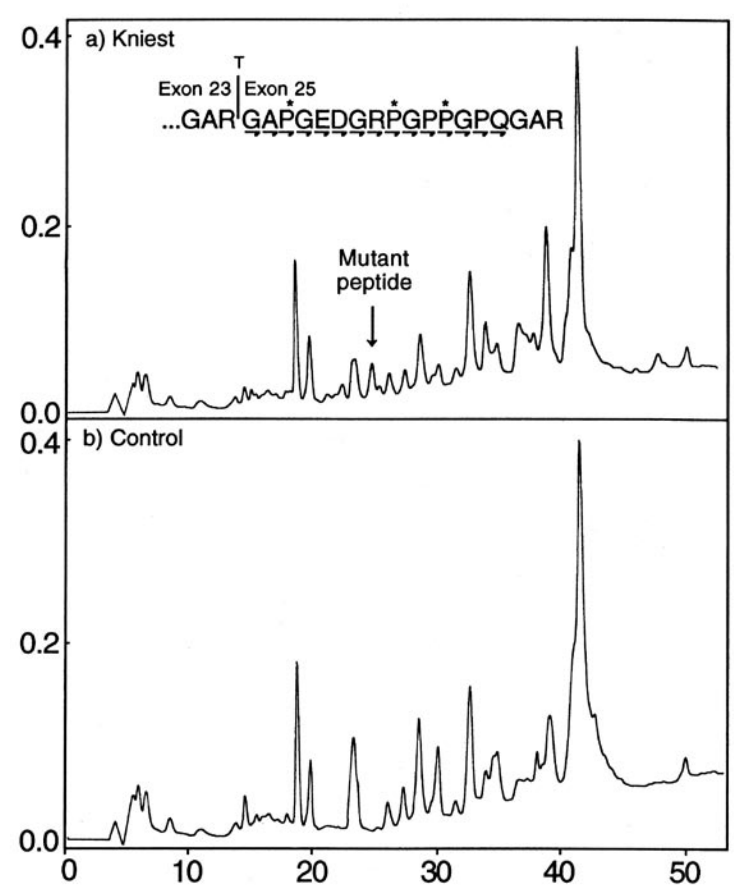

Figure 2: Fractionation by reverse-phase HPLC of tryptic peptides of α1(II)CB11 from (a) Kniest and (b) control human cartilages. The identified abnormal peptide sequence from the chain containing the deletion site is underlined in (a).

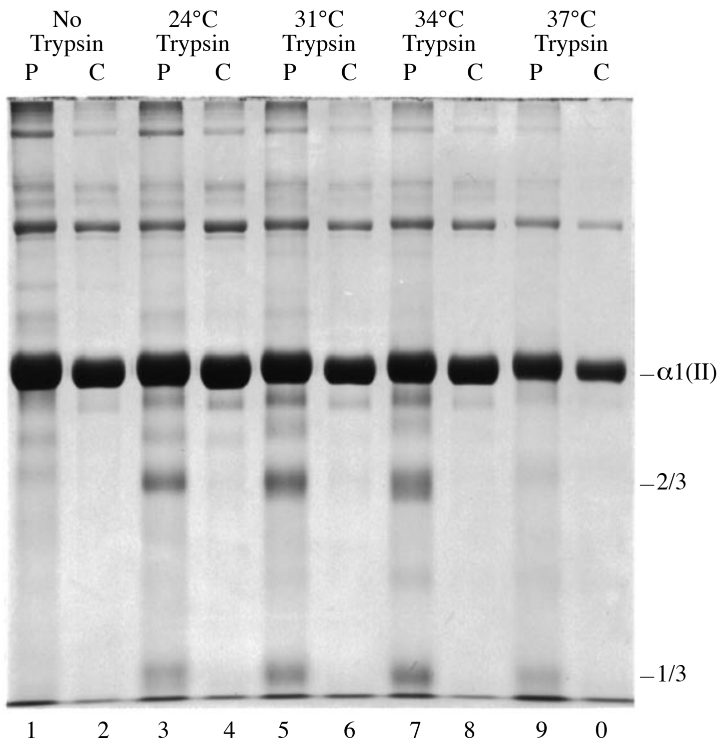

Figure 3A: Cleavage by trypsin of native type II collagen from Kniest cartilage. a) Electrophoresis (SDS-PAGE) of trypsin digests shows the degradation of Kniest collagen but not control collagen to 1/3 N-terminal and 2/3 C-terminal fragments at 24°, 31° and 34°C, with complete degradation of the fragments at 37°C. P=patient; C=control

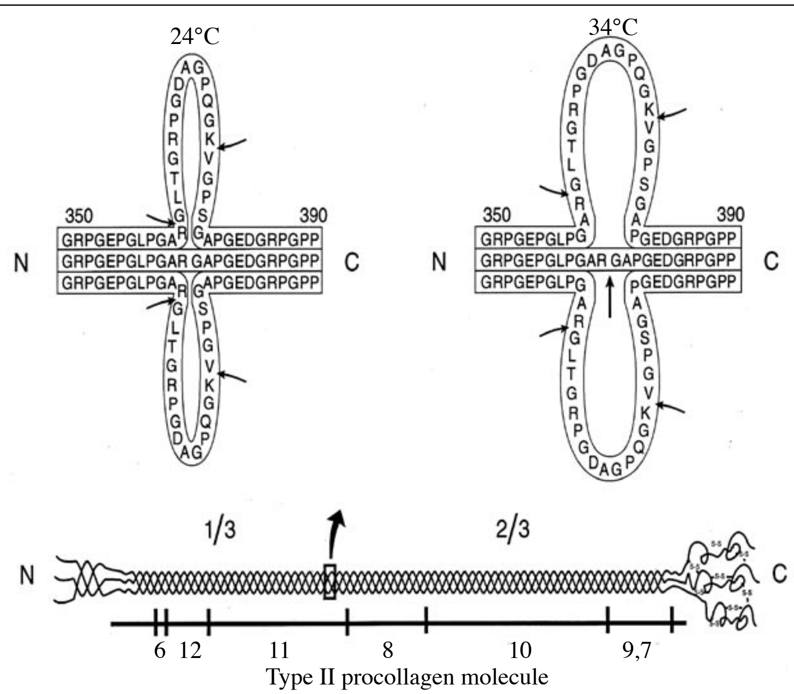

Figure 3B: Molecular illustration of the concept of misalignment of normal and deleted α1(II) chains at the site of deletion in the triple helix. The trypsin cleavage sites identified on sequence analysis are shown.

products.

Results and Discussion

The CB digest of Kniest cartilage showed a doublet for peptide α1(II)CB11 and slightly retarded mobility for all the major collagen type II CB peptides on SDS-PAGE, which indicated post-translational over-modification (Figure 1). The findings suggested a short peptide deletion in the faster form of peptide CB11. Further analysis of CB11 by tryptic peptide mapping and microsequencing revealed a novel tryptic peptide indicating that an 18 amino acid sequence corresponding to exon 24 (residues 361-378) was deleted (Figure 2). This exact deletion was confirmed by sequencing an endoproteinase Asp-N peptide that spanned the deletion site. The relative amounts of mutated and normal collagen α-chains in the cartilage matrix were about equal when calculated by the yields on protein microsequencing and the peptide band intensities of the CB11 doublet on SDS-PAGE. Molecular genetic studies established that the underlying defect was a single base change causing a splicing defect in one allele of the COL2A1 gene.

The following additional observations were made on the structural collagen of the cartilage. Failure to extract mutant α-chains in denaturing solvent (4 M guanidine hydrochloride, 0.05 M Tris, pH 7.4) showed that molecules containing the abnormal α-chains were incorporated and cross-linked into collagen fibrils. Further analysis of naturally cross-linked peptides indicated that both sites in the collagen molecule that participate in cross-linking had done so in normal ratio and amount (not shown). Native, extracted collagen molecules were also probed with trypsin to see if the triple-helical structure was disturbed by the deletion. (Trypsin cleaves protein chains at the carboxy-terminus of arginine and lysine residues, but not in a normal collagen triple-helix.) This experiment was designed to test whether a molecule that contained both normal and short chains, would fold into a triple-helix that ran smoothly but out of register across the deletion site. Alternatively, the normal chains might loop out causing a disruption at the mutation site but resume in register on either side (the latter concept is illustrated in Figure 3B). If exon 24 looped out, it was hypothesized that trypsin would cleave normal chains in the molecule within this domain. The results showed that this was so, with the normal α1(II) chains being cleaved within their exon 24 domain at 24°C. At 34°C the mutant chains were also cleaved at a new tryptic cleavage site created by the exon 23/exon 25 junction (Figures 3A, B). These findings indicate that mutated and normal chains do co-exist within the same molecule and that the triple-helix is dislocated at the deletion site, which probably results in a slightly shortened molecule.

The findings add to recent evidence that COL2A1 gene-splicing mutations are a common cause of Kniest chondrodysplasia. The results of the trypsin digestion experiments add support to a concept that the distinctive tissue phenotype of Kniest dysplasias is based on a class of mutations in type II collagen that alter the structure and stability of cross-linked collagen fibrils in a distinctive manner.

Acknowledgments

This report is a summary of the University of Washington contribution to a collaboration with colleagues at Cedars-Sinai Medical Center in Los Angeles under Dr. David Rimoin, supported by a Program-Project Grant from the National Institutes of Health.

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Osteoarthritis and Retirement in Professional Dancers

CAROL C. TEITZ, M.D. AND RAY F. KILCOYNE, M.D.*

Dance is very physically demanding on the joints particularly in the lower extremity. These demands are due not only to impact, but also to the extremes of range of motion required, particularly in ballet. Ballet dancers are also thought to be hypermobile, a condition associated with premature osteoarthritis. Professional dancers' performing careers tend to end when they are in their 30's. The purpose of this study was to identify the prevalence and relationship of hypermobility and osteoarthritis in a group of young retired professional dancers, and to assess the influence of these factors on their retirement from performance careers.

METHODS

Fourteen former professional dancers (nine women and five men) between the ages of 27 and 46 were examined by the first author. History included age at the onset of training, number of years of training in various dance disciplines, and age at which pointe work was begun (for females who had been ballerinas). In addition, all were asked about any injury they had suffered with regard to its location, treatment, mechanism, and time in the performing season. We also asked about any currently painful joints and about family history of scoliosis and bunion formation.

The physical examination included assesment of the spine for scoliosis, range of motion of all major lower extremity joints, tests of knee stability, and alignment of the knees, feet, and toes. In addition, four tests were used to assess generalized ligamentous laxity. These included the ability to touch the thumb to the anterior surface of the ipsilateral forearm, the presence of recurvatum at the knees and/or elbows, and the maintenance of the longitudinal arch of the foot when standing.

Radiographs were taken of both hips, knees, ankles, and feet in all subjects. They were then mixed in with radiographs of the same joints from twenty patients who had presented to the UW Sports Medicine Clinic and who were in the same age range as the dancers. All radiographs were read by the second author (a musculoskeletal radiologist) without knowledge of whether the film belonged to a dancer or non-dancer. Findings consistent with osteoarthritis such as sclerosis, joint narrowing, osteophytes, and cyst formation were noted. In addition the radiologist listed acetabular dysplasia, capsular calcifications, the angle of the first metatarsal relative to the second metatarsal, and the length of the first metatarsal relative to the second.

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RESULTS

The age of the males ranged from 30–46 with a mean of 34.7; the females ranged in age from 27–44 with a mean of 35.5. The age at which the males began dancing ranged from 7–21 with a mean of 15 years of age. The age at which the females began dancing ranged from 3–22 with a mean of 8 years of age. All dancers, with the exception of one woman who had only danced ballet, had danced both ballet and modern repertoires. The number of years danced by the men before stopping averaged 9.5 years for ballet and 8.8 years for modern. The number of years danced by the women before stopping averaged 14 years for ballet and 8 years for modern. Typically the dancers began in ballet and later switched to modern dance. Seven of the nine females had worked "en pointe." One started pointe work at the age of 5, whereas another didn't start until the age of 23. The mean age for starting pointe work was 10 years and 4 months. Two of the four males had suffered three knee injuries, and one each had suffered a back or ankle injury. Two of the knee injuries occurred during class as did the back injury. One knee injury occurred during rehearsal, and the ankle injury occurred during performance. Five of the nine females had suffered knee injuries, three had suffered back injuries, and four had suffered ankle injuries. Three of the five knee injuries occurred during rehearsal, two occurred in class. Two back injuries occurred in class, one occurred during rehearsal. All ankle injuries occurred during rehearsal.

At the time of the study, all of the females and two of the males were teaching dance. The males taught 8 and 12 hours per week. The females taught on average 15 hours per week with a range from 2–30 hours per week. Only one dancer cited a physical reason for stopping professional dancing. This was due to knee instability after tearing her anterior cruciate ligament. Three dancers stopped due to economic reasons. Two stopped because they no longer wished to be traveling and "having no social life." The remainder stopped for emotional reasons, often citing that they were no longer as good as they thought they should be.

Range of motion of the lower extremity joints is shown in Table 1. The smallest difference between range of motion in the right and left sides of any joint was zero, and the greatest difference was 45° (internal rotation of the hip). In the hip, the mean side to side difference was 7.18°. In the knee, it was 5.30°, and in the ankle it was 4.42°. In addition to range of motion, the knee exam revealed a positive patellar inhibition test in one

Table 1: Average range of motion in degrees.

	Females	Males
Hip		
Abduction	52	50
Adduction	31	29
Flexion	135	145
Internal Rotation	40	23
External Rotation	35	52
Thigh /Foot Axis	+8	+16
Knee		
Flexion	142	151
Quadriceps angle	15	12
Ankle		
Plantarflexion	78	85
Dorsiflexion	15	10
Eversion	31	19
Inversion	30	25

female dancer's knee. There were no positive patellar apprehension tests. Patellar tenderness was present in one male knee and in four female knees (one each). Medial collateral laxity was found in one male knee and in three female knees (two in one dancer). Lateral collateral laxity was found in five female knees (two each in two dancers). There was no genu valgum. Two males had 2 inches of space between their knees (genu varum), one had 2.5 inches. Six females had genu varum ranging from .5 to 3.5 inches with a mean of 2 inches. Two males and two females had a positive anterior Lachmann's test. One female had a pivot shift. During the foot exam, bunions were noted in no males and in five feet in three females. Hallux valgus was noted in no males and in two feet in two females (this was also confirmed radiographically). With the exception of ankle plantarflexion, none of the joints had ranges of motion significantly different from that of the general population. Furthermore, none of the dancers was considered hypermobile, defined as 3/4 positive tests for ligamentous laxity. Three female dancers had 1/4 tests positive and two had 2/4 tests positive. One of the male dancers had 2/4 tests positive.

Three female dancers complained of unilateral hip pain. One male and one female dancer complained of unilateral knee pain. two females complained of ankle pain, one unilateral and one bilateral, and two females complained of bilateral first MTP joint pain.

The radiographic findings are noted in Tables 2 and 3. When we looked at the site of pain and compared it to radiographic findings, only five of nine complaints were associated with obvious degenerative changes in the painful joint. Decreased range of motion was found in only two of nine painful joints.

Conclusions

None of the dancers in this study was hypermobile. Radiographic findings of osteoarthritis were found in thirty-three lower extremity joints of ten dancers compared with three non-dancers' hips. However, only nine dancers complained of pain in one or more joints, and these complaints were associated with radiographic findings of osteoarthritis in only five. Pain was associated with decreased range of motion in one dancer. Only one dancer retired because of a joint related problem, a torn anterior cruciate ligament. Although this study suggests that professional dance is associated with premature osteoarthritis in the lower extremity joints, these joints are not always symptomatic nor are they typically the cause of ending one's career as a professional dancer.

Table 2: Radiographic findings in dancers and non-dancers.

	Dancers	Non-dancers
Hip osteoarthritis	5 hips in 4 subjects	3 hips in 3 subjects
Acetabular dysplasia	5 hips in 4 subjects	none
Capsular calcification	10 hips in 7 subjects	1 hip
Knee osteoarthritis	4 pat/fem, 1 medial	none
Ankle osteoarthritis	13 ankles in 9 subjects	none
1st MTP osteoarthritis	10 joints in 5 subjects	none
Short first metatarsal	19 in 9 subjects	7 in 4 subjects

Table 3: Radiographic evidence of osteoarthritis in dancers.

DancerGenderHipKneeAnkle First MTPTotal
1F0
2 F11226
3 F22
4 F0
5 F2 2
6F22
7 F0
8 F123
9 F22
10 M112
11 M11125
12 M2125
13 M1124

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Exercise in the Health Care Prescription

Robert B. Schoene, M.D.

Human performance is a topic that crosses many areas of medicine. Within this term resides the synergism of body and mind which leads to a more productive and fulfilled life. In this context we have studied humans at the limits of performance in order to understand how to optimize day-to-day existence, whether it be in elite athletes at the extremes of high altitude and sea level competitions or in patients with severe limitations from heart and lung disease whose major goals are to walk to the mailbox or clean their house. Thus, interest in the relationship of exercise to overall well being became woven into the fabric of our everyday academic life.

Our first investigations along these lines explored variations in breathing control and exercise performance in women track athletes during different phases of the menstrual cycle. During the second half of the menstrual cycle, the week before the period, the female hormone progesterone is quite high and stimulates breathing. We studied elite track runners who were menstruating normally, runners who were not having their periods, and normal active women as controls. During this phase of the menstrual cycle, as compared to the first half, the breathing responses to low oxygen, high carbon dioxide, and exhaustive exercise were elevated with no difference being noticed in the amenorrheic athletes. The control women experienced a diminution in their exercise performance while the athletes did not. We attributed this difference to the fact that highly competitive athletes were not impaired by the experience of higher shortness of breath since they are accustomed to intense exercise every day. The changes were modest but consistent and focused our research on breathing responses and exercise performance in athletes as well as patients with lung disease.

Shortly thereafter we realized that similar physiologic responses played a role in maintaining adequate oxygen while climbing at extreme altitudes on Mount Everest. These investigations were stimulated by the fact that the level of oxygen available at extreme altitudes is so low that very brisk breathing responses during climbing are necessary to insure adequate oxygen in the lung for the blood to take to the tissues. Not all climbers breathe enough to allow them to go to these extreme heights. Additionally, we discovered some of the limits of physical performance and cost to the brain under these extreme conditions. For instance the level of oxygen above 24,000 feet is so low that there may not be enough available to insure that the brain, which is quite sensitive to oxygen deprivation, will continue to function well and may even undergo some transient damage. These findings in our research expedition to Everest in 1981 were the first to document clearly the inherent risks to the brain in venturing to extreme altitude. Furthermore, these lessons about the resilient and resourceful adaptations of the human body have taught us much about patients in the Harborview Intensive Care Units who also are trying to maintain adequate oxygen delivery to the tissues during heart and lung failure, severe infection, and trauma.

Studies during the intervening years have furthered our understanding of breathing control and maximal oxygen delivery in diverse groups ranging from elite synchronized swimmers, oars women, climbers, runners, and cyclists to patients with chronic obstructive lung disease, restrictive lung diseases, and survivors of the adult respiratory distress syndrome. Furthermore, we have documented an increased incidence of approximately 19%, as opposed to about 5% in the normal population, of exercise-induced asthma. Although we do not fully understand the reason why the incidence is higher in athletes, recognition and proper treatment can result in no impairment in performance at the highest levels of competition. This information has helped coaches and team physicians to be aware of this condition which, if recognized, is easily treatable so that athletes can continue to enjoy their sports and compete successfully, whether as "weekend warriors" or Olympic athletes.

It is never too late to begin exercise. In conjunction with the Division of Geriatrics we have collaborated on studies which show that healthy older individuals (ranging from 65 to 90 years of age) can train and improve their aerobic fitness, muscle strength and mass.

The clinical and physiologic

Finalists in the women's 1500 meters at the 1993 US Track and Field championships who, along with 250 other athletes, were subjects in a study of the incidence of exercise-induced asthma in elite athletes.

research has attained an even more exciting and intimate relationship to our medical practice. Recent data reports from a number of centers, including UWMC, have supported the hypothesis that exercise has profound implications on all levels of health. Over the last twenty years, many studies have supported the long-assumed contention that aerobic exercise will decrease the incidence of cardiovascular disease, such as heart attacks, strokes, hypertension, and decrease the levels of cholesterol and fats in the blood that lead to heart and vascular disease. Although the intensity of exercise that is necessary to convey a decreased incidence of myocardial infarction, hypertension and stroke is still an area of controversy, clearly what we thought to be true for many years has indeed been verified with scientific studies.

Of equal importance are the findings from many recent studies which show that any type of strength and weight bearing training in all age groups can enhance muscular strength and bone density and can decrease the level of disabilities and incidence of extremity and large joint fractures. This is particularly true in older age groups who have a high morbidity and mortality rate from such injuries and insure a great burden on health care costs.

This last year it has been our goal in conjunction with practitioners in Family and Internal Medicine, Women's Health, and the Bone and Joint Center at UWMC Roosevelt to incorporate exercise in all of our patients. We hope that at some point to initiate clinical investigations to test the hypothesis that both aerobic and strength-training exercise is beneficial to general health and should become an important part of the prescription that physicians give their patients. In the meantime, we are continuing our work on the effect of low oxygen on muscular performance, as well as trying to improve our understanding of what causes pulmonary edema in healthy

Amputee Athletes

DOUGLAS G. SMITH, M.D.

Physical exercise and athletic competition provide immeasurable benefits to the body and the mind. Although physical impairment may place new challenges to athletic participation, amputees have successfully competed in activities ranging from golf and bowling, to high school wrestling and football, to professional boxing. Every amputee is not ideally matched for every sport. Helping the amputee find an interesting and challenging activity, suggesting training protocols, and prescribing prosthetic modifications can assist in returning to athletics. The amputee may find training and re-learning lost skills to be frustrating, and discovering well-matched competition is often easier said than done.

As health care professionals we should encourage physical fitness, provide information on physical activities geared towards an individual with a physical impairment, and provide adaptive prosthetic or orthotic devices when appropriate. Remember, when discussing what sports are possible: never say never. To quote Jeff Keith, an above-knee amputee, who made a successful run across the states in June 1984, "disabled does not mean unable."

TRAINING

Cardiovascular conditioning through aerobic exercise program is critically important to all individuals. Recent amputees may be starting out in a more de-conditioned state, so specific consideration must be given to setting up a program with realistic goals and gradual improvement. Amputees have a unique training consideration in the interface of the residual limb and prosthesis. For amputee sports where a prosthesis is not worn, consideration should be given to protection of the residual limb from trauma and controlling edema in the residual limb. Stump protectors are lightweight sockets designed to allow full motion at the proximal joint and yet protect the residual limb from outside impact. Shrinker socks are often needed to control edema that can result from vigorous activity in an unprotected amputated limb. For sports where the prosthesis is worn, the skin of the residual limb is at increased risk of breakdown and ulceration. Consideration must be given to direct impact injury, increased severity and frequency of pistoning that can result in shear breakdown of the skin, and the increased moisture resulting from exercise induced perspiration.

SPECIAL PROSTHETIC CONSIDERATIONS

Skin-Socket Interface. New materials, especially the silicon based liners and suspension systems have been a major improvement. The silicone liners appear to lessen perspiration, decrease the motion and shear between the skin and the liner, and improve impact absorption. A silicon suspension system does add approximately $1200 to the initial cost of the prosthesis, and liners costing $320–$400 need replacement every 4 to 6 months. These silicone suspension sleeves are immensely popular with active amputees, and I believe that for the active patient the benefits are worth the cost. Amputee socks with a rim of silicon impregnated only at the top are a simpler, and less costly alternative in some patients. These socks can improve suspension without costly prosthetic mod-ifications, but do not quite offer the same degree of suspension. For the few patients who develop an allergic reaction to the silicon materials, other foam or gel liners are also available.

Skin cysts. The increased friction and perspiration from athletics can result in a higher frequency of ingrown hairs and other small skin cysts on the residual limb. Moist heat from a warm tea bag applied for 10–15 minutes, 3–4 times per day is a popular remedy from the amputee support group, and is felt to speed the resolution of these irritation skin lesions.

Impact Absorption. Reduction of impact from the prosthesis to the residual limb can occur at the liner, pilon, prosthetic joints, foot, shoe, and even the playing surface. The dynamic response feet, of which there are now many variations, are a huge im-provement from the traditional solid ankle cushion heel feet. Spring loaded pilons, similar to automobile shock absorbers, are also available to lessen the impact of foot over foot running. The Terry Fox Running Prosthesis is one such example and was built from ideas that Terry Fox conceived during his 3,330 mile run across Canada in 1980.

Rotational Units. Amputee golfers have noted that the lack of rotation in many lower extremity prostheses restrict the rest of the body from completing a full turn necessary for an effective golf swing. Special units are available to increase the rotation within the prosthesis. These are usually incorporated into the ankle unit of the prosthesis.

Waterproof Systems. Swimming is an excellent aerobic exercise for the entire body, and places little stress and impact on the residual limb. Prosthetic devices can be constructed to be functional in swimming or scuba diving. Consideration needs to be given in prosthetic design to avoid material prone to corrosion or water damage. Special suspension sleeves to keep the skin-socket interface dry are also required. Unique terminal devices that allow a swimming flipper to be securely attached in a plantiflexed position for swimming, but allow the flipper to be dorsiflexed up to accommodate walking are also now available.

Cycling/Pedaling. Cycling is an excellent activity for many lower extremity amputees and, like swimming, places relatively little stress and impact on the residual limb. Several considerations can be helpful in improving the ability of the amputee to cycle. Traditional prosthetic sockets can limit knee or hip flexion. Special consideration to lower socket trim lines or more flexible socket materials can improve the comfortable range of knee or hip flexion and decrease irritation. Many amputees prefer to have the prosthetic foot positioned more forward on the pedal to allow a more direct line of force transmission from the socket to the pedal. Securing the foot to the pedal to allow better force transmission but still allowing for quick release are very important considerations. Special adaptive clips and release mechanisms for the amputee have been developed. For transtibial amputees who want to improve upward pulling through their prosthesis, secure suspension often becomes the limiting factor. The silicon suction suspension systems mentioned above, can provide enough suspension to improve the upward pull through the prosthesis.

Running. Running is not for everyone. Although the news media has focused attention on the few amputees who have excelled at running, most amputees choose not to run. The impact to the residual limb, the frequency of skin breakdown, and the unpleasant aspect of soreness and pain in the residual limb are frequently mentioned as the reasons for choosing not to run. We definitely support running as an exercise for the interested amputees who choose to do so, but the potential problems need to be discussed and addressed. In addition to considerations of impact absorption, optimum prosthetic fit, suspension, and alignment are critical. Since most people land on the forefoot of the prosthesis when running, force transmission is slightly different than with the heel impact of walking. Specific attention needs to be given to minimizing anterior distal pressure and impact on the residual limb. Additional gel inserts or a full gel liner can help, as well as preventative skin care with products such as 2nd Skin™ or Spenco™ Skin Care Products.

Upper Extremity Terminal Devices. Many devices have been specially created to improve the ability of upper extremity amputees to participate in recreation activities. Adaptive devices to better hold fishing poles have been very popular. The special terminal device that allows gripping and swinging a golf club often can make the difference in returning to the course.

Summary

Every effort should be made to encourage and assist patients with physical limitations to resume participation in athletic activities that are appropriate for them. The adaptive devices and modifications for prostheses described above barely touch on the many innovations that are available. Further information is available in the table below about special resources related to sports for the disabled.

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Special Resources Related To Sports For The Disabled

American Amputee Foundation
Jack M. East, Executive Director
Box 55218, Hillcrest Station
Little Rock, AR 72225
(501) 666-2523

International Foundation for Wheelchair Tennis
Peter Burwash, President
2203 Timberlock Place, Suite 126
The Woodlands, TX 77380
(713) 363-4707

American Wheelchair Bowling Assoc.
Daryl L. Pfister, Secretary-Treasurer
N54 W15858 Larkspur Lane
Menomonee Falls, WI 53051
(414) 781-6876

International Wheelchair Road Racers
Joseph M. Dowling. President
30 Myano Lane, Box 3
Stamford, CT 06902
(203) 967-2231

Amputee Soccer International
Mr. Bill Barry
c/o Johnson and Higgins
1215 Fourth Avenue
Seattle, WA 98161
(206) 292-1900

National Amputee Golf Association
Bob Wilson, Executive Director
P.O. Box 1228
Amherst, NH 03031
(603) 673-1135

Amputees in Motion
Carol Hall, President
P.O. Box 2703
Escondido, CA 92025
(619) 454-9300

National Foundation of Wheelchair Tennis
Bradley Parks, President
940 Calle Amancer, Suite B
San Clement, CA 92672
(714) 361-6811

Handicapped SCUBA Association
Jim Gatacre, Program Director
116 West El Portal, Suite 104
San Clemente, CA 92672
(714) 498-6128

National Handicapped Sports
Kirk M. Bauer, Executive Director
1145 19th Street, NW Suite 717
Washington, DC 20036
(301) 652-7505

National Wheelchair Athletic Assoc.
3595 East Fountain Blvd. Suite L1
Colorado Springs, CO 80910-1740
(719) 574-1150

U.S. Amputee Athletic Association
Dick Bryant, President
P.O. Box 560686
Charlotte, NC 28256
(704) 598-0407

National Wheelchair Basketball Association
Stan Labanowich, Director
110 Seaton Building
University of Kentucky
Lexington, KY 40506
(606) 257-1623

U.S. Wheelchair Racquet Sports Assoc.
Chip Parmelly
1941 Viento Verano Drive
Diamond Bar, CA 91765
(714) 861-7312

National Wheelchair Softball Assoc.
William J. Scebbi, Executive Director
P.O. Box 33150
Denver, CO 80233
(303) 452-1212

Exercise-induced Compartmental Syndromes

FREDERICK A. MATSEN III, M.D.

Recurrent leg pain with exercise is a commonly observed symptom among active individuals. A relatively small number of patients with this symptom have recurrent compartmental syndromes due to intensive use of muscles.

PATHOPHYSIOLOGY

Muscle volume may increase at least 20% with exercise because of both increased capillary filtration and an increased blood content of exercising muscle. If the compartmental fascia is sufficiently lax, this increase in compartmental content can be accommodated without a significant increase in intracompartmental pressure. However, if increased muscle volume with exercise produces an increase in tissue pressure sufficient to interfere with muscle blood flow, a compartmental syndrome results. Vigorous muscle contraction alone can increase intramuscular pressure to levels that compromise muscle blood flow. Thus, the maintenance of circulation adequate to meet the high metabolic demands of rhythmically exercising muscle requires the rapid recovery of blood flow between contractions. In a recurrent compartmental syndrome, tissue pressure remains high between contractions, impeding muscle blood flow and producing a relative circulatory insufficiency as long as the vigorous exercise continues.

DIAGNOSIS

Recurrent compartmental syndromes differ from their more notorious cousin, the acute compartmental syndrome, in that symptoms recur with intensive use of the muscles of the affected compartment and dissipate with relative rest. Recurrent compartmental syndromes of the leg are typically found in athletes and military recruits. The patient typically notes a painful, tight sensation in the affected compartment along with weakness of the muscles in that compartment which comes on after a more or less predictable amount of exercise. For example, a patient with a recurrent anterior compartmental syndrome of the leg may develop a foot-slap on heel strike due to weakness of the tibialis anterior muscle. Occasionally, paresthesias are experienced in the distribution of the nerves running through the affected compartment.

The physical examination of the patient at rest is often unremarkable. Some patients may have fascial defects at the site of emergence of the superficial peroneal nerve from the anterior compartmental fascial. Thus, symptoms may arise from the compartmental syndrome, from herniation of muscle through the defect, or from local compression of the nerve.

Because this syndrome is produced by exercise, it is most useful to examine the compartment during and after vigorous exertion of the muscles in the compartment. The compartment may be most conveniently exercised by asking the patient to repeatedly contract the compartmental muscles against manual resistance until characteristic symptoms are produced. At this point the compartment may be palpated for tenseness and the muscles examined for weakness. When involvement is unilateral, the opposite side is used for comparison.

The common diagnoses requiring differentiation from recurrent compartmental syndromes include tendinitis, fatigue fractures, and the poorly understood entity known as shin splints. These conditions are probably more common causes of exercise-related leg pain than are recurrent compartmental syndromes. Although they may produce leg symptoms similar to those of recurrent compartmental syndromes, these conditions are not accompanied by indications of increased intra-compartmental pressure. In addition, whereas many patients can run through symptoms due to these conditions, such is not the case with compartmental syndromes.

While the history and physical examination are usually sufficient to make the diagnosis, tissue pressure measurements using the infusion technique may be helpful. In this method, a blood pressure transducer is used to monitor the pressure necessary to infuse saline at a rate of 0.1 cc per hour into the muscle of the suspected

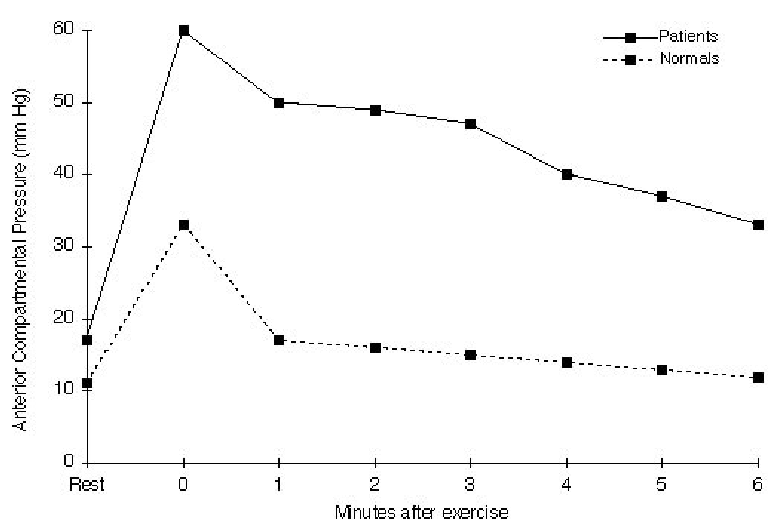

Figure 1: Results from our pressure exercise test in patients with recurrent anterior compartmental syndromes requiring surgery on clinical grounds (n=5), (solid line) and control subjects (n=12), (dotted line). Ordinate shows anterior compartment pressure at rest and after 3 minutes of repeated dorsiflexion at a rate of one per second against a 6 hg force. The patients demonstrated a higher post exercise peak pressure and a slower return to pre exercise values.

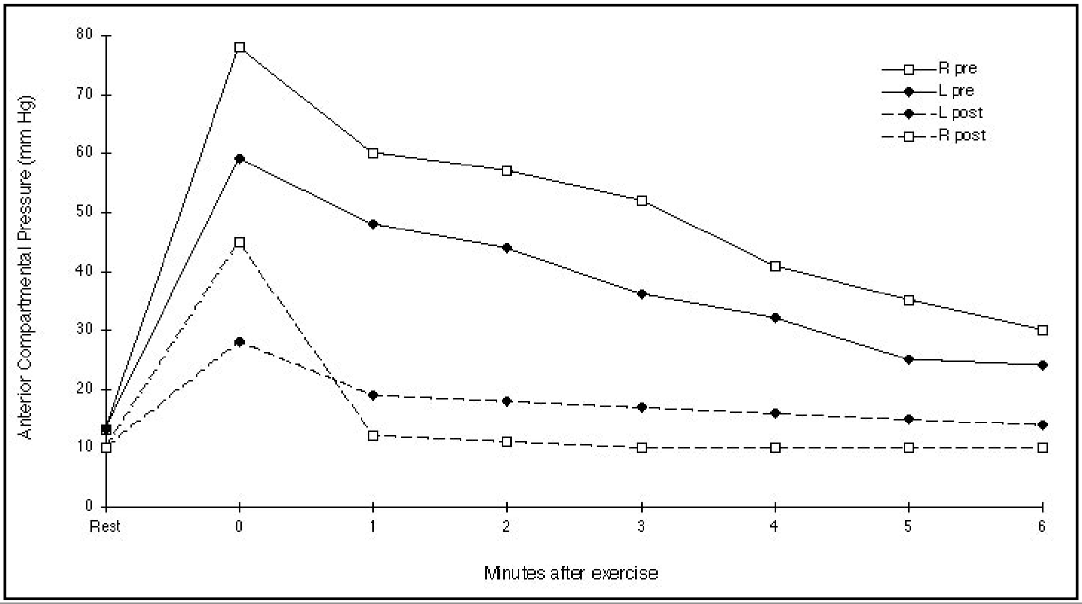

Figure 2: Results from pressure exercise test in a world class race walker. Pre decompression values are shown for the left and right legs (L pre & R pre). Surgical decompression of the anterior compartments restored the values essentially to normal.

compartment through an 18 gauge catheter. With the catheter in the muscle of the compartment, base-line readings are obtained. The patient is then asked to contract the compartmental muscles against resistance at a rate of one per second for three minutes. Particular notice is taken if the patient's symptoms are reproduced during the exercise test.

We studied seven anterior compartments of the leg in five patients believed to have recurrent compartmental syndromes because of their clinical findings. We also studied a control group consisting of six male and six female volunteers (age range 12 to 61 years; average age, 28 years). In our patient group, resting anterior compartment pressure averaged 16+2 mm Hg compared with 11+2 mm Hg in our control group (mean+SD). The post exercise pressure curve in the patient group deviated dramatically from that of the control group. For the patients, the post exercise pressures were higher and did not return to pre-exercise levels within six minutes (Figure 1).

Treatment

Many patients with recurrent compartmental syndromes due to intensive use of muscles are relieved to gain an understanding of their condition and are willing to modify their exercise program to avoid the resulting symptoms. Some serious athletes, however, are unable to modify their exercise program and request surgical decompression.

In recurrent compartmental syndromes due to intensive use of muscles, the surgical procedure is quite different from that used for treating acute compartmental syndromes. First, the procedure is not an emergency. Second, one compartment can usually be clearly identified as being responsible for the patient's symptoms. Third, post ischemic swelling is not anticipated after the operative procedure; thus, subcutaneous fasciotomy is appropriate. The fascial incision is made through two small skin incisions and runs the entire length of the compartment, leaving no fascial bridges. Care is required to avoid injuring the branches of the superficial peroneal nerve in decompressing the anterior compartment of the leg. At the end of the procedure, the skin is closed with a cosmetic suture. The patient is warned that the extremity may swell with dependency for a few days up to a few weeks after the procedure. A progressive exercise program is instituted one week after surgery.

To date we have operated on ten anterior compartments for recurrent compartmental syndromes. These have included runners, recreational walkers, a race walker, an ice skater, field goal kicker, a pilot, and a professional soccer referee. All had significant improvement after their surgical procedure and returned to their activities.

The following case report presents an instructive example of a recurrent compartmental syndrome due to intensive use of muscles:

A 32 year-old world class race walker had a 15 year history of painful tightness in both anterior compartments during exercise. His symptoms would typically appear in the first three or four miles of race walking at a competitive speed, although they could be avoided if he walked at a somewhat slower pace. The pain was accompanied by weakness of foot dorsiflexion noted as a foot-slap on heel strike. The patient also observed a vague numbness over the dorsum of his foot after the onset of pain. Although he was able to complete longer races and marathons, his speed was retarded by his symptoms.

Routine physical examination was unremarkable. No fascial hernias were detected. Upon repeated dorsiflexion of his foot against resistance, his anterior compartments became tense and his symptoms were reproduced. Anterior compartmental pressures were monitored using the continuous infusion technique during repeated contraction of the anterior compartmental muscles against resistance. Resting anterior compartment pressures measured 15 mm Hg on the left and 14 mm Hg on the right. Post exercise pressures were markedly elevated and showed a retarded return toward the pre-exercise level (Figure 2).

Subcutaneous fasciotomies of both anterior compartments were performed. Six weeks after operation the patient was asymptomatic. A repeat pressure test during exercise at this time revealed a normal response (Figure 2). The patient returned to full training and competition. He placed in the top five in the Pan American games six months after surgery.

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Transient Geometry of the Cervical Spinal Canal During In-

ALLAN F. TENCER, PH.D., RANDAL P. CHING+, JARROD CARTER*, RUTH OCHIA*, GEOFF RAYNAK*, JENS R. CHAPMAN, M.D., AND SOHAIL MIRZA, M.D.

A fracture of the cervical spine is serious, but usually recoverable. If the spinal cord is involved, however, non recoverable loss of function may be the end result. We hypothesized that spinal cord injury might be caused by any of three mechanisms: occlusion or constriction of its diameter, excessive elongation, and excessive shortening. The following describes a series of experiments in which spinal canal geometry changes have been monitored during simulated injuries.

SPINAL CANAL GEOMETRY MEASUREMENT METHODOLOGY

Two transducers have been developed for measurement of dynamic (20 msec duration) changes in cervical spinal canal diameter and length, as shown in Figure 1. The first uses a flexible PVC tube section placed within the cervical spinal canal of a cadaveric specimen after removal of the cord and nerve roots. The tube is attached upstream to a pressure transducer and a pump circulates water through the system and back to the reservoir. If the tube is constricted, an immediate pressure rise occurs upstream which is recorded by the pressure transducer. A second generation transducer, shown also in Figure 1, uses the same tubing filled with a conducting gel and six electrodes placed along the interior wall of the tube. The resistance measured between any two electrodes is dependent on the crossectional area of the tube between those electrodes along with the length between electrodes and the resistivity of the gel. This second generation device has two advantages over the first; it can be used when the spine undergoes extensive movement such as occurs during whiplash injuries. Secondly, the location of occlusion can be more specifically defined.

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THE EFFECT OF LOADING RATE ON SPINAL CANAL OCCLUSION

We hypothesized that under compressive impact a vertebra may fracture by one of two mechanisms. One is direct crushing of vertebral body bone. Another occurs as the pressure within the vertebral body rises, caused by fat and marrow located within the interstices of the trabecular bone and trapped within a decreasing volume as the vertebral body is compressed. The pressure rise is governed by the viscosity of the fat and marrow and the restriction to flow created by the vertebral body cortical shell and causes explosion of the body with retropulsion of bone into the canal. For the same input energy and loss of vertebral body height, loading rate may determine the extent of spinal canal occlusion. These results may provide guidelines for development of new types of padding systems which could prevent some of these injuries by controlling not just the energy absorbed but the loading rate during cervical spinal impact.

A pilot study was performed using six week old calf vertebral segments. The first generation occlusion transducer described above was placed in each, then 6 spines were loaded in direct axial compression at a rate of 400 msec from zero to peak load and fractured with loss of 25% of vertebral body height. The second group of six were fractured by impact over 20 msec. The same mean impact energy was applied to both groups, and canal occlusion was monitored. Post fracture CT scans and transient occlusion measurements showed dramatic differences in canal occlusion, with the low loading rate group sustaining compressive fractures with peak canal occlusions of about 10% and the high loading rate group demonstrating obvious canal occlusion which averaged about 47%. In ongoing studies the pressure rise within the vertebral body and the resistance to flow of the vertebral fat and marrow are being measured during impacts of different loading rates but similar energies. The overall goal is to define loading rate thresholds below which significant canal occlusion does not occur and then determine whether sports padding which controls loading rate can reduce canal occlusion during axial impact.

TRANSIENT AND RESIDUAL CHANGES IN CANAL GEOMETRY DURING AXIAL IMPACT

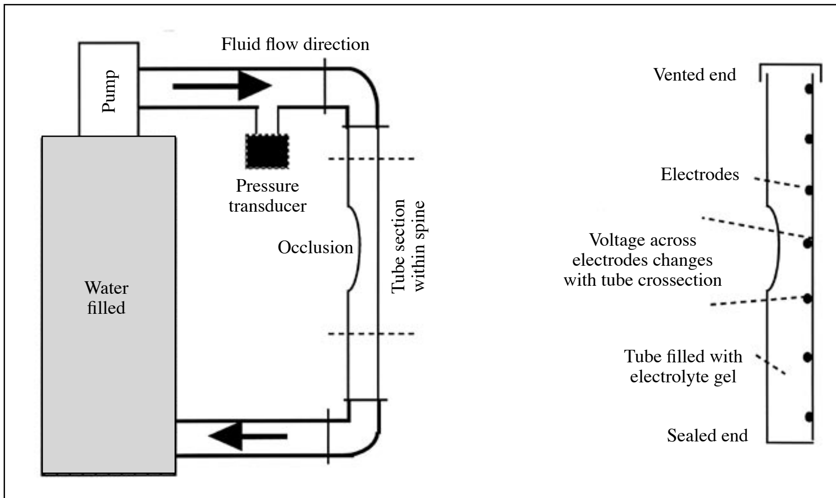

Figure 1: Schematic diagrams of two transducers used to measure spinal canal occlusion changes during simulated injuries, (left) first generation fluid flow system, (right) second generation resistance change system.

This study was designed to define geometric changes in cervical spinal canal geometry in burst fractures to determine whether residual post injury measurements of spinal damage, typically height loss and canal occlusion are predictive of the actual geometrical changes which occur during the impact event itself. To study these questions human cervical spines were mounted in a drop weight test frame, positioned in flexion to align the vertebra axially, instrumented as shown in Figure 1, and impacted using a drop weight to create the burst fracture.

Transient midsagittal spinal canal diameter during impact decreased by 70.5% compared to that of the intact spinal canal, while post injury, it was decreased by 9.4%, demonstrating that post injury observations do not correlate to the extent of occlusion actually occuring during the injury. In addition, these preliminary results indicate the following. The most likely position of the spine in which a burst injury would result is flexion, with the impact point just slightly anterior to the vertebral body. The mechanism of cord injury is canal occlusion. Occlusion can be caused not only by retropulsion of vertebral body bone into the anterior canal space but also by bulging of the ligamentum flavum from posterior with shortening of cervical column length, as shown in Figure 2. Current studies are comparing transient canal geometry changes due to axial compressive wedge fractures with those of high speed flexion and extension injuries.

Figure 2: Occlusion of the spinal canal in a burst fracture specimen due to bone retropulsion from anterior and ligamentum flavum bulge from posterior with segment shortening.

Post injury positioning of the spine after burst fracture

Some clinicians have observed that spinal cord injury symptoms may be worse by the time the victim reaches definitive care than at the onset of the injury in the field. One potential mechanism might be the position of the spine during emergency transport. A principle of emergency management consists of stabilization on a backboard which maintains cervical spinal lordosis and head position, and prevents movement during transport. We investigated the effect of spinal position (flexed, extended, etc.) on occlusion of the canal in burst fracture specimens post injury.

The specimens fractured in the previous study and classified as burst injuries were each mounted on a frame and instrumented so their direction and magnitude of angulation could be monitored as the spine was moved to different positions. Canal occlusion was also measured as described above. No traction was applied in this part of the study. The results are summarized in Figure 3, which is a plot of direction of spinal motion imposed manually and resulting canal occlusion expressed as percent of intact midsagittal diameter of the canal at the injury site.

Flexion of the spine appears to restore canal diameter to at least 85% of intact, compared to neutral position of about 76%, while extension reduces canal diameter to between 50% and 60% of intact. Considering that 70% of intact midsagittal diameter (i.e. 30% canal occlusion) is an approximate threshold for clinically significant cervical spine cord injury, it appears that significant changes in cord compression can occur just with spinal positioning post injury. The mechanism of canal occlusion (shown in Figure 2) is shortening of the spine along with extension causing the ligamentum flavum to bulge inwards and increasing canal occlusion. It is important to note that the position for transport used currently restores cervical spine lordosis and is similar to the position of extension that we measured. Further studies are planned to determine how spinal positioning affects canal occlusion after other types of cervical injuries.

Ongoing studies are addressing the following questions:

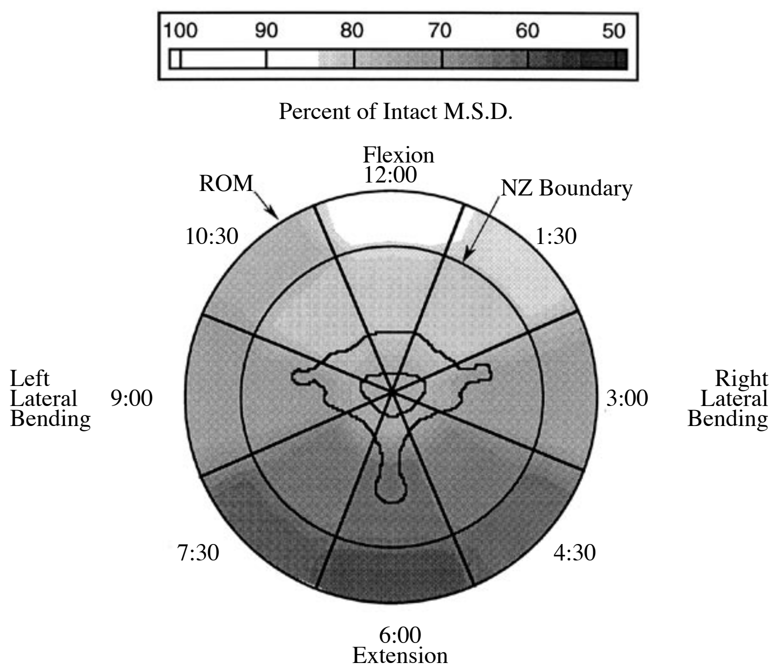

Figure 3: Diagram relating spinal canal occlusion to spinal angulation. Occlusion is expressed as percent of intact spine MSD (midsagittal diameter). Darker regions indicate directions of spinal motion which increase canal occlusion.

1. What is the mechanism of cord injury due to hyperflexion/extension?
2. What is the mechanism of injury due to "lateral bending whiplash" such as might be encountered during a side impact between two motor vehicles?
3. What tissues might be damaged in cervical whiplash (flexion-extension) injury resulting from low speed motor vehicle rear end collisions and what might be thresholds for damage?
4. Can more sensitive diagnostic tests for cervical whiplash be developed based on an understanding of the types and locations of tissue damage which occur?
5. With a newly published study demonstrating the ineffectiveness of 95% of seat headrests in preventing cervical whiplash, how does headrest design and position affect the potential for cord and tissue injury in low speed whiplash?

Acknowledgement

These studies were supported by grants from the AO Foundation, Berne, Switzerland, and by the National Center for Injury Prevention and Control, the Centers for Disease Control and Prevention, Atlanta, GA.

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Self-Assessed Deficits in Shoulder Function and Health Status in Individuals with Documented Rotator Cuff Tears

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Clinical conditions of the rotator cuff are common. The impact of these conditions on the patient's shoulder function and overall health status is highly variable. This report presents results obtained using standardized self-assessment questionnaires to determine the presenting status of patients with this condition and the changes in their status after management. Specifically, this study sought to answer three questions.

1. What deficits in shoulder function and health status are perceived by patients with documented rotator cuff defects?
2. Do age and gender correlate with the perceived deficits?
3. Which of these perceived health status and shoulder function deficits are lessened after management of rotator cuff tears?

In addition to addressing these specific questions, this study provides a practical and standardized method for documenting deficits in shoulder function and health status in patients with cuff tears.

METHODS

This study concerned a consecutive group of patients who:

1. Presented to one of us (FAM) for evaluation of their shoulder problem.
2. Satisfied the following pre-determined criteria for a documented rotator cuff tear: a history of functionally significant weakness of glenohumeral elevation and/or rotation, physical examination showing weakness of elevation and/or rotation, and definite identification of a full thickness cuff defect by one or more of the following: ultrasonography, arthrography, or MRI.
3. Had no previous surgery on the affected shoulder.
4. Completed self-assessment questionnaires (described below) at presentation and again after at least six months.

The mean age of the study population was 64 years (standard deviation of 16 years; range of 41 to 88 years). There were 44 males and 24 females. The mean follow-up was nineteen months (standard deviation, eight months; range; 6 to 34 months).

The SF 36 is a widely used general health status questionnaire which has been used to demonstrate the health status of control populations and populations with defined medical and psychological conditions, including the effectiveness of orthopaedic management. The SF 36 has no specific relevance to shoulder problems. In this investigation, eight SF 36 parameters were calculated for each submission by each patient as recommended by the authors of the instrument so that the maximum total score was 100 points for each parameter.

The Simple Shoulder Test (SST) is a practical shoulder-specific self-assessment tool. Its twelve questions were derived from common presenting complaints of patients with shoulder

Table 1: Deficits in shoulder function and health status at the time of initial diagnosis.

SST variable	normal mean	subject mean*	95% confidence interval †	p ‡
Comfortable at side	1.00	0.64	0.54, 0.73	<0.001
Sleep comfortably	1.00	0.30	0.21, 0.39	<0.001
Tuck in shirt	1.00	0.67	0.57, 0.76	<0.001
Hand behind head	1.00	0.59	0.49, 0.69	<0.001
Place coin on shelf	1.00	0.57	0.47, 0.67	<0.001
Lift pint to shoulder level	1.00	0.46	0.36, 0.56	<0.001
Lift gallon to head level	1.00	0.16	0.09, 0.23	<0.001
Carry twenty pounds	1.00	0.53	0.43, 0.63	<0.001
Toss softball underhand	1.00	0.49	0.39, 0.59	<0.001
Throw softball overhand	0.96	0.07	0.03, 0.13	<0.001
Wash opposite shoulder	1.00	0.41	0.31, 0.51	<0.001
Allow regular work	1.00	0.43	0.33, 0.53	<0.001

SF36 variable	control mean	subject mean *	95% confidence interval §	p ¶
Physical role function	70	29	20, 37	<0.001
Comfort	72	40	35, 46	<0.001
Physical function	77	61	55, 67	<0.001
Emotional role function	84	62	52, 73	<0.001
Social function	87	75	69, 82	<0.001
Vitality	61	58	53, 63	0.23
Mental health	77	75	71, 78	0.21
General health	68	72	66, 77	0.22

* positive values are clinically favorable
† confidence interval for binomial distribution
‡ p-value by Fisher's exact test against 80 normal subjects
§ confidence by interval for one-sample t-test
¶ p-value by one sample t-test against age and sex-matched controls

conditions. Subjects aged sixty to seventy years with normal rotator cuff sonograms have been shown to be able to perform essentially all of the SST functions, and the test-retest reliability of the SST is satisfactory for patients with compromised shoulder function.

The management for each shoulder was selected by the patient and the treating physician (FAM). Seventeen patients received surgical cuff repair, seven received subacromial smoothing with no cuff repair, and forty-four received non-operative management.

Data were collected and analyzed using commercially available databases and statistical software (Filemaker Pro, Claris and StatView, Abacus). Follow-up data were entered by an individual who was blinded to the initial status and the management selected (SED).

Results

Question 1: What deficits in shoulder function and health status are perceived by patients with documented rotator cuff defects?

For each SST question, the mean score at the time of presentation was computed, and ±95% confidence limits were calculated assuming a binomial distribution for these binary ("yes"/"no") variables (Table 1).

The fraction of "yes" SST answers ranged from 7% for the shoulder function "throw a softball overhand" to 67% for "tuck in shirt." All twelve SST deficits were significant at the $p<0.001$ level by Fisher's exact test, comparing the 68 cuff patients against 80 normal subjects.

The mean scores for the study group at the time of presentation were computed for each of the SF 36 variables, and ±95% confidence limits were computed assuming a t-distribution for the estimated mean (Table 1).

Statistically significant deficits were found in five of the eight SF 36 variables, namely "physical role function," "comfort (pain)," "physical function," "emotional role function," and "social function." No significant differences were found for "vitality (energy/fatigue)," "mental health," and "general health."

The control data for the SF 36 were derived from three separate population-based health status surveys. These reference data cohorts did not exclude individuals with chronic back pain, arthritis and other chronic conditions; thus these control data represent a population cross section and not the health status of "normal" individuals.

Question 2: Do age and gender correlate with the perceived deficits in shoulder function and health status?

While there are many factors which may affect the deficits perceived by patients with cuff tears (such as size of defect, duration of symptoms, on the job injury, etc.), in this cohort there were only sufficient data to statistically characterize their correlation with age and gender.

Results are shown in Table 2. The predictive value of gender (a binary variable) was assessed by Fisher's exact test for the SST and unpaired t-test for the SF 36. The predictive value of age (a continuous variable) was assessed with unpaired t-tests for the SST and Spearman rank correlation for the SF 36.

Gender had a marked effect on many SST shoulder functions; for example, 76% of male patients indicated they could "place hand behind head," compared to only 25% of female patients. This difference was significant with $p<0.001$ by Fisher's exact test. With the possible exception of the SF 36 "comfort" variable, age had no significant effect on any SST or SF 36 variable.

Question 3: Which of these perceived health status and shoulder function deficits lessened after management of rotator cuff tears?

A response variable is defined as the paired difference between a follow-up SST or SF 36 value minus the value at the time of presentation; thus positive values denote a favorable response to

Table 2: Gender and age as predictors of presenting deficits in shoulder function and health status.

	Gender Dependence mean SST score * split by gender				Age Dependence mean age split by SST		
SST variable	m	f	m-f	p †	yes	no	p ‡
Comfortable at side	0.78	0.38	0.41	0.001	64	64	0.56
Sleep comfortably	0.30	0.29	0.01	1.0	63	66	0.26
Tuck in shirt	0.85	0.33	0.52	<0.001	63	65	0.39
Hand behind head	0.76	0.25	0.51	<0.001	64	65	0.61
Place coin on shelf	0.65	0.42	0.24	0.002	63	65	0.56
Lift pint to shoulder level	0.54	0.29	0.25	0.08	65	63	0.43
Lift gallon to head level	0.24	0.00	0.24	0.01	63	69	0.10
Carry twenty pounds	0.76	0.08	0.68	<0.001	62	66	0.08
Toss softball underhand	0.65	0.17	0.49	<0.001	64	64	0.97
Throw softball overhand	0.09	0.04	0.05	0.65	64	69	0.45
Wash opposite shoulder	0.54	0.17	0.38	0.003	64	65	0.45
Allow regular work	0.57	0.17	0.40	0.002	64	64	0.92

	mean SF 36 score * split by gender				SF 36 correlation with age	
SF36 variable	m	f	m-f	p ‡	rho §	p ¶
Physical role function	31	24	7	0.73	0.25	0.12
Comfort	44	32	12	0.03	0.28	0.03
Physical function	66	50	16	0.01	0.18	0.16
Emotional role function	64	60	4	0.77	0.09	0.97
Social function	78	69	9	0.37	0.19	0.17
Vitality	62	49	13	0.04	0.15	0.24
Mental health	74	76	-3	0.65	-0.02	0.84
General health	72	70	2	0.86	0.05	0.74

* positive values are clinically favorable
† p-value by Fisher's exact test
‡ p-value by unpaired t-test
§ rho for Spearman rank correlation
¶ p-value by Spearman rank correlation

patient management (Table 3).

Almost all SST variables responded favorably to management. Only "tuck in shirt" and "wash opposite shoulder" failed to achieve $p<0.05$ by paired t-test.

SF 36 significance was assessed by paired t-test and Mann-Whitney U-test; these tests yielded essentially identical p-values. SF 36 variables "physical role function" and "comfort" were significantly improved after management.

Insufficient data were available to compare statistically the effects of non operative and operative management.

Discussion

In that patients are the ultimate judges of their own health and the effectiveness of their health care, patient self-assessment has an important role in initial and follow-up clinical evaluation.

This study establishes a rigorous self-assessment method by which patients can characterize their shoulder function and general health status. When applied to our study cohort of individuals with documented cuff defects, this method documented significant presenting deficits and demonstrated that some deficits were strongly affected by gender, but none by age. This fact needs to be considered when comparing groups of patients with rotator cuff tears. At follow-up, many presenting deficits were perceived to be diminished, even though the majority of these patients were managed non-operatively. This result, viewed against the background of the beneficial results reported for many methods of management, suggests that a large multipractice study will be necessary to determine the indications for different management options and to measure the effectiveness of individual protocols.

Table 3: Health status and shoulder function variables as affected by management of rotator cuff tears.

SST variable	response*	mean interval †	95% confidence p ‡
Comfortable at side	0.17	0.06, 0.28	0.002
Sleep comfortably	0.33	0.19, 0.47	<0.001
Tuck in shirt	0.10	-0.03, 0.23	0.13
Hand behind head	0.11	0.01, 0.22	0.03
Place coin on shelf	0.14	0.01, 0.27	0.03
Lift pint to shoulder level	0.21	0.08, 0.35	0.002
Lift gallon to head level	0.16	0.04, 0.28	0.01
Carry twenty pounds	0.17	0.06, 0.28	0.002
Toss softball underhand	0.19	0.06, 0.32	0.01
Throw softball overhand	0.20	0.08, 0.32	0.001
Wash opposite shoulder	0.10	-0.02, 0.22	0.11
Allow regular work	0.16	0.05, 0.27	0.01

SF36 variable	mean response*	95% confidence interval †	p ‡
Physical role function	16.4	6, 26	0.002
Comfort	14.1	8, 20	<0.001
Physical function	-2.4	-8, 3	0.42
Emotional role function	0.5	-11, 12	0.93
Social function	-1.3	-7, 5	0.67
Vitality	-1.9	-6, 2	0.35
Mental health	0.9	-4, 6	0.71
General health	-7.7	-11, -4	<0.001

* positive values are clinically favorable
† confidence interval by paired t-test
‡ p-value by paired t-test

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Arthroscopic Management of Shoulder Instability

DOUGLAS T. HARRYMAN II, M.D.

Shoulder instability is defined by Matsen, Lippitt, et al as the inability to maintain the humeral head centered in the glenoid fossa. Patients presenting with shoulder instability are usually between the ages of fifteen and forty. Unstable shoulders can be divided grossly into those that are displaced as a result of significant injury and others which become unstable without trauma. Key diagnostic criteria help us differentiate traumatic from atraumatic instability. This simple split into traumatic and atraumatic instability is often subdivided for treatment purposes according to the degree and direction of humeral head displacement. Treatment depends largely on symptoms or functional demand and not just on the anatomical lesion.

TRAUMATIC INSTABILITY

To date, 44 patients with traumatic instability have been treated with arthroscopic stabilization. Harryman repaired 27 of these patients using a direct intra-articular suture method developed at the University of Washington. The effectiveness and functional outcome of arthroscopic treatment for the initial 35 patients were included for this review (Table 1). Patients were considered for arthroscopic stabilization if they met the history and physical criteria described below and the diagnosis was further supported by radiographic findings:

1. A classic history of significant trauma with anterior humeral head displacement and/or episodic recurrent antero-inferior instability.
2. A clinical examination demonstrating apprehension or antero-inferior luxation on the crank test.
3. Radiographic evidence of a Hill-Sach's deformity, osseous Bankart lesion and/or erosion of the antero-inferior glenoid rim.

All patients failed non-operative management including initial immobilization followed by strengthening exercises. Five patients had failed previous open surgical stabilization. Each patient had symptoms of functional impairment restricting activities of daily living and/or sporting endeavors. All patients were offered open or arthroscopic surgical management and selected the latter.

The goal of the arthroscopic repair method was to duplicate the "all-inside" labral and capsular ligamentous repair described by Thomas and Matsen. The objectives of this surgical repair were to restore the gleno-labral concavity by anatomic suture reattachment of the labrum to the glenoid rim. All patients had a labral-ligamentous Bankart lesion. Significant articular cartilage and anterior glenoid rim erosion was identified in nearly 20% (Figure 1).

SURGICAL METHOD FOR TRAUMATIC INSTABILITY

After anesthesia administration, the diagnosis was confirmed by manipulating the unstable shoulder to reproduce the maneuver which provoked apprehension on outpatient examination. Glenohumeral arthroscopy was performed using a single posterior and two anterior portals for access. Once the Bankart lesion was identified and the retracted capsule and labrum freed from its bed, the anterior glenoid rim and scapular neck were decorticated.

The Seattle Bankart Guide, designed and tested in our arthroscopic laboratory, was inserted through the posterior cannula and locked in position on the anterior glenoid rim to drill holes for sutures. Sutures were placed through the anterior glenoid rim and capsular labrum to secure the ligaments anatomically to the glenoid rim (eight early patients also had an absorbable rivet device used in the repair). Two to five sutures, depending on the size of the Bankart lesion, were placed to afford an anatomic repair (Figure 2). Harryman determined this repair method proved safe, effective and durable to loads applied manually on clinical maneuvers.

RESULTS OF TRAUMATIC INSTABILITY

On preliminary review of the first 35 patients having an average follow-up of 28 months, (range of 7–44), we found a recurrent instability in four (11%) all requiring an additional open repair (Table 1). Three of five patients who had prior repair for instability developed recurrent symptoms after arthroscopic stabilization and required additional surgery. Only one of the 30 primary arthroscopic stabilizations developed recurrent instability and required open repair (3%). We are currently collecting follow-up functional results using the Simple Shoulder Test and SF 36 general health assessment.

Table 1: Summarized Results: Traumatic and Atraumatic Instability Repairs.

Instability Type	Traumatic	Atraumatic
# patients (#male/#female)	35 (29m/6f)	15 (11m/4f)
Average follow-up (months)	27.8 (7-45)	14.8 (7-43)
Average age at repair	31 (20-42)	32 (18-48)
Degree & Direction intability	6 s*/29 d*	4 md†/11 pi†
Success of 1° repair	29 of 30 (97%)	14 of 15 (93%)
Success of 2° repair	2 of 5 (40%)	0 of 1 (0%)
Recurrent instability	4 of 35 (11%)	1 of 15 (7%)

* s = subluxation, d = dislocation, † md = multidirectional, pi = poster-inferior

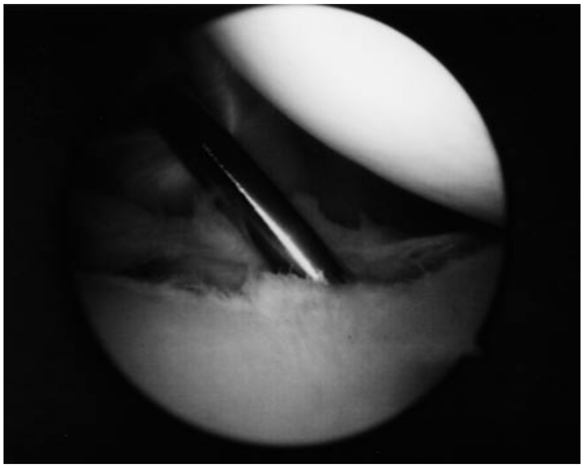

Figure 1: Labral-ligamentous Bankart lesion showing significant articular cartilage and anterior glenoid rim erosion.

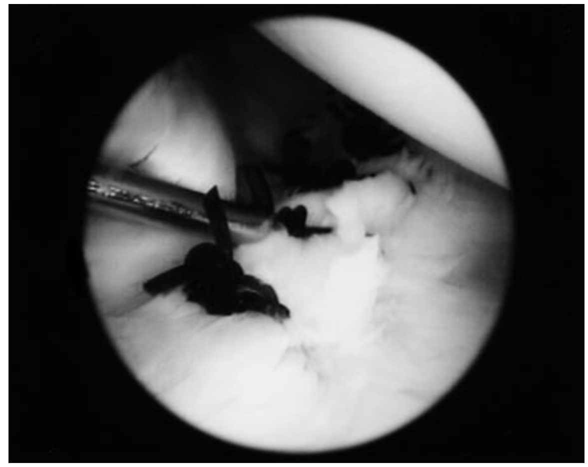

Figure 2: Anatomic repair of the labral ligamentous complex to the glenoid rim which helps to deepen the glenoid fossa.

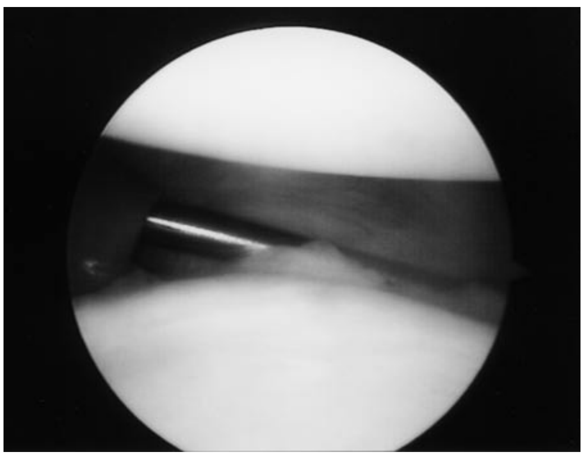

Figure 3: Posterior and inferior labral flattening and a partial detachment from the articular cartilage.

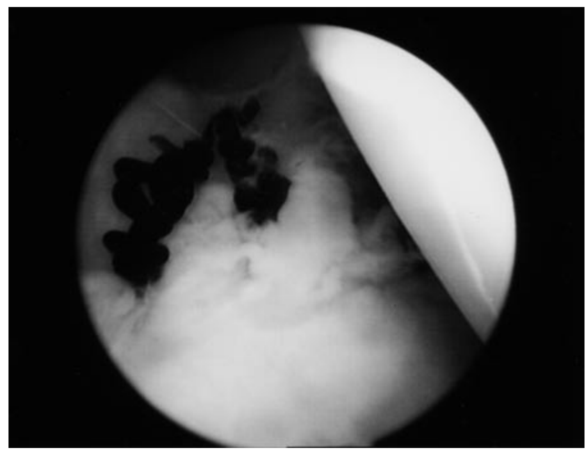

Figure 4: The capsular plication to the labrum reinforces and deepens the glenoid fossa while removing excessive capsular redundancy.

Postero-Inferior and Multidirectional Instability

Unlike traumatic antero-inferior instability, the pathologic lesion common to postero-inferior and atraumatic multidirectional instability is unclear. Suggested pathologies include: 1) excessive capsular compliance and redundancy, 2) glenoid rim and labral flattening or rounding, 3) asymmetrical rotator cuff weakness, and 4) loss of humero-scapular proprioceptive and/or neuromuscular coordination.

Diagnostic criteria for this diagnosis include: 1) instability with an insidious onset or after a minor injury, 2) symptomatic instability in a mid-range position (i.e., away from the extremes of motion), 3) symptomatic subluxation or dislocation especially on drawer, sulcus and jerk test, and 4) radiographic evaluation which may either be normal or show humeral head subluxation or posterior glenoid flattening or rounding.

At present, 31 patients with atraumatic instability have been enrolled in a prospective study utilizing arthroscopic surgical management. This report concerns the first 15 patients treated initially with 1) education regarding activities to be avoided, and 2) a conditioning exercise program of rotator cuff and peri-scapular muscle strengthening. Patients who met the diagnostic criteria outlined above, failed at least six months of non-operative management and exhibited persistent instability but no desire to dislocate voluntarily were considered operative candidates for arthroscopic stabilization. The operative goals were to stabilize the glenohumeral joint by removing capsular redundancy and to effectively deepen the glenoid concavity by performing a capsulo-labral plication. A deficient rotator interval capsule was identified in two patients.

Surgical Technique for Atraumatic Instability Repair

Under anesthesia, each shoulder was compared with the opposite side to confirm pathologic translation. All patients in this review demonstrated a positive jerk test with either displacement over the glenoid rim or frank dislocation postero-inferiorly.

Capsulo-labral plication requires a single anterior and posterior portal for instrument access. Arthroscopic exam revealed posterior and inferior labral flattening or rounding or a partial or complete detachment from the articular cartilage but no antero-inferior labral detachments were found (Figure 3). The capsule was typically redundant and often stripped away from the labrum resulting in a large posterior and inferior recess. Four patients also had significant antero-inferior subluxation which required plication. The rotator interval capsule was examined arthroscopically in all shoulders and found deficient in only one patient.

The peripheral rim of the glenoid labrum is roughened with a shaver. Next, a suture hook was used to plicate approximately one centimeter of the inferior capsule to shift it postero-superiorly up to buttress the glenoid labrum. Excessive capsular shift can restrict glenohumeral motion significantly. Five to nine sutures were placed through the capsule and between the deepest annular fibers of the glenoid labrum adjacent to the articular cartilage. This repair technique reinforces the labrum and deepens the glenoid fossa while removing excessive capsular redundancy (Figure 4). One patient with a full thickness defect of the rotator interval capsule also had rotator interval plication performed through the subacromial space. Postoperative management avoids capsular stretching and instead emphases an early active rotator cuff, deltoid and scapular strengthening motion program.

Results of Postero-Inferior and Multidirectional Repairs

Fifteen patients with a mean follow-up of 15 months (range 7–43) are included in this report. Five patients have recovered full motion relative to the opposite side. At present, only one patient, (who had failed a previous open capsular shift) developed recurrent instability (7%); no primary repair has failed to date. In this group, ten of twelve questions on the Simple Shoulder Test were improved except the ability to toss overhand and wash the back of the opposite shoulder. Eight of the ten categories on the general health SF 36 survey were improved except physical and emotional role. As in the open capsular shift, Obremskey determined there is risk of postoperative stiffness (71% for open shifts) but measurements of motion after arthroscopic stabilization reveal an early recovery of motion within the initial three to six months after surgery. Previously, lack of stiffness was identified as the best predictor of overall satisfaction for this procedure when performed open. In the present group, persistent instability was only reported by one patient whereas after an open shift two-thirds of patients reported persistent episodes of recurrent instability.

Summary

In conclusion, the early results of our arthroscopic methods used to manage shoulder instability appear safe and effective. Whether long-term results will prove comparable to open repairs is yet to be determined. For now, greater comfort, reduced scarring and lack of injury to the subscapularis appear to be the advantages of performing an arthroscopic repair. The preliminary results of arthroscopic capsular shift for postero-inferior and multidirectional instability appear to be better than the open procedure.

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Stabilization of Glenohumeral Arthroplasty—Geometrical Considerations

Peter W. Mitchell, M.D., Mark D. Lazarus, M.D., Shing-Wai Yung, M.D., and Frederick A. Matsen III, M.D.

Instability is a leading complication of total shoulder arthroplasty. In this procedure, the capsule and ligaments are released to restore motion. Thus glenohumeral stability must depend on mechanisms related to the glenohumeral surface geometry, such as concavity compression. Even though a wide variety of combinations of glenoid and humeral radii of curvature are commercially available in different prosthetic systems, the effects of varying glenoid and humeral head radius of curvature on the stability of the prosthetic glenohumeral joint has not been investigated. The goal of this study was to explore the effects of the relative geometry of the humeral and glenoid articular surfaces on the stabilization of the prosthetic shoulder in vitro.

The aim of our study was to compare some of the different geometric combinations of glenoid and humeral radii with respect to 1) the stability ratio (the ratio of glenohumeral compressive load to the displacing force necessary to displace the head from the glenoid), and 2) the glenoidogram (the lateral displacement of the center of the head as it translates across the glenoid face). The stability ratio is a measure of the effectiveness of concavity compression while the glenoidogram is a visual tool that helps compare the relative geometry of the humeral head and glenoid.

Methods

We selected glenoids with a 25mm and 27mm radius of curvature. The dimensions of these two glenoids are shown in Table 1. The humeral heads were of the following radii: 20, 22, 24, 25.4, 26, and 28mm. These were from two commonly used prosthetic systems. Non-metallic trial components were used to avoid interference with the sensors. The glenoid was fixed to a plastic model scapula which in turn was potted in plaster of Paris so that the face of the glenoid was oriented vertically upward. The potted scapula was secured to a force and torque transducer. The humeral components were inserted sequentially into a plastic model humerus. Electromagnetic position sensors were attached to the glenoid and the humerus.

Table 1: Glenoid Component Dimensions.

	25 mm radius Center-Rim* mm	25 mm radius Depth** mm	27 mm radius Center-Rim* mm	27 mm radius Depth** mm
Superior	16.5	6.2	17.5	6.4
Inferior	16.5	6.2	17.5	6.4
Anterior	12.3	3.2	13.0	3.3
Posterior	12.3	3.2	13.0	3.3

*Distance from glenoid center line to rim
**Measured along the glenoid center line

The trial protocol included two parts. First the humeral head was translated across the face of the glenoid under minimal (5N) compressive load while lateral translation from the glenoid face was recorded. Approximately seventy positions were recorded during this translation. The plot of the lateral translation of the head center during this translation is the glenoidogram. Glenoidograms were plotted for translation in the anterior to posterior and superior to inferior directions for each combination of glenoid and humeral head radius of curvature. A mathematical model was also developed to check the accuracy of the glenoidograms and to predict the glenoidogram for any combination

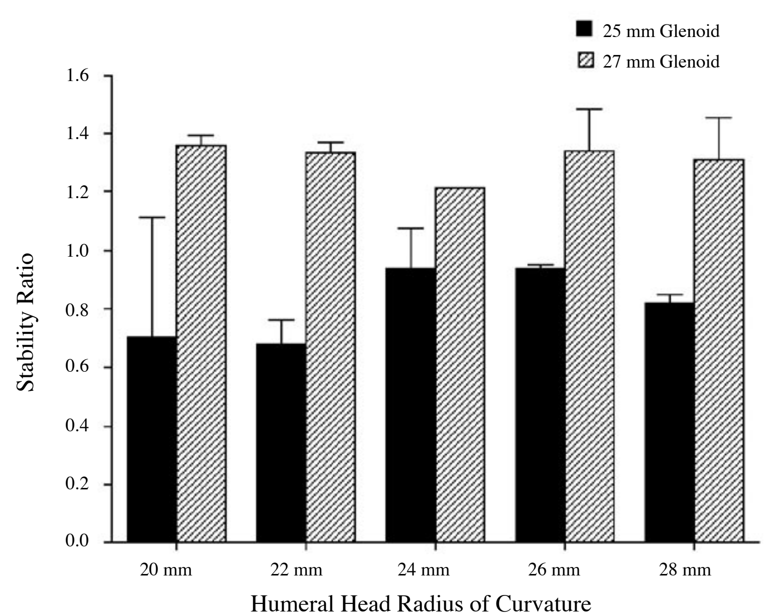

Figure 1: Stability Ratios in Inferior Direction.

of sizes.

In the second part of the protocol, the humeral head was compressed into the glenoid center with a normal load of 25N. A progressively increasing dislocating force was applied tangential to the face of the glenoid until dislocation occurred. The percent ratio of the peak translation force at dislocation to the compressive load is the stability ratio. Stability ratios were measured with two trials each in the anterior and inferior directions with all humeral head sizes but the 25.4 mm.

Table 2: Predicted and Measured Stability Ratios.

GlenoidGlenoidCenter-RimPredicted Stability RatioMeasuredRadius mmDepth mmmm (Center-Rim)/(Radius-Depth)Stability Ratio

25.06.216.50.90.9

25.03.212.30.60.627.06.417.50.91.3

27.03.313.00.6.7

Results

The measured stability ratios were not significantly affected by changes in humeral head radius but they were affected significantly by changing the radius of the glenoid for all but the 20mm head (Figure 1) (p-value <.05 by one-tailed student t-test). The stability ratios measured for the 25 mm glenoid with a closely matching humeral head were the same as that predicted by the formula:

Predicted Stability Ratio = Center-Rim Distance/(Radius-Depth)

However, the stability ratios for the 27 mm glenoid were much greater than predicted (see Table 2). The glenoidograms were substantially different for the different geometrical combinations. This was most apparent near the position where the head is centered in the glenoid. The glenoidograms for selected head radii are shown in Figure 2. The measured glenoidograms are very similar to those predicted from a geometric model in which the humeral head center moves about the glenoid rim with an arc of radius equal to the head diameter (Figure 3).

Discussion

Different prosthetic systems provide a wide variety of relative humeral and glenoid surface geometries. The mechanical effects of the different combinations have not been studied in detail. This investigation explores the effects of the relative geometry on stability ratios and glenoidograms.

The stability ratios were not affected by the diameter of the humeral head, indicating that it is the glenoid geometry that is the key determinant of glenohumeral stability from concavity compression. The stability ratios measured for the 25 mm glenoid agreed with those predicted. However, those for the 27 mm glenoid were much larger than predicted. While we do not have a robust explanation for this discrepancy, we recognize in retrospect that the stability ratios are affected by the friction between the humeral head and the glenoid. In vivo this friction is minimized by joint fluid lubrication and by smooth joint surfaces. In our in vitro study we did not lubricate the surfaces with joint fluid and we used plastic trial humeral heads and trial glenoids rather than the highly polished metal and high density polyethylene implants used clinically. These factors may have accounted for the differences noted, although further study is obviously needed.

The glenoidograms were close to those predicted geometrically. Glenoids with greater degree of mismatch between the humeral and glenoid radii of curvature allowed more translation near the centered position (Figure 2). It has been noted by others that the anatomical glenohumeral joint allows some translation due to the compliance of articular cartilage. A prosthetic glenohumeral joint does not have any compliance so it may benefit from a slight mismatch to allow minor translations without loading of the prosthetic rim. There are a number of other implications of changing the radius of the humeral component relative to that of the glenoid, such as contact pressures, wear, range of motion, and transfer of loads to the bone/prosthesis interface that were not addressed in this study.

This investigation does not determine the ideal prosthetic geometry, but it does suggest the ramifications of different glenohumeral combinations on the glenoidogram and stability ratios. While the ratio of humeral and glenoid radii of curvatures determines the amount of allowed translation before rim loading, the glenoid component alone determines the stability ratio. It appears important to control for frictional effects in the measurement of stability ratios.

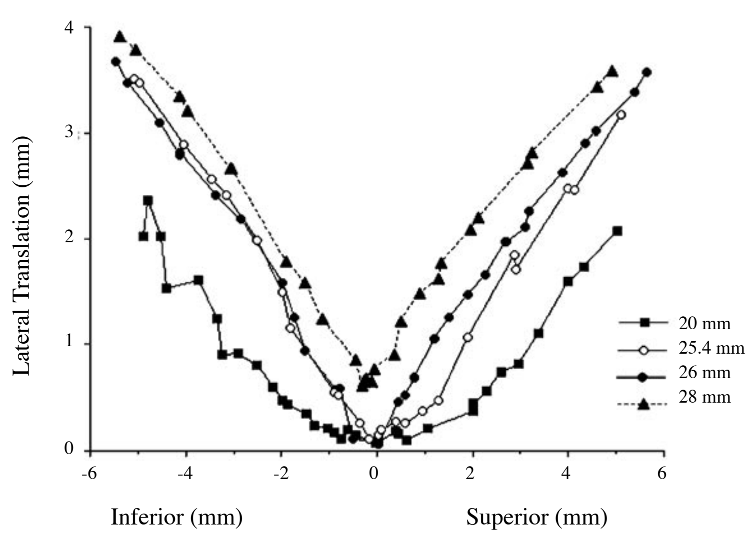

Figure 2: Inferior to Superior Glenoidogram (27 mm glenoid).

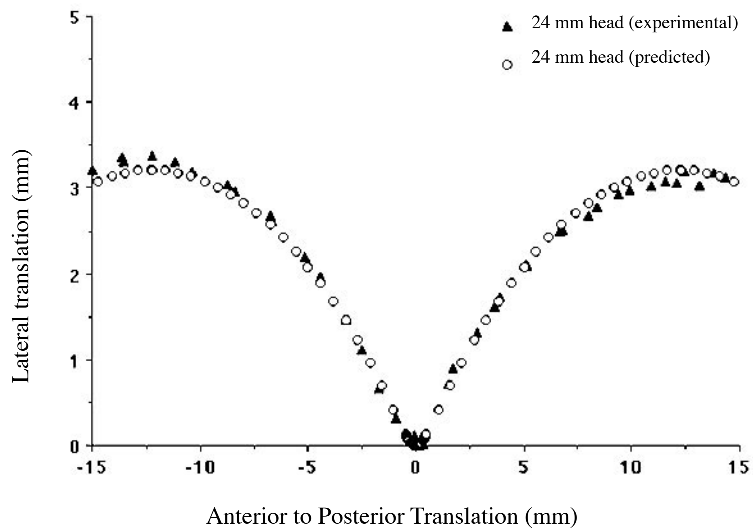

Figure 3: Glenoidogram (25 mm).

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Distal Radius Fractures in Young Adults: Biomechanics and Treatment

WILLIAM F. WAGNER JR., M.D. AND THOMAS E. TRUMBLE, M.D.

Distal radius fractures are the most common fractures that occur in adults. These fractures can occur after relatively trivial trauma in older patients with osteoporotic bone. In physiologically young or active patients, the fractures are often the result of more substantial trauma such as motor vehicle accidents, falls from heights, or injury during vigorous athletic activities. Physicians have looked at distal radius fractures in the past as a uniform group of injuries with a good prognosis. Even recent literature has failed to differentiate between fractures that disrupt the joint surface and those that avoid the joint and between fractures with minimal or significant comminution with regards to treatment recommendations and outcome variables.

This review will examine the biomechanics of distal radius fractures including current work we have done on intra-articular distal radius fractures. Treatment in the active patient will be discussed and a recently completed study on extra-articular fracture treatment will be included. Finally, we will present an algorithm for treatment of distal radius fractures in active adults that is currently being used in a prospective, multicenter study which was begun at the University of Washington, Department of Orthopaedics.

BIOMECHANICS

As the fractures collapse into extension, the contact characteristics change in the dorsal aspect of the wrist joint. This dorsal area corresponds to the area in which arthritis is seen clinically following distal radius malunion. As a result, most surgeons will not accept more than 15 degrees of angulation or more than 2–3 mm of shortening in the extra-articular component.

We have recently examined the biomechanics of simulated intra-articular malunions of the distal radius in an anatomic model focusing on the surface of the distal radius. The distal

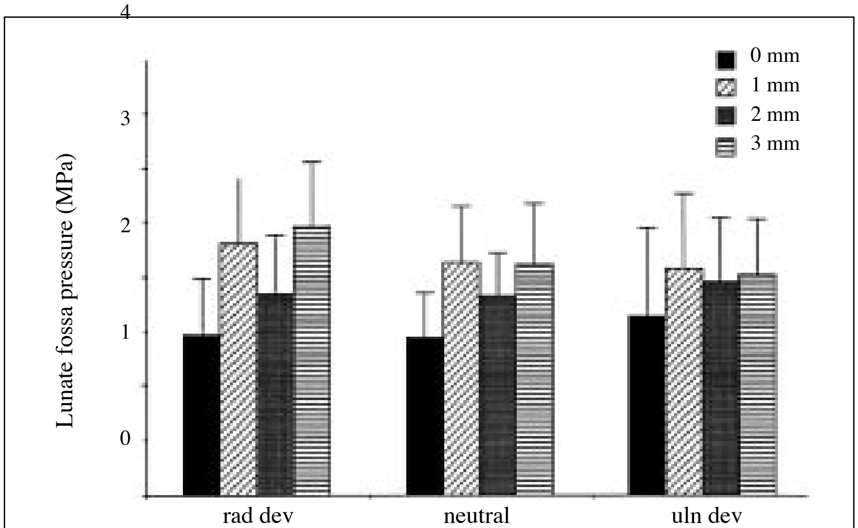

Figure 1: Graph showing effect of joint surface depression on joint loading pressures.

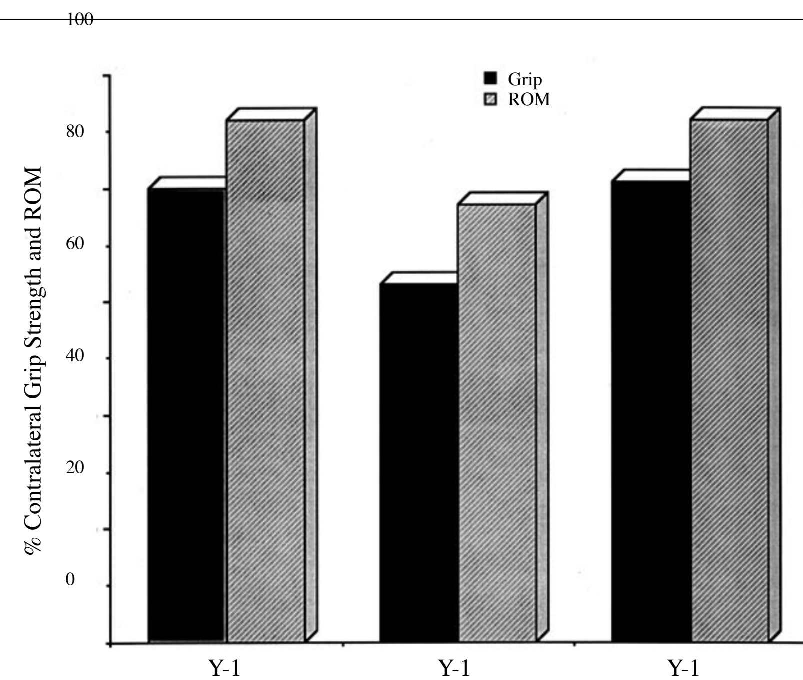

Figure 2: Graph showing outcome of extra-articular fractures in young patients where Y-1 are patients with comminution of one cortex who were treated with percutaneous pinning along, Y-2 are patients with comminution of two or more cortices and/or persistent shortening of the radius despite closed reduction who were treated with percutaneous pinning alone, and Y-3 are patients with comminution of two or more cortices and/or persistent shortening of the radius despite closed reduction who were treated with percutaneous pinning and external fixation.

radius joint surface can be divided into two saucer shaped areas called the scaphoid and lunate fossae. The study was designed to determine whether depressions of these fossae affect wrist joint contact characteristics. We found that the most significant effect on radiocarpal joint contact characteristics was with a depression caused by a fracture of the scaphoid side of the joint. Even with depressions as small as 1 mm changes in the contact characteristics of the wrist joint were observed (Figure 1).

These biomechanical findings correlate well with recent clinical investigations of distal radius fractures in the young or active adult which have shown that high complication rates are related to disruption and malalignment of the articular surfaces. When accurate restoration of the articular surface is possible, patients have improved quality of functional recovery. In a retrospective review of intra-articular fractures in young adults, many of whom were not treated with surgery to repair the joint surface, Knirk and Jupiter found indications of arthritis in 91% of fracture malunions with any observable degree of stepoff, and in all with 2 mm or more stepoff. Using a vigorous approach to repair the fractured joint surface, Trumble et al from the University of Washington found that preoperative stepoff, radial shortening, and total joint incongruity could be corrected resulting in improved patient strength, motion and relief of pain. Biomechanical and clinical studies, therefore, support the need for treatment when significant extra-articular angulation or shortening is present and when any intra-articular depression occurs.

Treatment

Despite the biomechanical data and the relative frequency of distal radius fractures, many basic issues of prognosis and treatment of these injuries continue to be unclear. Anatomic restoration and minimizing scar formation that limits joint motion are two primary goals of treatment. The ultimate goal must be treatment that results in function which allows young and active adults to return the activities and sports that they enjoy.

Extra-articular Fractures

Treatment recommendation for extra-articular fractures have included plaster immobilization, external fixation alone, external fixation and bone grafting, percutaneous pinning alone, percutaneous pinning and external fixation and open reduction and internal fixation. The goal of treatment is to maximize the patient's function by restoring the alignment and length of the radius. Healing without deformity helps to avoid limitation of motion and arthrosis of the wrist which can impair functional outcome. Cast immobilization alone avoids surgery and complications related to pin placement and removal but cannot maintain distraction to correct length or control the rotation of the distal fragment when comminution is present. External fixation provides distraction to maintain length of the radius but does not control the alignment of the distal fragment without applying translation forces that distort the DRUJ (distal radioulnar joint). Percutaneous pinning, especially the Kapanji technique, provides control of distal fragment rotation but does not maintain distraction. Combining external fixation and percutaneous pinning would appear to be a promising technique when there is persistent rotation of the distal fragment and comminution of the radius that foretells of problems with radius shortening.

With this in mind, we recently carried out a retrospective review of seventy-three patients who were treated with either Kapanji percutaneous pinning alone or in combination with external fixation unstable extra-articular fractures of the distal radius. The patients were separated into groups based on age (greater than or less than 55 years), whether or not one or more cortices demonstrated communition,

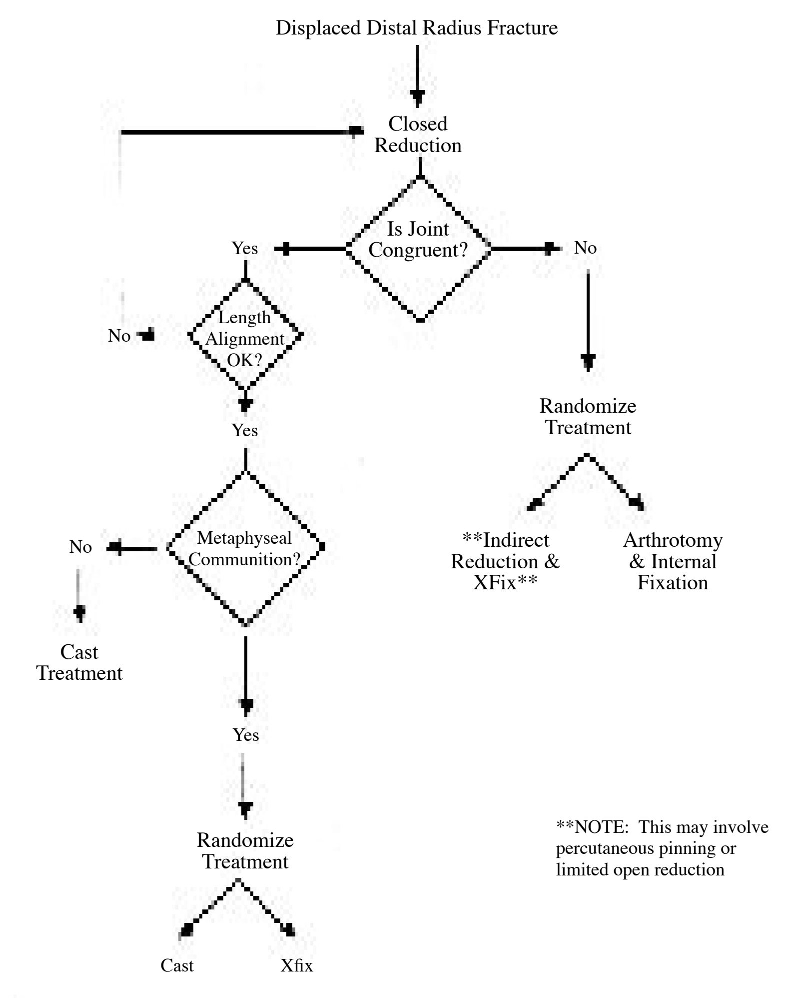

Figure 3: Algorithm for treatment of distal radius fractures in active adults.

and whether or not external fixation was used in addition to the percutaneous pins. Younger patients who had comminution of one surface and no external fixation (Y-1) and those who had comminution of two or more surfaces and external fixation (Y-3) had greater range of motion (92%±7% and 92%±3% respectively) and grip strength (80%±8% and 81%±8% respectively) than the patients who had two or more comminuted surfaces and no external fixation (Y-2) (77%±6% and 67%±9% respectively) ($p<0.001$) even after correcting for confounding variables of age, gender, handedness and severity of radiographic deformity at the time of the injury (Figure 2). A prospective study is underway to determine whether cast treatment or external fixation results in the best functional outcome in active patients with extra-articular fractures who have good alignment but significant metaphyseal comminution.

Intra-articular Fractures

Severe, intra-articular distal radius fractures are generally treated with either open reduction and internal fixation or indirect reduction plus percutaneous/external fixation. There is a tradeoff between precise anatomic restoration (which presumably is easier to achieve with open reduction) versus surgical soft tissue trauma and stripping during open reduction (which is probably minimized during percutaneous/indirect reduction). It is unknown which factor (anatomic restoration or soft tissue traumatization) more significantly affects functional outcome. Currently, the University of Washington Department of Orthopaedics is involved in an ongoing, multicenter, randomized, prospective study to determine the best treatment for these difficult fractures, which is shown in Figure 3.

Conclusions

The treatment of distal radius fractures in active adults is not as simple as once thought by physicians. Clearly, the goal of treatment is to return patients to their workplace and to their recreational and athletic endeavors. Prospective data currently being collected will modify the treatment algorithm discussed above to maximize the functional outcome in these patients.

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Biomechanical Analysis of Capitate Shortening with Capitate Hamate Fusion in the Treatment of Kienbock's Disease

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In 1910 Kienbock published his classic description of idiopathic avascular necrosis of the lunate, which is now commonly referred to as Kienbock's disease (Figure 1). He proposed that the degenerative changes seen in the lunate are related to avascularity. Yet the pathophysiology of Kienbock's disease remains unclear. Most theories focus on wrist biomechanics, postulating that certain anatomic variants predispose to lunate vascular compromise. Early authors proposed that a relatively short ulna, a so called "ulnar minus variant," generates increased lunate compressive forces. However, patients who undergo resection of the distal ulna for distal radioulnar joint pathology, which creates marked "ulnar minus variance," do not have an increased incidence of Kienbock's disease. Armistead also suggested that high compressive stresses on the lunate may be responsible for the changes seen in Kienbock's disease. He proposed that extreme wrist dorsiflexion causes the volar radiolunate and lunotriquetral ligaments to become tense and compress the lunate between the capitate and the distal radius. He postulated that repetitive compression loading of the lunate in this fashion leads to the avascular changes seen in Kienbock's disease.

While many factors may predispose to Kienbock's disease, it is likely caused by a combination of repetitive loading, vascular risk, and mechanical predisposition. Treatments have been based on each of these and most are designed to decrease compression loading of the lunate, both preventing lunate collapse and allowing lunate revascularization.

Kienbock's disease is staged according to lunate architecture and density (Table 1). A variety of treatments for Stages I–III Kienbock's disease are available including: immobilization, lunate excision, joint leveling procedures, lunate arthroplasty, and limited intercarpal arthrodeses. Immobilization rarely leads to a

Figure 1: A radiograph showing lunate fragmentation and abnormal lunate density, findings typically seen in Kienbock's disease.

decrease in pain and is associated with a relentless progression of lunate deformity and carpal collapse. Long-term results after lunate excision have been poor. Joint leveling procedures include both ulnar lengthening and radius shortening. These procedures, which have provided excellent results in "ulnar minus" patients, advance the ulnocarpal complex ahead of the radius, decreasing the compressive forces on the lunate. Unfortunately, these procedures are indicated only in patients with "ulnar minus" anatomy. Results of lunate implant resection arthroplasty, both biologic and prosthetic, have failed to prevent carpal collapse. Limited carpal arthrodeses advocated for the treatment of Kienbock's disease include scaphoid-trapezium-trapezoid (STT), scaphoid-capitate (SC), capitate-hamate (CH), and capitate shortening combined with capitate-hamate fusion (CSCHF). The rationale behind STT and SC arthrodeses is the prevention of carpal collapse by creating a more rigid support column on the radial side of the lunate which will bear a significantly greater proportion of the axial loads to the carpus, thus shielding the lunate from compressive loads. These arthrodeses link the proximal and distal carpal rows, preventing carpal collapse. Wrist motion is decreased by 50%, however. On the other hand, the biomechanical rationale behind CH arthrodesis is unclear. Chuinard and Zeman suggested that the capitate be fused to the hamate to prevent the proximal migration of the capitate-third metacarpal axis into the defect created by the gradual collapse of the lunate; however, the capitate and hamate are bound by strong ligaments which prevent motion between these bones. Furthermore, capitate-hamate instability does not play a role in carpal collapse; the mechanism of this collapse involves foreshortening of the scaphoid and distal migration of the triquetrum on the hamate. Similarly, CH fusion has been shown to be ineffective in reducing lunate loading. Recently, capitate shortening combined with capitate-hamate fusion has been proposed for treatment of

Table 1: Stages of Kienbock's Disease.

Stage I:	Normal Lunate Architecture Normal Density Normal Carpal Height No Osteoarthritis
Stage II:	Normal Lunate Architecture Increased Density Normal Carpal Height No Osteoarthritis
Stage IIIA:	Lunate Collapse Abnormal Density Normal Carpal Height No Osteoarthritis
Stage IIIB:	Lunate Collapse Abnormal Density Decreased Carpal Height No Osteoarthritis
Stage IV:	Lunate Collapse Abnormal Density Decreased Carpal Height Extensive Osteoarthritis

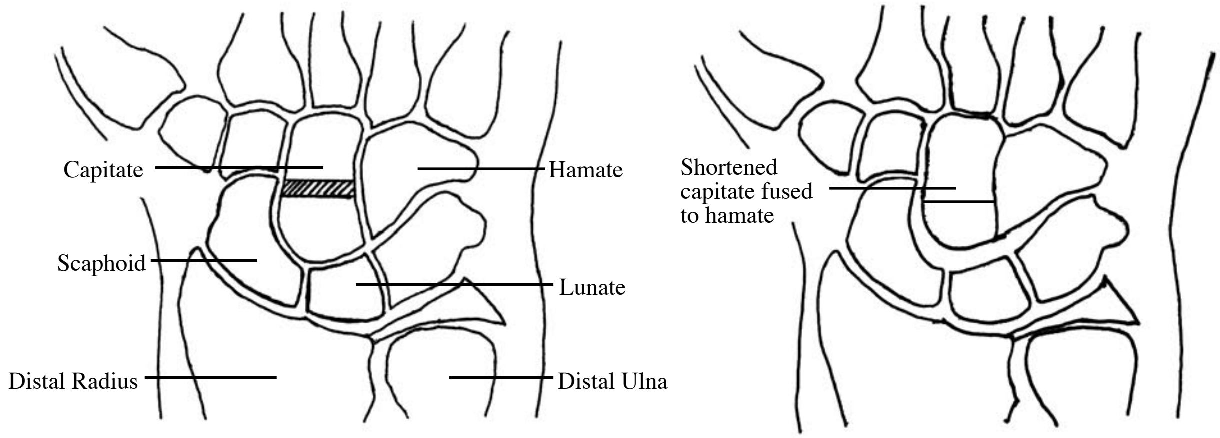

Figure 2: Diagram of capitate shortening with capitate-hamate fusion. (Left) Coronal section through a left wrist. The shaded area of the capitate depicts the 2-4 mm wafer of bone removed from the central capitate. (Right) The carpus after capitate shortening. The proximal capitate pole has been advanced distally and fused to the distal capitate. The shortened capitate is then fused to the hamate. The proximal pole of the hamate may be removed so that the proximal pole of the hamate conforms to the proximal pole of the capitate.

patients who are ulnar neutral (Figure 2). Early clinical results are promising. Horii predicted the biomechanical effects of CSCHF using a simplified two-dimensional mathematical model. The model predicted a decrease in lunate compressive loading by no more than 15% and marked overloading of both the scapho-trapezial and triquetral-hamate joints. The current study was undertaken to measure the biomechanical effects of CSCHF by direct measurement of intra-articular radiocarpal pressures in cadaver specimens before and after capitate shortening combined with CH fusion.

Methods

Seven cadaver upper extremities were prepared and mounted in a loading frame as described by Augsburger (Figure 3). Gross examination and radiographs were used to confirm the absence of gross abnormality, previous fracture, or arthritis. The flexor carpi radialis, flexor carpi ulnaris, extensor carpi radialis, extensor carpi ulnaris, and the flexor digitorum profundus were dissected and identified; these five tendons were designated the loading tendons. A dorsal wrist capsulotomy was performed between the third and fourth compartments and a V-shaped metallic reference marker was attached to the dorsal radius in this interval. The wrist capsule, interosseous membrane, TFCC, and palmar and dorsal radiocarpal ligaments were left intact. Each specimen was then mounted in the loading apparatus with the humerus

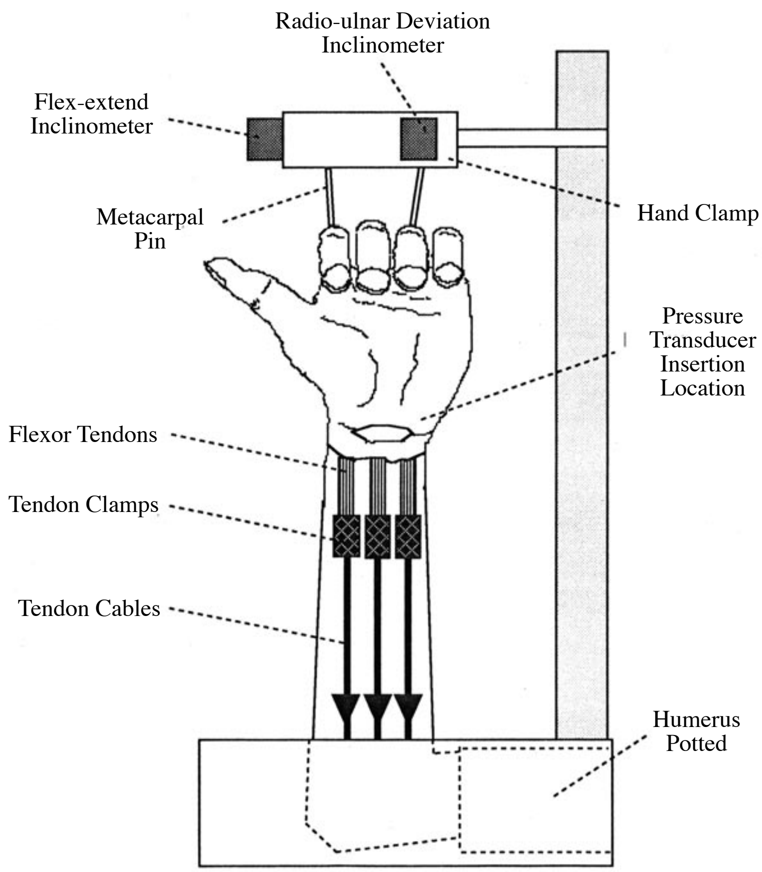

Figure 3: Diagram of the loading apparatus. The humerus is potted and fixed on a disk, which is rotated to alter pronation and supination. The elbow is positioned at 90 degrees of flexion. Wrist position (flexion, extension, ulnar deviation, and radial deviation) is manipulated by axial intramedullary metacarpal threaded Steinman pins which are rigidly fixed to an inclinometer bearing wrist frame. The wrist is loaded via the flexor and extensor tendons.

stabilized in a rotating disk and the wrist position fixed by intramedullary metacarpal pins to an inclinometer bearing wrist frame. Pronation and supination were adjusted through manipulation of the rotating disk. The wrist frame inclinometers determined wrist position in the flexion-extension and radial-ulnar planes. Clamps were then used to connect each of the load bearing tendons to loading cables. In order to describe wrist position accurately, a convention was adopted: in all descriptions of wrist positions, the radial-ulnar wrist position is specified prior to the pronation-supination position.

After each specimen had been mounted in the loading apparatus, a pressure sensitive film transducer was inserted on to the distal radial articular surface. The wrist was then loaded for 60 seconds through tension on the loading tendons. Each wrist position was tested twice; once with a low pressure transducer and once with super low pressure transducer. Each specimen was tested in 80 degrees of pronation, 80 degrees of supination, and neutral in three wrist positions: neutral, 14 degrees radial deviation, and 14 degrees ulnar deviation. For each transducer measurement, nine variables were recorded during load application:

1. flexion-extension wrist position
2. radial-ulnar wrist position
3. pronation-supination wrist position
4. total load applied to the wrist,
5. ECU force
6. FCU force
7. FCR force
8. ECRL force
9. FDP (all) force

After each specimen had been tested in all nine wrist positions, capitate shortening with capitate-hamate fusion was performed, as described by Almquist. Each specimen was then re-tested as described above.

Pressure transducer data was analyzed with regard to both scaphoid and lunate contact area and scaphoid and lunate force. The pressure film was analyzed using a HP digital scanner.

Results

In preliminary specimen testing, two wrists were tested in fifteen positions; however, pressure measurements were highly variable. Direct visualization of the carpus during loading demonstrated inconsistent articulation of the proximal pole of the hamate with the lunate. Because of this finding, the proximal pole of the hamate was shortened to conform to the proximal surface of the capitate in all specimens.

Radio-scaphoid, radio-lunate, and combined radio-carpal contact pressures were measured before and after capitate shortening. Average preoperative pressures were compared with average postoperative pressures using the two-tailed t-test. Of the nine wrist positions tested, average radio-scaphoid pressures were unchanged in seven positions and increased in two positions [radial deviation-supination ($p=.005$), and ulnar deviation-supination ($p=.001$)]. Figure 4 shows average radio-carpal contact pressures measured in 14 degrees of radial deviation and 80 degrees of supination. The average radio-scaphoid pressure increased from 1.8 MPa to 2.7 MPa ($p=.005$), the average radio-lunate pressure decreased from 1.8 MPa to 1.1 MPa ($p=.01$), and the average combined radio-carpal contact pressure was unchanged. Alternatively, lunate fossa contact pressures were unchanged in two positions (neutral-neutral and neutral-pronation), decreased moderately in two positions [ulnar deviation-neutral ($p=.07$), and ulnar deviation-pronation ($p=.08$)], and decreased significantly in five positions (all with $p<.05$: neutral-supination, ulnar deviation-supination and all radial deviation wrist positions). In all nine wrist positions, combined scapho-lunate contact pressures were unchanged. Figure 5 shows radio-carpal contact pressures measured in 14 degrees of radial deviation and 80 degrees of pronation. The average radio-scaphoid pressure increased from 2.1 MPa to 2.3 MPa (not statistically significant), the average radio-lunate pressure decreased from 1.6 MPa to 1.1 MPa ($p=.02$), and the combined scapho-lunate contact pressure was not statistically different.

Discussion

Our results show that capitate shortening combined with capitate-hamate fusion decreases compressive forces at the radio-lunate articulation with a concomitant increase in radio-scaphoid compressive forces in some wrist positions. Although a two dimensional mathematical model developed by Horii et al predicted a 40% decrease in radio-lunate pressure and a 21% increase in radio-scaphoid pressure, our study provides the first direct evidence that lunate compressive forces are decreased by capitate shortening. Furthermore, a statistically significant increase in radio-scaphoid

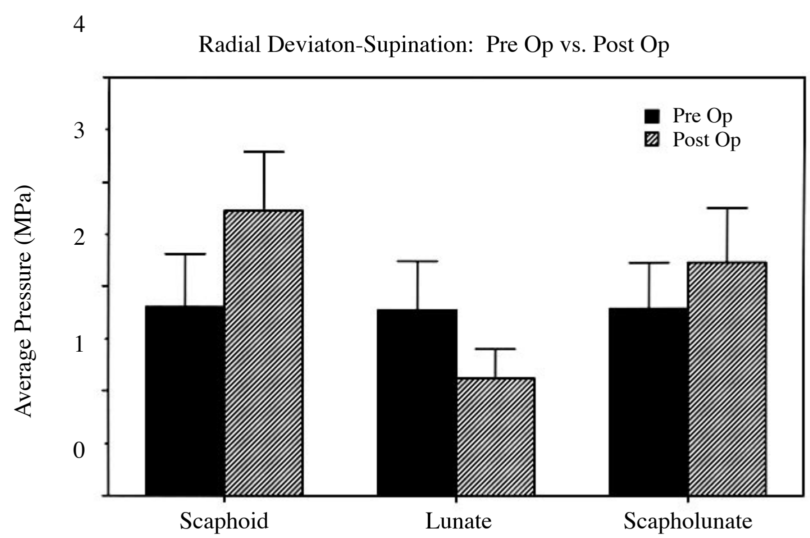

Figure 4: The bar graph depicts scaphoid, lunate, and combined scapho-lunate average articular contact pressures measured with the wrist in 14 degrees of radial deviation and 80 degrees of supination. Each result represents the average of the data collected from seven specimens. Standard deviations are indicated. The average radio-scaphoid pressure increased from 1.8 MPa to 2.7 MPa ($p=.005$), the average radio-lunate pressure decreased from 1.8 MPa to 1.1 MPa ($p=.01$), and the average combined radio-carpal contact pressure was unchanged.

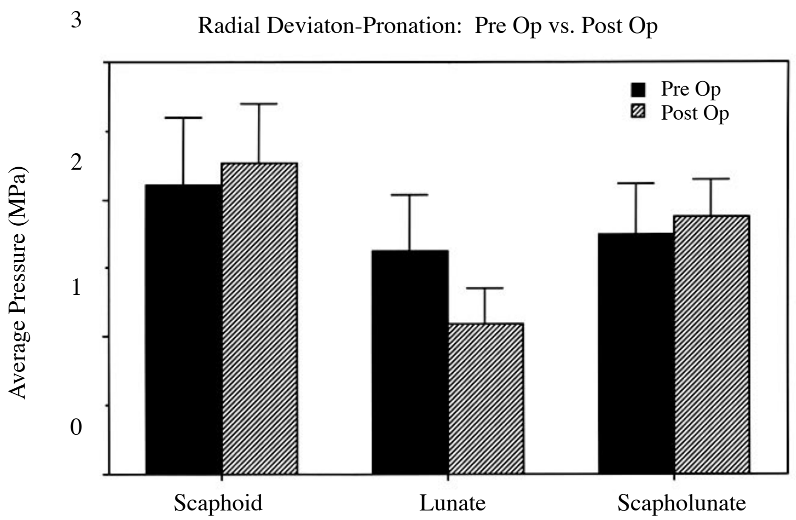

Figure 5: The bar graph depicts scaphoid, lunate, and combined scapho-lunate average articular contact pressures measured with the wrist in 14 degrees of radial deviation and 80 degrees of pronation. Each result represents the average of the data collected from seven specimens. Standard deviations are indicated. The radio-scaphoid average pressure increased from 2.1 MPa to 2.3 MPa (not statistically significant), the radio-lunate average pressure decreased from 1.6 MPa to 1.1 MPa (p=.02), and the average combined radio-carpal contact pressure was unchanged.

pressure was seen in only two of the nine wrist positions tested. The total radiocarpal compressive forces were found to be unchanged, suggesting that the distribution of contact forces between the distal radius and the TFCC is unchanged by capitate shortening.

This biomechanical study demonstrates the effectiveness of capitate shortening in decreasing compressive lunate loading, an effect which is thought to facilitate lunate revascularization and consolidation. Capitate shortening has been used successfully in Scandinavia, but is infrequently used in the United States. In an anecdotal report, Almquist reports excellent results, with prompt relief of pain, grip strength of 80% of the contra lateral wrist, and high patient satisfaction. 83% of his patients had revascularization and healing of the lunate. Similarly, Inoue reports excellent results after three years of follow-up. With this new bio-mechanical data, these encouraging clinical results, and the technical simplicity of CSCHF, we are hopeful that increased utilization of this procedure in Kienbock's disease will lead to improved outcomes.

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Effect of Lateral Ligament Reconstruction on Intra-articular Posterior Cruciate Ligament Graft Forces and Knee Motion

Vernon J. Cooley, M.D., Richard M. Harrington, M.S., and Roger V. Larson, M.D.

Injury to the posterior cruciate ligament (PCL) is thought to account for 3–20% of all knee ligament injuries. The true incidence of PCL injuries remains unknown because many isolated PCL injuries may go undetected. Many PCL deficient knees also have a combined ligamentous injury involving the posterolateral corner. The natural history of the PCL deficient knee is a matter of substantial debate. Whether the PCL-deficient knee is at risk for the development of degenerative changes is not clear at this time. In theory, compartment degeneration could result from acute chondral injury associated with PCL injury or from increased joint-contact forces created by the absence of the PCL. Although the treatment of the isolated PCL-deficient knee remains a matter of persistent controversy, there is general agreement that PCL deficiency, in association with other major ligamentous injuries, is a surgical problem, especially in acute injuries. The vast majority of knees undergoing PCL reconstruction for posterolateral instability require a lateral reconstruction as well. These patients with combined PCL and posterolateral deficiency are generally more symptomatic, with greater incidence of instability, re-injury and long-term degenerative changes. Recommended treatment for acute posterolateral injuries is acute repair of all injured structures. Unfortunately, acute injuries are often overlooked during the initial evaluation; delayed diagnosis prohibits primary repair of the posterolateral structures. Chronic symptoms may develop, which include difficulty with twisting maneuvers, negotiating stairs, and medial joint line pain.

We advocate reconstructing the lateral restraints along with the PCL in knees with posterolateral instability and propose that this is the best way to return the knee to a normal biomechanical state. Also, by restoring the lateral restraints, there will be load sharing with the PCL graft. This could be vitally important in a successful PCL reconstruction. A variety of procedures are advocated for late reconstruction of posterolateral instability. Reconstructive procedures typically involve either a tightening of lax lateral and posterolateral anatomic structures or the creation of a substitute restraint from the posterolateral corner of the knee to the anterior epicondyle. The two most common substitution procedures are the biceps tenodesis

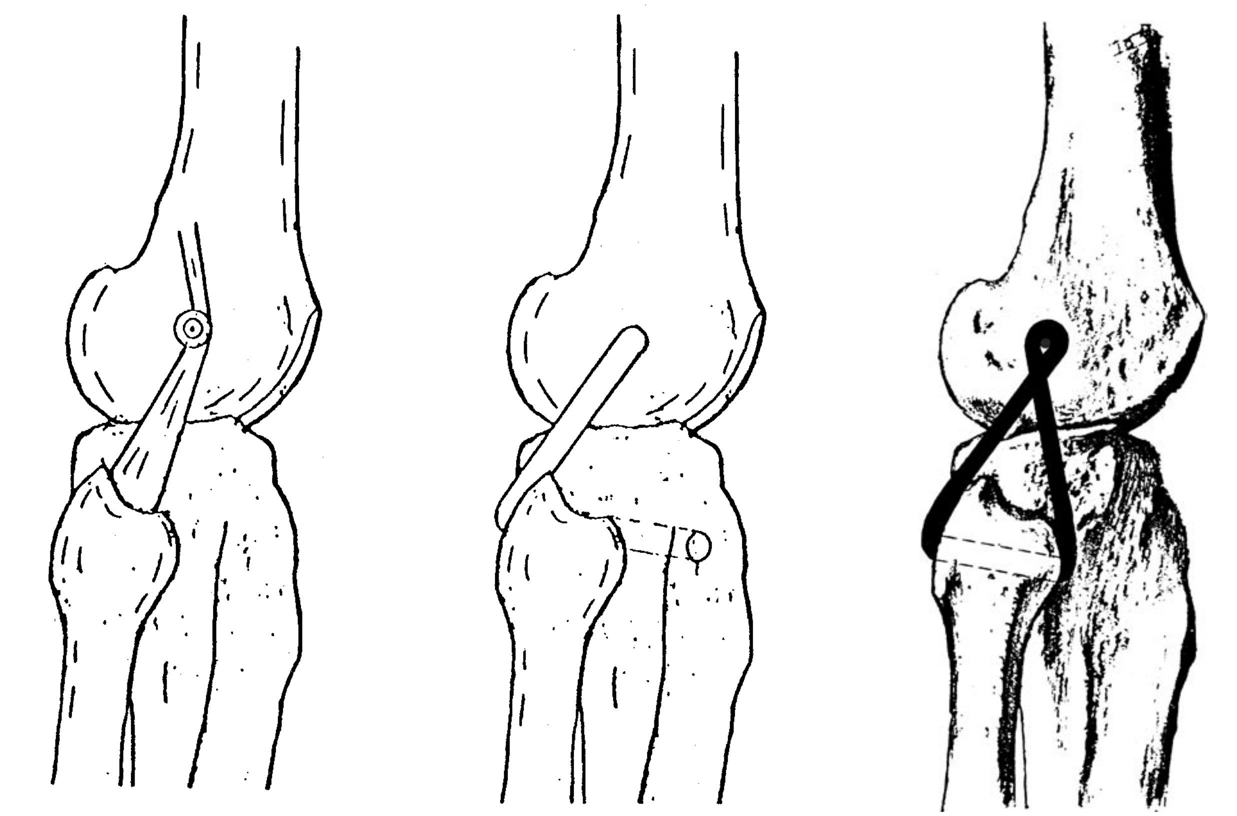

Figure 1A: Biceps tenodesis procedure (Clancy).

Figure 1B: Popliteus bypass procedure (Mueller).

Figure 1C: Technique for LCL reconstruction with semitendinosus free graft (Larson).

described by Clancy (Figure 1A) or the popliteus bypass procedure described by Mueller (Figure 1B). Most recently, a new procedure using a semi-tendinosus has been described by Larson (Figure 1C). In this study, we analyze the mechanical effects these different lateral reconstructive procedures have on the PCL graft and knee motion.

Methods

The study design consists of an analysis of variance of the resulting angular and spatial displacements of the knee joint and strains in the posterior cruciate ligament when subjected to four loading conditions at each of four knee flexion angles.

Specimens

Four female and three male (mean age 74, range 60–86 years) fresh cadaveric human knee joints were obtained. Specimens were harvested with approximately 15 cm of distal femur and 15 cm of proximal tibia. Skin and muscle tissues were removed, preserving ligaments and joint capsule. Each specimen was tested in this order with the following treatments (see Table 1).

Loading fixture

A Plexiglas frame was constructed which holds the proximal femur fixed while allowing the distal tibia to displace and rotate. The tibia mounting fixture could be fixed at knee flexion angles of 0, 30, 60 and 90 degrees, while still allowing the tibia to rotate freely relative to the femur. Load of 100 N posterior drawer was applied by controlling the air pressure supplied to an air cylinder acting through a cable and pulley system attached to the tibia mounting fixture. External torque of 5 N-m was applied through 2 air cylinders attached through a cable and pulley system to the tibia mounting fixture. Loads were always applied in the following sequence (starting with knee flexion angle 0 and increasing by 30 degrees until 90 degrees was reached):

Knee flexion angle 0, 30, 60, 90 degrees:

a) no external loads applied, gravitational load of tibia and mounting fixture
b) 100 N posterior drawer
c) 100 N posterior drawer +5 N-m external torque
d) 5 N-m external torque

Spatial Measurements

Displacements and rotations of the femur and tibia were measured with an electromagnetic, six-degree-of-freedom tracking instrument. The transmitter unit establishes a global coordinate system which was parallel with the anatomic axes of the knee, when the knee was in 0 degree flexion. Receiver units were mounted on graphite rods placed in both the femur and tibia, aligned with the anterior direction. The anterior/posterior, medial/lateral and proximal/distal displacements and varus/valgus, flexion/extension and internal/external rotations were measured in the global coordinate system.

Strain Measurements

Strain in the posterior fibers of the intact posterior cruciate ligament and the reconstructed PCL were measured using a miniature displacement transducer (DVRT, differential variable reluctance transducer). The PCL was approached from the posterior side of the knee with the joint at 0 degrees flexion angle and no load applied, and the transducer was aligned to measure displacements along the fiber direction.

Statistical Analysis

A repeated measures analysis of variance was performed on the posterior displacement, external rotation and strain in the posterior fibers of the PCL to determine the significance of the effects of treatment and load. The dependent variables (posterior displacement, external rotation, strain) were grouped into compact variables so that they were treated as one factor in the analysis, each with four levels of knee flexion angle (0, 30, 60 and 90 degrees). Post hoc testing was performed, using Fisher's Protected Least Significant Difference with $p \leq 0.05$, to determine which combinations of treatment and load were significantly different.

Results

When transforming the displacements and rotations of the tibia from the global coordinate system into the local tibia coordinate system, the initial resting position of the tibia under no external loads was used as the reference position for each knee flexion angle. The applied loads were posterior drawer and external torque, alone and in combination, the resulting posterior displacement and external rotation were much larger than the medial/lateral or proximal/distal displacements, and will be presented in the following graphs. The combination of 100 N posterior drawer +5 N-m external torque produced the largest motion for all knee flexion angles and treatments, so the results for this loading condition are presented.

Displacement

The average posterior displacement of the tibia for the intact, PCL deficient,

Table 1: Specimens were tested in the following order with the treatments listed.

1. Intact joint capsule and ligaments
2. Posterior cruciate ligament excised

Treatment: Perform intra-articular patellar tendon PCL reconstruction

3. No posterolateral reconstruction
4. Clancy (biceps femoris tenodesis) procedure
5. Larson (semitendinosis tendon) procedure
6. Mueller (popliteus bypass) procedure

Treatment: Incise lateral collateral and popliteal ligaments

7. Mueller procedure
8. Clancy procedure
9. Larson procedure
10. No posterolateral reconstruction

Treatment: Incise PCL reconstruction

11. No PCL or posterolateral constraints

and PCL and posterolateral ligaments deficient knee are shown in Figure 2A. Incising the posterolateral ligaments allowed significantly larger posterior displacement of the knee for all three loading conditions. For drawer plus torque loading the mean increase in posterior displacement for all four knee flexion angles was 1.41 mm, $p<0.0001$.

The average posterior displacement of the tibia for the knee with patellar tendon PCL reconstruction and intact posterolateral ligaments is shown in Figure 2B. Adding the Mueller, Clancy or Larson procedures to the PCL reconstruction does not make a significant difference when the posterolateral structures are intact.

The posterior displacement of the tibia for the knee with patellar tendon PCL reconstruction and incised posterolateral ligaments is shown in Figure 2C. Adding the Mueller, Clancy or Larson procedures to the PCL reconstruction does make a significant difference under all three loading conditions. The largest difference was between the Larson procedure and no posterolateral reconstruction: mean difference for all four knee flexion angles was 0.93 mm, $p<0.0001$.

External Rotation

The average external rotation of the tibia for the intact, PCL deficient, and PCL and posterolateral ligaments deficient knee are shown in Figure 3A. Incising the posterolateral ligaments allowed significantly larger external rotation of the knee for all three loading conditions. For drawer plus torque loading the mean increase in external rotation for all four knee flexion angles was 11.4 degrees, $p<0.0001$.

The average external rotation of the tibia for the knee with patellar tendon PCL reconstruction and intact posterolateral ligaments is shown in Figure 3B. Adding the Mueller, Clancy or Larson procedures to the PCL reconstruction does not make a significant difference when the posterolateral structures are intact.

The average external rotation of the tibia for the knee with patellar tendon PCL reconstruction and incised posterolateral ligaments is shown in Figure 3C. Adding the Mueller, Clancy or Larson procedures to the PCL reconstruction does make a significant difference under all three loading

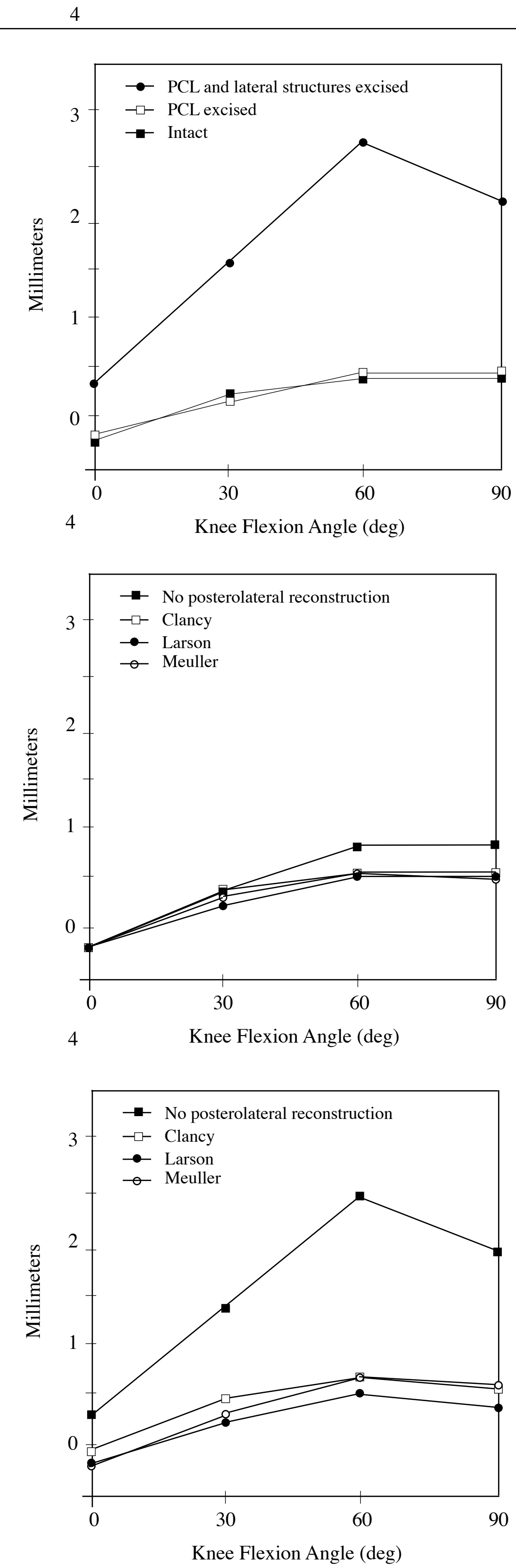

Figure2A: (Top) The average posterior displacement of the tibia for the intact, PCL deficient, and PCL and posterolateral ligaments deficient knee.
Figure 2B: (Middle) The average posterior displacement of the tibia for the knee with patellar tendon PCL reconstruction and intact posterolateral ligaments.
Figure 2C: (Bottom) The posterior displacement of the tibia for the knee with patellar tendon PCL reconstruction and incised posterolateral ligaments.

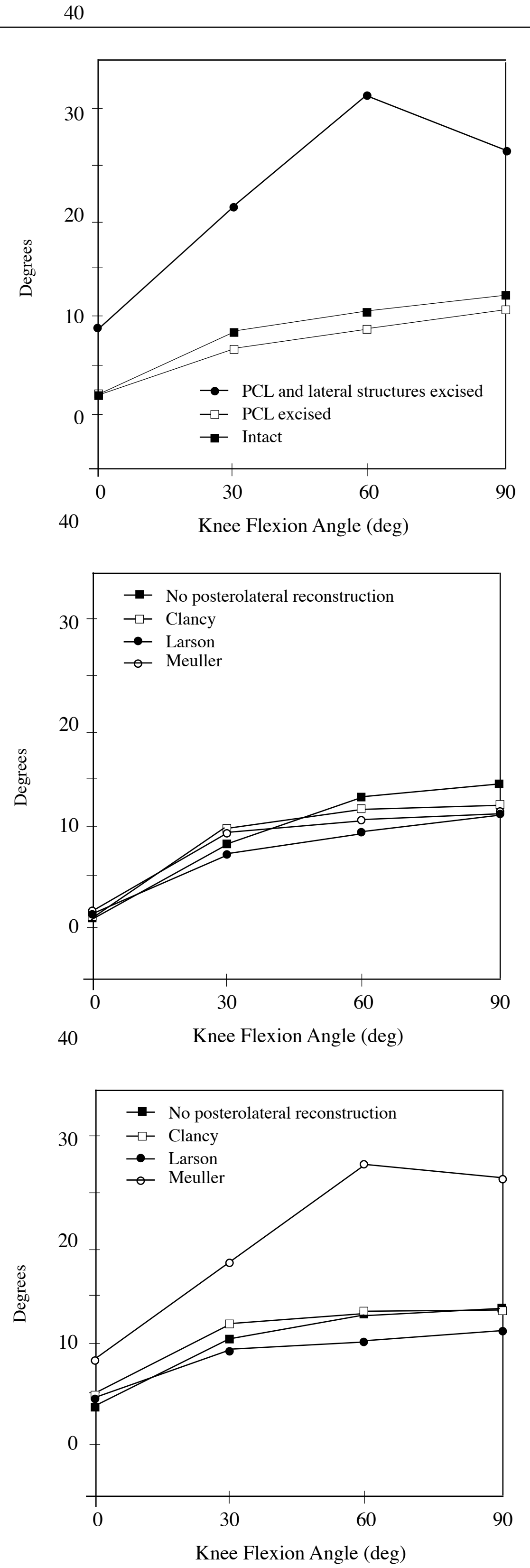

Figure3A: (Top) The average external rotation of the tibia for the intact, PCL deficient, and PCL and posterolateral ligaments deficient knee.
Figure 3B: (Middle) The average external rotation of the tibia for the knee with patellar tendon PCL reconstruction and intact posterolateral ligaments.
Figure 3C: (Bottom) The average external rotation of the tibia for the knee with patellar tendon PCL reconstruction and incised posterolateral ligaments.

conditions. The largest difference was between the Larson procedure and no posterolateral reconstruction: mean difference for all four knee flexion angles was 10.6 degrees, p=0.0005.

Strain

The reference position for the calculation of strains was taken as the initial length measurement with the knee at 0 degrees flexion angle and no load applied. Flexing the knee to 30, 60 and 90 degrees produced strains in the posterior fibers of both the intact and reconstructed PCL with only gravitational loads applied. Applying posterior drawer and/or external torque caused strain in the PCL at all knee flexion angles. The combination of 100 N posterior drawer and 5 N-m external torque produced the largest strains for all knee flexion angles and treatments, so the results for this loading condition are presented. The strains in the posterior fibers of the patellar tendon PCL reconstruction are shown for the knee preparations with intact lateral structures (Figure 4A). The posterolateral reconstructions increased strain slightly at 0 degrees knee flexion, and reduced the strain in the PCL at knee flexion angles of 30, 60 and 90 degrees.

The Mueller augmentation had the largest effect, reducing strain by 3.7% at 30 degrees knee flexion. None of the treatments was significantly different from the others under this loading condition. For the knee preparations with the lateral collateral and popliteal ligaments incised (Figure 4B), the lateral reconstructions reduced the strain in the reconstructed PCL relative to no reconstruction.

The largest difference occurred at 0 degrees knee flexion angle where the mean strain for the Larson procedure was -3.7%, and the mean strain for no reconstruction was 3.0%. This difference did not reach significance (p=0.058) because of large variations between specimens. However, under the 5 N-m external torque load, both the Larson (-4.0% strain) and the Clancy (-2.4% strain) reconstructions were significantly less than no reconstruction (2.3% strain), p=0.04.

Discussion

Using this experimental knee testing system, we model the immediate

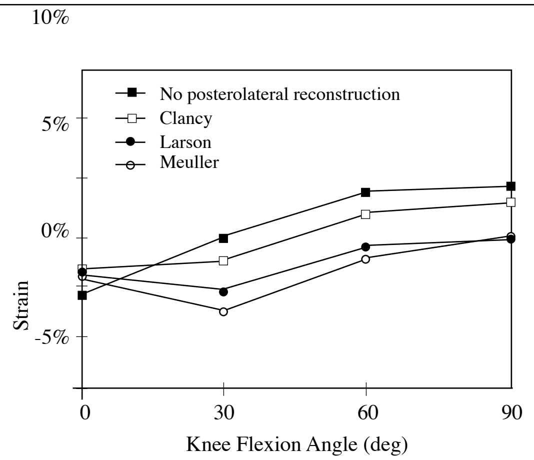

Figure 4A: The strains in the posterior fibers of the patellar tendon PCL reconstruction are shown for the knee preparations with intact lateral structures.

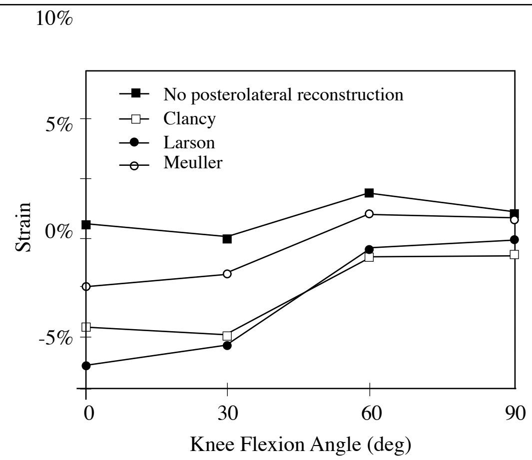

Figure 4B: In knee preparations with the lateral collateral and popliteal ligaments incised, lateral reconstructions reduced the strain in the reconstructed PCL relative to no reconstruction.

postoperative mechanical effect of different lateral reconstructive techniques on PCL graft forces and knee motion. Reconstructing the lateral restraints along with the PCL in knees with posterolateral instability is the best way to return the knee to a normal biomechanical state. Furthermore, restoring the lateral restraints allows load sharing with the PCL. This could be vitally important in a successful PCL reconstruction. The posterolateral region of the knee, being extra-articular, is a more favorable environment for graft healing and maturation. Serious stress relaxation during the healing period is less apt to occur in a strong, well-positioned posterolateral graft than in an isolated intra-articular PCL graft. The posterolateral reconstruction may be viewed as an extra-articular reinforcement of the intra-articular PCL graft, reducing forces on the intra-articular construct during the critical healing period. This has been shown in the literature to take place when an iliotibial band tenodesis is added to an intra-articular reconstruction of the anterior cruciate ligament. More importantly, if an injured knee does not respond to forces in a fashion similar to the normal knee, it is unlikely that it will function effectively. Our data shows that knees that have a posterolateral and PCL injury require reconstruction of all of the injured structures and that any one of the three lateral reconstructive procedures tested is equally effective. These findings will need to be validated clinically.

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Isometry of the Lateral Collateral and Popliteofibular Ligaments and a Technique for Reconstruction

Roger V. Larson, M.D., John A. Sidles, Ph.D., and Timothy C. Beals, M.D.

Acute or chronic isolated varus or posterolateral instability of the knee is uncommon. Injury to the lateral and posterolateral structures, however, is relatively common in association with an injury to either the anterior or posterior cruciate ligament. Recognition and treatment of varus and posterolateral instability of the knee is important clinically in that it may significantly effect the outcome in the treatment of cruciate ligament injuries. Failures of reconstructions of both the anterior and posterior cruciate ligament may in many cases be the result of unrecognized and untreated posterolateral instability.

Confusion regarding the diagnosis and treatment of posterolateral instability is due in part to the complexity and incomplete understanding of the anatomy and biomechanical functions of the numerous posterolateral structures. In a recent ligament cutting paper published by Wrobel et al it was noted that significant posterolateral instability could not be created until the lateral collateral ligament was sectioned. Investigators, including Maynard et al and Martin et al, have recently emphasized the importance of the popliteofibular ligament in preventing posterolateral instability. This ligament represents a static portion of the popliteus tendon that extends from the posterior aspect of the fibular head to the anterior aspect of the lateral femoral epicondyle.

Repair of damaged posterolateral structures is often complicated by distortion to or loss of anatomic structures. In such instances it is often necessary to utilize grafts to restore the posterolateral structures. It was our goal in this study to document normal ligament length relationships from the fibular head to the lateral femur in intact knees under various loading conditions. Utilizing this information we then developed a procedure for reconstructing the lateral collateral and popliteofibular ligaments utilizing a free semitendinosus tendon graft.

Experimental Technique

The objective of our study was to determine ligament length patterns in eleven normal unembalmed cadaveric knees utilizing only quantitative measurements of anatomy and motion. The motion of each intact knee under various loading conditions was digitally recorded and subsequently each knee was dissected and the bony anatomy digitized. The resulted digitized data was then utilized, along with computer search programs and an interactive graphic display terminal, to investigate all isometric and nearly isometric potential insertion sites from the fibular head to the lateral femur. A thorough description of the experimental technique has been published by Sidles, Larson et al.

Results

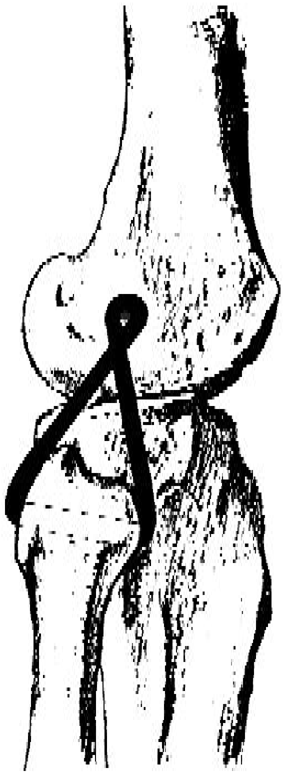
The results of the experimental study revealed that isometry or near isometry is maintained from the entirety of the fibular head to the lateral femoral epicondyle. It was noted that the length changes from the posterior aspect of the fibular head to the anterior aspect of the epicondyle and from the anterior aspect of the fibular head to the posterior aspect of the epicondyle were most favorable. This information is schematically presented in Figure 1.

Operative Procedure

Utilizing the isometry data a surgical technique was developed to reconstruct the lateral collateral ligament. The technique involves the use of a free semitendinosus autograft. The graft is attached to the fibula by passing it through a fibular head drill hole which is oriented from anterior to posterior through the largest diameter portion of the fibular head. The band exiting the posterior fibular head is then routed beneath the biceps femoris tendon and beneath the iliotibial band to the lateral femoral epicondyle. The portion of the semitendinosus graft exiting the anterior fibular head is passed beneath the iliotibial band to the lateral femoral epicondyle. The grafts are fixed to the femur by placing a low profile screw and washer around which the grafts are passed in a figure-eight fashion (Figure 2A). The figure-eight course optimizes the isometry of each band of the reconstruction. The portion of the graft passing from the posterior fibular head to the anterior femoral epicondyle represents a reconstruction of the popliteofibular ligament and provides a restraint limiting posterolateral rotation. If minimal varus laxity exists the procedure can be modified to pass both bands of the graft from the posterior fibular head to the anterior epicondyle as in Figure 2B. The grafts are then fixed to the anterolateral tibia after exiting the anterior fibula.

Discussion

Figure 1: Isometric areas relative to fibular head.



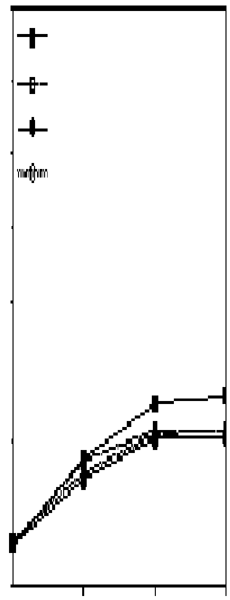


Figure 2A Figure 2B

Figure 2A: Technique for LCL reconstruction with semitendinosus free graft.
Figure 2B: Modification of procedure when only popliteofibular ligament reconstruction desired.

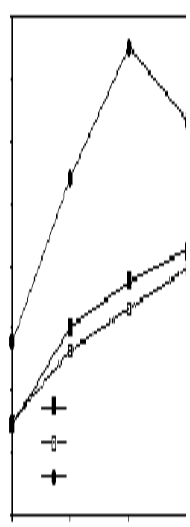
structures is often inadequate for treating posterolateral instability since tissues are frequently deficient and identification difficult. These procedures also involve extensive surgical exposure and dissection. The passage of tissue from the posterolateral corner of the tibia to the anterior femoral epicondyle mimics the path of a dynamic popliteus muscle tendon unit, but the attachment point on the posterolateral tibia undergoes extensive length changes relative to the lateral femoral epicondyle during knee motion. The attachment point on the posterolateral tibia is also significantly closer to the axis of posterolateral rotation than is the fibular head thus providing less of a mechanical advantage. The biceps tenodesis appropriately routes tissue from the fibular head to the anterior aspect of the lateral femoral epicondyle. This procedure however requires sacrificing the important function of the biceps femoris tendon and often results in overconstraint of the knee. By utilizing a semitendinosus free graft through the fibular head restoration of the popliteofibular ligament can be accomplished without sacrifice of the biceps tendon.

Previously described techniques for reconstructing the lateral collateral ligament have involved replacement in the anatomic position at the tip of the fibula. This is a difficult area to expose and a difficult site for graft fixation. The reconstruction of the lateral collateral ligament through a fibular head drill hole provides excellent fixation to the fibular head and maintains acceptable isometry to the lateral femoral epicondyle. The posterior band is effectively placed to prevent posterolateral rotatory movement.

Techniques for reconstruction of posterolateral instability include:

1) tightening of existing tissues which are frequently deficient
2) creating a restraining band from the posterolateral tibia to the lateral femoral epicondyle (Figure 3A), or
3) creating a tenodesis of the biceps femoris tendon from the fibular head to the anterior femoral epicondyle (Figure 3B).

We have felt that tightening existing



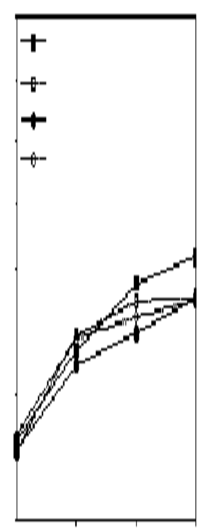


Figure 3A Figure 3B

Figure 3A: Popliteus bypass procedure (Mueller).
Figure 3B: Biceps tenodesis procedure (Clancy).

Conclusions

1. The entire fibular head is relatively isometric to the lateral femoral epicondyle throughout a full range of knee motion.
2. There is slightly improved isometry from the posterior aspect of the fibular head to the anterior aspect of the epicondyle and from the anterior aspect of the fibular head to the posterior aspect of the epicondyle.
3. Reconstruction of the lateral collateral ligament can be accomplished by passing a graft through a fibular head drill hole then attaching at the lateral femoral epicondyle.
4. Improved isometry of the LCL graft can be accomplished by routing the graft through the fibular head drill hole to the lateral epicondyle in a figure of 8 course.
5. The posterior band of a figure-eight LCL reconstruction recreates the popliteofibular ligament and provides a restraint to posterolateral rotation.

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The Effect of Semitendinosus and Gracilis Tendon Harvest for Anterior Cruciate Ligament Reconstruction

Peter T. Simonian, M.D., Scott D. Harrison, M.D., Vernon J. Cooley, M.D., Eva M. Escabedo, M.D., David A. Deneka, M.D., and Roger V. Larson, M.D.

Donor site morbidity is a concern after autologous anterior cruciate ligament (ACL) reconstructive surgery. The two most common sources for autologous graft include the central third of the patellar tendon, or the semitendinosus and gracilis tendons. Excellent functional results have been reported using either source. When a portion of the patellar tendon is used, it is typically based on the central third with a bone block at each end, one from the patella and the other from the tibial tubercle. Postoperative complications can include patellofemoral pain and stiffness as well as quadriceps weakness. Patella fracture has also occurred. Rupture of the patellar ligament is a rare complication. Interestingly, patellofemoral pain, although much less common, has been reported after semitendinosus and gracilis tendon harvest. Two studies reported minimal donor site morbidity after semitendinosus and gracilis tendon harvest. Lipscomb found no significant difference in hamstring strength after harvest of both the semitendinosus and gracilis tendons. However, there was no attempt to evaluate individual muscles of the posterior thigh for atrophy or hypertrophy. Cross et al evaluated four patients with magnetic resonance imaging (MRI), EMG, and dynamometer testing six months after ACL reconstruction. Based on this group, they concluded that these tendons regrow and are probably functional.

The purpose of this study was to evaluate the effect of harvest of both the semitendinosus and gracilis tendons for ACL reconstruction at a minimum of three year follow-up. Specifically, the effect on the knee function, the knee extension and flexion strength, the size of the individual posterior thigh muscles, and the remnants of the harvested semitendinosus and gracilis tendons were evaluated.

Materials and Methods

Nine patients with a minimum of 36 months (range 36–48) of follow-up after ACL reconstruction with free semitendinosus and gracilis autograft were studied. Five were male and four were female. Six of the operated knees were right and three were left. The average age was 28 years (range 20–42). At final follow-up, each patient was evaluated by four functional scales (IKDC, HSS, Lysholm, and Tegner). Each patient also had a dynamometer evaluation and a comprehensive MRI study of both the operated and non-operated knees. The dynamometer tests were performed using a Cybex (Lumex Corp., Ronkonkoma, NY) machine on each knee at 90 and 180 degrees per second.

MRI was performed on both the operated and contralateral non-operated knees of each of the nine patients, using a T1-weighted volume acquisition sequence (TR=39 ms, TE=6 ms, Flip Angle=45°, and field of view=180mm). An independent console work station was utilized to image the knee region in sagittal, coronal, and axial planes at 0.7 mm contiguous increments. For each knee the axial image obtained at 10 cm above the medial joint margin was used to calculate the cross-sectional area for the biceps femoris, semimembranosus, and sartorius muscles. This allowed comparison of the cross-sectional area of both normal and operated knees at the same level above the joint. Using multiple imaging planes, including curved reformations, the remnants of the harvested semitendinosus and gracilis tendons were visualized throughout their course, and the level of the distal insertion (where the tendon ended) of each was recorded relative to the medial joint line. This was compared to the insertion points of the contralateral normal knee. Positive values represent measurement in mm of the tendon attachment proximal to the joint line and negative values represent attachment distal to the joint line (Figure 1).

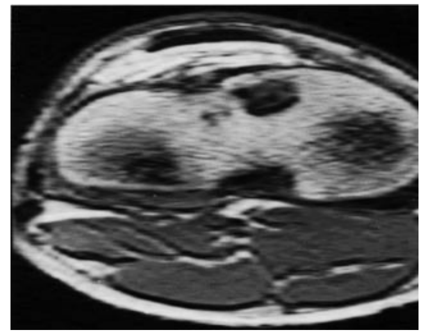

Figure 1: Representative MRI example of an operated knee 4.9 mm below the joint line demonstrating the absence of the semitendinosus and gracilis tendons medially.

Results

The average functional evaluation scores were: HSS–47.9; Lysholm–88; and Tegner–0.27. The average percent quadriceps strength of the operated to the non-operated was 93.7. All but two patients demonstrated a decrease in quadriceps strength; however this decrease was not significant ($p<0.05$) using a two-tailed paired t-test. The average percent hamstring strength of the operated to the non-operated was 95.3. All but two patients demonstrated a decrease in hamstring strength; this also was not significant ($p<0.05$). One patient had an increase in both hamstring and quadriceps strength on the operated side.

MRI evaluation of the cross sectional areas of the biceps femoris, semimembranosus, and sartorius muscles of both knees at the same level above the joint were not significantly different ($p<0.05$) using a two-tailed paired t-test. The distal-most insertion of the semitendinosus and gracilis tendon remnants were variable. However, the operated side insertion was always more proximal than the non-operated side with an average difference of 26.7 mm (range 11–32 mm) for the semitendinosus and an average difference of 47.1 mm (range 17–72 mm) for the gracilis. In three cases the semitendinosus tendon remnant was not present at the most superior level imaged (10 cm above the joint margin); these three were not included in the average difference in insertion site determination above. These three patients had an average decrease in knee flexion strength of 10.3% on the operated side compared to the non-operated side; this was a greater decrease in strength than the remaining six patients who had a 1.8% decrease. The concavity along the posterior margin of the semimembranosus normally containing the semitendinosus was well visualized in these three patients and was empty. The sartorius muscle and tendon were visualized in all images bilaterally with symmetric size and normal insertion (Table 1).

Discussion

The dynamometer results reported here demonstrated no significant difference between the operated and non-operated hamstring and quadriceps strength. However, our results showed slightly less hamstring strength after harvest of both the semitendinosus and gracilis tendons (95.3% compared to the non-operated extremity) than those reported by Lipscomb et al (99% compared to the non-operated extremity). The results of quadriceps strength reported by Lipscomb et al was 96% of the non-operated extremity, our results were essentially the same at 94.7%. There were two possible explanations for maintaining hamstring strength after harvest of the semitendinosus and gracilis tendons. Either they remain functional, or there is compensatory hypertrophy of the undisturbed knee flexors. We attempted to evaluate these explanations with MRI.

There was no compensatory hypertrophy based on comparison of cross sectional MRI areas of the biceps femoris, semimembranosus, and gracilis muscles of both knees measured the same level above the joint. Although determining an insertion point of the remains of the harvested tendons does not evaluate function, all visualized remnants had a discrete identifiable insertion proximal to that on the nonoperated side, with an average difference of 26.7 mm (range 11–32 mm) for the semitendinosus and an average difference of 47.1 mm (range 17–72 mm) for the gracilis. Although, each of these cut tendons were attached more proximal than their nonoperated counterparts, the difference

Table 1: Summary Data Table.

Functional Scores					Dynamometer		MRI Tendon Insertion				Muscle Cross Sectional Area					
Pt	IKDC	HSS	Lysh	Tegner	%quad streng	%ham streng	Insert ST Op	Insert ST Non-op	Insert Grac Op	Insert Grac Non-op	BiFem Op	BiFem Non-op	SMemb Op	SMemb Non-op	Sart Op	Sart Non-op
1	A	50	94	0	-13	-11	no	-60	+36	-22	564	558	1483	1616	385	370
2	B	47	90	0	+8	-6	-35	-51	-28	-45	1357	1195	2011	1756	434	426
3	B	49	89	0	-19	+13	-23	-54	+23	-42	810	885	1078	1237	287	432
4	A	49	91	0	-6	-5	no	-53	+10	-51	936	808	1188	1205	424	414
5	B	48	86	1	-16	-7	-36	-47	-18	-40	1189	1316	1599	1428	469	603
6	C	46	46	1	-1	-15	no	-57	+15	-51	904	854	1336	1420	332	339
7	A	47	99	0	-4	-9	-20	-44	+28	-45	878	1055	1033	1302	363	348
8	A	49	90	0	-8	-13	-16	-48	+7	-33	1058	1103	1456	1382	349	397
9	A	48	100	0	+2	+11	-29	-51	-28	-45	941	905	1762	1826	392	364
AVE		47.9	88	0.27	-6.3	-4.7					960	964	1438	1464	382	410
SD											75	76	107	74	19	27
p value					0.06	0.19					0.90		0.66		0.23	

% quad streng: Dynamometer measured decrease (negative values) or increase (positive values) quadriceps % strength compared to the non-operated extremity (averaged at 90 and 180 degrees per second).

% ham streng: Dynamometer measured decrease (negative values) or increase (positive values) hamstrings % strength compared to the non-operated extremity (averaged at 90 and 180 degrees per second).

Insert ST Op: MRI measured distance (mm) of the semitendinosus insertion on the harvested side. The joint line was the zero point; values proximal to the joint line were negative and values distal to the joint line were positive.

Insert ST Non-op: MRI measured distance (mm) of the semitendinosus insertion on the non-operated side. The joint line was the zero point; values proximal to the joint line were negative and values distal to the joint line were positive.

Insert Grac Op: MRI measured distance (mm) of the gracilis insertion on the harvested side. The joint line was the zero point; values proximal to the joint line were negative and values distal to the joint line were positive.

Insert Grac Non-op: MRI measured distance (mm) of the gracilis insertion on the non-operated side. The joint line was the zero point; values proximal to the joint line were negative and values distal to the joint line were positive.

Bi Fem Op: MRI measured cross sectional area (mm) of the biceps femoris muscle belly on the operated extremity.

Bi Fem Non-op: MRI measured cross sectional area (mm) of the biceps femoris muscle belly on the non-operated extremity.

SMemb Op: MRI measured cross sectional area (mm) of the semimembranosis muscle belly on the operated extremity.

SMemb Non-op: MRI measured cross sectional area (mm) of the semimembranosis muscle belly on the non-operated extremity.

Sart Op: MRI measured cross sectional area (mm) of the sartorius muscle belly on the operated extremity.

Sart Non-op: MRI measured cross sectional area (mm) of the sartorius muscle belly on the non-operated extremity.

p-value: Two tailed paired t-test.

of 26.7 mm for the semitendinosus and 47.1 mm for the gracilis is considerbly less than the length of graft harvested. This would seem to indicate a degree of regrowth or scar formation in the majority of cases. We could not visualize a discrete insertion for three semitendinosus tendons on the operated side. The MRI images were likely not proximal enough to visualize these tendon remnants. These three patients had an average decrease in strength of the operated hamstrings of 10.3% compared to the non-operated side; this was a greater decrease in strength than the remaining six patients who had a 1.8% decrease. Based on the dynamometer results for the entire group, the more proximal attachment did not appear to significantly decrease strength.

We conclude that tendon harvest of the semitendinosus and gracilis muscles does not significantly compromise function and strength despite a more proximal insertion of the tendon remnant, and that the majority of cases demonstrated some but never complete regrowth of these tendon remnants.

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Acute Knee Dislocations and the Role of MRI

Jens R. Chapman, M.D., Peter T. Simonian, M.D., and John Hunter, M.D.

Use of the MRI with the dislocated knee is a valuable clinical tool. Traumatic knee dislocation is generally considered a rare lesion, although many authors believe that it is more common but goes unrecognized because of spontaneous reduction during initial rescue or resuscitation. The dislocation is classified as anterior, posterior, lateral, medial or rotatory and described by the position of the tibia relative to the femur. Anterior and posterior dislocations account for 50–75% of cases. The mechanism usually involves violent forces, such as motor vehicle accidents or falls from a significant height, and multisystem traumatic injuries are often coexistent. Serious vascular injury to the popliteal vessels occurs in one-third of cases and peroneal nerve injury in one-fourth.

Accurate diagnosis and classification of the associated soft tissue damage is important in operative planning of the knee reconstruction. The dislocation may be difficult to evaluate clinically because of associated injuries, especially ipsilateral lower extremity and pelvic fractures. While physical examination and plain radiographs remain the mainstays of diagnosis, examination under anesthesia with stress films or intra-operative arthroscopy at the time of repair have been advocated. The availability of magnetic resonance imaging may offer added information to the orthopedic surgeon in the preoperative evaluation and surgical planning of the repair and limit the severe and potentially disabling effects of knee dislocation. The purpose of this study was to compare the accuracy of MRI to actual findings at surgery.

Materials and Methods

Seventeen knee dislocations in fifteen patients were evaluated. There were eleven male and four female patients with an average age of 26 years (ranging 14–51 years). One patient had an open dislocation (7%). Three patients had associated tibial plateau fractures requiring open reduction and internal fixation (20%); these comprised two Lateral plateau fractures and one biplateau fracture. Four knees in three patients required vascular reconstructions (27%) and were performed prior to the MRI and surgical stabilization as emergent procedures.

Following physical examination, vascular assessment and plain radiographs, patients were evaluated with an MRI scan of the knee prior to acute surgical stabilization.

The impact of the MRI on the surgical treatment was also assessed. A check list for each knee was created to record the injured structures after MRI prior to surgery by the radiologists and post-operatively by the surgeons recording actual surgical findings. This allowed evaluation of the MRI accuracy.

Surgical treatment consisted of a midline, longitudinal transpatellar tendon arthrotomy, limited notchplasty, posteromedial and/or posterolateral incisions as indicated by the MRI and clinical findings. All complete collateral ligament disruptions were repaired if mid-substance or reattached if avulsed from bone. Cruciate ligament avulsions were reattached with pull-through sutures through drill holes. Cruciate reconstructions were performed preferentially with patellar tendon or achilles tendon allografts except in two patients who chose a patellar tendon autograft.

Postoperativley all patients had immediate range of motion with continuous passive and active assisted programs.

Data analysis was performed to assess the specificity, sensitivity and predictive value of the MRI in this constellation of injuries and whether this was different for anterior, medial, lateral or posterior structures.

Table 1: The frequency each ligament was injured and particular operative treatment.

	True Positive	False Negative	True Positive	False Negative
Medial Structures:	19 (56%)	2 (6%)	13 (38%)	0 (0%)
Medial Collateral Lig.				
PosteroMed. Capsule				
Lateral Structures:	23 (67%)	1 (3%)	6 (18%)	4 (12%)
Lateral Collateral Lig.				
PosteroLat. Capsule				
Anterior Structures:	17 (50%)	0 (0%)	17 (50%)	0 (0%)
Anterior Cruciate Lig.				
Patellar Tendon				
Posterior Structures:	35 (69%)	1 (2%)	13 (25%)	2 (4%)
PosteriorCruciate Lig.				
PosteroLat. Capsule				
PosteroMed. Capsule				

Table 2: The positive and negative values for each side of the knee.

% Repaired or% Not Ligament Injured% InjuredReattached% ReconstructOperated				
Medial Collateral	9/17 (53%)	6/9 (67%)	0 (0%)	3/9 (33%)
Lateral Collateral	13/17 (76%)	9/13 (69%)	1/13 (8%)	3/13 (23%)
Anterior Cruciate	15/17 (88%)	4/15 (27%)	8/15 (46%)	3/15 (20%)
Posterior Cruciate	13/17 (77%)	5/13 (38%)	5/13 (38%)	3/13 (23%)

See represenatitve Figures 1AB, 2AB, 3AB, 4AB, 5, 6ABC, and 7.

Results

Table 1 outlines the positive and negative values for each side of the knee. For the medial structures: sensitivity of MRI was 1.00; specificity of MRI was 0.86; positive predictive value was 0.86; negative predictive value was 1.00. For the lateral structures: sensitivity of MRI was 0.79; specificity of MRI was 0.86; positive predictive value was 0.94; negative predictive value was 0.60. For the anterior structures: sensitivity of MRI was 1.00; specificity of MRI was 1.00; positive and negative predictive values were 1.00. For the posterior structures: sensitivity was 0.93; specificity was 0.92; positive predictive value was 0.96; negative predictive value was 0.85.

Table 2 details the frequency each ligament was injured and particular operative treatment.

Discussion

Physical examination, plain radiographs, and vascular studies are crucial first steps towards identifying the injured structures in suspected knee dislocations but may not provide all the answers. In an awake, cooperative patient, a physical examination of the joint is limited acutely by pain and swelling and is subject to the examiners experience and grading preferences of instability severity. In the polytraumatized patient, other surgical insults, concomitant fractures, presence of vascular repairs and the difficulties of assessing a pharmacologically paralyzed patient in an intensive care setting limit the efficacy of clinical assessment. The MRI offers the possibility of objectively demonstrating soft tissue injuries in complex knee disruptions.

In this prospective study of seventeen dislocated knees in fifteen patients use of the MRI was a valuable clinical tool in patients who are to be treated with surgical repair and/or reconstruction. The MRI was accurate in identifying the lesions on all sides of the joint but a negative result on the lateral side was the least predictive. This is predominantly due to the difficulty in identifying anatomical structures in this region.

Use of the MRI with the dislocated

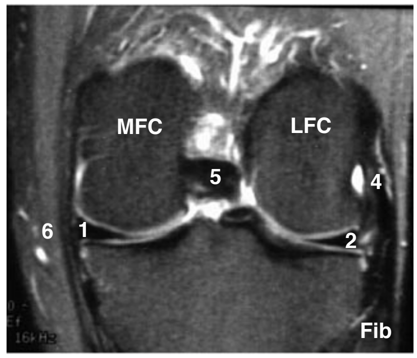

Figure 1A: Normal meniscocapsular relationships, coronal plane. FSE proton density with fat suppression: normal posterior knee anatomy on MRI.

1=posterior horn medial meniscus
2=posterior horn lateral meniscus
3=popliteus tendon in the sheath
4=LCL
5=PCL
6=MCL.

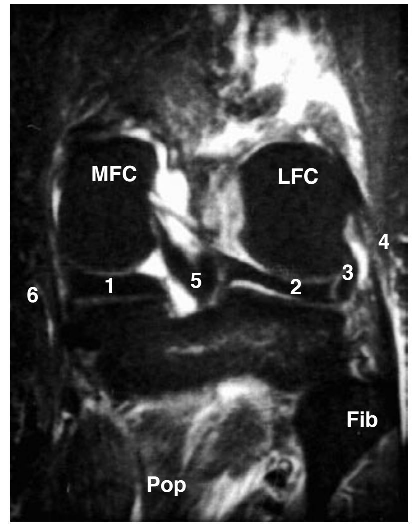

Figure 1B: STIR MR sequence in a patient with knee injury, joint effusion and bright signal in the popliteus muscle indicating contusion (Pop). Note the close apposition of the capsule to the meniscus, tibia and femur. The stripe of signal between the medial meniscus (1) and the deep fibers of the MCL (6) is normal as is the bright fluid signal in the popliteus tendon sheath (3).

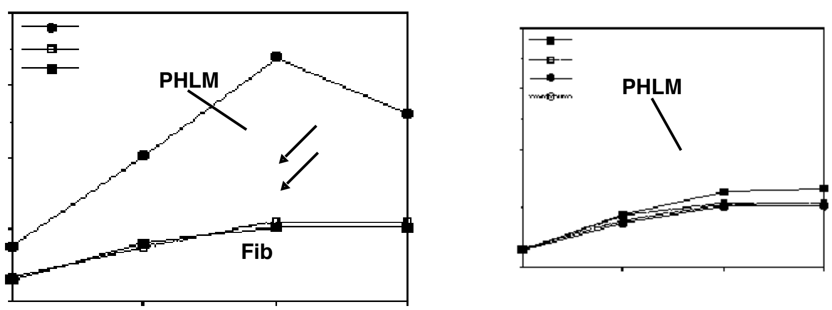

Figure 2: Normal posterolateral MRI anatomy, sagittal plane. A, B. Normal sagittal FSE proton density images demonstrating the normal signal intensity of the popliteus muscle (Pop) and the normal appearance of the muscle, tendon (PT, arrows) and tendon sheath traversing the posterior horn of the lateral meniscus (PHLM).

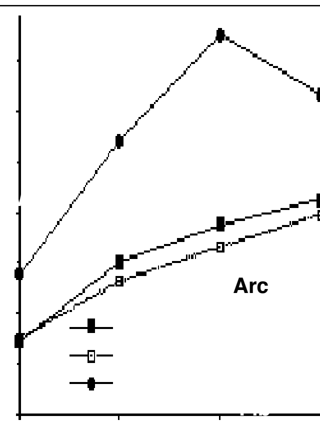

Figure 3A: Case 13. Note the increased signal in the popliteus muscle (Pop) and arcuate complex (Arc), the latter of which is disrupted.

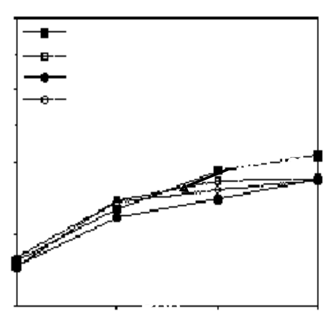

Figure 3B: Sagittal FSE proton density image through the lateral plateau shows increased signal in the popliteus muscle (Pop) and an abnormal musculotendenous junction (M-T jct).

Fib=fibular head
LFC=lateral femoral condyle
MFC=medial femoral condyle
G-mh=medial head of gastrocnemius

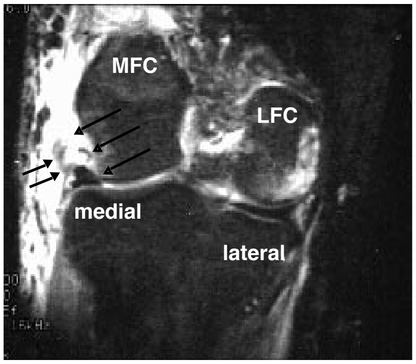

Figure 4A: (Case 11) Coronal STIR MRI. The lack of definable MCL indicates a tear of this structure. The image further shows medial meniscocapsular separation with stripping of the capsule off the distal femur (arrows), separation of the medial meniscus from the distal femur, and a remnant of capsular/ligamentous tissue attached to the superior margin of the medial meniscus (black arrows).

Figure 4B: Medial and lateral meniscocapsular junction tears. Gradient echo MRI radial images shows increased signal intensity along the tibia both medially and laterally indicating meniscocapsular junction tears (white arrows).

Fib=fibular head
LFC=lateral femoral condyle
LFL=lateral collateral ligament
MFC=medial femoral condyle
P=patella

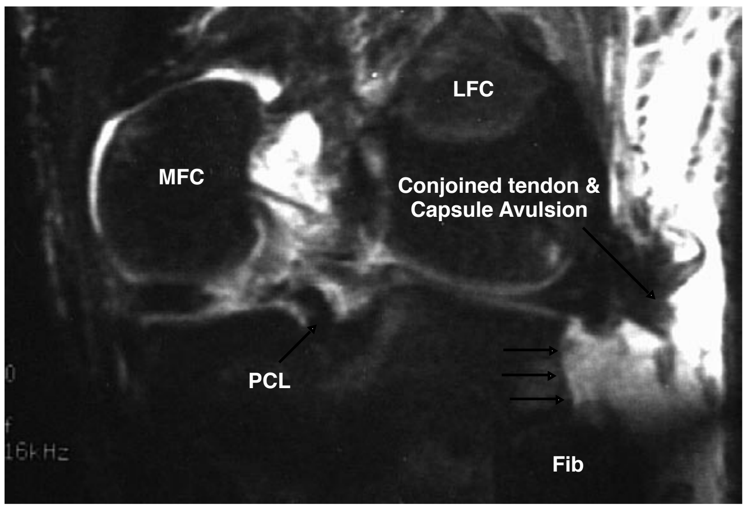

Figure 5: Posterolateral corner tear. Coronal STIR MR image shows increased signal intensity along the lateral tibia (arrows) consistent with stripping of the capsule. The retracted remnant of the conjoined tendon, avulsed off the fibular head is indicated as well. This patient required amputation for vascular complications.

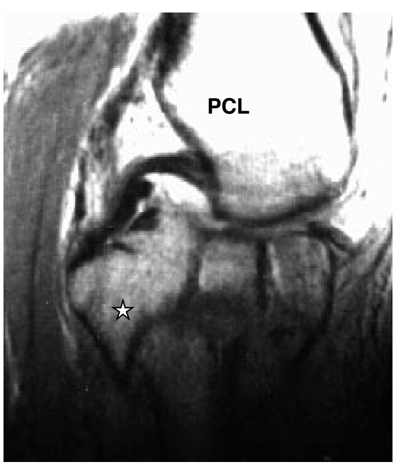

Figure 6A: (Case12) Tibial plateau fracture with knee dislocation. Sagittal FSE proton density images of the knee, anterior to reader's right. The ACL is attached to large anterior plateau fragments (star).

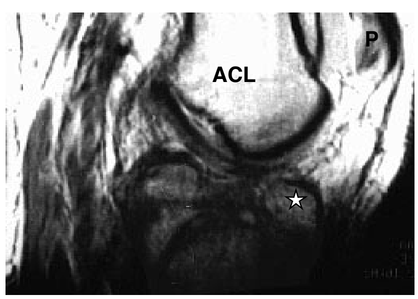

Figure 6B: (Case12) Tibial plateau fracture with knee dislocation. Sagittal FSE proton density images of the knee, anterior to reader's right. The PCL is attached to large posterior plateau fragments (star).

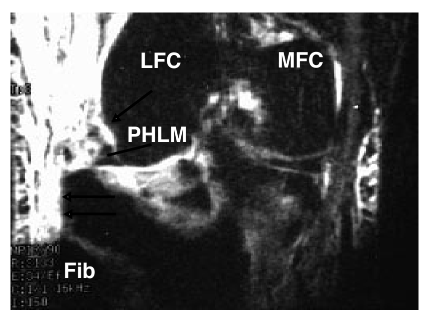

Figure 6C: Coronal STIR image demonstrates displacement of the posterior horn of the lateral meniscus (PHLM) away from the femur and marked displacement from the tibia (arrows), compatible with extensive meniscocapsular separation. The medial side was normal.

Figure 7: Effect of internal fixation devices on the MR image. Sagittal FSE proton density image with fat suppression through the femoral notch demonstrates a titanium retrograde nail used for repair of a femoral fractuire. Note that the ACL (arrows) is easily seen despite being displaced by the nail. Titanium implants cause the least troublesome MR artifacts in our experience.

P=patella

knee is a valuable clinical tool. The information available preoperatively from the MRI allows for detailed surgical planning, including availability of allografts, exposures required and incisions used as well as a detailed and accurate operative plan for the order of repair and reconstruction.

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Repair of Acute Patellar Ligament Tears with Semitendinosus Augmentation and Immediate Motion

Roger V. Larson, M.D. and Peter T. Simonian, M.D.

Mid-substance patellar ligament tears are uncommon and can be difficult to repair because of tissue loss and compromise at the disrupted ligament borders. The goals of repair to the acutely ruptured patellar ligament include: restoration of the quadriceps mechanism to allow strength and maximal range of motion; restoration of anatomic congruity of the patellofemoral joint to avert chondromalacia and decrease the incidence of a painful patellofemoral articulation; restoration of vascularity of the disrupted ligament to assure maximal functional tendon strength; and splinting of the patellar ligament repair to allow early mobilization.

Almost all reported surgical procedures for repair of fresh and neglected ruptures of the patellar ligament utilize lengthy immobilization (minimum of six weeks) in a plaster cast. However, significant changes in bone, joint, and soft tissue may result from immobility. Mechanical stimuli are important in maintaining the functional integrity of tendons, ligaments, and bones.

Allograft material to augment the disrupted knee extensor mechanism was used as early as 1927. Kelikian et al first used the semitendinosus tendon to bridge the patellar tendinous gap in a single case reported in 1957. Levy et al used a tension-reinforcement-suture technique utilizing a synthetic Dacron graft. This enabled immediate mobilization of the knee after surgery, eliminating prolonged immobilization in a cast. All of their patients began active physical therapy on the first day after surgery and did not require a second surgery for hardware removal. However the long term strength of synthetic reconstructive materials is questionable.

Also recognizing the importance of early mobilization, Mueller recommends repair of the ruptured patellar ligament with an absorbable suture protected with a figure-eight tension band wire which is passed through the quadriceps tendon insertion and the tibial tubercle insertion. The figure-eight tension band protects the repair of the tendon and makes early mobilization possible. However, the tension band wire should be removed after about six months.

Mandelbaum et al reported a single case of reconstruction of a neglected tear of the patellar ligament utilizing the semitendinosus and gracilis as an internal splint of the patellar tendon in conjunction with Z-lengthening of the quadriceps tendon in a single stage procedure. This reconstruction differed from the previous studies because it allowed early mobilization and rehabilitation and did not require a second surgery for hardware removal or the use of synthetic material.

We are reporting the surgical technique and case histories of four acute mid-substance patellar ligament ruptures that underwent primary surgical repair along with semitendinosus autograft augmentation. The goal was to allow immediate mobilization of the knee with a single operative procedure.

Materials and Methods

Surgical Technique

The semitendinosus tendon was harvested in the standard fashion used for anterior cruciate ligament reconstructions. A vertical incision is made over the pes anserinus, and the insertion of the semitendinosus tendon is identified. The semitendinosus tendon is isolated and sharply removed from its tibial attachment. The tendon is then harvested as a free graft utilizing a tendon stripper. Extraneous muscle is trimmed from the tendon, and a Bunnel stitch of non-absorbable suture is placed in each end of the tendon.

Next tranverse drill holes are made at the distal pole of the patella and at the tibial tubercle (Figure 1). The drill holes are made just large enough to allow tendon passage. The semitendinosus tendon autograft is placed through the drill holes either one or two passes depending on the tendon length. The tendon can be placed as a loop or figure-eight. In the present study the tendon was placed as a loop (Figure 1). The correct tension is placed on the graft by evaluating patellar position. This is done by obtaining an intraoperative lateral radiograph with the knee in 30 degrees of flexion and matching the patellar position to a preoperative lateral radiograph of the opposite knee in the same amount of flexion. When the correct patellar position is obtained, the sutures on each end of the graft are tied together to complete the circuit.

The patellar ligament ends are then repaired at the correct length with the Krackow suture technique utilizing non-absorbable suture. The

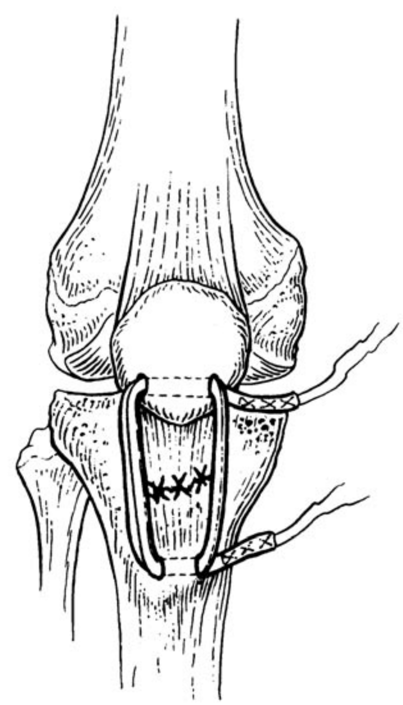

Figure 1: Diagram of the patella ligament augmentation technique. A drill hole is made from medial to lateral at both the level of the tibial tubercle and at the distal pole of the patella. The semitendonosus tendon autograft is placed through the drill holes one or two passes depending on the ligament length. The correct tension is placed on the graft by evaluating patellar position radiographically. When the correct patellar position is obtained the sutures on each end of the graft are tied together to complete the circuit.

semitendinosus graft is also sutured to the repaired tendon as needed to secure fixation.

Rehabilitation Protocol

Continuous passive motion (CPM) machines were used immediately after surgery and continued for approximately two weeks post-operatively. Patients were also seen periodically in physical therapy for passive and assisted active range of motion and isometric strengthening exercises. At two weeks post-operative, low resistance stationary cycling was started and aggressive physical therapy was continued to strengthen the quadriceps and increase the range of motion.

Patients utilized crutches for balance with weight bearing as tolerated in an extension brace for the first eight weeks. The brace was removed frequently for CPM and physical therapy.

Patients were discharged the day after surgery, except for the case that involved more than an isolated patellar ligament injury.

Results

Cybex Strength Evaluation

The results are reported in Table 1. In each case the quadriceps and hamstring strength are essentially symmetrical except Case 4, which is likely due to the combination of injuries.

Lysholm Knee Scoring Scale

The results are reported in Table 1. The average score was 97.5 (range 89–100). Case 1 had a score of 96 because of reported swelling of the knee with severe exertion. Case 4 was unusually low probably because of the combination of injuries. Specifically, he lost 5 points in the areas of both instability and pain. The pain was described to be deep within the joint rather than anterior. He lost an additional point for reporting slight impairment with squatting.

One-Leg Hop

Evaluation of one-leg hop as described by Tegner and coworkers was performed. The average distance of three one-leg hops for each leg, with the arms held behind the back, are also reported in Table 1. In each case the distances of the operated verses the non-operated leg are essentially symmetrical except Case 4, which is likely due to the combination of his injuries. Again, Cases 1 and 2 are the same patient therefore a normal control is lacking.

Range of Motion

The range of motion was only significantly different from the non-operated knee in Case 4 , again this is likely due to the multiple injuries of this joint (Table 1).

Radiographic Evaluation

The patellar ligament length (Table 1) measured from the inferior pole of the patella to the tip of the tibial tubercle on the lateral radiograph with the knee in 30 degrees of flexion was equal to the non-operated side in each case. There is no evidence of patellofemoral arthritis on the sunrise views.

Discussion

The stated treatment goals of the acutely ruptured patellar ligament were achieved in these four cases: restoration of the quadriceps mechanism to allow strength and maximal range of motion; restoration of anatomic congruity of the patellofemoral joint to avert chondromalacia and decrease the incidence of a painful patellofemoral articulation; and splinting of the patellar ligament to allow early mobilization.

The one-legged hop test was most recently evaluated by Noyes et al in ACL deficient knees. They concluded that one-legged function tests had a low sensitivity rate; however, the high specificity and low false-positive rates indicated that these tests can be used to confirm limb assymmetry. They suggested that the tests be used in conjunction with other clinical assessment tools to provide confirmation of the extent of lower limb functional limitations. Therefore we include this specific test in our evaluation even though we were evaluating the extensor mechanism rather than the ACL.

Mandelbaum et al reported a single case of reconstruction of a neglected tear of the patellar ligament utilizing the semitendinosus and gracilis as an internal splint of the patellar ligament in conjunction with Z-lengthening of the quadriceps tendon in a single stage procedure. The graft was placed as a figure-eight with ends approximated using a Krackow suture technique in a similar fashion to our cases. This reconstruction differed from the

Table 1: Functional evaluation at an average final follow-up of 40 months (range 20-66 months).

	CYBEX (ft. lbs.) quad 90 deg	CYBEX (ft. lbs.) ham 90 deg	CYBEX (ft. lbs.) quad 180 deg	CYBEX (ft. lbs.) ham 180 deg	Lysholm Score	One-leg hop (ft.)	Range of Motion	Patellar lig. length (cm)
CASE 1 (operated R)	106	95	89	79	96	4.8	0-140	5.5
CASE 2 (operated L)	107	94	87	82	100	4.9	0-135	5.5
CASE 3 (operated)	138	66	112	63	100	2.85	0-145	5.5
CASE 3 (non-op)	134	75	98	72	100	2.9	0-145	5.5
CASE 4 (operated)	59	44	49	77	89	1.75	0-128	5.0
CASE 4 (non-op)	86	63	77	53	100	3.6	0-142	5.0

previous reports of hamstring tendon augmentations reported in the literature because it allowed early mobilization and rehabilitation.

We approached the acute mid-substance patellar ligament rupture using similar rationale that Mandelbaum applied to his case of neglected rupture. In addition, to assure more anatomic position of the patella in our cases, intraoperative radiographs were obtained to compare to preoperative radiographs of the normal knee.

Conclusion

The four cases presented of immediate mid-substance patellar ligament repair with semitendinosus augmentation utilized immediate mobilization to decrease the time period and improve the final outcome of rehabilitation. We also demonstrated a technique for determining patellar position intraoperatively. A second surgery for hardware removal was not needed. These two factors of early and improved rehabilitation, and the decreased chance of a second surgery are economically valid. Further no functional loss was demonstrated in these patients undergoing semitendinosus and gracilis tendon harvest. All four knees in the study went on to excellent function. For these reasons, we recommend this procedure in the setting of acute patellar ligament ruptures.

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A Biomechanical Analysis of the Squeeze Test for Sprains of the Syndesmotic Ligaments of the Ankle

CAROL C. TEITZ, M.D. AND RICHARD M. HARRINGTON, M.S.

The syndesmotic ligaments of the ankle include the anterior tibio-fibular ligament, the posterior tibio-fibular ligament, and the interosseous ligament. Injuries of these ligaments are often difficult to diagnose when they are incomplete or not associated with fractures. When, in the face of syndesmosis injury, routine radiographs fail to show mortise widening, stress radiographs in external rotation and abduction may reveal a latent diastasis. Some patients with injury to the syndesmosis have no obvious mortise widening even on stress films, yet their recovery time is longer than for patients suffering from sprains of the lateral ankle ligaments. Often called "high sprains", these injuries are frequently associated with subsequent heterotopic ossification.

The "squeeze test" was described in 1990 by Hopkinson et al as a clinical test for detecting these "stable" syndesmosis injuries. The test is performed by compressing the fibula to the tibia above the midpoint of the calf. The test is positive when proximal compression produces pain in the area of the distal tibio-fibular and interosseous ligaments, and injuries such as fractures of the tibia or fibula, compartmental syndrome, contusions, abrasions, or cellulitis have been ruled out. Both Hopkinson and Taylor found a correlation between a positive squeeze test, delayed return to activity, and subsequent calcification in the region of the tibio-fibular ligaments and interosseous membrane inferring injury to these structures.

In previous cadaveric studies by Burns et al, sectioning of the syndesmotic ligaments produced on average only 0.24 mm widening of the mortise, and no significant change in tibiotalar contact area or peak pressure. However, when the deltoid ligament was cut, diastasis increased to 0.73 mm, tibiotalar contact area decreased by 39% , and peak pressure in the tibiotalar joint increased by 42%. Similarly, external rotation of the fibula was not noted after sectioning only the anterior tibiofibular ligament, but increased after the anterior part of the deltoid or the posterior talofibular liogament were cut. The sequence of cutting did not affect the mobility patterns seen.

Although the mechanism of syndesmosis injury is commonly thought to be due to an abduction and external rotation force, no tenderness to palpation of the deltoid ligament was noted in Hopkinson's patients. It may be that the squeeze test identifies those patients in whom one or more ligaments of the syndesmosis have been injured but in whom the deltoid is still intact, i.e. a "stable" syndesmosis injury. We hypothesized that the pain produced distally by a proximal squeeze is due to tension on the remaining fibers when part of the syndesmotic ligament complex has been torn. The purpose of this study was to examine what fibular movement, if any, occurs at the level of the ankle mortise when compression is applied proximally, and one or more of the syndesmotic ligaments are torn.

METHODS

Fresh cadaveric human lower limbs extending from mid thigh (approximately 15 cm above the knee) to toes were obtained (Department of Biological Structure, University of Washington). Skin and muscle tissues were removed from the proximal femur to allow mounting in a clamp such that the leg hung over the edge of a table with the knee flexed 90 degrees and the foot free, simulating the clinical conditions of the squeeze test.

The calf musculature and skin remained intact. Small sections of skin were removed about the ankle anteriorly exposing the tibio-fibular, interosseous, and lateral ankle ligaments; posteriorly exposing the posterior tibiofibular ligament, and medially exposing the deltoid ligament. Graphite rods were secured with methylmethacrylate into drill holes in both the fibula and tibia, aligned with the medial/lateral direction. Polhemus electromagnetic six-degree-of-freedom tracking units were mounted on these rods to measure displacement, rotation, and angulation of the distal fibula relative to the tibia. In addition, a miniature displacement transducer with barbed prongs was inserted near the origin and insertion of the anterior tibio-fibular ligament to measure strain in its fibers and the distance between the fibula and the tibia at the level of the anterior tibio-fibular ligament after it is cut.

The distance from the knee joint to the ankle joint was measured and a line was drawn on the specimen at the midpoint of the leg. All squeezes were applied just above this line. The squeeze was applied manually (by the same person) as well as by a clamp which had been designed and calibrated to apply loads between 0–300 N. These loads were determined by testing the amount of force generated by three volunteers on a LIDO pinch tool.

Measurements of displacement, angulation, rotation, and strains were made with all ligaments intact (INT). Serial sectioning was then carried out, measuring these same motions, by cutting ligaments in the following sequence: anterior tibiofibular ligament sectioned halfway (ATF1), anterior tibiofibular ligament sectioned completely (ATF2), interosseous membrane sectioned (IO), posterior tibiofibular ligament sectioned (PTF), deltoid ligament sectioned (DELT), anterior talofibular ligament sectioned (ATAF), and calcaneofibular ligament sectioned (CF). In the ligament-intact state and after each ligament had been sectioned, measurements were made under no load (no squeeze) and with a manual squeeze of approximately 190 N. These conditions and measurements were repeated three times. Then a squeeze was applied mechanically using loads of 90N, 135N, and 180N.

The specimens were compared by calculating the root-mean-square magnitude of the displacements and rotations, allowing comparison of the magnitude of the motion without consideration of the anatomic plane in which it primarily occured. A repeated

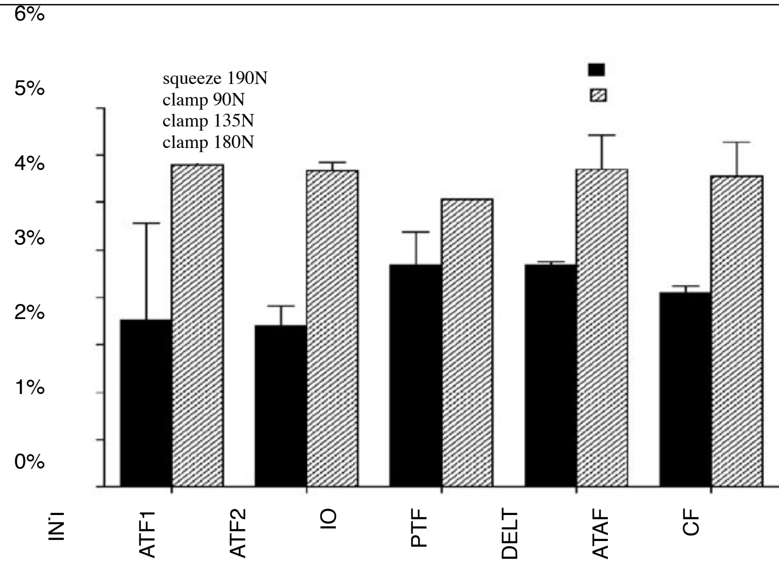

Figure 1: Tibiofibular separation of the anterior tibtifibular ligament. The reference position for the calculation of tibiofibular separation measurement int: intact, ATF1: 1/2 of the anterior tibiofibular ligament cut, ATF2: the rest of the anterior tibiofibular cut, IO: interosseous membrane cut, PTF: posterior tibiofibular ligament cut, DELT: deltoid ligament cut, ATAF: anterior talofibular ligament cut, CF: calcaneofibular ligament cut.

measures analysis of variance (Statview, Abacus Concepts, Berkeley, CA) was performed on the displacement, rotation and strain in the anterior tibiofibular ligament to determine the significance of the effects of sectioning and loading (squeezing). Post hoc testing was performed, using Fisher's Protected Least Significant Difference with $p \leq 0.05$, to determine which combinations of sectioning and load were significantly different.

Results

Squeezing the calf caused strain and motion at the distal tibio-fibular joint in all three anatomic planes. The largest motion was either external rotation or valgus bending of the distal fibula relative to the tibia. The actual amount of motion produced by the squeeze did not discriminate between which ligaments had been cut. As measured by the displacement transducer, the distance between the tibia and fibula at the level of the anterior tibiofibular ligament increased sequentially after each ligament was cut, up to and including the deltoid ligament (Figure 1). The change in tibiofibular separation from the unloaded to the loaded condition also increased as each ligament was cut.

Conclusions

Squeezing the calf produces motion at the distal tibio-fibular joint, in particular causing the distal tibia and fibula to separate with the fibula rotating externally and bending into valgus relative to the distal tibia. Although the motions are small, we infer from these findings that the pain noted during a "positive" squeeze test is due to the strain produced in the remaining fibers of the syndesmotic ligament complex as the distal fibula moves away from the distal tibia.

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

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