University of Washington Department of ORTHOPAEDICS Research Report 1994

1994 Research Report
Department of Orthopaedics
University of Washington

**UNIVERSITY
OF WASHINGTON
SCHOOL OF
MEDICINE**

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FOREWORD

The wonderful 1948 drawing by M.C. Escher shown on our cover seems so symbolic of our times: a right hand and a left hand creating each other and forming an infinite recursion. Whether it be quality science supports quality practice supports quality science . . . or . . . we teach so that we can learn so that we can teach .... These cycles repeat themselves in a way that recalls Escher's artistic infinities. Making sense, or even keeping our orientation, during these countless revolutions is the challenge we all face. Yet, the department continues to succeed, and indeed lead, in implementing beneficial change in the way we do research, the way we teach, and the way we provide care.

Our 1994 Research Report gives a series of glimpses as to why we are regarded as one of the country's leading academic orthopaedic departments. The breadth of the our research continues to range from the most fundamental investigations in molecular biology to measuring the effectiveness of our efforts to optimize the health of our patients.

Our department's continued success is emblemized by its leadership in teaching, research, and patient care. At the annual ORS/AAOS/ specialty society meetings our faculty and residents made nearly 90 presentations. Among the excellent presentations by our residents at the Orthopaedic Research Society, Brodie Wood's investigation entitled Corticosteriod Treatment Reduces Venous Capacity in the Rabbit Epiphysis, sponsored by John Clark, received the society's New Investigator Award.

The quality of the science is indicated by the department's continued ranking as one of the top three orthopaedic programs in research grant awards from the National Institutes of Health, the highest of any public university. Principal investigators on these grants include Michelle Battie, Stan Bigos, Linda Sanded, John Sidles, and Marc Swiontkowski. The NIH has acknowledged David Eyre's "consistent and excellent contributions to scientific knowledge" by giving special Merit status to one of his principal grants.

Linda Sandell earned VA Merit Review Funding, Bruce Sangeorzan received VA funding, Allan Tencer has received a grant from the Centers for Disease Control and Prevention, and Chappie Conrad and Jim Vahey were awarded OREF grants. While this substantial level of peer-reviewed grant funding covers only part of the cost of our research program, it is a testimony to the excellence of our investigative endeavors.

Several special recognitions should be mentioned. Bruce Sangeorzan received from the American Academy of Orthopaedic Surgeons the prestigious Kashiwagi-Suzuki Japanese-American Traveling Fellowship. Michelle Battie received the 1994 Volvo Award for Low Back Pain Research. Doug Harryman received the Alonzo J. Neufeld award from the Westem Orthopaedic Society for his arthroscopic work.

The quality of the department's teaching is reflected in the excellence of the training programs and the outstanding candidates who seek residency positions. Several have been recognized this year for academic excellence: Peter Simonian received the AOA/Zimmer Traveling Award, won the 1994 American Fracture Association 26th Annual Henry W. Meyerding Memorial Award, and was named to the faculty for the The Second International Consensus Meeting on Surgery of the Pelvis and Acetabulum. Mohammed Diab received the Best Resident Paper of 1993 Award from Orthopaedic Review andlntermedicsOrthopaedics. Sohail Mirza won the First Annual Edwin L. Laumen Spine Award for 1994.

The department has embarked on a collaboration with the Washington State Chapter of the Arthritis Foundation to investigate better ways to provide health information to persons with arthritis. This collaboration was recently recognized by a substantial award from the Lockwood Foundation to develop an interactive educational resource in the new Bone and Joint Center at the Roosevelt primary care outpatient facility that will open this fall.

Publications continue to issue forth from the faculty, including three new books: Biomechanics in Orthopaedic Trauma (Lippincott), The Shoulder: A Balance of Mobility and Stability (AAOS), and Practical Evaluation and Management of the Shoulder (Saunders).

At this writing, the department is on the verge of establishing its second endowed chair, the Sigvard T. Hansen, Jr., Endowed Chair for Traumatology Research. This chair will serve to perpetuate the vast contributions Dr. Hansen has made to the department, to Harborview Medical Center, and to the field of orthopaedic traumatology.

Our 1994 Resident Research Days program hosts Victor Goldberg, professor and chairman from Case Western Reserve, as research guest professor. This two-day program, generously sponsored by the University of Washington Orthopaedic Alumni, along with the Fred W. Hark, M.D., and William A. Hark, M.D., Lectureship Award from the Orthopedic Research and Education Fund, presents an exciting program based on the research of our residents.

These and the many other accomplishments of the Department of Orthopaedics are only possible with the loyalty and hard work of the many members of our team: the faculty, residents, staff, alumni, patients, friends, colleagues, donors, and other supporters who have enabled the department to achieve at the highest level. With great appreciation, we salute each of you. The field of orthopaedics enters uncharted waters, but as members of the departmental team, we enter them together!

F. A. Matsen III

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

Triple Arthrodesis Using Internal Fixation in Treatment of Adult Foot Disorders

Bruce J. Sangeorzan, M.D
Douglas G. Smith, M.D.
Robert G. Veith, M.D.
Sigvard T. Hansen, Jr., M.D.

Triple arthrodesis is the simultaneous surgical fusion of the talonavicular, talocalcaneal, and calcaneocuboid joints. It is intended to correct cavus or planus deformities, resist muscle imbalance, relieve the pain of arthritic joints, and bring about a neutral plantigrade foot that is stabilized against medial/lateral forces. The current concept of triple arthrodesis evolved in the early 1900s based on the following observations outlined by Ryerson.

Calcaneus and equinus deformities are relieved by talectomy and tendon transfer, but varus and valgus of the hindfoot tends to recur after this operation. Further, patients with polio walked better with an artificial limb because artificial limbs were capable of motion only in flexion and extension, "the only necessary motions in ordinary walking" (Ryerson, p. 457). Third, in a normal ankle joint the talus is held by the malleoli with sufficient stability to prevent medial and lateral motion of the bone. If the other bones are fastened to the talus, a foot should be obtained that is incapable of lateral deviation.

Our study assessed the results of a specific technique of triple arthrodesis in adults. It evaluated whether rates of recurrence, pseudarthrosis, incomplete correction, lost correction, or associated tarsal arthroses mirrored those of children. In addition, we suggest an objective method to assess the correction of deformity.

Methods

Study Group

We used a retrospective case study format to evaluate the results of triple arthrodesis in skeletally mature patients operated upon between 1979 and 1987, inclusive. We excluded patients whose operations were done for sequela of traumatic disorders of the talus or calcaneus, because techniques used to salvage these injuries are more complex. All other patients who had simultaneous fusion of talonavicular, talocalcaneal, and calcaneocuboid joints were included in the study.

We identified 48 adult patients with 53 fused feet. Forty patients with 44 fused feet were available for follow-up for an average period of 4.9 years (range 2.5 to 11.3 years). The average age of the patients at operation was 41 years (range 17 to 72). We evaluated patients by questionnaire and physical exam.

Preoperative diagnosis was Charcot-Marie-Tooth disease in 15 feet, ruptured tibialis posterior tendon with degenerative hindfoot arthritis in nine, polio in two, painful flatfoot in two, tarsal coalition in two, inflammatory arthritis in three, idiopathic midfoot collapse in two, and other neuromuscular disorders in nine feet. Twenty of the fused feet had cavus or cavovarus deformity; 19 had planovalgus deformity; and five feet had a mixed deformity or neutral position. Surgeons performed tendon transfers simultaneously in 18 of the patients, other bony surgical procedures in seven, and bone graft in nine patients.

Surgical Technique

All operations followed a specific technique developed by the senior member of our team (STH), using rigid internal fixation with screws. The technique employed two incisions. A medial longitudinal incision is made in the interval between the anterior and posterior tibial tendons beginning just anterior to the tibia and extending out across the talonavicular joint to the navicular cuneiform joint. This incision is used to expose the talonavicular joint and the anterior and middle facets of the subtalar joint, and to reduce the talonavicular joint. A lateral incision is made in one of two ways; an oblique sinus tarsi incision as described by Ollier, or in a few cases, a longitudinal incision beginning just distal to the fibula and extending across the calcaneocuboid joint. The lateral incision is used to expose the posterior facet, the lateral aspect of the talonavicular joint, and the calcaneocuboid joint.

FIGURE 1: Schematic representation of a dorso-plantar view of the right foot. The dashed line (-----) shows the talus position in pes planus. The dotted line (. . . .) shows the position in a varus forefoot.

When the joint surfaces are exposed, cartilage is denuded. The joints are derotated until a neutral hindfoot position is achieved. For a valgus hindfoot, the angle between the talus and calcaneus is diminished by outward rotation of the talus in relation to the calcaneus. The opposite rotation is used to correct a varus hindfoot (Figure 1).

Shortening of the medial column to correct forefoot abduction is achieved by rotating the talus and compressing the talonavicular joint.

In dramatic deformities, a small amount of bone is resected to achieve a corrected position. Multiple drill holes are placed in the subchondral bone and a trough is made for bone graft on opposing surfaces of the joint to be fused. The talonavicular joint is reduced and transfixed with a compression screw or a cortical screw inserted in a lag fashion (Figure 2). The talocalcaneal joint is compressed with a 6.5-mm screw oriented across the posterior facet. In the early years, the screw was directed downward from the lateral aspect of the talar body at the junction with the anterior articular surface of the ankle joint. Now we direct the screw from the dorsoplantar aspect of the tuberosity of the calcaneus up into the talar body. This change was instituted to avoid disturbing the blood supply to the talar neck. The calcaneocuboid joint is fixed last, with a cortical lag screw directed from the anterior process of the calcaneus to the cuboid (Figure 3).

Postoperative Management

Postoperatively, the patients are placed in a splint for two weeks, then sutures are removed and the foot is placed into a short-leg cast for two to 14 weeks, with the earlier patients averaging 12 to 14 weeks and the more recent patients spending substantially less time in plaster. Patients are allowed to bear weight-of-limb on the operative side as soon as comfortable. The time to complete weight bearing varied significantly due to the variable preoperative diagnoses and deformities as well as changes in treatment during evolution of the technique. The current regimen includes two to six weeks in plaster, allowing patients to bear weight-of-limb. Unless there is a sign of delayed healing, the patient is then allowed full weight bearing in a commercial walking brace. The postoperative regimen is altered in some patients with simultaneous tendon transfers or other special needs.

FIGURE 2: The corrected position with internal fixation in place.

Follow-up and Evaluation

All patients in the study had greater than two years follow-up. We performed follow-up examination in all but five patients who resided out of state. In these five patients follow-up information was obtained by administering the same questionnaire by telephone interview and through exams by local physicians. To diminish examiner and patient bias, one of the authors, who operated on only six cases, performed the follow-up exams on all 43 in-state patients.

We graded outcome using the clinical criteria of Hallgrimsson as modified by Angus and Cowell. A good result had fusion in all joints, no pain or minimal pain after vigorous activity, no or minimal deformity, no callosity formed, and no joint degeneration. A fair result had fusion in two of the three joints (excluding a painful talonavicular joint), slight pain after light use, a single callosity, and moderate deformity or mild joint degeneration. A failure was described as pain at rest, a painful pseudarthrosis or multiple pseudarthrosis, severe deformity, marked callous formation, or severe joint degeneration.

In addition, points were assigned according to the Arthritis Impact Measurement Scales (AIMS), modified to include questions about shoe wear. The AIMS, an index of the health status in patients with

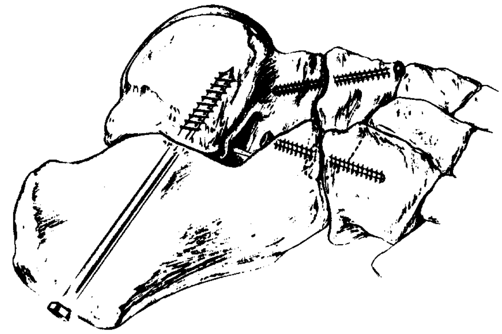

FIGURE 3: A schematic representation of the lateral view of the foot with screws in place.

musculoskeletal disease, is a valid, reliable, self-administered questionnaire designed to assess the outcome of treatment in arthritis patients. Functional activities are assigned numerical value, with higher numbers designating more functional limitation. Though the validity of the scale is not established for outcome from surgical procedures, the numerical assignment allowed us to get "average" functional levels for patient activities considered to represent quality of life issues. Finally, each was asked to characterize level of satisfaction as either satisfied with surgery, satisfied with reservations, or unsatisfied. We assessed the hindfoot position by examining the patients in standing position, facing away from the examiner.

Radiographic evaluation included measurements made by at least two examiners. Standing or simulated weight-bearing radiographs obtained preoperatively, postoperatively, and at healing were used to measure the following angles: lateral talocalcaneal, lateral talometatarsal, anteroposterior (AP) talocalcaneal, and AP talometatarsal. The AP talocalcaneal angle could not be measured on a substantial number of radiographs due to overlapping shadows. Our inter-examiner differences were large, ‰

and we felt this measurement was not sufficiently reliable to employ in the study. For the other three angles, we measured correction in degree change from the preoperative to postoperative radiograph.

Results

The patients judged the outcome of surgery as satisfactory in 30 feet, satisfactory with reservations in 12, and unsatisfactory in two. According to the clinical criteria of Angus and Cowell, 34 feet had a good result, six had a fair result, and four were failures. In radiographic parameters, improvement averaged 17 degrees in the lateral talometatarsal angle, 11 degrees in the lateral talocalcaneal angle, and 18 degrees in the AP talometatarsal angle. Those feet with the original deformity of flexible flatfoot showed slightly greater radiographic improvement in the forefoot (as measured by the talometatarsal angle) in comparison to those whose initial deformity was cavus. We found no difference in the amount of correction achieved in the hindfoot between cavus and planus feet (as measured by the talocalcaneal angle), and no measurable difference between immediate postoperative measurements and those made at healing.

There were two radiographic and clinical nonunions; one in the talonavicular joint and one in the calcaneocuboid. Both these pseudarthroses went on to union after bone grafting. Two cases had incomplete reduction of varus deformity. One required a calcaneal osteotomy. The four results classified as failures include two nonunions and two varus deformities.

The average patient can walk comfortably outdoors on level ground but has some trouble in more vigorous activity such as climbing stairs. The average patient has mild pain at least once per month, but not severe enough to restrict activity. The average AIMS score for Activities of Daily Living suggested little to no restriction in daily function.

Hindfoot position was in varus in two feet, neutral in 12, and 3 to 10 degrees of valgus in 30 feet. Ankle range of motion averaged 9 degrees of dorsiflexion and 29 degrees of plantarflexion.

The technique of triple arthrodesis is exacting. Ingram has stated that triple arthrodesis requires "exactness and precision" and "the accuracy and care of a cabinetmaker." There is a significant incidence of pseudarthrosis, undercorrection or overcorrection of deformity, recurrence of deformity, avascular necrosis of the talus, and progressive degenerative changes in the associated articulations.

Discussion

Assuming proper indications for surgery, poor outcomes result from pseudarthrosis, incomplete correction of the deformity, recurrence of deformity, avascular necrosis of the talus, and degenerative changes in the ankle and midfoot. Most, if not all, of these complications are influenced by technical factors such as alignment of the joints and sparing the blood supply of the operated bones.

The rationale for internal fixation follows from its effective use in treatment of traumatic disorders and from observations reported in the literature. Recurrent deformity and incomplete correction clearly could be influenced by the use of rigid internal fixation. Ryerson stated that the position of the foot could be difficult to maintain and recommended passing chromic suture through the bones to maintain the reduced position. He felt that correction was easily lost in the early postoperative period, particularly during cast change. Friedenberg believed that recurrences were the result of insufficient control of the tarsal bones in plaster and could be detected within the first postoperative month. He felt that later recurrences only came about with pseudarthrosis. Patterson had fewer recurrent deformities when using this so-called Ryerson technique with suturing of bone.

We reserve triple arthrodesis for patients for whom prior procedures have failed, who have uncorrectable deformity, or have developed secondary changes in the joints. There are two differences between our study and most of the previous studies on triple arthrodesis. First, our study involves only adults. Skeletally immature patients differ in many ways, making any comparisons speculative. Second, unlike most previous reports, all the patients in our study were operated on by the same technique regardless of deformity or primary disease process.

Interpretation of much of the literature is clouded by inclusion of many different techniques, some of which resect substantial bone. Because of these differences, we are unable to draw definitive conclusions of diminished morbidity. However, our rates of nonunion, recurrence, and correction are lower and the correction achieved better than results reported in the literature. This study demonstrates that triple arthrodesis using internal fixation can be an effective method of correcting a deformed foot and that patients are likely to return to normal functional activities with minimal pain in most cases.

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Collagen Expression in Early Skeletal Pattern Formation

Linda J. Sandell, Ph.D.

Cartilage provides a structural anlage for the deposition of bone. The fibrillar collagen, type II, is generally considered to be specifically expressed in cartilage. However, in 1986, Thorogood and colleagues discovered the presence of type II collagen in embryonic chicken epithelial structures adjacent to mesenchyme destined to become skeletal tissue. This observation led them to propose a role for type II collagen in the induction of chondrogenesis. Moreover, type II collagen is also present in chicken embryonic structures such as notochord and neural retina. Type II collagen has been localized at the epithelial-mesenchymal interfaces during morphogenesis of other noncartilaginous tissues of developing chicken embryos, and recently the type II procollagen has been confirmed in mouse embryos by immunohistochemistry and in situ hybridization to mRNA.

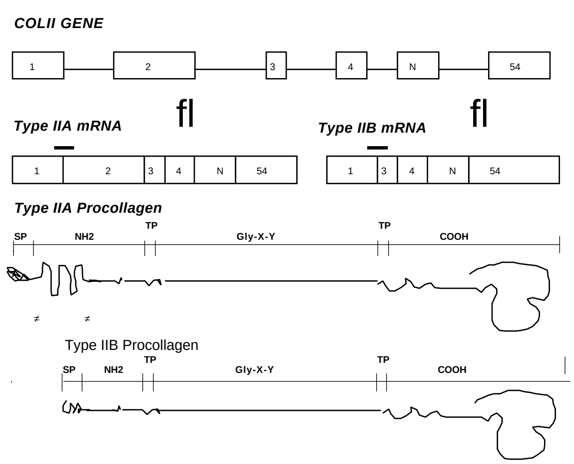

FIGURE 1: The COL2A1 gene, type IIA and type IIB procollagen mRNAs, and type IIA and IIB procollagens. Exons are indicated as open boxes. Oligonucleotide probes specific for type IIA and type IIB procollagen mRNA are indicated by bars above the respective mRNAs. In the procollagen molecules, SP is the signal peptide, NH_2 is the amino-terminal propeptide, TP is the telopeptide, Gly-X-Y indicates the triple helical domain, and COOH is the carboxy-terminal propeptide. The regions indicated by a straight line are triple helical and regions indicated by the curved lines are globular portions of the protein. The differentially spliced domain is indicated by arrows under the type IIA procollagen.

Our earlier research showed that type II procollagen exists in two forms generated by alternative splicing of the pre-mRNAs (Figure 1). These two splice forms are differentially expressed by distinct cell populations during chondrogenesis in the human vertebral column. One procollagen form, called type IIB, lacks the cysteine-rich domain of the NH_2 propeptide and is expressed by chondrocytes, the cells resident in cartilage. The other procollagen splice form, type IIA, contains the cysteine-rich domain and is expressed by chondroprogenitor cells surrounding the cartilage. Recent work has shown the presence of type IIA procollagen in remnants of the notochord in the human stage XXI embryonic vertebral column.

Our study sought to determine whether type IIA procollagen, the new splice form, was present in the skeletal precursor tissues. We used embryonic mouse tissue because of the availability at early stages of development. Using probes that independently identify the two splice forms of type II procollagen mRNA, we showed that the somites and other early skeletal primordial embryonic structures express type IIA procollagen mRNA. Type IIB appears only when cartilage has formed. The expression of type IIA procollagen in precartilaginous structures prior to the expression of type IIB by chondrocytes indicates that a change in splice form is necessary to form cartilage. In contrast, some noncartilaginous tissues, particularly epithelia, appear to transiently express type IIA procollagen mRNA. Surprizingly, we also observed type IIA and not type IIB procollagen mRNA during formation of intramembranous bone, a process that does not involve cartilage. Type IIA procollagen or the novel sequence in the propeptide may play a role in establishing the pattern of future skeletal development. ‰

Type IIA Messenger RNA Precedes the Expression of Type IIB in Embryogenesis

Our previous experiments localized the expression of type IIA procollagen mRNA (+ exon 2) to chondroprogenitor cells of developing cartilage and type IIB mRNA expression in chondrocytes. This observation led us to hypothesize that the type IIA message temporally precedes the type IIB form.

To confirm this hypothesis, we examined early embryos by in situ hybridization for the expression of both type II mRNAs. In sections of a day 11 embryo (stage 18), the commencement of condensation by mesenchymal cells was apparent in the somites (Figure 2A, B). Expression of type IIA procollagen mRNA was localized to these cells and to those forming the primordium of the skeleton including the basioccipital (clivus), basisphenoid, and nasal bones (Figure 2C). Furthermore, the IIA transcript was expressed by cells in the branchial arches (Figure 2C). We also noted intense hybridization in the second branchial arch (indicated by an arrow). No hybridization to the type IIB mRNA was observed in adjacent sections (Figure 2D); diffuse hybridization to type I procollagen mRNA was observed throughout the section (not shown).

Expression of Type IIA and IIB Procollagen mRNAs in the Cranium and Appendicular Skeleton

Figure 3 shows the overall hybridization pattern in the day 18 mouse embryo, in particular the developing structures of the chondrocranium, vertebral column (C1 and C2), the tracheal rings, the sternabrae, developing nasal bones, and mandible. Type I collagen mRNA was primarily expressed by osteoblasts in the calvaria, manilla, and mandible. Type IIB procollagen mRNA was expressed by the chondrocytes in the cartilage primordia of the supraoccipital temporal bones (stained darkly). Type IIB procollagen mRNA was observed wherever overt cartilage was present. The spatial pattern of collagen expression was also observed in the cartilage primordia of the supraoccipital bone.

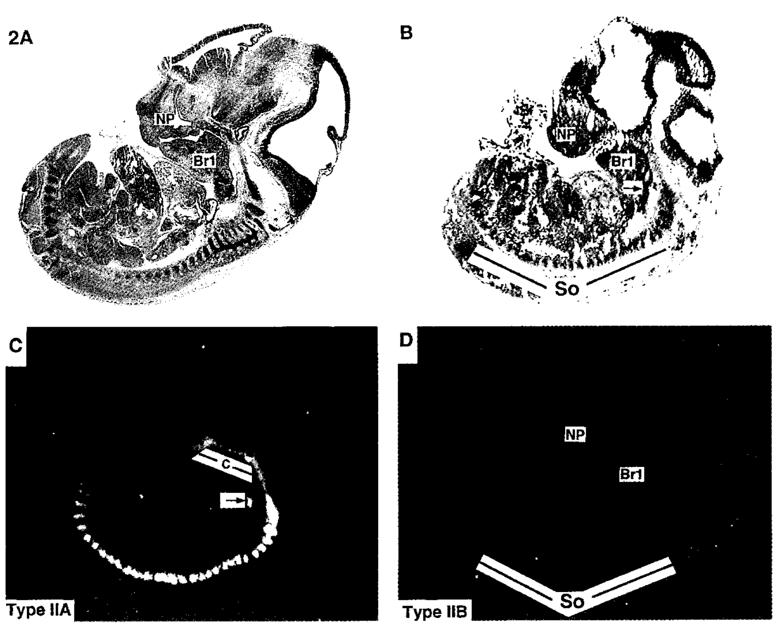

FIGURE 2: Expression of type IIA and type IIB procollagen mRNAs in E11 mouse. Panels A and B are brightfield and C and D are darkfield. Panels **A** and **B** show commencement of condensation in the somites (So) in paraffin-embedded (A) and frozen (B) sections. The following structures are also evident: nasal process (NP) and the mandibular portion of the first branchial arch (Br1) and second branchial arch (arrow). Panel **C** shows localization of type IIA mRNA by in situ hybridization in the somites, branchial arches, and primordia of the cranial (c) floor. Panel **D** shows absence of transcripts for the type IIB message in a serial section.

Expression of Procollagens During Intramembranous Bone Formation in the Mandible

The mandible is of particular interest because, with the exception of Meckel's cartilage, it is formed by the process of intramembranous ossification. The mandible (M in Figure 3) is clearly demarcated by type I collagen mRNA expression (3C). Very little expression of type IIB was observed (Figure 3D). Remarkably, abundant hybridization to type IIA mRNA was observed in the mandible (Figure 3B). Upon closer examination, the type IIA expressing cells in these areas appeared to be mesenchymal cells or cells that lined spicules of ossifying matrix. No hybridization to type IIB mRNA was observed in areas of intramembranous ossification and no overt cartilage was observed in the mandible. At this point, the Meckel's cartilage is receding. Consequently, even though this bone does not develop through a cartilaginous primordium (and does not express "cartilage" type IIB procollagen), the cells express type IIA mRNA indicative of a skeletal precursor population.

The finding that the early, non-cartilage expression of type II collagen is the type IIA splice form will serve to focus attention on type IIA procollagen and potentially on the NH_2-propeptide in induction of chondrogenesis and development of the chondrocranium and vertebral column. Our studies show that this domain contains the major portion of the N-propeptide with 69 amino acids including 12 cysteine residues. The finding of transient expression of type II collagen in certain epithelial-mesenchymal boundaries led Thorogood and colleagues to propose that chondrogenesis is elicited by a matrix-mediated interaction and, due to the specific temporal and spatial localization, that matrix molecule may be type II collagen. In light of our finding that the type II collagen in question is type IIA, we propose that the active component of induction is encoded by exon 2.

Expression of Type IIA Procollagen in Cartilage and Bone Formation

The expression of type IIA mRNA appeared in both systems of ossification. In intramembranous ossification, mesenchymal cells and cells adjacent to spicules of bone appeared to coexpress procollagen mRNA types I and IIA. We saw no expression of the type IIB form. The expression of type II collagen in intramembranous bone development appears to disprove earlier postulates that this process of ossification only involved the synthesis of type I collagen. Our observations indicate the expression of type II collagen in intramembranous ossification is the IIA and not the IIB procollagen form. Consequently, while intramembranous ossification does not proceed through a cartilaginous phase, still the type II gene is expressed. No cartilage is observed due to the lack of switch in type II collagen mRNA splice form.

Collectively, these results suggest that precursor mesenchymal cells involved in bone formation, which replace either a membranous or cartilage anlage, have the capacity to diverge along different morphologic pathways. In the intramembranous model, mesenchymal cells that differentiate into osteoblasts express types I and IIA procollagen mRNAs and eventually commit to the osteoblast phenotype and cease production of type IIA. In endochondral ossification, mesenchymal cells switch their expression from type I to IIA to IIB, which appears to be concomitant with their differentiation along a chondrocyte lineage. Type IIA procollagen, then, appears to mark a skeletal precursor cell. These events could be controlled by bone and cartilage morphogenetic proteins. Figure 4 presents a simple model for a proposed mechanism.

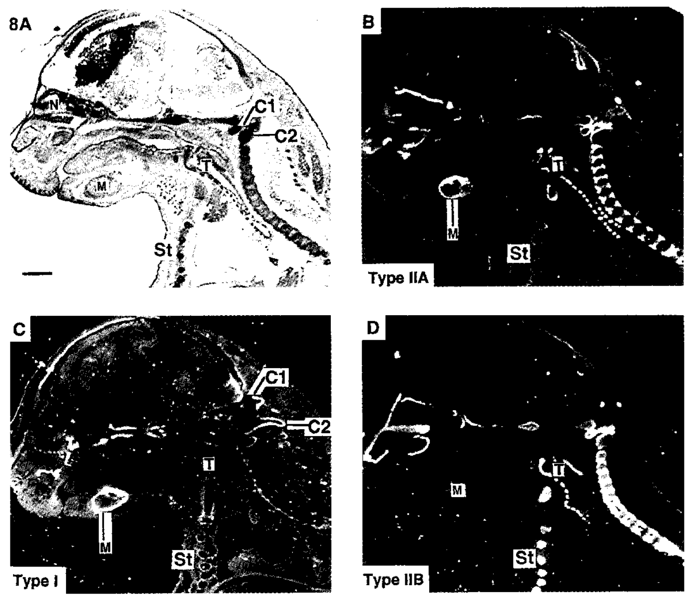

FIGURE 3: Expression of type IIA, type I, and type IIB procollagen mRNAs in E18 embryo. Panel A is brightfield and panels B, C, and D are darkfield: **(A)** structures of the chondrocranium and thorax; **(B)** expression of type IIA surrounding the vertebral bodies and in the developing nasal (N) cartilages, sternebrae (St), and trachea (T); **(C)** type I mRNA expression in the ossifying regions of the first two cervical vertebrae (C1 and C2); **(D)** expression of type IIB mRNA within the developing vertebral bodies as well as the above structures. Both types I and IIA messages, but not type IIB, are expressed in the mandible (M) where intramembranous ossification is occurring. Bar = 1 mm (7.5 x magnification).

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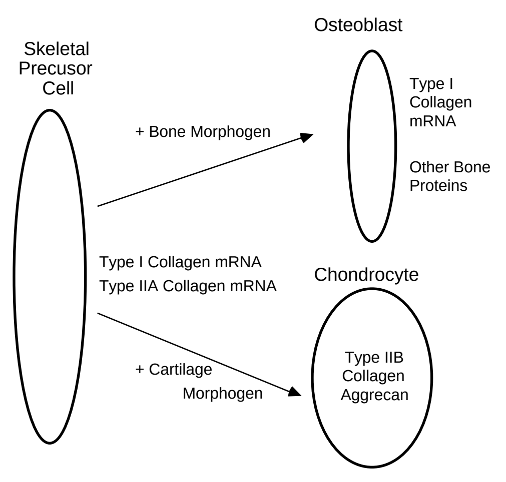

FIGURE 4: Diagram of a skeletal precursor cell with subsequent differentiation into an osteoblast (to form bone) or a chondrocyte (to form cartilage). The choice could be made by the availability of a specific morphogenetic protein for bone or cartilage.

Deformation of Collagen Fibers in Loaded Articular Cartilage

Hubert Nötzli, M.D.
John M. Clark, M.D., Ph.D.

We developed a model of articular cartilage collagen matrix organization based upon scanning electron microscopy (SEM). In this model, rows of parallel collagen fibers run continuously from the calcified layer to the surface, where they turn and form the tangential lamellae (Figure 1). This pattern holds in most adult joints. Both advocates and opponents of this model have questioned the functional role of the vertical collagen fibers in a tissue that is loaded by compression. Many theories have been proposed, but none are proven. An ideal way to test such theories is to observe how the radial fibers behave under loads.

In this study we used SEM to describe the deformation of collagen fibers in tibial plateaus of whole rabbit knees under physiologic loads. We used new techniques of freezing and protein fixation to preserve the specimen in the shape it assumed under load.

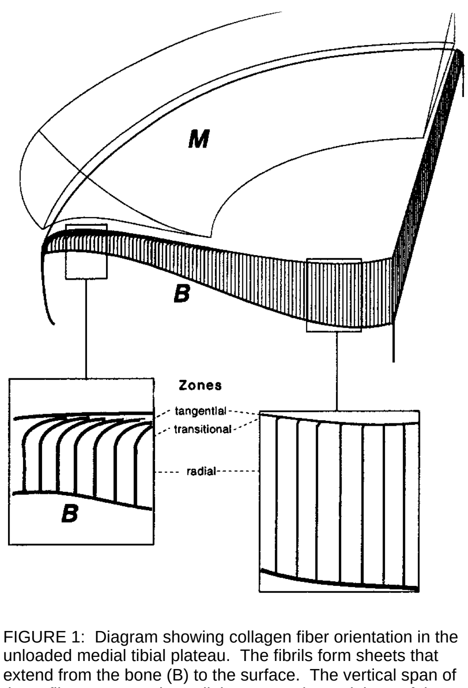

FIGURE 1: Diagram showing collagen fiber orientation in the unloaded medial tibial plateau. The fibrils form sheets that extend from the bone (B) to the surface. The vertical span of these fibers creates the radial zone. In the periphery of the plateau these sheets turn centrally as they reach the surface, where they form the typical overlapping lamellae characteristic of the tangential zone. In the center, where the cartilage is quite thick and is not covered by the meniscus (M), the fibrils do not extend into the surface. Thus, the collagen orientation of the central plateau is uniformly radial.

Methods

The knees in this study were taken from mature New Zealand white rabbits. Each knee was subjected to loading in a position of 90 degrees of flexion using a device that applies loads by exerting a simulated quadriceps force on the patella while blocking further extension of the knee (Figure 2). The configuration of the loaded knee was preserved by flash-freezing in cold isopentane, followed by fixation by freeze-substitution in alcohol-based fixative solutions.

We varied three parameters: (1) magnitude of load, (2) presence of a meniscus, and (3) duration of load.

Magnitude of Load: The simulated quadriceps pull was arbitrarily set at half, 1.1, or four times the rabbit body weight. For reference, the load generated by four times body weight pull was termed “high” and the others “low.”

Duration of Load: The knees were loaded for periods of 30 seconds or 25 minutes.

Menisectomy: In some specimens, the medial meniscus was removed.

Once loaded, a specimen was frozen by immersion in isopentane cooled to -165° C in liquid nitrogen. This freezes the tissue instantaneously, far faster than does liquid nitrogen. While still frozen, the cartilage is placed in a cold alcohol solution for fixation. As the alcohol dissolves the ice in the tissue, the proteins are fixed so that the cartilage does not change shape once brought to room temperature. This preserves the specimen in the shape it assumed while under the load. Each rabbit knee was then prepared for microscopy.

Results

The cartilage collagen fibers in the material fixed by freeze-substitution were indistinguishable by SEM from those fixed by conventional aqueous glutaraldehyde solutions. The collagen fibers showed two distinct alterations where the cartilage of the tibial plateau was indented by the femoral condyle or loaded indirectly by an intact meniscus (Figure 3). All loaded fibers displayed a regular, sinusoidal crimp with a period of roughly 10 microns. Where the cartilage was visibly indented, the fibers also were sharply bent (Figure 4). The angle and location of the bend corresponded to the degree of indentation of the surface. Where the cartilage was compressed more than 20%, the superficial segment of the bent fibers was turned into an alignment virtually parallel to the surface.

Removal of the medial meniscus made it possible to compare loaded to unloaded fibers in the same specimen. The point of femoral contact was visible as an indentation with a well-defined edge in regions where the cartilage was thick. Therefore, the junction between loaded and unloaded regions could be easily identified (Figure 3). In the unloaded cartilage surrounding an indentation, the radial collagen fibers were slightly bowed, but displayed no sharp bending point. The collagen fibers in unloaded regions had no crimp.

In contrast, fibers under the femoral condyle displayed the typical sinusoidal deformity in all knees. We observed crimping and accentuated bending of collagen fibers beneath the meniscus in the loaded knees.

Discussion

This study showed that when cartilage of the tibial plateau deforms under normal compressive loads, the radial collagen fibers first crimp and then bend as the load increases. The bend mimics the pattern normally seen in the periphery of the plateau (Figure 1). That is, the cartilage in the center of the plateau transiently acquires a tangential zone. The degree of deformity manifests as an increased ratio of tangential layer to radial layer thickness, and corresponds to the magnitude and duration of the applied load.

In general, articular cartilage has a layer of tangential collagen at the surface. The observation that radial collagen fibers of the loaded central tibial plateau bend over to form such a layer *de novo* suggests that articular cartilage adjusts thickness by altering the ratio between radial and tangential zones. It is conceivable that, if not loaded for periods of time, normally bent-over collagen fibers could also straighten out somewhat, allowing the cartilage to swell.

Since Benninghoff (1922) first described the radial fibers, students of cartilage structure have wondered what role they perform in a tissue that is apparently loaded in compression. The observed crimping of loaded radial fibers suggests that they resist swelling of the cartilage while it is resting. Maroudas and colleagues have reported significant hydrostatic pressure within unloaded cartilage. The tissue pressure may stretch the fibrils enough to straighten an inherent crimp that reappears as the cartilage is slightly compressed and the collagen fibrils relax. Thus, we hypothesize that the thickness of the radial and tangential zones reflects a balance between external compressive forces and internal swelling pressure.

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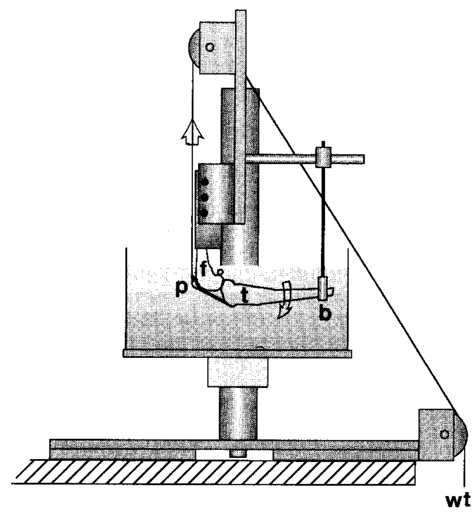

FIGURE 2: The device used for loading rabbit knees. A quadriceps force is applied with weights hung from a cable attached to the patella. Knee extension is blocked by a bar against the tibia.

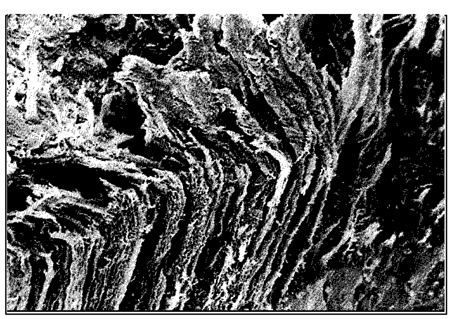

FiGURE 3 (above): Light micrograph of the medial tibial plateau fixed under load (magnification 45x). The femoral condyle has left a deep indentation in the cartilage of the tibial plateau.

FIGURE 4 (left): Vertical collagen fibers in loaded plateau; loading causes a sharp bend (Mark = 100 µ).

Evidence for Copolymeric and Antiparallel Cross-Linking of Collagens I and II in the Intervertebral Disc

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The framework of the intervertebral disc is formed from a mixture of types I and II collagen fibrils distributed radially in opposing concentration gradients. Type II collagen dominates in the nucleus pulposus and type I collagen in the outer annulus fibrosus. The proportion of type II collagen in human annulus fibrosus is much higher than in discs of quadruped animals. In addition to these two major collagens, disc tissue also contains an assortment of other collagen types in lesser amounts, including types III, V, VI, IX, XI, XII and XIV. As part of a study to understand how the various kinds of collagen are organized in this complex matrix, we set out to determine whether collagens I and II are segregated in separate fibrils in distinct matrix subdomains or can copolymerize in hybrid fibrils.

Methods

Human annulus fibrosus was dissected from adolescent disc tissue removed at surgery to correct idiopathic scoliosis. Tissue was extracted in 4M guanidine HCl containing protease inhibitors to remove proteoglycans and matrix proteins. The insoluble, cross-linked collagen was solubilized by proteolysis with bacterial collagenase at 37˚C for 24 hours. Peptides containing pyridinoline cross-links were isolated and purified by sequential molecular sieve (BioGel P10), ion-exchange (DEAE), and reverse-phase (C8) high-performance liquid chromatography (HPLC). Column eluents were monitored for 220 nm absorbance to detect all peptides and for 3-hdroxypyridinium fluorescence specifically to detect peptides cross-linked by pyridinoline residues. We identified isolated peptides by microsequencing on a Porton 2090E gas phase sequencer with on-line PTH-amino acid identification and in some cases by electrospray mass spectrometry.

Results and Discussion

The most prominent cross-linked peptides were derived from homotypic linkages between type II collagen molecules or between type I collagen molecules. However, in addition to these expected structures, we isolated additional peptides containing pyridinoline residues that were heterotypic in origin. Thus, a three-chained peptide that embodied an α1(I)C-telopeptide was linked to an α1(II)C-telopeptide to triple-helical residue 87 in a fragment from the α1(II) chain (Figures 1 and 2). The peptide yield from this collagen type I/II copolymeric site of interaction was about 10% of the yield of homopolymeric type II/II peptides from the equivalent site. This finding means that to a significant extent, types I and II collagen molecules become copolymerized and cross-linked effectively in the same fibril or, at least, by fusion of lateral fibrils to form thicker fibrils.

From the same digests of human annulus fibrosus, we repeatedly recovered cross-linked entities that appeared to embody telopeptides from opposite ends of the type I collagen molecule. Through more rigorous chromatography we established a peptide structure that consisted of an α1(I)N-telopeptide linked to an α1(I)C-telopeptide and to an α1(I) residue 930 helical site (Figure 3). This peptide clearly had originated from a site of interaction between two collagen molecules that presumably pointed in opposite directions but were in register (i.e., were antiparallel but not staggered). The centro-symmetrical placing of the four cross-linking sites in type I collagen (two telopeptides, two helix) would allow this to happen if some molecules became packed in fibrils pointing the wrong way round, or perhaps more likely if adjacent, antiparallel fibrils fused and cross-link laterally to form a thicker fibril assembly. This implies a versatile molecular mechanism of collagen interaction that could allow fibril branching and perhaps a source of increased material strength. Alternatively, it may be

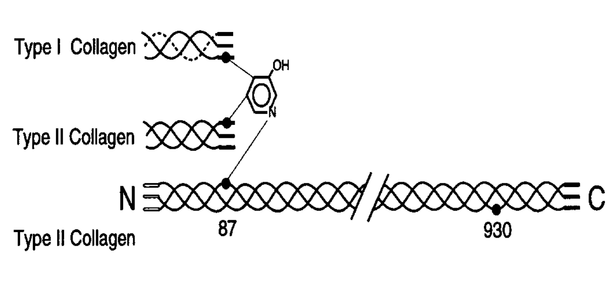

FIGURE 1: Mollecular illustration of heterotypic cross-linking between types I and II collagens.

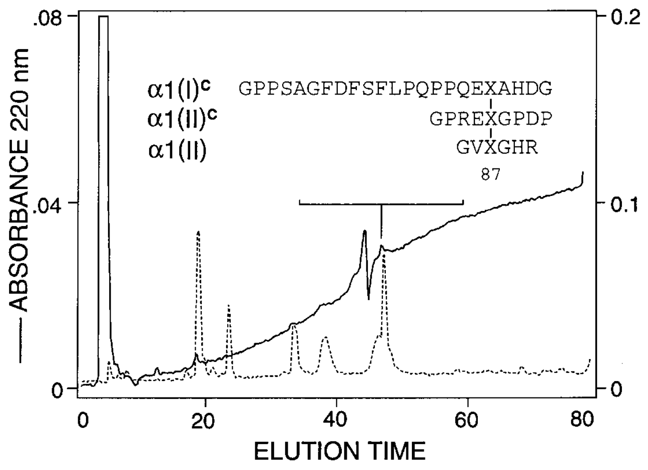

FIGURE 2: A heterotypic (type I/II) pyridinoline cross-linked peptide resolved by reverse-phase HPLC from a bacterial collagenase digest of human annulus fibrosus.

evidence in mammals for a fundamental new concept of collagen fibril structure recently discovered in invertebrate collagen.

In summary, these findings provide evidence that types I and II collagens can copolymerize and form antiparallel intermolecular cross-linking in type I collagen in the annulus fibrosus. The observations have broad new implications for the organization of collagen assemblies generally but in particular for fibrocartilaginous tissues.

Supported by NIH grants AR36794 and AR37318.

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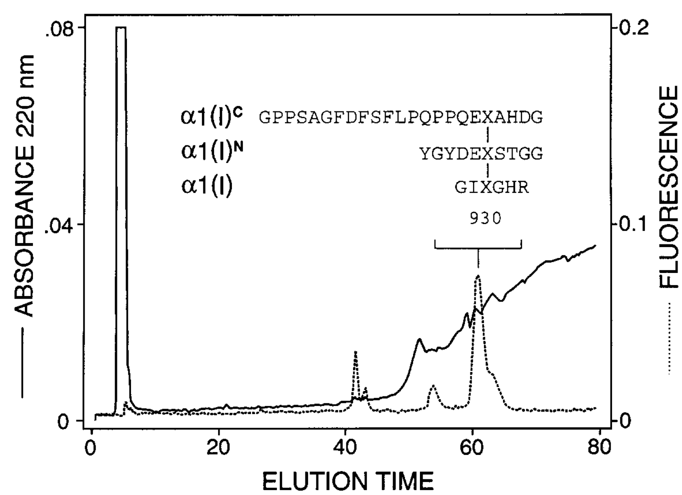

FIGURE 3: A pyridinoline cross-linked peptide from a site of antiparallel interaction in type I collagen of human annulus fibrosus isolated by reverse-phase HPLC.

The Effects of Freeze-Drying and Rehydration on Cancellous Bone

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Surgeons in North America routinely use musculoskeletal grafts of bone and soft tissue for a wide spectrum of musculoskeletal procedures. Approximately 10-15% of the three million orthopaedic procedures performed in the United States each year involve some form of bone grafting.

The Food and Drug Administration (FDA) recently issued emergency regulations for such grafts in an effort to eliminate substandard sources of musculoskeletal grafts and minimize risk of potential disease transmission to patients. While patient safety is the most important concern, the quality of grafts for reconstruction also remains a significant issue because many processing techniques lack a scientific basis.

TABLE 1: Matched Graft Comparisons for Strength and Stiffness

Group	Test Graft	Control Graft	Mean %	*p*-Value
Compressive Strength				
1	FZR	FZL	103.0 ± 4.1	0.87
2	FD24	FZ	92.6 ± 13.0	0.64
3	FDO	FD24	189.0 ± 35.0	0.05
4	FD-IN	FD-EX	62.0 ± 5.2	0.02
Stiffness				
1	FZR	FZL	98.9 ± 15.9	0.97
2	FD24	FZ	124.0 ± 26.0	0.55
3	FDO	FD24	133.0 ± 35.0	0.18
4	FD-IN	FD-EX	58.0 ± 9.7	0.01

Typically, bone grafts are processed as frozen, freeze-dried, or irradiated, or are treated with ethylene oxide. All these forms of processing are presumed to produce a graft of less strength than a more natural, vascularized osseous segment. Some of these processing techniques (freeze-drying, irradiation, and ethylene oxide) might have a deleterious effect on the compression and stiffness strength of the subsequent graft depending upon how the processing techniques were applied and on the size and configuration of the graft. Similar effects on soft-tissue grafts (such as patellar grafts used for anterior cruciate ligament reconstructions) also raise some concerns.

Freeze-drying is a process that involves the desiccation of bone at low temperature. When the graft is thawed and implanted in a patient, rehydration can be achieved either passively (after implantation) or actively in a vacuum (*in vacuo*). While *in vacuo* rehydration is a quicker method of graft rehydration, all grafts become passively rehydrated after implantation by patient serum and other body fluids.

This study examines some of the effects of the rehydration of freeze-dried grafts on compressive strength and stiffness. It is the initial experiment in a series that will investigate the effects of processing techniques for musculoskeletal grafts.

Methods

The bone grafts used for testing were 14-mm cancellous dowels taken from tibiae and femora of matched human cadaveric donors. All donors were in the acceptable age range (18-60 years) for cadaveric tissue. To eliminate anatomic variations as a variable, we matched each graft with a graft taken from the same location on the contralateral limb, and all experimental comparisons were carried out between matched pairs. The dowels were cut to 15-mm length and stored at -80°C before freeze-drying, which was done at the Northwest Tissue Center. Residual moistures were determined to be less than 3% based on dry weight assessed by gravimetric method.

Grafts from the right versus left extremity demonstrated a variation of 1-3% for these matched pairs in the frozen controls. Further matched pairs compared freeze-dried versus frozen, freeze-dried unrehydrated versus freeze-dried rehydrated over 24 hours, and freeze-dried *in vacuo* versus *ex vacuo* rehydration. We tested both compression and stiffness for these four different matched pairs.

Results

In this study of carefully matched grafts, rehydration produced decreased compression strength and stiffness of the dowels. This maximum decrease in compressive strength was demonstrated in the freeze-dried grafts rehydrated *in vacuo*, which had only 62% of the compressive strength of the *ex vacuo* rehydrated counterparts (Table 1). Stiffness for similar comparison matches showed a 58% mean comparison of the freeze-dried *in vacuo* versus freeze-dried *ex vacuo* (Figures 1 and 2). There are significant reductions in compression strength (p value = 0.02) and stiffness (p value = 0.01). Table 2 presents mean values for compression and stiffness testing.

Discussion

In the past, few studies have shown the distinct deleterious effect of freeze-drying on structural bone grafts. However, our study showed a distinct weakening of freeze-dried grafts, especially when evaluated after hydration. We found a

TABLE 2: Mean Values for Compression and Stiffness Testing		
	Compression	
Groups	Testing (N)*	Stiffness (N/mm)
FZR	1040	252
FZL	1081	249
FD24	789	936
FZ	905	157
FDO	1295	419
FD24	746	384
FDIN	647	289
FDEX	992	574

*N = newtons

decrease in compression and stiffness with rehydrated grafts.

These results contradict several prior studies that showed no significant decrease in compression strength of freeze-dried bone in various animal models. Pelker and colleagues did not find a significant difference in compression strength of freeze-dried bone in rat vertebral bodies. Triantafyllou also found some reduction in bending strength of freeze-dried bovine bone, and Komander tested human axial femoral segments, finding a decrease in bending, compression, and torsion after freeze-drying in transverse or axial femoral segments. In a poorly controlled study, Malinin and colleagues found no significant decrease in bending strength of human femoral cross segments following freeze-drying. None of these prior studies addressed the biomechanical changes associated with rehydration after freeze-drying. Similarly, none involved carefully matched graft pair systems from human bone, as did our study.

The results of our experiment raise some concern regarding the use of freeze-drying in structural grafts, which probably should be procured as frozen grafts or, perhaps, frozen grafts combined with irradiation. Ethylene oxide remains a sterilization technique of some notoriety because of previous concerns regarding toxicity related to residual ethylene glycol, which may be either inflammatory or carcinogenic depending on the residual levels. The federal government has carefully regulated these materials out of concern for both environmental and patient safety. The biomechanical effects of ethylene oxide on musculoskeletal grafts have been extensively investigated.

We believe that our results have significant value in predicting strength. This experiment showed excellent control of any anatomic variation by using matched single donor controls from the contralateral extremity. We caution surgeons regarding the possible decrease in strength of freeze-dried grafts, especially those grafts with a segment length longer than 5 cm. Further studies are in progress regarding the effects of freeze-drying and rehydration on cortical bone and the various types of processing used on patellar tendon grafts.

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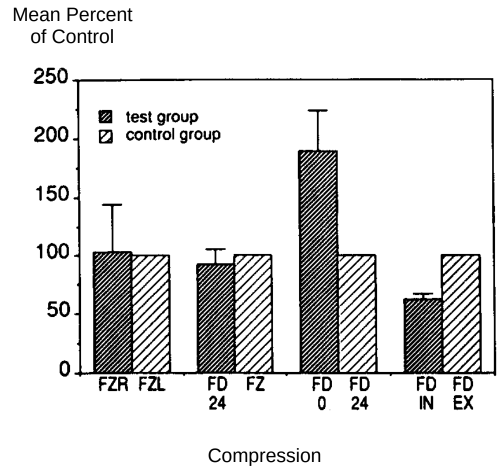

FIGURE 1: Compression testing by matched pairs.

Key to Abbreviations

FZ = frozen graft
FZR = frozen, right
FZL = frozen, left
FD24 = freeze-dried rehydrated 24 hours
FD 0 = freeze-dried without rehydration
FD IN = freeze-dried rehydrated *in vacuo*
FD EX = freeze-dried rehydrated *ex vacuo*

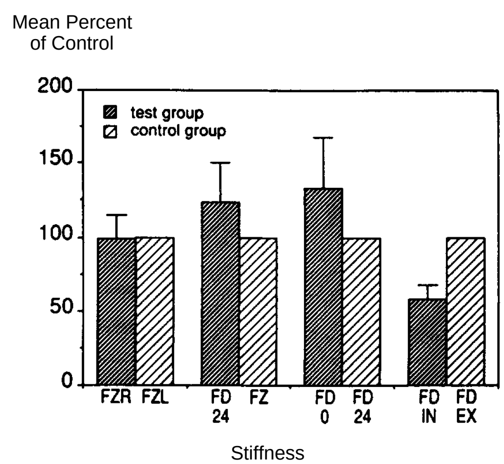

FIGURE 2: Stiffness testing by matched pairs.

Optimizing Knots Used Arthrscopically

Todd D. Loutenheiser, B.S.
Matthew P. France, M.D.
John A. Sidles, Ph.D.
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Simple tasks can become technical challenges for arthroscopists because instruments replace hands for certain steps of intra-articular repairs. The ability to tie secure knots arthroscopically is essential to achieve an effective repair and optimal results comparable with open repairs.

Monofilament suture is relatively stiff and slippery; it is more difficult to tie securely than is braided suture. Yet, because of its strength and slow absorption, it is preferred by many surgeons for intra-articular repairs.

Knots tied arthroscopically commonly consist of an initial "slip knot" to remove slack and a series of half-hitches. The initial slip knot may be as simple as an overhand throw, a series of nonidentical half-hitches, or a complex noose. Half-hitches, instead of square throws, always result when asymmetrical tension is applied to the strands. For this reason, the security of knots tied arthroscopically may not be equivalent to hand-tied square knots, and a greater rate of failure may occur.

We conducted this study to determine: (1) whether the current practice of tying knots arthroscopically provides a secure fixation point for low and high loading conditions, and (2) whether the surgeon can modify the method or sequence of throws to minimize knot slippage or breakage.

Methods

The initial throw in a strand of #1 polydiaxone suture (PDS II ® Ethicon Co.) was a simple "overhand throw" or a complex "Duncan loop" slip knot, recommended by Wolf for arthroscopic shoulder ligament repair (Figure 1A). After the slip knot, three half-hitches in one of four combinations were placed to secure the knot (Figures 1B, 1C, and 1D). We tied a total of 10 knots of each configuration.

We tested each knot by pulling apart two rings that were enclosed inside the loop. Knot displacement was measured with a magnetic position sensor mounted on the handle of the mobile ring and the applied force was measured by a transducer attached to the stationary ring.

After preloading, we applied an additional 15- and 30-newton cyclic load for 10 repetitions to distract the suture loop (Figure 2). After cyclic loading, each knotted loop was pulled to failure at a steady, midrange rate. Failure was defined as the maximum force that resulted in slippage or breakage of the loop at 3 mm or less.

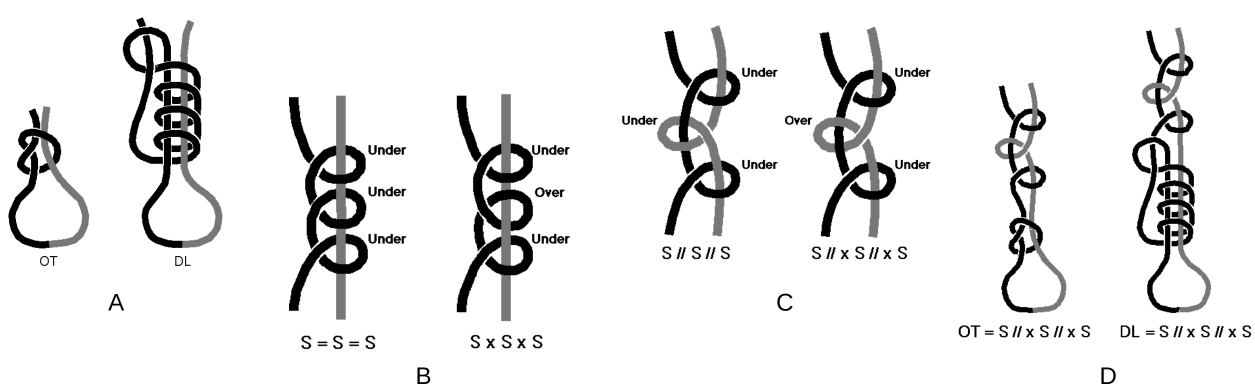

FIGURE 1A-B: **(A)** The OT designates the simple overhand throw and the DL designates the complex Duncan loop slip knot configurations. **(B)** Half-hitch configurations without post switching. Labels "under" and "over" indicate the direction for the initial pass around the post. The direction of the half-hitch loops is either identical (S=S=S) or reversed (SxSxS); Tera and Aberg (1976) coding.

FIGURE 1C-D: **(C)** Half-hitch configurations with post switching. Half-hitch loops are either switched and identical (S//S//S) or switched and reversed (S//xS//xS). **(D)** The knot combinations shown above exhibited the least loop displacement under load and the best loop holding capacity. The DL=X//xS//xS configuration outperformed all other knots.

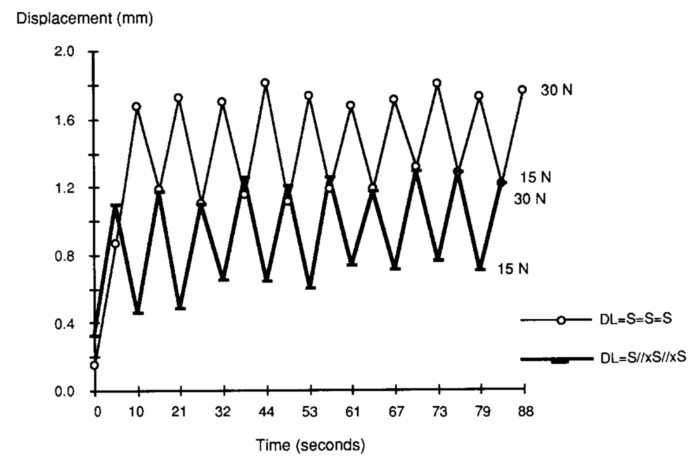

FIGURE 2: Suture loop enlargement under repetitive cyclic loading.

Results

Cyclic: Low-load Tests

Knots with half-hitches placed on the same post usually slipped before or after the first 15 to 30-N load application (OT=S=S=S and OT=SxSxS, 100% slip; and DL=S=S=S, 20%). We found the switched-post/reverse-throw configurations (DL=S//xS//xS and OT=S//xS//xS) displaced less at 30-N than did loops without post switching (DL=S=S=S and DL=SxSxS, $p < .0001$), and had significantly smaller displacements between the initial 15-N load and the final 30-N load ($p < .0002$) compared to all other configurations (except the DL=S//S//S knots, Figure 3).

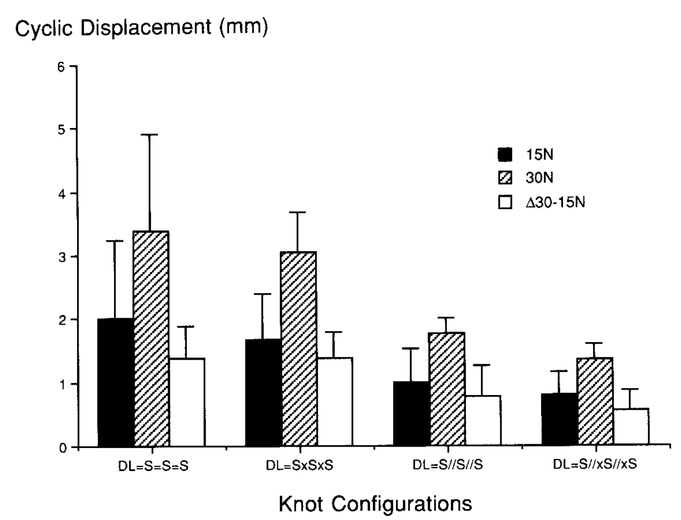

FIGURE 3: Displacement of Duncan loop knots under cyclic loads.

Load to Failure (3 mm of displacement)

All knotted suture loops in this study failed by expanding to greater than 3 mm. We found that all knots that did not include post switching for half-hitches (DL=S=S=S, DL=SxSxS, OT=S=S=S, and OT=SxSxS) were no different from each other statistically and failed at loads approximately half of the best knots, which included post switching ($p < .0001$, Figure 4).

Knots that not only had half-hitch post switching but also reversal of the half-hitch direction (DL=S//xS//xS and OT=S//xS//xS) sustained the greatest load at 3 mm of displacement. The DL=S//xS//xS knot configuration always held better than all other knot configurations ($p < .0002$, except the OT=S//xS//xS knot).

Ultimate Failure: High-load Test

All suture loops knotted without half-hitch post switching ultimately failed by complete slippage. All loops failing by breakage displaced more than 5 mm. Also, knots initiated with the Duncan loop had higher ultimate failure strength for similar configurations.

Discussion

After a surgical repair, the suture line is loaded repetitively by muscular activity, mobility, and therapy. We believe this study, which employs cyclic slow-rate, low-load conditions at forces consistent with manual laxity testing in the cadaveric shoulder, as well as standard high-load, fast-rate conditions, challenges the holding capacity of knots and produces practical results. ‰

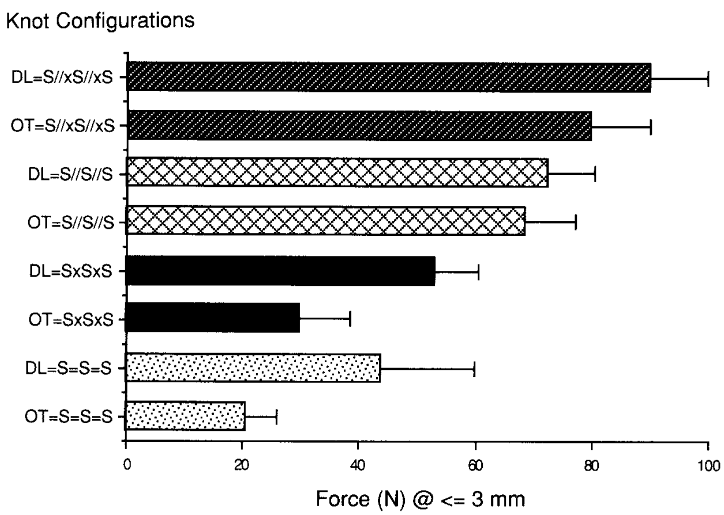

FIGURE 4: Loop holding capacity at 3 mm or less* of displacement. (*Maximum force in newtons when knot failure occurred at less than 3 mm.)

Our results revealed that knots initiated with a complex slip knot resisted low repetitive "clinical" loads without failure and exhibited greater strength at high ultimate loading than did those with a simple slip knot (Figure 4). Our cyclic loading data clearly indicate that when subjected to repetitive stress, all knotted loops of PDS enlarge progressively (Figure 2). This increase in loop size could result in loss of apposition of repaired tissue. Under load, PDS suture can elongate up to 30% of its length, which may compromise healing of the repair.

We agree with Brouwers (1991) and Wolf (1991) that switching the post after each successive half-hitch is critical to optimizing the holding capacity of a knot. Furthermore, failure by knot slippage is minimized by successive reversal of the half-hitch direction over and under the post strand. The best knot was achieved by combining a complex slip knot with reversed half-hitches on alternating posts (Figure 1D). Knots with this configuration had the least displacement and the greatest loop-holding capacity for all tests.

Summary

Our recommendations for tying arthroscopic knots with slip knots and half-hitches include:

1. Always switch the post strands for every throw after securing the first half-hitch following a slip knot.
2. Always reverse the half-hitch direction (over and under) the post for each half-hitch throw
3. Use *at least* three half-hitches on alternate posts and reversed loops to secure a slip knot. A greater number of half-hitches will add additional knot security.

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Summary of Lumbar Spinal Fusion: A Cohort Study of Complications, Reoperations, and Resource Use in the Medicare Population

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Spinal fusion is a more complicated procedure than laminectomy or discectomy alone, because it involves bone grafting with or without internal fixation devices. Thus, it involves a larger dissection, two incisions, and longer operating time. More complications and longer hospital stays might be anticipated, but have rarely been assessed.

Data from the National Hospital Discharge Survey demonstrate that all forms of lumbar spine surgery increased during the decade from 1979 through 1990, but spinal fusions showed the largest percentage increase. One rationale for performing spinal fusions is to reduce the need for future surgery, but there is little consensus as to appropriate diagnostic criteria for spine instability or the indications for lumbar spine fusion.

Most indications for spinal fusion lack evaluation through controlled trials, and reoperation rates have generally been reported only for small samples with incomplete follow-up and variable duration. Our study compared the outcomes of surgery performed with and without fusion in a national cohort of Medicare recipients for whom uniform data were available.

Methods

For all Medicare patients who had lumbar spine surgery in 1985, we obtained Medicare claims data for one year prior to 1985 and four years after the index operation. We excluded patients with operations in the cervical or thoracic spine, as well as patients with a malignancy, spinal infection, inflammatory spondylitis, fracture, or vehicular trauma. Our study population divided into broad diagnostic categories (herniated discs, spinal stenosis, degenerative disc disease, possible instability, and miscellaneous disorders). Although the coded diagnoses reflect those recorded by the attending physicians, there may by substantial variation among surgeons in their diagnostic criteria and practices — a common problem in observational studies. We also examined outcomes according to the type of surgery described, including laminectomy, discectomy, fusion, or combinations of these procedures. When examining complication rate or hospital length of stay, we controlled for any co-existing medical diagnoses.

Results

There were 27,111 patients who met our entry criteria, of whom 1,524 received lumbar fusions. As expected in the Medicare population, the mean age was 72 years (range, 59-97 years) and 57% were women. The most common diagnosis overall was spinal stenosis, although 49% of those who had non-fusion surgery had herniated discs. Approximately 44% of those who had fusion had spondylolisthesis or other indications of possible instability. Because of these differences, we conducted stratified analyses according to diagnosis and procedure. We also performed multivariate analyses to control simultaneously for patient age, sex, race, comorbidity, previous back surgery, and diagnosis.

Overall, complications and costs were higher for fusion surgery than non-fusion surgery (Table). The same pattern held true for two subgroups: discectomy with and without fusion, and laminectomy with and without fusion, and also for subgroups based on diagnosis (e.g., patients with spinal stenosis).

Multivariate analyses controlling for age, sex, race, comorbid conditions, previous surgery, and diagnosis, showed that patients undergoing fusion had a complication rate 1.9 times greater than those who had surgery without fusion. The blood transfusion rate was 5.8 times greater, the nursing home placement rate was 2.2 times greater, and hospital charges were 1.5 times greater (all significant at $p < 0.0005$). Furthermore, six-week mortality was 2.0 times greater for patients undergoing fusion ($p = 0.025$). ‰

TABLE: Short-term Outcomes and Resource Use for Patients Undergoing Lumbar Spine Surgery With and Without Spinal Fusion

	Any Lumbar Surgery		Discectomy		Laminectomy		
	With Fusion (n = 1,524)	Without Fusion n = 25,587)	With Fusion (n = 380)	Without Fusion (n = 12,042)	With Fusion (n = 730)	Without Fusion (n = 10,490)	Fusion Alone (n = 317)
Six-week postoperative mortality (%)	1.2†	0.7	1.1	0.6	1.1	0.9	1.6
In-hospital complications (%)	14.7*	7.7	12.1*	5.8	15.8*	9.8	16.4
Blood transfusion (%)	46.7*	12.5	49.0*	8.9	45.3*	16.6	45.7
Discharged to nursing home (%)§	4.2*	2.4	8.2*	1.7	3.0	3.1	1.6
Mean length-of-stay, days	15.7*	13.2	15.8*	12.9	15.5*	13.4	15.9
Mean inpatient hospital charges, 1985 dollars#	10,091.0	6,754.0	9,631.0*	6,336.0	10,162.0*	7,152.0	10,198.0

*Significantly different from surgery without fusion ($p < 0.0005$)
†Significantly different from surgery without fusion ($p = 0.04$)
#Does not include professional fees.
§Includes only patients not admitted from a nursing home.

The figure shows the probability of reoperation over time according to diagnosis and procedure. After four years, 11.9% of fusion patients had undergone reoperations compared to 10.2% of non-fusion cases. A multivariate analysis controlling for multiple confounders showed no significant difference between fusion and non-fusion cases with regard to four-year reoperation rates. For the four years of follow-up, hospital charges related to back pain were significantly higher for patients who received fusions than for those who had surgery without fusions.

Discussion

This study is the first to offer evidence that, for older adults, lumbar spinal fusion is associated with greater postoperative morbidity, mortality, and in-hospital resource use than is spinal surgery performed without lumbar fusion. This finding should not be surprising, because of the greater complexity of fusion procedures. The results were consistent with our earlier study in Washington State, which included a younger population, but for which data on reoperations were unavailable.

Many selection factors could bias such nonrandomized comparisons, so our data should be interpreted cautiously. However, the wide geographic and specialty variations in rates of lumbar fusion suggest that there is substantial clinical overlap in the populations who received surgery with or without fusion. For example, a California patient who underwent surgery for spinal stenosis and received a fusion might be virtually identical to a New England patient who had surgery without fusion, enhancing the validity of a comparison. Our study had the advantage of being broadly representative of surgeons in community practice, with virtually complete follow-up. Nonetheless, it suffers from the predictable limitations of ICD diagnostic and procedure codes, and its potential for inaccurate coding. It is a fundamental epidemiologic principle that misclassification tends to reduce observed differences, rather than accentuate them.

Our data suggest an urgent need for a uniform definition of spinal instability and the indications for spine fusion. To avoid the hazards of nonrandom comparisons, we advocate performing randomized trials to compare the risks and benefits of specific surgical procedures with alternative approaches for clearly defined patient samples.

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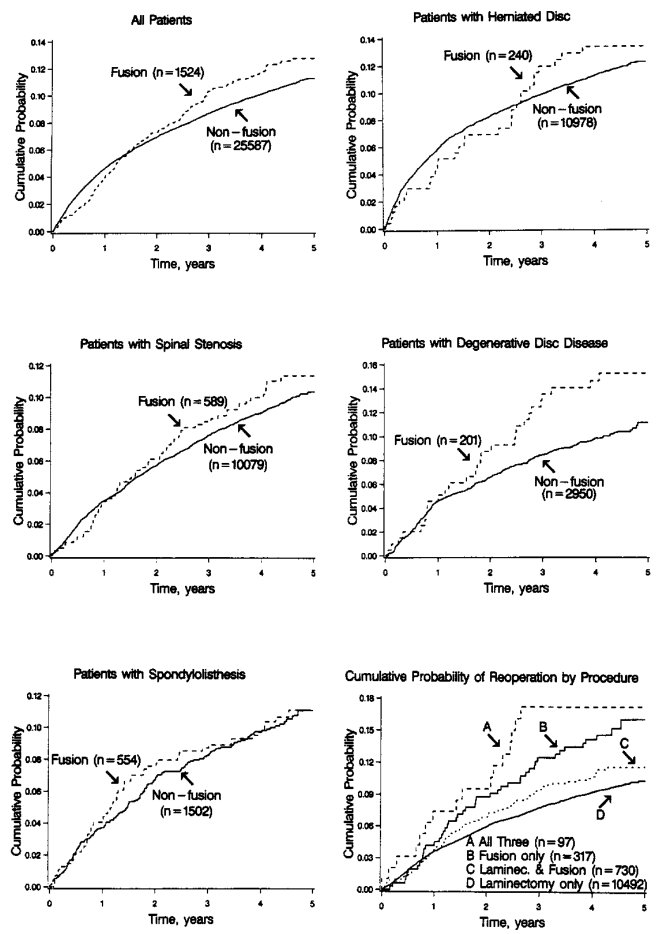

FIGURE: Cumulative probabilities of reoperation for selected diagnostic and procedural groups. The graph of reoperations by procedure excludes discectomy alone and discectomy plus fusion for visual simplicity, because of extensive overlaps with the laminectomy curves.

Open Reduction Through a Medial Approach for Developmental Dislocation of the Hip

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During infancy, open reduction of developmental dislocations of the hip is necessary if closed reduction is unsuccessful. Four approaches to open reduction include the postero-medial, anteromedial, anterior, and anterolateral. The anteromedial approach, first described by Ludloff in 1908, accesses the hip joint by developing the plane between the adductor longus and pectineus muscles. This exposure provides direct access to the major obstacles blocking reduction. However, because the medial circumflex artery courses under the psoas muscle close to the dissection, critics of this approach have suggested that it increased the risk of vascular injury and secondary avascular necrosis of the femoral head. Nevertheless, several features make this approach attractive, including direct access to the joint, minimal dissection, and inconspicuous residual scar.

During the early 1970s, one of the authors (LTS) introduced this approach at Children's Hospital and Medical Center, where it became the standard method for open reduction. We conducted this study to determine the effectiveness of the procedure and to assess the incidence of avascular necrosis.

Methods

Between 1972 and 1983, 77 hips in 71 patients were managed by open reduction through the Ludloff approach. Open reduction was done only if closed treatment had failed. The surgeons used the technique as described by Ludloff, but made an oblique rather than a longitudinal skin incision to make the residual scar more acceptable. In 66 hips (63 children) follow-up evaluation extended for a mean of six years with a minimum of 24 months. We exluded 11 hips in eight children for whom the minimum 24 months of follow-up was not available.

Results

Avascular necrosis was evident preoperatively in two hips (3%) and was noted postoperatively in another seven hips (11%). We found a correlation between the age of the patient at the time of the operation and post-operative avascular necrosis, with an increased prevalence of the complication in patients who had been managed with the open reduction after the age of 24 months. One redislocation and two subluxations were noted at the time of the first changing of the cast, four weeks postoperatively. Although the acetabular index decreased from a mean of 38 degrees preoperatively to a mean of 16 degrees at the time of follow-up, acetabular dysplasia did not resolve in 33% of the hips and pelvic osteotomy was performed. We rated the outcome using Severin's criteria. The results showed: class I, 44 hips; class II, 19 hips; and class III, 3 hips.

Discussion

The results of this study have confirmed our impression that the Ludloff approach is a safe and effective method to obtain a reduction in developmental dislocation of the hip if closed reduction is unsatisfactory. In the infant over 18 months of age, we consider the Ludloff approach inappropriate for several reasons. The incidence of avascular necrosis increases, and a concurrent pelvic osteotomy and limboplasty is often appropriate in these older infants and children. These concurrent procedures are best performed through an anterolateral approach.

Our series had an 8% incidence of avascular necrosis for hips reduced in infants under 18 months of age. This rate is acceptable and consistent with other closed and open approaches to reduction. The medial circumflex artery courses around the iliopsoas muscle and is vulnerable to damage regardless of the approach. The direct view provided by the Ludloff approach probably makes injury to this vessel less likely than other approaches where visualization is more restricted.

The principal causes of avascular necrosis are excessive pressure on the femoral head and vessels due to the position of the hip in the cast, and variations in vascular pattern of circulation to the femoral epiphysis. Regardless of the approach, good operative technique is essential. This involves careful dissection, release of the iliopsoas tendon, capsulotomy, incision of the transverse acetabular ligament, and removal of the pulvinar and possibly the ligamentum teres.

A potential disadvantage of the medial approach is the inability to perform a limboplasty. The limbus is an intra-articular fibrocartilagenous structure that normally extends laterally beyond the acetabular margin, increasing the stability of the hip. In these dislocated hips, the limbus is enfolded into the joint, often producing an obstacle to reduction. After closed reduction, remodeling of the limbus occurs over several weeks. During this remodeling process, if the capsular constriction is severe, the femoral head may be compressed between the limbus and capsule with enough pressure to impair epiphysial circulation and cause avascular necrosis.

Reshaping and repositioning the limbus (limboplasty) is not possible through the Ludloff approach. In these hips, the femoral head is positioned under the inverted limbus. Remodeling of the limbus proceeds, but without the excessive pressure on the femoral head as the capsular contracture and iliopsoas tendon have been released. Our study suggests that in infants under 18 months of age, remodeling of the limbus following open reduction by the Ludloff approach occurs spontaneously without producing a significant risk of avascular necrosis.

Acetabular development was inadequate in one-third of the hips in our series. In these children, correction of residual acetabular dysplasia was accomplished by acetabuloplasty with a Salter or Pemberton osteotomy. The indications for pelvic osteotomy are not clearly defined. We suggest that pelvic osteotomy is appropriate if improvement of acetabular dysplasia is incomplete or inadequate after a period of observation. Following reduction, we recommend using a brace at night to splint the hips in abduction until three years of age. Acetabuloplasty is appropriate if the signs of dysplasia are not improving, i.e., the acetabular index, "tear drop," and acetabular roof ossification.

Acetabular dysplasia may have a significant genetic basis. An observation period of 12 to 36 months reveals the potential for spontaneous acetabular recovery. Hips remaining dysplastic are identified and corrected with acetabuloplasty. Based on our previous studies, we recommend acetabuloplasty before four years of age.

Summary

We consider the Ludloff approach to be a safe and effective method for the treatment of developmental dislocation of the hip in infants who are less than 18 months of age. The advantages of this approach include direct access to the ilioposias, the transverse acetabular ligament, and the constricted capsule; minimum loss of blood; and a cosmetically acceptable scar.

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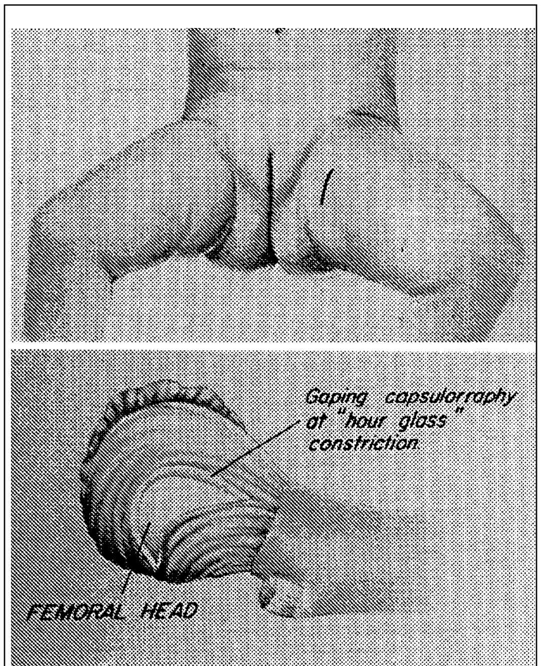

FIGURE: (Top) Illustration of the incision for open reduction through the Ludloff approach. (Bottom) Following open reduction, the femoral head falls into the acetabulum and the gaping capsulorraphy at the original "hour glass" construction. Note the site of the divided psoas tendon.

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Plate Fixation of Femoral Shaft Fractures in Multiply Injured Children

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Philip J. Kregor, M.D.

The management of isolated femur fractures in children is relatively uncomplicated. Good results are expected using a variety of nonoperative methods such as skin traction, skeletal traction, and immediate hip spica casting.

The polytraumatized child is different, however. In these patients, difficulties with skin breakdown, patient agitation, spasticity secondary to head injury, open wounds, and the need for frequent transport limits the use of conventional treatment methods. Operative stabilization of femoral shaft fractures in children with multiple injuries allows improved mobilization and pulmonary toilet, stable reductions, and a decrease in the hospital stay and / or cost. We believe the indications for operative stabilization include head injury, seizures, spasticity, open fractures, floating knee, and vascular injury in the fractured extremity.

We retrospectively evaluated 13 multiply injured children (10 years of age or less, range 5 years 0 months to 9 years 11 months) with femoral shaft fractures treated using compression plating after open reduction. All the children were treated at Harborview Medical Center in Seattle from 1986 to 1990. Twelve of the 13 children were available for follow-up.

These 12 patients had 15 fractures; nine were closed, and six were open. The six open fractures were classified according to Gustilo and Anderson as three type I, two type II, and one type IIIA. Six children were pedestrians, five were involved in a motor vehicle accident, and one was injured after a 50-foot fall. These patients had an average of 2.8 associated injuries, defined as: (1) a head injury that required neurosurgical consultation and / or intracranial monitoring, (2) pneumothorax or lung contusion, (3) facial fracture, (4) extremity injury, or (5) abdominal trauma requiring laparotomy. The Injury Severity Score averaged 25 (range 13-38).

All but one patient had surgery within 24 hours of injury. All cases involved lateral exposure of the femur with open reduction and internal fixation. Open wounds were treated with initial irrigation, debridement, and fracture fixation. Each femur fracture was stabilized with a single plate. The surgeons selected implants based on the patient's age and size of femur. The implants used were: seven 3.5-mm dynamic compression plates, seven 4.5-mm narrow dynamic compression plates, and one 4.5-mm limited-contact dynamic compression plate.

Delayed primary closure was performed at five to seven days after injury; drains were used in all but one case. No cases required bone grafting. Follow-up averaging 26 months was available for 12 patients and included functional assessments and radiographs, as well as scanograms for nine patients.

There were no infections. All fractures healed radiographically at an average of six weeks after injury; 14 fractures (93%) showed anatomical reduction and union. All 15 plates were removed at an average of 10 months postsurgery and no plate breakage nor refractures were seen. All patients had hypertrophic scar formation, and for three patients plastic surgeons performed scar revisions at the time of plate removal.

All patients were walking without assistive devices at final follow-up. Two patients had residual head injury and resultant spastic quadriparesis, which prevented a normal gait. One patient had a mild limp at 11 months after injury.

Seven of the nine patients with scanograms had an uninjured contralateral femur. Femoral overgrowth averaged 0.9 cm in these patients. Two patients had ipsilateral tibial fractures with combined femoral and tibial overgrowths of 2.4 and 2.1 cm.

Considerations

Trauma is second only to infection in producing morbidity in children. Isolated pediatric femoral shaft fractures are well treated with nonoperative means. Treatment options for a femoral shaft fracture in a polytraumatized or head-injured child aged 10 years or less include external fixation, flexible medullary rod fixation, or compression plating. External fixation is complicated by pin site infections and restriction of joint motion.

The literature describes numerous cases of refractures and loss of reductions after fixator removal. Flexible medullary devices do not provide rotational stability, nor do they prevent shortening in segmental or comminuted fractures. Rigid medullary fixation is successful in adolescents, but difficult in our younger patient group because of their femoral anatomy. Standard locking nails are not small enough to fit the femoral canals of children. The femoral neck capsular and vascular anatomy, as well as the trochanteric apophysis, complicate antegrade femoral nailing in these children.

Plate fixation provides immediate rigid fixation of the femoral shaft fracture, allowing safe mobilization of the hip and knee joints so the patient can walk safely. Pin care is not needed, infections are avoided, and supplementary casting is not necessary. Several clinical series have shown excellent results from compression plating of femoral shaft fractures in children. Our patients mirror these outcomes. The disadvantages include the need for plate removal and the poor cosmetic appearance of the scar.

This retrospective series does not prove that open reduction and internal fixation is superior to other treatment methods in this patient population. It does demonstrate that in children aged 10 years or less, plate fixation is a good treatment option with a high rate of union, low risk of infection, ease of mobilization, and low risk for a functionally important limb length inequality.

A Case Study

A 10-year-old boy was struck by an automobile while riding his bicycle. He sustained a closed head injury, femoral shaft fracture, splenic rupture, and an avulsion of the left kidney. He was treated emergently with intracranial pressure monitoring, exploratory laparotomy, splenectomy, left nephrectomy, and compression plating of the femoral shaft fracture. His head injury resolved without deficits, and he returned to competitive swimming three months after injury. The plate was removed eight months after injury. Femoral lengths were symmetrical at one-year follow-up.

Fracture of the femoral shaft.

Plate fixation, lateral view.

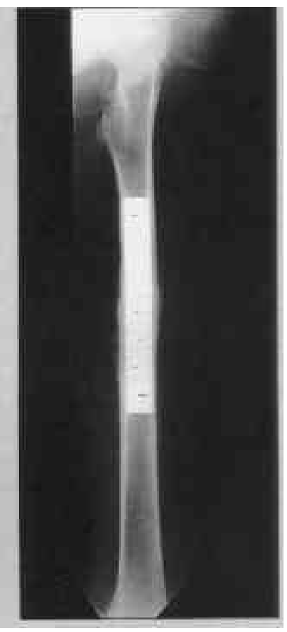

Plate fixation, frontal view.

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Outcome Following Open Reduction and Internal Fixation of Severe Intra-articular Distal Fractures

Thomas E. Trumble, M.D.

Many reports of distal radius fractures are confusing because extra-articular and intra-articular fractures are combined. While the extra-articular fractures commonly occur in an older age group and generally require cast treatment without surgery, the patients with intra-articular fractures are generally younger and have a severe disability as a result of lost strength and wrist motion that affect their occupational and recreational activities. Several classification systems emphasize different aspects of these significant injuries.

FIGURE 1 (left): Despite external fixation with distraction at an outside institution, there was still significant displacement of the intra-articular fragments.

FIGURE 2 (right): Following open reduction and internal fixation, a congruent joint surface was established and the patient was allowed to start exercises immediately in the postoperative period to restore motion.

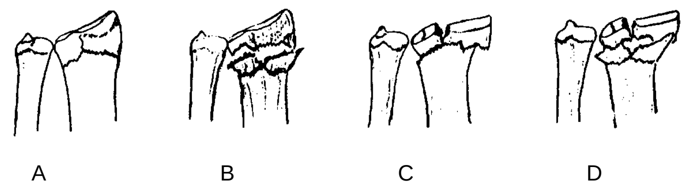

FIGURE 3: Classification of intra-articular distal radius fractures.

Despite reports demonstrating the success of singular methods for treatment, i.e., external fixation alone (Figure 1), restoration of the articular surface often requires a more complex approach. If the articular surface of the joint is not adequately repaired, permanent arthritis can result (Figure 2). The treatment and ultimate functional outcome has not been clearly defined based on these overlapping classification systems.

The goals of our study were:

1. To devise a classification system that would predict the type of treatment necessary.
2. To determine if radiographic correction of the fracture alignment could be maintained and whether this aproach could avoid traumatic arthritis.
3. To evaluate the clinical and radiographic factors that correlated with outcome.

Consequently, we developed a classification system that allowed us to provide systematic treatment.

Classification of Intra-articular Distal Radius Fractures

We classified the radius fractures (Figure 3) as follows so as to predict the treatment that the patient would require:

Type A: Minimal extra-articular comminution and minimal step-off (loss of congruency) of the articular surface.

Type B: Extra-articular comminution but minimal separation of the articular surface.

Type C: Minimal extra-articular comminution but displacement of the intra-articular fracture with loss of the joint surface congruency.

Type D: Significant extra-articular comminution and loss of joint surface congruency.

Based on these classifications and the biomechanical principles that (1) external fixation devices are necessary to maintain the length of the radius when there is significant extra-articular comminution, and (2) internal fixation is necessary to restore a congruent joint surface when displacement exists after closed treatment, treatment for these fractures has been standardized as follows:

Type A: cast immobilization
Type B: external fixation
Type C: internal fixation and bone grafting
Type D: internal fixation, bone grafting and the application of an external fixation device.

Methods

We evaluated a consecutive group of 49 patients with an average follow-up of 38.3 months (range 24-69 months, SD $\pm$ 12.3 months). Their average age was 37 years (range 17-79 years). All patients with severe angulatory deformity of the distal radius articular surface were treated with closed reduction initially and radiographic measurements were made to determine the type of treatment required. This study focused only on patients with type C and D injuries that had a disruption of the articular surface requiring internal fixation. Nineteen of the patients were rated as having type C (AO classification C2) and 21 of the patients had type D (AO classification C3.2 and C3.3).

We devised an Injury Scoring System (IS) to rate the injuries according the number of articular fracture fragments as well as to assign points for carpal injuries. At follow-up the patients had their grip strength and range of motion measured as a percentage of the contralateral side. Pain was rated on a scale of 0-100 based on specific functional limitations with occupational and recreational activities. We then calculated a combined functional rating based on pain, strength, and motion.

We obtained radiographs at the time of injury, after closed reduction, and then during the follow-up course until the last evaluation when we obtained radiographs from the injured as well as the noninjured wrist so that loss of alignment could be reported as a percentage of the contralateral side. This was done to normalize the radiographs because parameters such as the radial and palmar tilt of the radius vary from patient to patient.

Analysis of Data: The student's t test, multivariant, and single-variant regression analyses were used to determine the levels of statistical significance.

Results

Both the alignment and articular congruency had significantly improved in the final postoperative radiographs as compared to the initial closed-reduction maneuver ($p < .01$, Figure 4). Preoperative loss of palmar tilt and radial tilt measured 15.1° $\pm$ 14.6° and 5.6° $\pm$ 5.2°, respectively. At final follow-up the loss of radial tilt and palmar tilt measured 0.9° $\pm$ 1.5° and 3.7° $\pm$ 4.9°, respectively. The step-off (vertical displacement of two fracture fragments) and gap (diastasis of fracture fragments) measured 2.6 $\pm$ 1.2 and 2.8 $\pm$ 0.3 mm, respectively, and these were corrected to 0.4 $\pm$ 0.7 and 0.2 $\pm$ 0.5 mm respectively (Figure 4). There were no significant differences between the initial postoperative correction and the final correction of any of the parameters, indicating that the intraoperative correction was maintained at the time of fracture union.

At the final follow-up examination the relative grip strength and range of motion averaged 69.1% $\pm$ 21.6% and 74.6% $\pm$ 18.3% of the contralateral side. The patients' combined functional rating correlated by regression analyses with the number of fracture fragments and with the congruency of the joint surface but not with age, hand dominance, palmar tilt, or radial tilt (Figures 5, 6). The combined functional rating did correlate with the length of the radius. The type of approach used, dorsal versus volar, was not statistically significant due to the small number of fractures with volar displacement requiring a volar approach. We noted significant change in the combined functional rating once a deformity greater than 1 mm was present in the articular surface (Figure 6). There was no significant difference in the final congruency and alignment of the fractures in type C versus type D. Consequently, there were no significant differences in clinical outcome in type C versus type D fractures. ‰

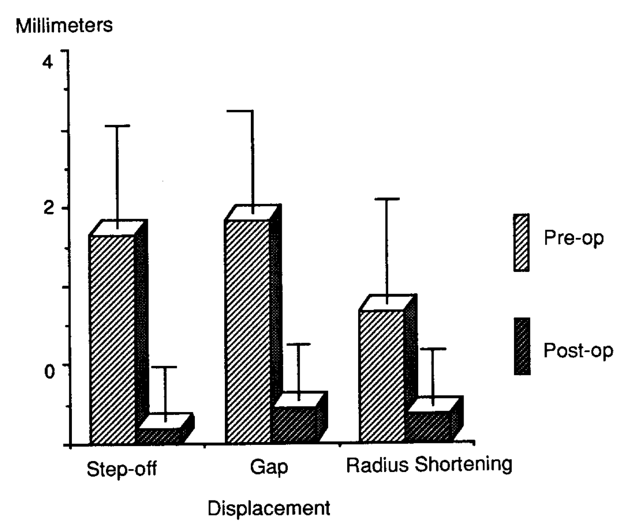

FIGURE 4: Pre- and postoperative measurements of the intra-articular step-off and gap, as well as the residual shortening of the radius, demonstrated that significant improvement was achieved and maintained following surgery.

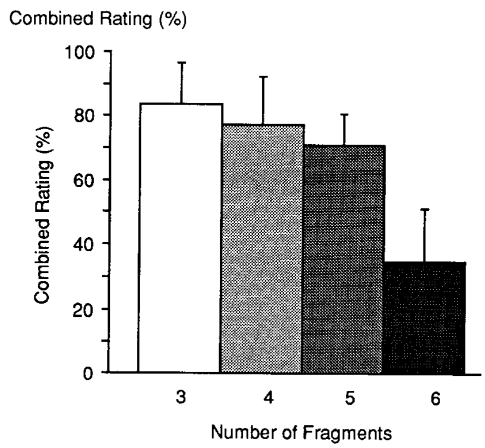

FIGURE 5: Combined functional rating demonstrated a significant decrease when more than five fracture fragments were present.

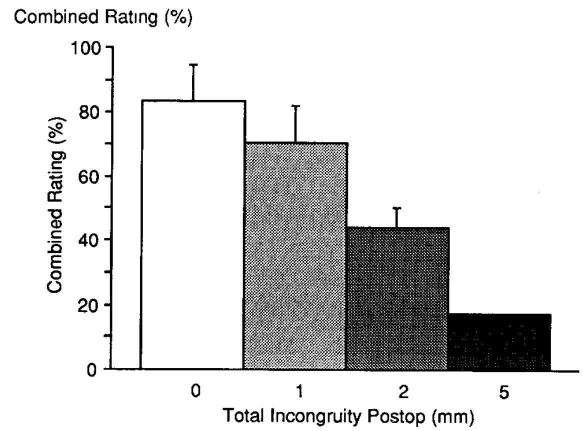

FIGURE 6: A significant decrease in the combined functional rating occurred when a total incongruity measured 1 mm or more.

Conclusion

1. The classification system based on extra-articular comminution and intra-articular congruency satisfactorily predicts the type of treatment necessary.

2. Open reduction and internal fixation improves articular congruency and alignment of the distal radius, which can be maintained satisfactorily until fracture union.

3. Joint surface congruency and length of the distal radius correlated with improved clinical outcome, whereas radial or palmar tilt did not correlate with outcome. The number of fracture fragments had a significant impact; patients with more than five fracture fragments had significantly less hand function and increased wrist pain. Optimal reduction of the articular surface requires an alignment to within 1 mm of the contralateral side.

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Biomechanical Effects of Internal Fixation of the Distal Tibiofibular Syndesmotic Joint: Comparison of Two Fixation Techniques

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Allan F. Tencer, Ph.D.

Malleolar fractures of the ankle are common injuries. Weber classified these injuries into three groups — A, B, and C — according to the fracture pattern and the mechanism of injury. The type C pattern is caused by loading the foot in pronation and eversion. It consists of a fracture of the fibula located proximal to the distal tibiofibular syndesmosis, an avulsion of the medial collateral ligament or medial malleolus, and a complete tear of the tibiofibular syndesmotic ligament and the interosseous membrane up to the level of the fibula fracture (Figure 1, left). Widening of the intermalleolar space with a lateral shift of the talus under the tibia results in joint incongruency. The type C fracture accounts for 20% of all ankle fractures and is associated with the highest rate of late degenerative arthritis as compared to types A and B.

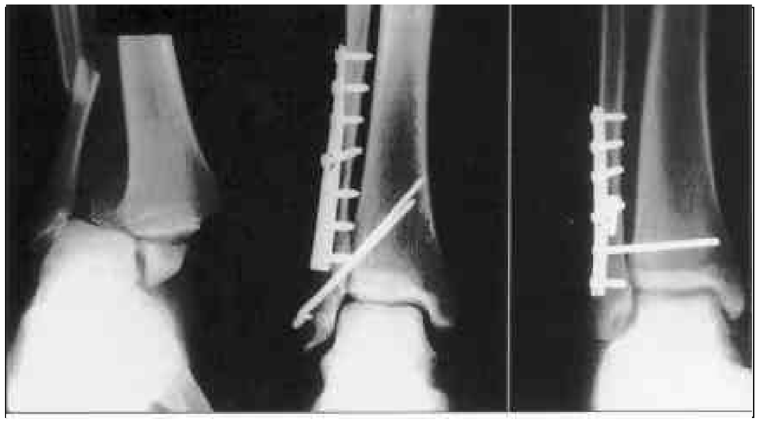

FIGURE 1: (Left) One example of type C fracture-dislocation of the ankle. Two methods of internal fixation of the tibiofibular syndesmosis were compared in this study (center): fixation with two oblique 1.5-mm Ø trans-syndesmotic Kirchner wires, and (right) suprasyndesmotic screw fixation.

Open reduction and internal fixation is the treatment of choice in type C malleolar fractures. Associated internal fixation of the tibiofibular syndesmosis is required in those cases where fixation of the distal fibula does not provide adequate stability to the ankle mortise, particularly if the fracture of the lateral malleolus is located more than 5 to 7 cm proximal to the ankle joint. The standard technique involves placement of a transverse tricortical suprasyndesmotic neutralization screw across the fibula to the tibia. This type of fixation, however, provides a rigid link that may interfere with the normal motion at the syndesmotic joint, eventually limiting ankle range of motion and causing local discomfort, implant failure, or pain. Early removal of these syndesmotic screws is recommended during a second surgical procedure after a period of healing.

A less rigid technique of syndesmosis fixation employs two oblique, trans-syndesmotic K-wires. This technique, not known to cause the above complications, does not require early hardware removal and appears to be clinically advantageous.

Our hypothesis is that K-wire fixation allows more normal motion of the ankle joint, while maintaining sufficient joint stability throughout the course of healing of the syndesmotic ligaments. This study compares the biomechanical effects on the tibiotalar joint of two methods of internal fixation of the tibiofibular syndesmosis in type C malleolar fractures. We compared fixation using the suprasyndesmotic screw technique to the trans-syndesmotic ‰

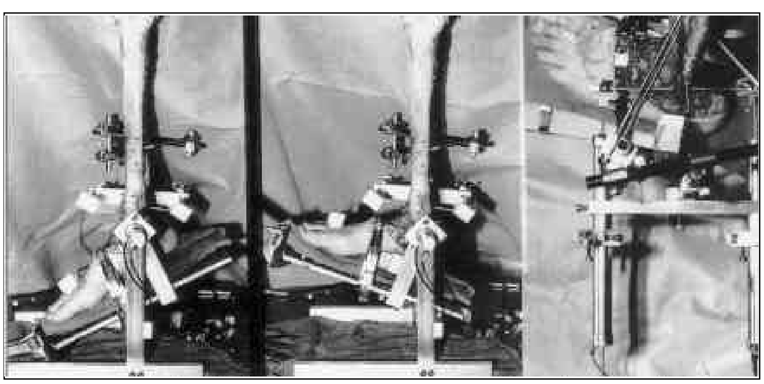

FIGURE 2: The foot rests on a tilting platform that allowed positioning of the ankle joint in selected orientations (left, center). Same setup seen from above with external fixator frame and the two motion transducers (LVDT) (right).

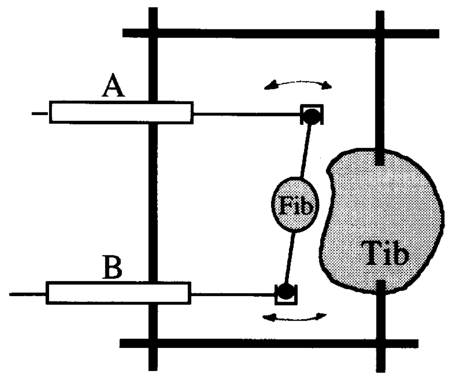

FIGURE 3: An external fixator frame inserted on the tibia linked two motion transducers (LVDT). The lateral and angular motion between distal tibia and lateral malleolus were recorded by tracking the motion to balls attached to a pin inserted through the lateral malleolus.

Kirchner-wire technique and measured the effects of these implants on the range of motion of the distal tibiofibular joint and the articular congruency of the injured and stabilized ankle joint.

Methods

We tested eight skeletonized fresh cadaver lower extremities. The proximal and distal tibiofibular syndesmotic joint, the interosseous membrane, the articular capsules, and ligaments at the knee and ankle joints were left intact. We used motion transducers to measure relative motion between the tibia and fibula, and evaluated joint load transmission with pressure-sensitive film (Fuji Prescale). The foot was fixed to a tilting platform allowing 30 degrees of plantar flexion and 30 degrees of dorsiflexion (Figure 2). A rotationally variable differential transformer (RVDT) monitored the angles of ankle plantar and dorsiflexion. The femoral stump was potted in dental plaster, allowing fixation to the loading apparatus. A materials tester applied a constant axial load of 700 newtons to the femoral stump with the knee in extension.

The medial-lateral displacement and the relative rotation between distal tibia and lateral malleolus were recorded using two linearly variable differential transformers (LVDT) fixed to the tibia, oriented horizontally, and arranged to track the position of two balls fixed to the ends of a pin mounted anterior to posterior in the lateral malleolus (Figure 3). Motion of the lateral malleolus was recorded as function of the angle of ankle flexion-extension.

Pressure distribution in the intact tibiotalar joint was recorded under 700 newtons of load using pressure-sensitive film (Fuji Prescale) previously cut to the shape of the joint and introduced prior to loading between the articular surfaces through the anterior arthrotomy. After recording motion and contact pressure in the intact specimen throughout the range of flexion to extension, we created a Weber type C injury by performing an osteotomy of the fibula 10 cm above the line of the ankle joint, sectioning the interosseous membrane and the syndesmosis distal to the osteotomy, and sectioning the deltoid ligament.

We performed fixation by anatomical reduction and stabilization of the fibula osteotomy with a 6-hole one-third tibular plate. The syndesmosis was then anatomically reduced and stabilized with either a transverse suprasyndesmotic 3.5-mm neutralization screw or with two obliquely inserted trans-syndesmotic 1.5-mm Kirchner wires (Figure 1). Anatomical reduction of the syndesmosis was ensured by predrilling the K-wire or screw holes before simulating the injury. We recorded tibiofibular motion and contact pressure distribution after applying each type of fixation.

To analyze data, we used a non-parametric Wilcoxon paired test at each ankle angle to compare values for the normal joint with those of fixed osteotomized specimens.

Results

Normal Tibiofibular Joint

In the uninjured specimens, lateral translation and external rotation of the lateral malleolus occurs while the ankle is moved from plantar to dorsiflexion (Figure 4). Our specimens showed displacements of up to 1.25 mm and rotations of up to 2 degrees. The most consistent finding was widening of the syndesmosis with dorsiflexion and narrowing with plantar flexion.

Fixed Osteotomized Joints

Study of the averaged plots (Figure 5a) showed that fixation with either a syndesmotic screw or K-wires limited narrowing of the ankle mortice in more than 15 degrees of plantar flexion when compared to uninjured ankles ($p < 0.05$). Syndesmotic widening in ankle dorsiflexion did not appear to be limited by fixation with implants. A comparison of lateral malleolar rotation showed that neither implant significantly limited intact and stabilized specimens (Figure 5b).

Contact Pressures

Pressure prints showed that the physiological pressure distribution of the tibiotalar joint was altered after the type C injuries. Regardless of the implant used for fixation of the syndesmotic joint, the contact area displaced laterally compared to that of the normal joint (Figure 6).

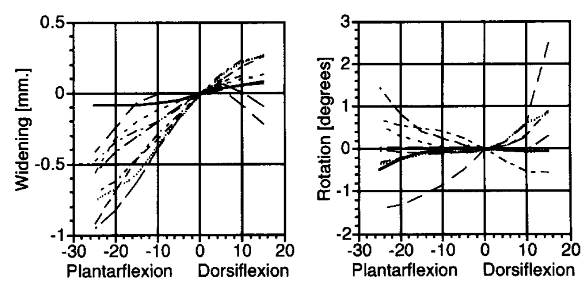

FIGURE 4: (Left) Intermalleolar widening (mm) and (right) rotation of the lateral malleolar (degrees), plotted as function of the angle of plantar flexion-dorsiflexion of the tibiotalar joint (degrees) for nine intact specimens.

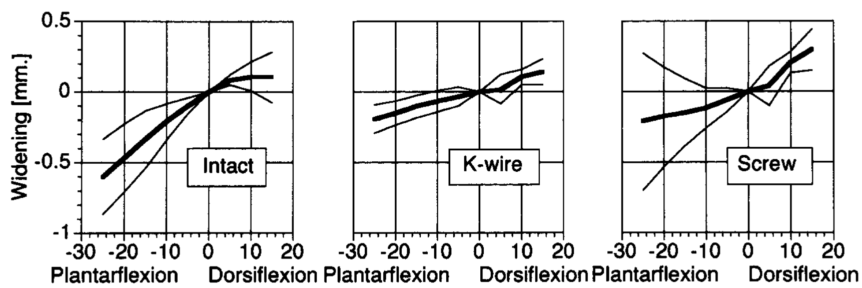

FIGURE 5a: Intermalleolar widening (mm) as a function of the angle of flexion-dorsiflexion of the tibiotalar joint (degrees). (Left) Intact joint, (center) type C injury stabilized with a pair of oblique K-wires or, (right) a syndesmotic screw. (Thicker lines = mean values, thinner lines = range of values.)

Discussion

K-wire fixation of the syndesmosis has been used for more than three decades and offers some clinical advantages. These implants do not show fatigue or loosening, and usually can be left in situ until all hardware is removed, thus sparing the patient an additional operative procedure. K-wires would appear to be a less rigid form of fixation than screws.

However, our experimental data did not show any difference between fixation with the screw or K-wire in this respect. Both provided adequate stability to the injured syndesmosis, but both altered the biomechanics of the joint. Neither was able to prevent perturbation of the load distribution in the tibiotalar joint.

Conclusions

During motion of the ankle joint from plantar to dorsiflexion, the normal syndesmotic joint widens up to 1.25 mm and the lateral malleolus rotates externally up to 2 degrees. Fixation of the syndesmosis with either screws or K-wires limits the physiological medial-lateral displacement of the lateral malleolus, but does not prevent its physiological rotation. Both fixation methods produce a lateral shift of the load distribution on the talus as compared to the uninjured ankle specimen. Therefore, both tested implants appear equivalent from a biomechanical perspective.

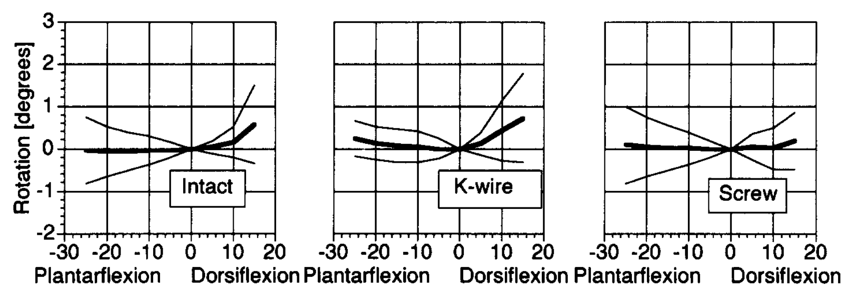

FIGURE 5b: Rotation of the fibula with respect to the tibia as function of the angle of plantar flexion dorsiflexion of the tibiotalar joint (degrees). External rotation, postive. (Left) Intact joint, (center) type C injury stabilized with a pair of oblique K-wires, or (right) a syndesmotic screw. (Thicker lines = mean values, thinner lines = range of values.)

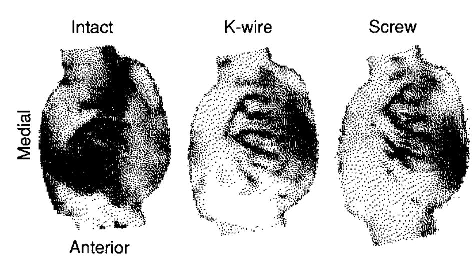

FIGURE 6: Example of contact area in the tibiotalar joint in specimen #7. (Left) Intact, (center) the same specimen with a type C injury stabilized with two oblique K-wires, or (right) a syndesmotic screw. Load transmission is shifted laterally in both internal fixation models as compared to the normal joint.

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(continued on page 31)

Functional Outcome of Below-Knee Amputation in Peripheral Vascular Insufficiency: A Multicenter Review

Douglas G. Smith, M.D.

Other investigators participating in this multicenter review were: Pinzur MS, Gottshalk F, Shanfield S, deAndrade R, Osterman H, Roberts JR, Orlando-Crombleholme P, Larsen J, Rappazzini P, and Bockelman P.

We conducted a retrospective review of the 299 patients who had a below-knee amputation (BKA) performed between 1987 to 1989 at one of the six Veterans Affairs medical centers with a Special Team for Amputation, Mobility, and Prosthetics / Orthotics (STAMP Program). Although this study suffers many of the deficiencies of a retrospective review, it offers a cross-sectional description of the current natural history of patients with peripheral vascular insufficiency severe enough to require a major lower-limb amputation.

Methods

We evaluated all veterans with gangrene or foot infection complicating peripheral vascular insufficiency who required a below-knee amputation between 1887 to 1989. All six centers have active vascular surgery programs that attempt limb salvage when indicated. Amputation level selection was based on the clinical examination of an experienced amputation surgeon and a laboratory assessment of vascular inflow as determined by ultrasound Doppler, and / or measurement of transcutaneous oxygen tension. To a varying degree, surgeons at the six institutions also considered evalutions of rehabilitation potential, nutritional competence, and immuno-competence to determine amputation level. Functional ambulation was rated before surgery and at follow-up using the ambulatory scale originally developed by Hoffer et al. to evaluate myelomeningocele, and later adapted to amputee function by Volpicelli and colleagues.

In this study population, 192 patients (64%) had diabetes mellitus. Seventy-six patients (25%) were already unilateral amputees. The surgical technique consisted of the standard long posterior flap in 276 patients (92.3%), sagittal flaps in six (2%), and guillotine open technique in 17 (5.7%). Anterior-posterior "fishmouth" skin flaps were not used in any patients. Rigid plaster dressings were used postoperatively in 225 patients (75.3%); 42 patients (14%) were managed with a pneumatic dressing and early weight bearing. Soft dressings were used in 22 patients (7.4%) who had primary wound closure and 20 (3.3%) whose wounds were left open.

Results

Patients were observed for two years, until their rehabilitation progress had stabilized or until they died. By two years, 109 patients (36.5%) had died, which reflects the severity of underlying disease in this population. Wound failure or infection occurred in 40 patients (13.4%); 20 limbs were salvaged at the below-knee amputation level, while 20 required revision to the knee-disarticulation or above-knee amputation level.

The table presents ratings of functional ambulation before amputation and at follow-up evaluation. In the community ambulation groups (independent and limited), 146 of the 168 patients (86.9%) maintained their functional independence following amputation. Prosthetic rehabilitation was initiated by fitting 264 patients; 229 (86.7%) were able to use a prosthesis to some degree for limited walking.

The general agreement on surgical technique and postoperative rehabilitation between the six programs is noteworthy. For the few patients who had alternative treatments, specific individual reasons accounted for the variation in protocol.

Discussion

The consistency of demographic and outcome data between the six centers speaks well for the representative nature of this information. The ambulatory capacity of the patients at follow-up evaluation supports the multidisciplinary approach to amputation and rehabilitation. The results also suggest that these patients are extremely ill and have a limited life expectancy, but that they can remain active and independent with appropriate care. Their short life expectancy mandates that rehabilitation not be delayed until the residual limb matures, as that period may represent a major portion of a patient's remaining lifetime. Aggressive rehabilitation techniques including rigid dressings or pneumatic dressings combined with early weight bearing are successful in keeping patients in this population ambulating at or near their preamputation level.

TABLE: Functional Ambulation of 299 Patients

Ambulatory Level	Walking Capacity	Preoperative	Postoperative
6	Independent community ambulator	116	104
5	Limited community ambulator	52	42
4	Unlimited household ambulator	36	25
3	Limited household ambulator	33	36
2	Supervised household ambulator	22	27
0/1	Transfer/bedridden	40	65

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A Practical Tool for Evaluating Function: The Simple Shoulder Test

Frederick A. Matsen III, M.D.

It is the opportunity and challenge of orthopaedists to improve the function of their patients. Now more than ever, orthopaedic surgeons are being called upon to document the functional benefits of their treatment approaches. Effectiveness and appropriateness of treatment are obviously provider-specific, or, as we like to say, "the surgeon *is* the method." However, the stated requirements of "proper outcome studies" place such investigations beyond the reach of those who need them the most: individual practicing orthopaedists.

We propose a simple and practical evaluation approach that calls upon the patient to do the evaluating. Using this approach, the surgeon can develop a three-part management paradigm: (1) a person's function is as good, but only as good, as the patient perceives it to be; (2) the need for treatment of a given condition is indicated by the functional loss attributable to it; and (3) the value of an orthopaedist's treatment for a specified condition is indicated by the durable *change* in the function of those receiving it (which requires a pretreatment baseline determination and long-term, sequential posttreatment determinations of *all* those treated by that surgeon).

By expressing function in patient-understandable terms, the surgeon gains not only the advantage of the patients' ability to do the evaluation at home, but also the advantage of being able to communicate the results easily to prospective patients, answering such questions as "If I let this surgeon perform this operation on me, how much better is my function likely to be, how long will it take to get better, and how long will the improvement last?"

The Simple Shoulder Test (SST) is a group of "yes" or "no" questions including some of the most common presenting complaints of patients to our shoulder and elbow service (Table 1). We have found that more than 95% of patients in the 60 to 70-year age group without shoulder disease respond "yes" to these questions. The shoulder function of 47 patients meeting strict criteria for degenerative glenohumeral joint disease had substantially poorer function (Table 2).

SSTs were available on 29 patients with degenerative glenohumeral joint disease immediately prior to shoulder arthroplasty performed by a single surgeon, on 15 of these patients at six-month follow-up, and on nine at over one-year follow-up. While not a consistent series with the same number in each group, the results (Table 3) indicate how pre- and postoperative SST results can be used to demonstrate the effectiveness of an individual orthopaedist's surgical procedure in improving the function of shoulders with degenerative joint disease.

To the original 11 questions of the SST, we have added a twelfth: "Would your shoulder allow you to work full time at your regular job?" We have now collected a second series of 80 patients with degenerative glenohumeral joint disease; the pretreatment SST profile of this group looks remarkably like that of the first series (Table 4). These profiles will serve as the pretreatment evaluation for a forthcoming longitudinal study of treatment effectiveness in degenerative joint disease of the shoulder by an individual orthopaedist.

TABLE 1: The Simple Shoulder Test

1. Is your shoulder comfortable with your arm at rest by your side?
2. Does your shoulder allow you to sleep comfortably?
3. Can you reach the small of your back to tuck in your shirt with your hands?
4. Can you place your hand behind your head with the elbow straight out to the side?
5. Can you place a coin on a shelf at the level of your shoulder without bending your elbow?
6. Can you lift 1 pound (a full pint container) to the level of your shoulder without bending your elbow?
7. Can you lift 8 pounds (a full gallon container) to the level of your shoulder without bending your elbow?
8. Can you carry 20 pounds at your side with the affected extremity?
9. Do you think you can toss a softball underhand 10 yards with the affected shoulder?
10. Do you think you can toss a softball overhand 20 yards with the affected extremity?

TABLE 2: Percentage of the normal subjects and the patients with degenerative glenohumeral disease (DJD) who answered "yes" to the questions of the SST.

	Normal %	DJD %
Comfortable at rest?	100	70
Sleep comfortably?	100	22
Tuck in shirt?	100	30
Hand behind head?	100	22
Coin at shoulder level?	100	77
1 lb to shoulder level?	100	70
8 lbs to shoulder level?	97	19
Carry 20 lbs?	98	87
Toss underhand 10 yds?	95	4
Wash other shoulder?	100	20

TABLE 3: Change in the percentage of patients answering "yes" to 11 SST questions before and at 6 months and more than 12 months after shoulder arthroplasty for degenerative glenohumeral disease (DJD).

	Preop	6-Months Postop	12-Months Postop
Comfortable at rest?	72	100	100
Sleep comfortably?	13	100	100
Tuck in shirt?	21	67	100
Hand behind head?	18	86	100
Coin at shoulder level?	72	93	100
1 lb to shoulder level?	67	94	100
8 lbs to shoulder level?	19	54	56
Carry 20 lbs?	88	100	90
Toss underhand 10 yds?	4	48	56
Wash other shoulder?	13	72	78

In conclusion, the Simple Shoulder Test is an example of a practical patient self-assessment of functional status. Using the SST, data can be collected easily both before and sequentially after treatment. Comparing the pre- and posttreatment functional assessments for an individual surgeon demonstrates the effectiveness and appropriateness of that surgeon's treatment. The results of such a study can be communicated directly to patients and to payers of health care.

TABLE 4: Comparison of the percentages of pretreatment "yes" responses to the SST questions between two groups of patients with degenerative glenohumeral joint disease.

	DJD #1 (n = 47) %	DJD #2 (n = 80) %
Comfortable at rest?	70	70
Sleep comfortably?	21	20
Tuck in shirt?	30	40
Hand behind head?	21	42
Coin at shoulder level?	77	63
1 lb to shoulder level?	70	57
8 lbs to shoulder level?	18	23
Carry 20 lbs?	87	60
Toss underhand 10 yds?	69	59
Toss overhand 20 yds?	8	12
Wash other shoulder?	20	30
Do usual work?		45

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RESIDENT PAPERS & ABSTRACTS

Corticosteroid Treatment Reduces Venous Capacity in the Rabbit Epiphysis

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John M. Clark, M.D., Ph.D.

Winner of the New Investigators Award at the 1994 Annual Meeting of the Orthopaedic Research Society

Avascular necrosis of bone is now recognized as a serious clinical problem. In our institution, about one-third of the renal transplant recipients have evidence of femoral head necrosis on screening MRI scans. In these cases, and many of the others seen in our clinic, corticosteroid therapy is known to be the cause. Although numerous papers have been written on the subject, no one has shown how the drug causes bone death. Most recent work has focused on arterial occlusion, either by fat embolism or intimal injury, but these theories cannot plausibly explain most features of the disease.

Experimental studies have shown that corticosteroids cause three dramatic changes in bone marrow: increased fat content, diminished blood flow, and increased pressure. We proposed that the only mechanism that could explain all these changes would be impingement by enlarged fat cells on marrow veins followed by engorgement and reduced flow in these segments of the vascular tree. To test this hypothesis, we used microscopy to measure the venous capacity of bone marrow before and after treatment with corticosteroids.

Methods

The easiest and most reliable way to measure the size of structures on microscopic slides is automated analysis of digital images. To accomplish this with accuracy, it is necessary to preserve the anatomic dimensions of the various structures and also stain them distinctly so that a video system can distinguish among them by color or shade. We developed two unique methods for this purpose. We fixed and stained the fat cells using osmium ligands. This rendered them a dark brown color and prevented the lipid from washing out during processing. The blood vessels were washed out and fixed in their anatomic state of distention by perfusion under pressures that matched normal levels. Thus prepared, the venous sinuses in the marrow appear as clear spaces under the microscope. The portion of the marrow devoted to hematopoiesis (the production of blood cells) was stained light blue or green.

Rabbits were treated for two to 14 days with dexamethasone (a common form of corticosteroid) and the vessels of their hind limbs were then perfused with fixative. Slides showing sections through the center of the upper tibia and femoral head were prepared for microscopy and analyzed with an automated technique. Micrographs taken of analogous regions were converted to digital images and the cross-sectional areas occupied by fat, vessels, and hematopoietic elements were computed. We also examined the material with electron and light microscopes to obtain information about lipid deposition and vascular anatomy.

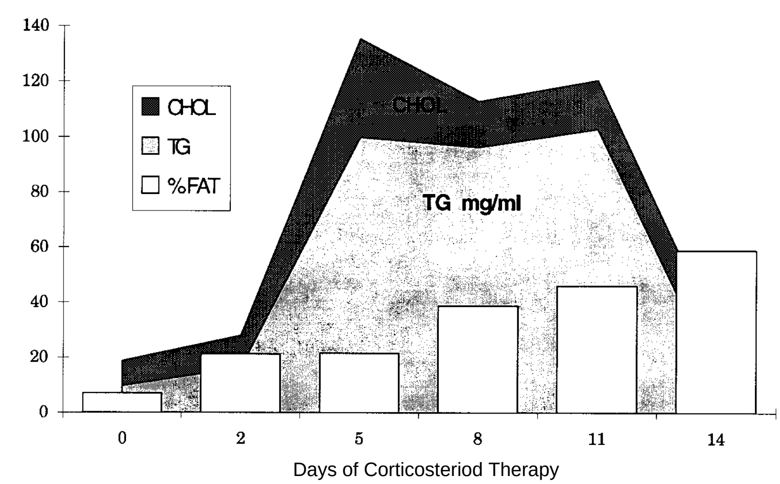

FIGURE 1: The increase in marrow fat (as a percentage of marrow space) measured in the rabbit femoral head and serum lipids.

Results

As expected, the amount of fat in the bone increased with the treatment (Figure 1). In young animals, this fat accumulation occurred exclusively in the epiphyses, the usual site of necrosis in humans. This increase in marrow fat paralleled a hyperlipidemia. In both normal and treated animals, the distribution of fat cells throughout the epiphyses was not uniform, and more fat was always present in the center, away from the articular surface (Figure 3). The effects of treatment were most dramatic in the center, where all marrow elements were displaced by fat. Even though the treatment periods were short, signs of marrow injury were apparent by EM at five days, and by light microscopy at seven. No intra-arterial fat (fat embolus) was seen in any of the specimens, but after treatment, we observed fat cells adjacent to vessels in the subchondral region, a location devoid of fat in the normal animals.

The area occupied by the marrow veins dropped by 50% with five days of treatment. In the central areas of the epiphyses, the veins were completely ablated. Our electron microscopic studies of the sinuses showed evidence of damage and rupture as early as five days. Frank hemorrhage was evident by 11 days.

Discussion

This study is the first demonstration of a vascular abnormality on the venous side of the bone marrow circulation following steroid exposure. In several ways, venous occlusion provides a better explanation for the effects of corticosteroids than does fat embolism or other proposed types of arterial obstruction. Increased resistance in the venous bed will inhibit blood flow and also raise marrow pressure, an effect that could not be caused directly by arterial occlusion. The changes occurred rapidly, which fits with our clinical impression that short bursts of steroid treatment can damage bone. The arterial lesions described by other investigators take weeks or months to develop and probably are caused by sluggish blood flow following occlusion of their venous drainage. Fat embolism, which is still a popular theory, simply was not present in our animals. Furthermore, the fat cell enlargement happened so quickly that it casts doubt on the idea that serum lipids are somehow deposited in the marrow.

These results have challenged us to review our approach to core decompression as a treatment of avascular necrosis. Drilling of the femoral head has been advocated to decrease pressure and increase blood flow. While this method makes some intuitive sense, most patients come for treatment long after their exposure to high-dose steroids. We now believe that the disease evolves over a short time, and any invasive treatment will be most effective if given during the time of the insult, rather than after the fact.

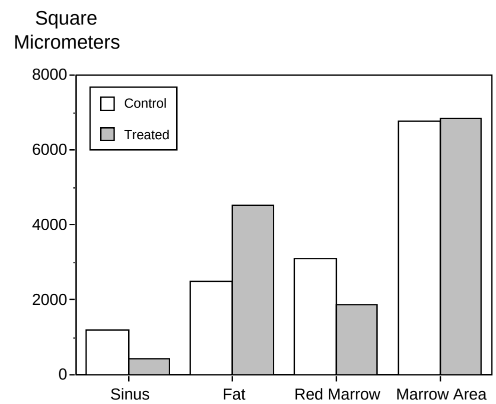

FIGURE 2: The changes in fat, venous spaces, and hematopoietic elements in marrow following five days of steroid treatment.

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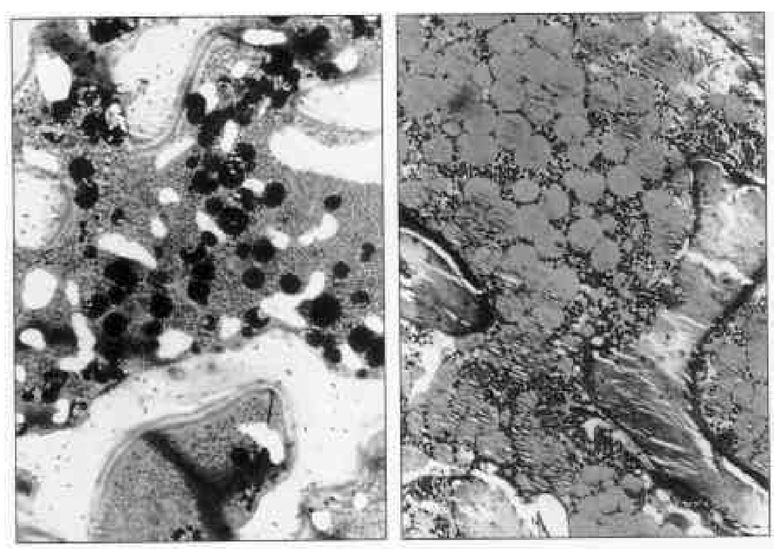

FIGURE 3: Marrow from equivalent areas treated for five days (left) compared to control (right). Note changes in fat and vascular space.

The Unstable Anterior Pelvic Ring: Comparison of Plating Techniques and Retrograde Medullary Screw Fixation

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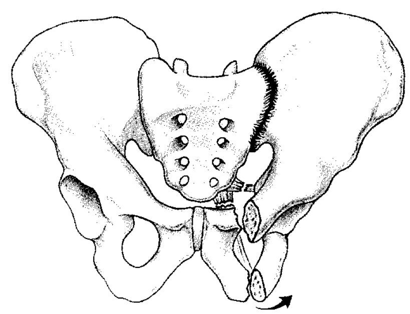

FIGURE 1A: Disrupted pelvis with the APC type II injury (unilateral pubic rami fractures, ipsilateral SI joint, sacrospinous, and sacrotuberous ligament disruptions).

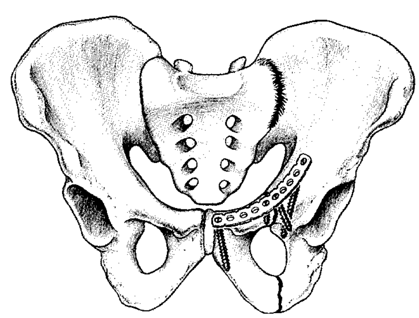

FIGURE 1B: Disrupted pelvis fixed with a contoured 10-hole 3.5-mm reconstruction plate to the superior ramus with four 3.5-mm screws.

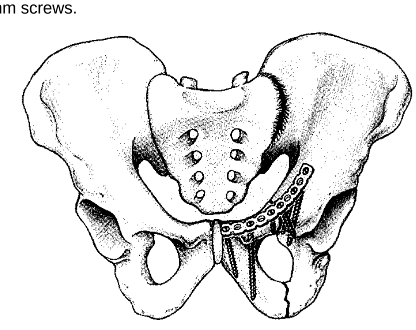

FIGURE 1C: Disrupted pelvis fixed with a contoured 10-hole 3.5-mm reconstruction plate to the superior ramus with six 3.5-mm screws.

Anterior pelvic ring disruptions can be divided into two groups, symphysis pubis dislocations and pubic rami fractures. Plate stabilization is the standard form of internal fixation advocated for both types of anterior pelvic injuries. Wide surgical exposures are necessary to manipulate, realign, and stabilize the bone fragments using a plate held with screws.

For most pubic rami fractures, the more difficult and extensive ilioinguinal exposure is recommended. This surgical approach is difficult and potentially hazardous to the adjacent soft tissue structures, including the neurovascular structures. If the pubic ramus fracture fragments could be manipulated, reduced, and stabilized percutaneously, then the large ilioinguinal incision and its potential complications could be avoided.

Our study compared the biomechanical characteristics of different pubic rami fixation techniques. Specifically, we contrasted the biomechanical properties of percutaneous retrograde medullary screw fixation of the superior pubic ramus with those of standard anterior pelvic ring plating. We attempted to identify the optimal length of a medullary ramus screw necessary to sufficiently stabilize the superior pubic ramus fracture as a part of an unstable pelvic ring fracture. We also compared different plating techniques by using different screw numbers through the plate.

Methods

Specimen Setup: We obtained six fresh-frozen, non-embalmed cadaveric pelvic specimens, along with intact lumbar vertebrae to L4 and the proximal two-thirds of the intact femora. The mean age of the donors was 79 years (range 76 to 96 years). The sacroiliac, iliolumbar, sacrotuberous, sacrospinous, arcuate, and symphyseal ligaments as well as the hip capsular tissues were preserved. Each femur was secured in an aluminum cylinder with potting compound in preparation for mechanical testing. Because the pelvis could rotate freely through the hip joints, anterior and posterior chains stabilized the pelvis by simulating muscle forces that normally maintain the pelvis upright. The fourth lumbar vertebral body was potted in a fixture to facilitate loading of the pelvis in a materials testing machine.

Loading Arrangement: Each specimen was loaded in the standing position through the lumbar spine fixture. Loads to simulate compression were applied using a ball transfer on the end of the materials testing machine actuator. Force to a magnitude of 1,000 newtons was applied through three cycles.

Experimental Sequence: The loading protocol was applied to each pelvis in the following sequence: (1) Intact (Int); (2) Injured (Inj): unilateral superior and inferior midposition pubic rami osteotomies, with ipsilateral anterior SI joint, sacrospinous, and sacrotuberous ligamentous disruptions; (3) fixed anteriorly with a 10-hole 3.5-mm reconstruction plate contoured to the superior ramus and secured with four 3.5-mm cortical screws (P4S); (4) fixed anteriorly with a 10-hole 3.5-mm reconstruction plate contoured to the superior ramus and secured with six 3.5-mm cortical screws (P6S); (5) fixed anteriorly with a 4.5-mm medullary cortical screw directed retrograde within the superior pubic ramus measuring 80 mm in length and ending medial to the hip joint (SRS); (6) fixed anteriorly with a 4.5-mm medullary cortical screw directed retrograde within the superior pubic ramus measuring 130 mm in length, passing cephalad to the joint, thereby engaging the lateral iliac cortex (LRS). (Figures 1A-1E)

Motion Measurement: Displacement during loading was measured by three liquid mercury strain gauges, 25 mm in length. One gauge was secured transversely across the anterior surface of each SI joint, while the third gauge was similarly located across the superior pubic ramus osteotomy. Each strain gauge was calibrated before application. The strain gauge output with displacement is linear from approximately 10 to 50% strain; therefore, each gauge was preloaded to approximately 10% strain when affixed across the SI joints and SP. Inclinometers were fixed to the sacrum and each ilium posteriorly to measure the relative flexion in the sagittal plane of the sacrum with respect to the ilium. Each inclinometer has a resolution of 0.001 degrees and a range of $\pm$ 60 degrees.

Statistical Analysis of Data: Data from the strain gauges, inclinometers, and material testing machine load cell were recorded on a personal computer with an analog-to-digital converter. Means and standard deviations were calculated for each condition, and differences tested at the $p < 0.05$ level using the Wilcoxon signed-rank test. Each intact specimen served as its control for each modification.

Results

Effects of Injury: A comparison of the intact and injured pelvic specimens showed that loading of the injury caused significant ($p < 0.05$) deflections at both the disrupted superior pubic ramus and the injured SI joint. Motion of the contralateral intact SI joint was not significantly different in the intact versus the disrupted specimens (Figure 2).

Effects of Fixation: All forms of internal fixation controlled displacement at the superior pubic ramus osteotomy when compared to the disrupted specimen without fixation ($p < 0.05$). The number of plate screws, whether four or six, did not significantly alter displacements at either the disrupted ramus or SI joint. Likewise, the length of the retrograde medullary ramus screw, whether medial to or beyond the acetabulum, did not significantly affect displacements at either the disrupted ramus or SI joint. Sacroiliac joint deflections and flexion angulations were not significantly controlled by any of the forms of anterior pelvic ring fixation (Figure 2).

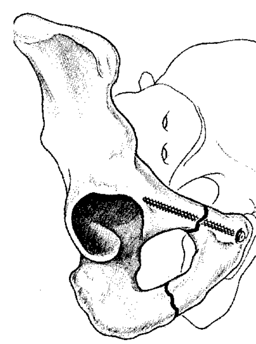

FIGURE 1D: Disrupted pelvis fixed with a 4.5 mm-retrograde ramus screw 80 mm long, short of the joint.

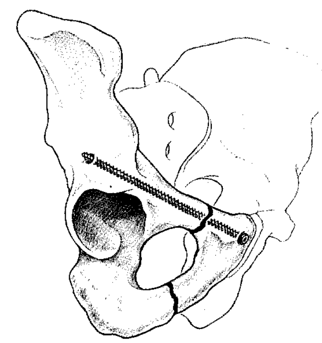

FIGURE 1E: Disrupted pelvis fixed with a 4.5-mm retrograde ramus screw 130 mm long, engaging the iliac cortex beyond the hip joint

Discussion

Possible complications of the ilioinguinal exposure for open reduction and plate fixation of fractured rami include bladder injury, spermatic cord laceration, femoral and obturator nerve neuropraxias, iliac artery thrombus formation, and deep infection. Malleable plates have been used to fix ramus fractures, but we have no information on the optimal plate length and the optimal number of anchoring screws. The literature contains no reports of percutaneous internal fixation or studies evaluating open reduction with internal fixation of pubic ramus fractures.

We found that all the forms of ramus fixation significantly stabilized the superior ramus when compared to the disrupted specimen.

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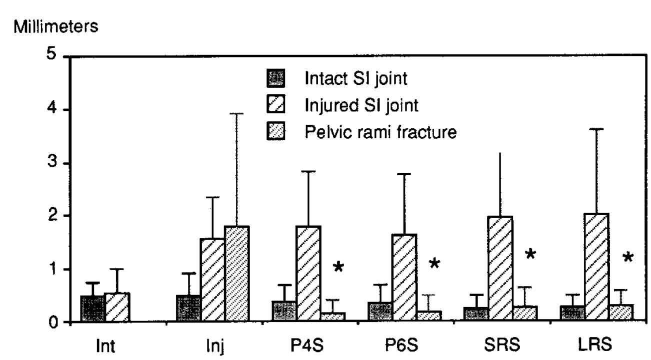

FIGURE 2: Joint displacement to compression loading of the intact and injured pelvis with different types of fixation (Int=intact; Inj=disrupted pelvis with the APC II injury; P4S-disrupted pelvis fixed with a contoured ten-hole 3.5-mm reconstruction plate to the superior ramus with four 3.5-mm screws; P6S-disrupted pelvis fixed with a contoured ten-hole 3.5-mm reconstruction plate to the superior ramus with six 3.5-mm screws; SRS-disrupted pelvis fixed with a 4.5-mm retrograde ramus screw 80 mm long, short of the joint; LRS-disrupted pelvis fixed with a 4.5-mm retrograde ramus screw 130 mm long, engaging the iliac cortex beyond the hip joint.)

Fibronectin Is a Major Component of the Extracellular Matrix of Tracheal Cartilage

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Tracheal cartilage contains significant amounts of the trimeric 148 kDa extracellular matrix glycoprotein known as cartilage matrix protein (CMP). The CMP content of the bovine tissue appears to increase with age while decreasing in extractability as assessed by polyclonal RIA. Therefore, we attempted to identify and characterize potential CMP cross-linking sites in adult bovine tracheal cartilage (BTC). Although we looked for cross-linking sites, instead we found evidence that fibronectin also is a prominent component of the extracellular matrix of adult bovine tracheal cartilage, comprising approximately 25% of the dry weight of the tissue.

Methods

We used bovine tracheae obtained from cattle of various ages at slaughter and stored frozen at -20˚C prior to analysis. The tracheal rings were carefully dissected free of soft tissues and perichondrium, finely minced on ice, ground to a fine powder under liquid nitrogen, and then extracted with 4M guanidine HCl, pH 7.5 at 4˚C for 24 hours. Cyanogen bromide (CNBr) and trypsin digestions were carried out on portions of the washed residue. Conditions for trypsin digest were 1% trypsin (w / w) in a minimum volume of 0.2M NH_4HCO_3 at 37˚C for 24 hours. Supernatant and washing were combined, lyophilized, weighed, and compared to the trypsin-insoluble, lyophilized pellet. CNBr digestion was carried out in 70% formic acid under argon at room temperature for 24 hours using a concentration of 2.5 mg CNBr per mg dry weight of tissue. We then redissolved the CNBr-digest of bovine tracheal cartilage in 0.1% trifluoroacetic acid (TFA) and noted a significant acid-insoluble component. This TFA-insoluble residue was analyzed by SDS-PAGE and then transblotted onto PVDF membranes for sequencing. We performed Edman sequence analysis of phenylthiohydantoin (PTH) N-terminal amino acids on a gas-phase protein microsequencer (Porton 2090E) equipped with on-line high-performance liquid chromatography (HPLC) analysis using the manufacturer's standard program.

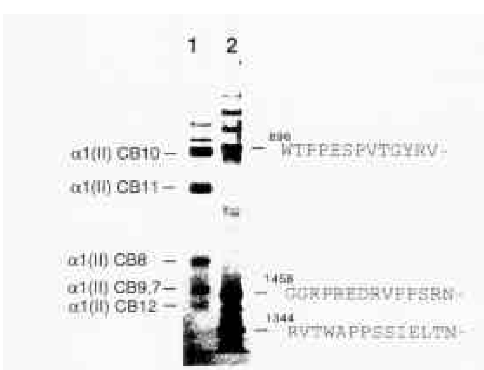

FIGURE 1: SDS-PAGE of acid-soluble (lane 1) and acid-insoluble (lane 2) fractions of CNBr-digested tracheal cartilage. Fibronectin CB-peptides dominate in the acid insoluble and collagen type II CB-peptides in the acid soluble.

Results and Discussion

The pool of acid-insoluble material from CNBr-digested BTC increased with age in the three age groups we analyzed: 4 months, 6% insoluble; 2 years, 37% insoluble; and 5 years, 57% insoluble. The trypsin-soluble pool of BTC, prepared under non-denaturing conditions, also increased with age. The yields of trypsin-released material (after 4M guanidine HCl extraction and renaturation) were 11%, 26%, and 59% of matrix dry weight, respectively, from 4-month, 2-year, and 5-year-old BTC. In contrast, articular cartilage from the 5-year animal treated similarly yielded only 12% of its dry weight as trypsin-soluble material.

The figure shows a PVDF blot of the acid-insoluble fraction of CNBr-digested 5-year BTC. All sequenced bands proved to be cyanogen bromide peptides of bovine fibronectin. Their N-terminal amino acid sequences are shown in single letter code.

Based on recovered dry weights of the various tissue fractions and on the yields of protein bands on electrophoresis estimated by their staining intensity and sequencing results, fibronectin accounted for approximately 25% of the dry weight of 5-year-old bovine tracheal cartilage. This finding is remarkable in that fibronectin rivals type II collagen on a weight basis and may become the most prominent protein in the tissue. Certainly, in combination, fibronectin and CMP eventually exceed the content of collagen by weight. These data agree with previous biosynthetic studies demonstrating that tracheal cartilage explants retain a much greater portion of newly synthesized fibronectin within the matrix, compared with articular cartilage explants.

It would appear, therefore, that fibronectin takes on a major structural role in respiratory tract cartilage, in contrast with the hyaline cartilages of articular surfaces, which in general contain only small amounts of fibronectin. It will be important to characterize further the fibronectin deposited in tracheal cartilage in terms of the particular splicing variant expressed from the fibronectin gene.

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Structural Studies on Human Type IX Collagen

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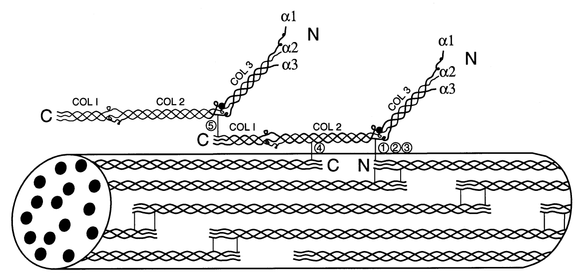

FIGURE: The sites of covalent interactions of human type IX collagen and type II collagen and between type XI collagen and molecules.

Cartilage contains primarily types II, IX, X, and XI collagens. The type IX collagen molecule is a heterotrimer consisting of genetically distinct α1, α2 and α3 chains that are disulfide bonded. Each chain consists of four noncollagenous (NC) and three collagenous (COL) domains. Both a proteoglycan form and a non-proteoglycan form of the molecule have been identified in bovine cartilage. Type IX collagen is covalently cross-linked to type II collagen in chick and bovine tissues. Type IX collagen molecules also form covalent cross-links with other type IX collagen molecules in bovine cartilage.

Our studies show that in human cartilage, type IX collagen is covalently cross-linked to type II collagen as well as to other molecules of type IX collagen, a pattern paralleling that observed in bovine tissue. We also present evidence that, if the proteoglycan form of type IX collagen is present in human cartilage, it is a minor component.

Methods

We used pepsin to extract collagens from human fetal articular cartilage. Reducible cross-linking residues were labeled with tritiated sodium borohydride ([^{3}H]$NaBH_4$). COL1(IX) and COL2(IX) trimers were resolved by molecular sieve chromatography. Individual α1(IX) and α3(IX) COL2 domains were resolved from α2(IX) COL2 by reversed-phase, high-performance liquid chromatography (rp-HPLC). In a reaction with sodium periodate ($NaIO_4$), purified tritium-labeled COL2 domains released cross-linked telopeptides, which were then resolved from the COL2 domains by rp-HPLC.

Borohydride-reducible cross-links and periodate-released telopeptides containing tritium label were detected by liquid scintillation spectrometry. Fractions exhibiting tritium activity were subjected to amino-terminal protein sequencing on a gas-phase protein microsequencer. Pyridinoline cross-links were detected by monitoring fluorescence. Samples were obtained directly from HPLC and from protein transfer and sequencing membrane (PVDF membrane) following transblotting of proteins separated by sodium dodecyl sulfate-polyacrylamide gel electrophoresis (SDS-PAGE). Western blot analysis using a rabbit polyclonal antiserum against bovine type IX collagen was performed on transblotted intact type IX collagen chains extracted from human fetal cartilage in 1M sodium chloride or in 4M guanidine-hydrochloride. Chondroitin sulfate glycosaminoglycan side chains were cleaved from type IX collagen molecules using the enzyme chondroitin sulfate types A, B, and C lyase.

Results and Discussion

Individual COL2(IX) domains were resolved into two peaks by rp-HPLC. SDS-PAGE showed that the early peak consisted of a 33kDa protein fragment representing α2(IX) COL2, and that the late peak consisted of a 33kDa α1(IX) COL2 protein fragment and a 41kDa α3(IX) COL2 fragment. Both showed fluorescence and tritium activity, indicating that they contained reducible divalent and pyridinoline cross-linking residues.

Column fractions containing the α2(IX) COL2, α1(IX) COL2, and α3(IX) COL2 domains were pooled separately and the component proteins were further resolved by SDS-PAGE. Following electroblotting onto PVDF membrane, direct amino-terminal sequencing of each protein band was performed. The results, together with the data obtained from direct sequencing of periodate-released telopeptides, demonstrated that: (1) the α1(IX) COL2 helical region contained a cross-linking site for either the α1(II) N-telopeptide or α3(IX) NC1, (2) the α2(IX) COL2 helical region is cross-linked solely to α1(II) N-telopeptide, and (3) the α3(IX) COL2 helical region, in addition to forming cross-links with α1(II) N-telopeptide or α3(IX) NC1, has a distinct site of covalent linkage to α1(II) C-telopeptide. The figure schematically illustrates the sites of covalent interaction of human type IX collagen with type II collagen and between type IX collagen molecules.

Western blot analysis of intact type IX collagen chains showed that, whereas treatment with chondroitinase ABC caused a slightly retarded migration and increased staining intensity of α2(IX) extracted with 1M sodium chloride, there was no significant effect of chondroitinase on type IX collagen chains in the 4M guanidine-hydrochloride extract. Our results suggest that the proteoglycan form is a minor component of the bovine and human cartilage extracellular matrix.

(continued on page 45)

Stabilizing Properties of the Halo Vest

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The ability of the halo apparatus to stabilize the injured cervical spine is a subject of controversy. Since 1959 the device has been used extensively to treat these difficult injuries. Various studies have reported on cases of failure of immobilization, concerns about the motion-limiting potential of the apparatus, optimum design of the halo ring and pin structure, and influence of vest length on stability.

We developed the hypothesis that motion of the injured spine immobilized with a halo apparatus may be influenced by the fit and interface friction of the vest on the torso, rigidity of the material composing the vest, and the arrangement and stiffness of the vest halo-ring connecting bars. Our study objectives were to: (1) develop a laboratory model capable of reproducing the properties of the system under study, (2) assess the relative influence of each of the components of the apparatus to the motion of the injury site, and (3) evaluate the relative effectiveness and stability offered by commercially available halo devices.

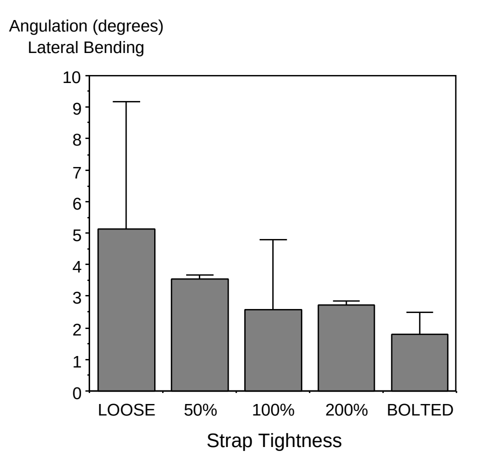

FIGURE 1: Spine angulation decreases in flexion and bending with increasing strap tightness.

Methods

Fresh human cervical spine specimens from C1 to T1 were stripped of soft tissues and potted at C2 and T1. The specimens were placed in anatomic location in a fiberglass torso and a rigid plastic skull was attached to C2. A posterior ligamentous lesion was created between C5 and C6 until bilateral facet dislocation occurred. A certified orthotist applied a halo ring to the skull and fitted vests on the model. Inclinometers were placed on the C5 and C6 vertebral body, the vest, and the torso. A 150-N load in flexion, extension, and bending was applied by a cable attached to the skull at the vertex. After each load we recorded the relative change in sagittal and coronal plane angulation between C5 and C6 and between the vest and the torso.

Part 1: Study of the Halo Components. We investigated halo parameters of vest strap tightness, vest-thorax interface friction, vest deformation, and upright rigidity. Three runs on two specimens were conducted for each parameter. Buckle transducers attached to the straps measured vest strap tightness. These gauges were calibrated to a reference tension set by a certified orthotist as normal vest tightness on a patient in a clinical setting. This setting was designated as 100% normal vest strap tightness. Measurements were made at 0%, 50%, 100%, and 200% of this force.

We investigated vest thorax interface friction by varying the interface material between the vest and the torso. Sheepskin on leather (coefficient of friction $u = 0.305$) approximated the in vivo sheepskin on human skin interface ($u = 0.342$). We compared this interface to sheepskin on plastic ($u = 0.169$) and sheepskin on suede ($u = 0.572$). Vest deformation was evaluated by sequentially bolting the vest to the thorax. We studied upright rigidity by sequentially tightening bar connections to 2 in-lbs, 25 in-lbs, and 100 in-lbs torque, and then adding additional crossbars for a rigid superstructure.

Part 2: Study of Commercially Available Halo Vests. We compared nine commercially available halo vests (ACE I, ACE 2, Bremer Airflow, Bremer Classic, Friddle, IQM, JMS, Lerman, and PMT). Three runs were conducted on each of four specimens.

Results

To distinguish significant differences between mean values in each experiment we used a one-way analysis of variance (ANOVA), with significance established at the 95% confidence level.

Part 1: Study of the Halo Components. The figures present results for laterial bending, which is representative of all the data. Increasing chest strap tightness decreased spinal angulation significantly (Figure 1). Increasing the friction of the vest thorax interface material did not produce significant differences in the C5-C6 motion for the three interfaces tested. Eliminating vest slip decreased spinal motion, but eliminating deformation of the vest itself showed no differences (Figure 2). Stiffening the upright structure beyond 25 in-lbs torque on the connections had no benefit in decreasing spinal motion.

Part 2: Study of Commercially Available Halo Vests. Bremer Airflow and JMS vests allowed greater

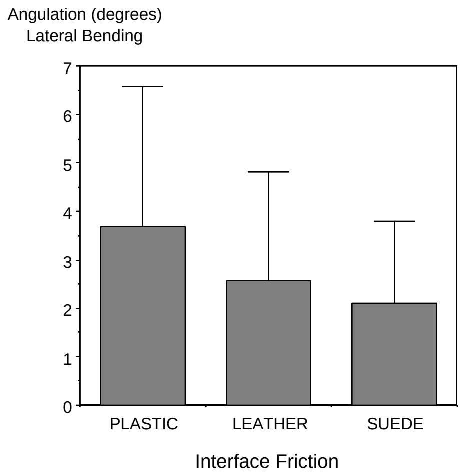

FIGURE 2: Varying the interface friction made no significant difference in spine angulation.

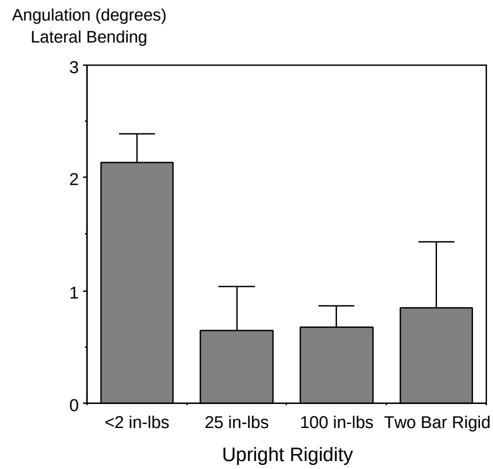

FIGURE 3: Increasing upright rigidity did not decrease spinal motion.

spinal angulation in lateral bending than did other devices (Figure 3). In flexion, Bremer Airflow and IQM allowed greater motion; in extension, ACE 2 and JMS vests allowed more motion.

Conclusions

Vest strap tightness and vest slip affect the stability of the injured spine immobilized in the halo apparatus. Altering the vest torso interface and further stiffening the connecting bar superstructure have little effect. Most commercially available halo vests are similar in providing stability to the injured cervical spine.

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Humeroscapular Balance: The Limits of Angular Stability Provided by Glenoid Geometry

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Both active and passive mechanisms contribute to glenohumeral stability including muscular forces, capsular and ligamentous forces, joint vacuum, limited joint volume, adhesion and cohesion properties, and concavity compression. Many studies address the stability at the extremes of motion where the glenohumeral ligaments and capsule become effective. Relatively little investigation has addressed glenohumeral stability in the midrange of motion associated with most functions of daily living. In the midrange of motion, the ligaments and capsule are relatively lax to afford the glenohumeral joint great mobility.

TABLE 1: Geometric Measurements for Eight Specimens

	Mean (SD)	Range
Radius of curvature (mm)		
humeral head	25 (2)	22-28
glenoid	25 (3)	22-28
AP glenoid width (mm)		
labrum-intact	27 (2)	24-30
labrum-excised	23 (2)	21-26
anterior rim defect	20 (2)	18-22
SI glenoid width (mm)		
labrum-intact	35 (2)	32-38
labrum-excised	30 (1)	28-32
Glenoid version (degrees)		
anteroposterior*	-7 (4)	-16 to -2
superoinferior†	-1 (7)	-8 to 12

*negative sign corresponds to retroversion
†negative sign corresponds to inferoversion

This investigation explored the mechanism of humeroscapular balance and related the positions of balance stability to clinically determinable landmarks. A final goal was to examine the effect of labral and glenoid rim defects on the ability of the glenoid to balance the resultant glenohumeral joint reaction force.

Methods

Eight fresh-frozen cadaver shoulders were used for this study. Specimens were thawed in a cold water bath and all soft tissues were removed except the glenoid labrum. We defined palpable scapular reference points and measured the radii of curvature of the humeral head and glenoid, the AP width and SI width, and the glenoid AP version and SI version.

The glenoid center line was defined as the line perpendicular to the surface of the glenoid fossa at its midpoint. The scapula was mounted in a container such that the glenoid center line was oriented vertically upward. The humerus was prepared by placing an intramedullary rod coaxially within the shaft. An apparatus was designed that allowed the humeral head to be loaded with a vertically oriented, axial force of 10 N onto the vertically facing glenoid. The 10 N force and vertical loading direction represented the resultant glenohumeral joint reaction force. The container with the mounted glenoid was oriented so that the glenoid could be rotated in a defined direction about the center of the humeral head. The glenoid was rotated slowly, increasing the angle between the glenoid center line and the vertical joint reaction force until the humerus dislocated from the glenoid. The *balance stability angle* was defined as the maximal angle between the resultant glenohumeral joint reaction force and the glenoid center line before dislocation occurred. The specimens were tested sequentially in the anterior, posterior, superior, and inferior directions. The process was repeated after the glenoid labrum was excised, and again after a 3-mm bony defect was created in the anterior glenoid rim. Each test was performed three times.

The AP balance angle of stability was calculated by summing the anterior and posterior angles of stability, and the SI angle was calculated by summing the superior and inferior angles of stability. The balance angles from the eight specimens were averaged and standard deviations were calculated. A two-tailed, paired student's t-test was used to determine the significance of orientation, of labral excision, and of an anterior bony defect on angular stability.

Results

Table I displays the averages of the geometric measurements. Table II shows the average balance angles of stability for the eight specimens. Labral excision resulted in a significant decrease in the angles of stability in both the AP and SI directions ($p < 0.01$). Before and after labral excision, the balance angle of stability in the SI direction was significantly greater than in the AP direction ($p < 0.01$). A 3-mm anterior bony defect caused a significant decrease in the balance angle of stability in the anterior direction ($p < 0.01$).

TABLE 2: Balance Angles of Stability for Eight Specimens

	Stability Angles (degrees) Mean (SD)					
	Ant	Post	AP	Sup	Inf	SI
Labrum intact	19 (2)	18 (3)	37 (3)	26 (3)	31 (6)	58 (5)
Labrum excised	17 (3)	16 (2)	33 (3)	25 (3)	25 (4)	50 (5)
Anterior rim defect	12 (2)					

Discussion

These data demonstrate that the glenohumeral articulation (even without the capsule and ligaments) is intrinsically stable throughout a substantial range of positions in which the resultant glenohumeral joint reaction force is balanced within the glenoid fossa. In the midrange of shoulder motion, the glenohumeral capsule and ligaments are lax and cannot exert major stabilizing effects. Humeroscapular balance provided substantial stability in these experiments.

The significance of the labral contribution to shoulder stability is controversial. In this study, labral excision significantly decreased the balance angles of stability in the AP and SI directions ($p < 0.01$). A Bankart defect is commonly associated with anterior instability. This study demonstrated that a 3-mm anterior bony defect analogous to a Bankart lesion significantly decreased the balance angle of stability in the anterior direction. The angle of stability decreased by an average of 36° ± 11% when compared to the specimens with the labrum intact.

Humeroscapular balance occurs as long as the resultant glenohumeral joint reaction force passes within the glenoid fossa. Our study provides data on the range of angles of the resultant glenohumeral joint reaction force that can be stabilized by this mechanism. The stability is independent of the magnitude of the resultant glenohumeral joint reaction force. However, balance stability is dependent upon the direction of the force. The larger the arc subtended by the glenoid concavity, the larger the range of directions of the resultant glenohumeral joint reaction force that will be stabilized by it. Conversely, instability will result when the resultant glenohumeral force is not balanced within the glenoid. Balance may be optimized by (1) coordinating the muscular activity around the glenohumeral joint so that the resultant glenohumeral joint reaction force is directed within the glenoid fossa, or (2) modifying the humeroscapular relationship so that the glenoid is positioned to capture the existing resultant glenohumeral joint reaction force.

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Unstable Anterior Pelvic Ring (from page 37)

These results indicate that a retrograde screw placed percutaneously after closed reduction of the superior pubic ramus fracture provides ante-rior pelvic stability comparable to that of a reconstruction plate secured along the superior pubic ramus after open reduction through an ilioin-guinal approach. Violation of the hip joint by the retrograde screw is a concern; yet, we found that the shorter screw placed medial to the hip joint provided stability comparable to the longer retrograde screw, which extends beyond the hip joint.

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Kinetic Analysis of an Instrumented Medial Hinge Knee Brace for Medial Compartment Gonarthrosis

Eric J. Bowton, M.D.

Painful medial knee compartment gonarthrosis is a common condition in young and middle-aged adults that usually is associated with early idiopathic osteoarthritis or posttraumatic arthritis, especially after previous medial meniscectomy. Conservative measures may not relieve symptoms, and surgical options may not be indicated because of relatively young age or absence of severe symptoms. Knee bracing may be an option in this situation. Braces reduce medial knee pain, possibly by reducing medial compartment forces, but the mechanism is unknown.

One possible mechanism is valgus knee bracing, whereby the brace prevents varus deformity during weight bearing. The mechanical axis of the knee and the center of joint load is shifted from the medial knee compartment toward the lateral compartment. The literature contains a few reports describing the clinical results of valgus knee bracing for medial compartment gonarthrosis, but no reports using gait analysis.

To determine the mechanism of brace action, we used gait analysis to evaluate a medial hinge knee brace prescribed for medial compartment gonarthrosis. We analyzed data on varus knee angle, ground shear, and knee adduction moment to determine if the brace changed knee alignment or changed the forces acting on the knee, specifically, knee adduction moment. Our study used a case/control design (the case was the braced knee, and the control was the unbraced knee). We performed clinical evaluation and three-dimensional gait analysis using five video cameras (60 Hz) and two force plates (1000 Hz). A kinematic analysis evaluated motion, specifically the varus/valgus angle in the coronal plane; and the kinetic analysis evaluated forces, specifically the adduction moment.

Data collection included varus/valgus angulation and ground shear at dynamic mid-stance. *Total adduction moment* was calculated from the knee alignment and ground shear. Data was analyzed using the student's paired t-test, comparing the patient's knees braced and unbraced. The null hypothesis for the "valgus knee bracing" mechanism was that the medial hinge knee brace does not affect the varus angle, ground shear, or adduction moment of the braced knee, compared to the unbraced knee, during the weight-bearing phase of gait.

The initial study involved eight adult patients with painful medial compartment gonarthrosis. The varus knee angle was reduced in seven of eight patients by a small but significant amount, averaging 1.2 degrees ($p = 0.03$ with paired single-tailed t-test). The ground shear force was reduced in four patients and increased in four; the total adduction moment was rejected for the effect of the brace on varus alignment, and accepted for the effect on ground shear and adduction moment.

Clinically, all eight patients had relief of knee pain using the brace. Pain relief could be due to reduction of varus knee angle, reduction of adduction moment, enhanced proprioception, or placebo effect.

Initially, our results were somewhat confusing because the adductor moment is calculated from measurements of knee angle and ground shear data. We were surprised that ground shear and adduction moment with the brace for half the patients actually increased. We hypothesized that a component of the total adduction moment was absorbed by the medial hinge and bypassed the knee joint. This could provide for less knee compartment adductor moment, despite overall increased total adductor moment. (Total adductor moment equals knee compartment adductor moment plus adductor moment absorbed by hinge).

Thus, the medial hinge knee brace may reduce medial knee compartment joint forces by reducing knee varus or by absorbing knee adduction moment through the medial hinge, or a combination of both mechanisms. We plan to use an instrumented knee brace to evaluate whether or not the brace functions as a medial knee strut. The results of our study will have implications for brace design.

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Follow-up of the Inferior Capsular Shift Procedure for Atraumatic Multidirectional Instability

William T. Obremskey, M.D., M.P.H.

Multidirectional instability (MDI) has long been a difficult orthopaedic diagnostic and treatment problem. We previously identified a subset of patients with the AMBRII syndrome, an acronym derived from the first letter of words describing symptoms and treatment. These patients have an atraumatic onset, multidirectional instability, and bilateral glenohumeral laxity; rehabilitation is the treatment of choice and, if this fails, an inferior capsular shift is performed with closure of the rotator interval through an anterior axillary exposure.

We intended to select a group of patients with AMBRII syndrome who had not had previous surgery and had no history, radiographic, or surgical evidence of a traumatic event. We retrospectively reviewed 28 such patients treated from 1986 to 1991 by surgical stabilization because of persistent symptoms despite an average 17 months of rehabilitation.

Twenty-six patients were contacted at an average of 27 months postoperatively. They completed a questionnaire on function, pain, instability, motion, and strength. Seventy-four percent of patients contacted were satisfied with the function of their shoulder. Forty-six percent were able to return to recreational activities and 69% returned to work at their previous jobs. Surprisingly, 39% had occasional pain in their shoulder and 68% had occasional symptoms of instability. Ten percent of shoulders required further surgical stabilization.

Statistical analysis was used to determine prediction of the outcome of the ICS procedure. Regression analysis showed that return of shoulder range of motion to preoperative status was the best and most consistent predictor of patient satisfaction and good shoulder function on the Simple Shoulder Test ($p < .01$).

This study has emphasized several points: (1) Multidirectional instability, as any problem, needs to be strictly defined to be accurately assessed and evaluated. (2) Rehabilitation is the primary and only treatment for the majority of patients with atraumatic MDI or AMBRII syndrome. (3) An inferior capsular shift, if not overtightened, can improve the function of a shoulder with AMBRII, but patients still occasionally have complaints of pain and stability. (4) Factors other than capsular laxity, such as muscular strength, coordination, and glenoid shape, may be as important in AMBRII syndrome.

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Type IX Collagen

(from page 39)

These properties of human type IX collagen imply a function in modifying the surface of type II collagen fibrils and in providing a means of indirect covalent interaction between fibrils. This heteropolymeric structure and the previous observation that type IX collagen is cleaved by stromelysin point to novel molecular mechanisms of collagen network stabilization and remodeling in cartilage matrix.

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April 1993 Through May 18, 1994

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 carry out without this extra support from our alumni, faculty, and friends in the community. We owe a special thanks to the University of Washington Rresident Alumni who have made significant contributions to help further the education of our current residents.

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