The Cleveland Clinic Department of Orthopaedic Surgery in the 21st Century

Joseph P. Iannotti, M.D., Ph.D.
Chairman, Department of Orthopaedic Surgery

The Department of Orthopaedic Surgery at The Cleveland Clinic is proud to be recognized as a national leader in musculoskeletal care, ranking fifth in the nation in the annual survey of health care conducted by U.S. News & World Report. We accept the responsibility this leadership position carries to advance the specialty through research and education. Over the last year, important changes have been made in the department to enhance our effectiveness in both areas. These changes, and all that we do, support our ultimate goal: to improve the care of patients with musculoskeletal disorders.

Our growing clinical staff now numbers 50 full-time physicians and surgeons, representing nine general and subspecialty areas of orthopaedics. They manage more than 200,000 outpatient clinic visits and perform more than 9,000 surgical procedures annually at The Cleveland Clinic main campus and at nine regional practices. Our patients, whether physician- or self-referred, hail from throughout North America and the world.

New Center of Orthopaedic Research
A major initiative of the Department of Orthopaedic Surgery is the establishment of a Center of Orthopaedic Research, the cornerstone of our restructured and expanded investigative arm. With two major components — musculoskeletal research and clinical outcomes — the center promotes collaboration between clinicians and basic scientists in areas of common interest. Of special interest are bridge programs designed to bring bench research to the bedside. Teams of investigators include surgeons, molecular biologists, bioengineers and biostatisticians.

Musculoskeletal research
Musculoskeletal research includes 27 principle investigators. Together they have been awarded annual funding of $4.35 million for basic science research and $682,000 for clinical research from federal, private, institutional and industrial sources.

Moving to a Six-Year Curriculum: Training the Physician Scientist for a New Orthopaedic Era

Thomas E. Kuivila, M.D.

“Orthopaedic surgeons must not only be skilled at what they do, but understand when to do it and why it works,” Alan H. Wilde, M.D., former chairman of the Cleveland Clinic Department of Orthopaedic Surgery, once said to me. He continued, with an expression of contempt on his face, “Otherwise they aren’t orthopaedists, they are just bonesetters.”

While the real bonesetters of history went the way of barber surgeons, Dr. Wilde’s comments increasingly ring true. As we focus on implants, high-tech equipment and technique, we run the risk of becoming mere technicians who miss or lose the medical science behind repair, regeneration and reconstruction. Many already lament that this is occurring today with greater and greater frequency as the gap widens between the bench researcher and clinician. A comparison of the programs of the 1980 and the 2001 Orthopaedic Research Society annual meetings demonstrates an appalling lack of participation by clinicians.

How to avoid becoming “bonesetters”
We share the opinion of many clinicians, scientists and educators that the solution begins with training more physician scientists. These are not lab...
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scientists who happen to be physicians, but clinical orthopaedic surgeons who know the way to and around a lab. These are physicians with skills in grant writing, research design and protocols, and statistical analysis. They understand and appreciate the applicability of hot bench work (tissue engineering, growth factor biology and cartilage repair, to name a few) to the clinical realm.

It would be impossible, however, to add lab time to a five-year residency program without diluting clinical aspects. The solution, of course, is to add time to the training program. This is the rationale behind the new, six-year training program in orthopaedic surgery at The Cleveland Clinic. In instituting our six-year program, we join the Universities of Pennsylvania, Iowa and Pittsburgh, as well as John Hopkins University and others, and we are happy to report that we continue to attract bright and motivated medical students.

The new six-year curriculum

The four residents who began their formal postgraduate orthopaedic education at The Cleveland Clinic in July 2001 will be the first group to complete the new curriculum. Each resident will spend a dedicated research year in the lab working with Cleveland Clinic musculoskeletal scientists acquiring the skills to make them genuine physician scientists. Trainees will do their laboratory stint mid-residency, after obtaining a solid grounding in clinical orthopaedics and with two full years of clinical time remaining.

A relatively intense series of seminars, lectures and discussions covering biomechanics, biomaterials and orthopaedic biology is planned to complement day-to-day research experience. The curriculum will be updated constantly and each resident will be exposed to each topic at least twice during the residency years.

Response is enthusiastic

The response by the more than 450 medical students applying to The Cleveland Clinic Orthopaedic Surgery Residency Program this year was overwhelmingly enthusiastic.

The staff of the Department of Orthopaedic Surgery is excited about entering this new era of resident education and looks forward to the contributions our upcoming physician scientists will make to our specialty. While other U.S. residency programs also will make the transition to a six-year program over the next decade, few can match the depth of clinical material, research personnel and research facilities The Cleveland Clinic offers. We are proud of past residents’ accomplishments and anticipate our new curriculum will take us to the next rung of the ladder leaving the bonesetters of the past where they should be — in ancient history.

Musculoskeletal Disease Researchers Uncover Molecular Mechanisms of Extracellular Matrix Destruction

Suneel S. Apte, M.D., Ph.D.

The completion of the Human Genome Project is a landmark development for musculoskeletal disease research. Exciting new information from the project facilitates the goal of understanding arthritis and other musculoskeletal diseases at the most fundamental molecular level. For several years, the Department of Biomedical Engineering at the Cleveland Clinic’s Lerner Research Institute has been supplying the genome databases with gene sequence, protein and genetic information that is relevant to musculoskeletal disease, especially arthritis.

In turn, the department has used gene discovery information from the Human Genome Project to help us identify enzymes that may have the ability to destroy cartilage and extracellular matrix (ECM), as well as molecules that protect cartilage against the action of these enzymes.

Both the enzymes and protective molecules are being manufactured in our laboratory by recombinant DNA technology using cultured cells as protein factories. Once obtained in a pure form, these molecules can be used to conduct biochemical studies, develop diagnostic tests and antibodies, or engineer new cartilage.

Important studies under way now in our laboratory are designed to determine the structure of some of these molecules and identify their interactions with each other by manipulation of genes or proteins. The fundamental questions being asked about the molecules are: What do they look like? Where are they located? What controls their production? What are all the possible interactions and functions in which they participate? What roles do they have outside of cartilage?

Our group also uses genetic methods, such as introduction of mutations into proteases, to determine their function. Analysis of transgenic mice deficient in the enzymes provides information about their roles during skeletal development and can shed light on inherited skeletal disorders and orthopaedic disorders in children.

The evolution of medical advances from basic research such as this often takes many years. The biology and biochemistry of cartilage and arthritis are extremely complex and require in-depth studies of individual molecules. On the other hand, the impact of such fundamental work can be enormous. With the greater understanding of disease processes and the power of technology comes the potential to alter current thinking and develop innovative strategies to improve management of musculoskeletal disease. Someday, genes which protect cartilage from destruction could be harnessed for gene therapy to prevent the progression of the disease.

The role of extracellular matrix

All organs in the body are made of cells surrounded by ECM, the supporting and mechanical framework of tissues and organs. In cartilage and bone, which mainly function as mechanical support, ECM is extremely important; has a special structure and is much more abundant than in non-mechanical organ tissues. Abnormalities in many of the numerous molecules which comprise ECM can lead to connective tissue disorders such as osteoarthritis, brittle bone diseases such as osteogenesis imperfecta or osteoporosis, idiopathic scoliosis, frozen shoulder and tennis elbow – diseases for which the precise cause has not been identified. Abnormalities may arise from inherited or congenital defects, or ECM molecules may be affected by inflammatory and autoimmune diseases.

Molecular research into ECM structure and function and its destruction, therefore, has occupied a front-line position in connective tissue biology and orthopaedic research. Our group focuses on the proteolytic processes by which ECM molecules are broken down. Excessive activity of protease enzymes is recognized as the key mechanism by which cartilage is lost from arthritic joints. The key to understanding how cartilage is broken down is to identify which proteases are responsible, how they are normally controlled and what goes wrong in arthritis.

The laboratory is funded currently by the National Institutes of Health, the National Arthritis Foundation and the Northeast Ohio Chapter of the Arthritis Foundation.
Kyphoplasty, a New Treatment for Osteoporotic Vertebral Compression Fractures
Isador Lieberman, M.D.

Kyphoplasty is an innovative technique that combines vertebroplasty with balloon catheter technology developed for angioplasty. The procedure shows great promise in the treatment of painful, progressive osteoporotic or osteolytic vertebral compression fractures. Cleveland Clinic orthopaedic surgeons have been instrumental in its development and clinical evaluation.

Kyphoplasty involves extra- or transpedicular cannulation of the vertebral body under fluoroscopic guidance, followed by insertion of an inflatable bone tamp (figure 1). Once inflated, the tamp restores the vertebral body toward its original height, while creating a cavity to be filled with bone cement. Cement is injected under relatively low pressure (see series of drawings on right).

Vertebroplasty, from which the kyphoplasty technique evolved, was developed in response to limited results of medical and surgical modalities to stabilize and strengthen collapsed vertebral bodies. Interventional neuroradiologists, first in France and then in the United States, began transpedicular percutaneous bone cement injections in 1986. Vertebroplasty offers significant benefits: reduced or eliminated fracture pain, prevention of further collapse, a rapid return to mobility and prevention of bone loss caused by bed rest. However, it does not address spinal deformity. It also requires high-pressure cement injection using low-viscosity cement, which leads to cement leaks in 30–40% of procedures, according to recent studies.

Kyphoplasty has several potential advantages over vertebroplasty. It restores vertebral body height with a low risk of cement extravasation. Kyphoplasty is well tolerated and is associated with statistically significant improvements in pain and function.

In an initial Phase I Cleveland Clinic Institutional Review Board-approved study, published in Spine, (Lieberman et al, Spine Vol 26 No 14 July 2001), 70 consecutive kyphoplasty procedures were performed in 30 patients over 38 sessions. Of these patients, 24 had painful primary (n=19) or secondary (n=5) osteoporotic vertebral compression fractures unresponsive to nonoperative modalities. Six patients presented with painful compression fractures due to multiple myeloma. The average duration of symptoms was 5.8 months (range 0.5–24). Symptomatic levels were identified by correlating the clinical data with magnetic resonance imaging findings of marrow signal changes consistent with compression fractures. The levels treated ranged from T6 to L5, with the majority at the thoracolumbar junction.

Outcome data were obtained by comparing preoperative and latest postoperative SF-36 data. All 30 patients tolerated the procedure well and improvement in pain and mobility was seen early. Virtually all patients subjectively reported immediate relief of their typical fracture pain, and no patient complained of worse pain at the treated levels. Radiological height measurement of all 70 levels treated (regardless of fracture age) demonstrated that in 70% of the vertebral bodies, kyphoplasty restored on average 47% of the lost height. Cement extravasation into the perivertebral veins was noted in only six vertebral bodies (8%) in the early cases, and they were all clinically insignificant. SF-36 scores for bodily pain, physical function, role physical, vitality and mental health all showed statistically significant improvement either reaching or approaching the age-matched SF-36 historical controls. At final follow-up, no major complications related directly to use of this technique or the inflatable bone tamp were reported.

Since August 1998, orthopaedic surgeons here have treated more than 100 patients and 250 vertebral bodies. Results of the initial series have been maintained in the most recent follow-up of over 70 consecutive patients out to 14 months. It appears, like hip fracture surgery, that kyphoplasty will be most successful with early intervention.

Vertebral Body Compression Fractures Adversely Impact Overall Health

An estimated 700,000 pathological vertebral body compression fractures occur in the United States each year. Of these, more than one-third become chronically painful. The majority of these fractures (about 85%) are the result of primary osteoporosis; the remainder are due to secondary osteoporosis or osteolytic spinal metastases. These compression fractures lead to progressive deformity and changes in spinal biomechanics and are believed to contribute to increased risk of further fracture.

Whether the fracture is painful or not, the spinal deformity caused by two or more fractures dramatically impacts health, daily living and medical costs through loss of lung capacity, reduced mobility, chronic pain, loss of appetite and/or clinical depression. With each osteoporotic vertebral compression fracture, a 9% loss in predicted forced vital capacity and a 15% age-adjusted increase in mortality can be expected.

Traditionally, vertebral body compression fractures were treated medically and rarely with surgical modalities. Unfortunately, the medical management of painful fractures (bed rest, hospitalization, narcotic analgesics and bracing) does nothing to restore spinal alignment and compounds problems associated with osteoporosis. Due to the poor quality of osteoporotic bone and the inherent risks and invasive nature of surgical treatment of vertebral body compression fractures, the procedure has been limited to cases in which there is concurrent spinal instability or neurologic deficit.
The meniscus is a critical component in the optimum biomechanical functioning of the knee joint. The menisci contribute significantly to load bearing, shock absorption and stability of the knee joint, and may also play important roles in lubrication and proprioception. The meniscus did not always enjoy such a reputation, however. At one time, the meniscus was not even classified as a tissue, but rather a functionless remnant of the leg musculature. However, a classic study by Fairbank, later confirmed by many others, demonstrated that removal of the meniscus leads to degenerative changes in the articular cartilage of the joint.

A substantive body of literature now supports the contention that the menisci protect the articular cartilage from osteoarthritic changes. The importance of the meniscus in protecting cartilage was illustrated in a recent retrospective study of 1,740 knee joints by Lewandrowski and colleagues. The study revealed that the presence of tears and degeneration of the meniscus correlated with the degree of damage to the articular cartilage. Acute anterior cruciate ligament (ACL) ruptures frequently are associated with simultaneous or secondary meniscal tears, and the incidence of meniscal lesions increases with chronic ACL insufficiency.

Despite its importance, the literature on the biology of the meniscus is relatively sparse compared with the extensive coverage that articular cartilage has received. The menisci of the knee joint are semilunar structures interposed between the femoral condyles and the tibial plateaux. Histologically, the meniscus is a fibrocartilaginous tissue composed primarily of water and an interlacing network of collagen fibers interposed with cells. In addition, the extracellular matrix contains small amounts of minor collagens and proteoglycans. Knowledge of the cellular biology of the meniscus and the organization of the molecular components in the extracellular matrix would be of great value in the management of meniscal problems by the orthopaedic surgeon and the rational design of tissue-engineered meniscal substitutes.

**Repair of the meniscus**

The meniscus, unlike articular cartilage, can repair tears in its structure. Cleveland Clinic researchers have studied the cells and extracellular matrix of the normal meniscus and the cellular and molecular mechanisms in the repair of tears in the damaged tissue.

The cells of the meniscus are responsible for synthesizing and maintaining the extracellular matrix. At least two distinctive cell types can be identified in the tissue. Lining the superficial zone at the surfaces of the tissue are relatively flat cells with no obvious pericellular matrix. In contrast, the main body of the tissue contains cells with the appearance of cartilage chondrocytes that are round or ovoid and contain a distinctive pericellular matrix. We refer to the latter as fibrochondrocytes because, unlike chondrocytes, the matrix they make is fibrous. For satisfactory healing of the meniscus to occur, cells need to be attracted to the area, migrate into the site, attach to the clot or existing matrix, divide, remodel the existing matrix and assemble a new matrix that eventually should become integrated into the adjacent meniscal tissues.

We have determined that cells that populate the wound in a meniscus express a distinctive phenotype characterized by the expression of alpha smooth muscle actin (SMA). These cells appear to come from the meniscus adjacent to the wound and from the superficial lining zone of the tissue. The cells in the superficial lining zone divide, express the SMA phenotype and migrate into the wound site. They appear to be key players in the repair of the wound. Are these cells poorly differentiated cells derived from progenitor cells that can differentiate into the appropriate fibrochondrocyte? The Clinic’s research team is actively working on this issue. The answer to this and other intriguing questions should illuminate our understanding of meniscal biology and help usher in a new era of biological intervention in the orthopaedic management of meniscal problems.

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**Cleveland Clinic Sports Health**

The Cleveland Clinic Sports Health and Orthopaedic Rehabilitation program is part of the Cleveland Clinic Department of Orthopaedic Surgery, consistently rated as one of the 10 best in America by U.S. News & World Report.

We provide care for the full range of orthopaedic problems, including sports- or exercise-related injuries. Our entire staff is dedicated to creating personalized rehabilitation programs for musculoskeletal problems or injury, as well as athletic training for maximizing athletic performance.

Our Sports Health staff provides care for the Cleveland Browns, Cleveland Cavaliers, Cleveland Rockers, Cleveland Indians, John Carroll University, Cleveland State University and Baldwin-Wallace College, as well as for many local high school athletic teams and community recreation programs.

We offer sports health and rehabilitation services in convenient locations, including Cleveland Clinic Main Campus and Lutheran Hospital, and at suburban locations in Beachwood, Chagrin Falls, Euclid, Independence, Lorain, Mentor, Solon, Strongsville, Westlake and Willoughby Hills. For more information, call 877/440-TEAM.

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![Figure 1 Image](image1.png)

**Figure 1** Gross anatomical view of the medial and lateral meniscus.

![Figure 2 Image](image2.png)

**Figure 2** Polarized light microscopy of the knee joint meniscus after staining with Sirius Red. The tissue is composed of bundles of circumferential fibers with interlacing smaller fibers.
New Advances in the Treatment of Posterior Cruciate Ligament Injuries of the Knee

Richard D. Parker, M.D., and John A. Bergfeld, M.D.

Posterior cruciate ligament (PCL) injuries of the knee present a diagnostic and management challenge. However, patients can return to prior range of motion, strength, and functional levels if the injury’s extent is determined and treated promptly, say Cleveland Clinic orthopaedic surgeons.

Many patients with PCL injuries present with nonspecific pain and swelling following knee trauma – often from sports – that can be confused with an isolated PCL injury and combined capsuloligamentous injury, as well as the degree (partial vs. complete), is essential to determining appropriate treatment. Less than 20% of patients with isolated complete PCL injuries require surgery while 80% are treated successfully with extensive rehabilitation. In contrast, 90% of patients with combined complete PCL–capsuloligamentous injuries require surgery. “In addition, chronic, isolated PCL injury is an indication for surgery if patients fail rehabilitation and continue to experience pain and limited function,” says Richard D. Parker, M.D., Head of the Section of Sports Medicine and Medical Director of Sports Orthopaedic Rehabilitation in the Department of Orthopaedic Surgery.

In PCL reconstruction, Dr. Parker and Cleveland Clinic Sports Health Director John A. Bergfeld, M.D., began performing an arthroscopically assisted tibial inlay technique in 1993 after carrying out preliminary cadaveric reconstructions and biomechanical studies. Once a PCL injury has been diagnosed, distinguishing between an isolated PCL injury and combined PCL–capsuloligamentous injury, as well as the degree (partial vs. complete), is essential to determining appropriate treatment. Less than 20% of patients with isolated complete PCL injuries require surgery while 80% are treated successfully with extensive rehabilitation. In contrast, 90% of patients with combined complete PCL–capsuloligamentous injuries require surgery.

A definitive diagnosis requires a complete knee physical exam with an emphasis on the posterior drawer test at 90°, with the tibia in neutral and internal rotation, to test PCL integrity. Assessment of potential associated capsuloligamentous injuries is performed by tests such as Lachman ACL test and varus/valgus tests at 0° and 30° flexion. Often, magnetic resonance imaging (MRI) helps establish the diagnosis.

Once a PCL injury has been diagnosed, Drs. Bergfeld and Parker showed that the tibial inlay technique is more stable to posterior translation at all flexion angles than the tibial tunnel technique and the intact knee. This was especially true at higher flexion angles where statistical significance was reached at 30°, 60°, and 90° (P<0.01) compared to the tunnel technique, whereas statistical significance was reached at 60° (P<0.02) and 90° (P<0.01) compared to the intact knee. In addition, it was found with repetitive loading (cycling) of the reconstructed knees that the inlay technique maintained its statistically significant stability in comparison to the tunnel technique and became similar in terms of stability to the intact knee.

The surgery requires general or regional anesthesia. Once the patient is under anesthesia, the surgeon repeats the physical examination of both knees to ensure that the appropriate diagnosis has been made. An arthroscopy of the injured knee is performed to diagnose and treat any chondral or meniscal injuries, as well as, to debride the remnants of the torn PCL. The ligaments of Wrisberg and Humphrey (if present) are preserved. The femoral stump of the PCL is debrided, and the position for the femoral tunnel exit is marked. If an autograft is chosen, the arthroscopy is stopped, and the central third bone – patellar tendon – bone is harvested.

For an isolated complete PCL injury or a complete PCL with associated capsuloligamentous injury other than the ACL, we use either the bone – patellar tendon – bone autograft or Achilles tendon allograft, whereas when the PCL and ACL require reconstruction we prefer allograft bone – patellar tendon – bone for the ACL and Achilles tendon for the PCL,” say Drs. Bergfeld and Parker.

Through a mini-arthrotomy, the graft harvest incision, accurate tunnel placement is confirmed and drilled in the medial femoral condyle. The patient is then placed on another operating room table in the prone position and an approach to the medial head of the gastrocnemius and the medial hamstring tendons to the posterior tibia is performed. “This approach allows for direct visualization of the tibial origin of the PCL, while still protecting the important neurovascular structures,” adds Dr. Bergfeld. The PCL remnant at its origin is removed, and a cortical window is fashioned to the same dimensions as the bone portion of the graft. The bone portion of the graft is then secured with a 6.5-millimeter cannulated screw and washer to the posterior tibia at the tibial origin of the PCL. The remaining graft is passed into the femoral tunnel, the posterior wound is closed, and the patient is returned to the supine position for associated capsuloligamentous reconstruction/repair and final PCL graft tensioning and fixation. After wound closure, a knee brace or immobilizer is applied and locked at 0° extension.

PCL reconstruction using this technique at The Cleveland Clinic is an outpatient procedure; patients stay for 23 hours. Postoperative rehabilitation by a team of physical therapists and athletic trainers begins as early as 2 days postoperatively and continues until satisfactory outcome has been achieved. “Our goal is to return patients to sedentary work/school in one week, moderate work in three months and sports in six to 12 months, depending on the sport and extent of the injury and surgery,” say Drs. Bergfeld and Parker.
In the next few years, cell therapy is likely to become important, if not critical, to optimizing the performance of bone grafting procedures in the operating room. Today, autologous cancellous bone is the gold standard of graft materials. However, it poses several drawbacks which have fueled interest in orthopaedic tissue engineering of cells and matrices. Significant morbidity is associated with the harvest of iliac crest bone graft. Also, the amount and availability of autogenous bone may be insufficient for many clinical problems. As a result of these disadvantages, many surgeons have begun supplementing graft sites with aspirated bone marrow, an effective osteogenic graft that is probably underused in current clinical practice. Bone marrow aspirates obtained from the iliac crest will contain an average of about 1,000 osteoblastic progenitor stem cells per milliliter, as well as other cells rich in cytokines. They also contain fibrin that may facilitate rapid revascularization.

In our laboratory in The Cleveland Clinic Department of Biomedical Engineering, we have developed a method to increase the concentration and selection of connective tissue progenitor cells from bone marrow. This method can supply five to 20 times the number of progenitor cells than routine bone marrow aspirates provide. Higher concentrations of osteoblastic progenitor cells have resulted in significant improvements in the quality and reliability of posterior spinal fusions in an animal model using both mineralized and demineralized allograft bone as a carrier.

Methods of bone marrow concentration are now being evaluated in prospective clinical trials in the Department of Orthopaedic Surgery as an alternative to autogenous cancellous bone graft for inducing spinal fusion and for treatment of non-union of long-bone fractures.

For more information or reprints of articles related to bone marrow grafting and/or bone marrow-derived stem cells and progenitors, call 216/444-5338 or e-mail Dr. Muschler at muschlg@ccf.org.
Implantable Electrical Stimulation in High-Risk Hindfoot Fusions

Brian G. Donley, M.D.

Implantation of electrical stimulation devices to promote fusion in hindfoot arthrodesis poses promise in patients with known risk factors for non-union. The Cleveland Clinic Department of Orthopaedic Surgery Foot and Ankle Center recently conducted the first study ever of this potentially beneficial technique for the foot and ankle.

The role of electrical stimulation, a relatively noninvasive method to deliver a stimulus to promote bone healing, has been demonstrated in both animal and clinical investigations. Several investigations have shown external electrical stimulation devices promote posterior spinal fusions.

However, external devices are subject to patient application and proper placement. Implantable devices, on the other hand, are portable and less cumbersome and guarantee 100% patient compliance. The clinical effect of implantable electrical stimulation may be to mitigate the impact of risk factors.

The hypothesis for our study was that risk factors for non-union in patients undergoing hindfoot arthrodesis could be identified, and implantation of an electrical stimulator would positively influence surgical outcome in high-risk patients.

Between March 1996 and January 1999, 13 patients undergoing hindfoot fusion with at least one risk factor for non-union had an electrical stimulator implanted. Cigarette smoking was confirmed in 11 patients. A history of non-union was present in seven patients, and a combination non-union and smoking occurred in six patients.

Six ankle, two subtalar, three tibiotalar, and two tibiocalcaneal arthrodeses were performed. Twelve patients underwent internal screw fixation; one had an intramedullary nail placed in a retrograde fashion. The age range was 40 to 78 years, with a mean age of 45.

Local bone graft was used for all ankle fusions. Iliac crest bone graft was used for all other fusions or when a previous ankle non-union was present. The electrical stimulator was placed through a separate skin incision in the posterior and lateral aspect of the calf. Electrodes were tunneled beneath the skin to the incision site and inserted into the region of the fusion. Care was taken to avoid contact between the titanium leads and the internal fixation devices.

The initial postoperative splint was changed at one week. Casts were changed at three, six and nine weeks postoperatively and were converted to walking boots at 12 weeks. Patients were kept strictly non-weight bearing for three months. Radiographs were taken at one, three and six months, and at one and two years. Each patient had a minimum of one-year follow-up with an average of 24.6 months.

Successful fusion was achieved in 12 patients (92%) based on clinical and radiographic examination. The mean preoperative pain score was 8.5 ± 1 (range 7-10) compared to 1.9 ± 1 (range 1-6) postoperatively. The mean preoperative modified American Orthopaedic Foot and Ankle Society score was 31.2 ± 13 (range 15-55) compared to 85.4 ± 14 (range 45-100) postoperatively. These improvements were statistically significant at P<0.01.

The electrical stimulator battery was bothersome to eight patients, painful to one, and subsequently removed in four patients. There was no evidence of breakdown or leakage of the device generator battery. Twelve of the 13 patients reported they would choose the operation again under the same circumstances.

Multiple studies in the literature involving arthrodesis of the lumbar spine support the clinical use of electrical stimulation to aid in the fusion process. Results of this first Cleveland Clinic Foot and Ankle Center study suggest that implantable electrical stimulation also is beneficial for hindfoot fusions in patients who are at high risk for non-union. Identification of factors that are most likely to increase the risk of non-union may help in scripting the surgical management of these patients. Continued investigation is under way here.

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Figure 1: Radiograph of non-union of ankle

Figure 2: Post-operative lateral radiograph of fusion of ankle with electrical stimulator in place

Figure 3: Post-operative mortise radiograph of fusion with electrical stimulator in place
Fast walking velocity is a major contributor to falls and fall-related injuries, particularly for maintaining cartilage function. Hyaluronan and proteoglycans molecules provide cartilage with its shock-absorbing ability to withstand compressive loads. When their synthesis is compromised, the tissue can become less active than our other study subjects and carabiners used for rock-climbing.

In this system, substances that enter the system (glucose, glucosamine) can be measured once they exit. In addition, the amounts of the relevant matrix molecules that are synthesized and either released into the medium or retained in vivo can be measured as a function of time.

This trip led to a fall due to the subject's insufficient recovery step length. The insufficient step was the result of an interaction between the woman's walking velocity and reaction time. These two variables caused a large percentage of the falls among older adults in this study. This device, developed by the Clinical Biomechanics and Rehabilitation Laboratory, analyzes mechanisms of falling.
The United States Tennis Association (USTA) created its men's over-90 Super Senior circuit three years ago because the over-85 division was filling up, the Wall Street Journal recently reported. USTA sponsors four championships around the United States, in which 97-year-olds can challenge their younger rivals. The oldest competitive women's division is still for the over-85s, but an over-90 group is expected soon.

The age range defined as "elderly" is climbing in this country for athletes and for our patients as well. Twenty years ago, age 75 was considered the upper limit for elective total hip and knee arthroplasty. Today, it is not unheard of to replace a hip or knee in patients in their 90s. In the last five to seven years, the average age of older arthroplasty patients at The Cleveland Clinic has crept up toward 80. Older people may be excellent candidates and should not be denied elective surgery solely based on age.

Potential benefits of surgery include substantial pain relief, improved range of motion, ability to perform ordinary, though not vigorous, activities and a return to work or independent living. While data regarding total hip arthroplasty for fracture exist, data on elective procedures are scarce. Existing studies show that 92.97% of aged patients undergoing hip arthroplasty are able to return home or to their previous living arrangement. Data reveal nearly total relief of pain on weight bearing in 90% of patients at varying follow-up intervals. Sleep improved in more than 90% of patients. In addition, more than 80% of elderly patients were ambulatory five years postoperatively, several studies report.

Compared to nursing home care, the assumed alternative if arthroplasty is not performed, arthroplasty can reduce health care costs significantly, according to one study.

**Indications**

Surgery should be considered when an appropriate trial of conservative therapy, including analgesia, adequate rest, weight reduction, physical therapy and non-weight-bearing exercise, has been exhausted. The primary indication for total knee or hip arthroplasty is pain. Pain from osteoarthritis can become continuous, resulting in restrictions and limitations in function. Chronic pain can lead to profound loss of mobility and self-care abilities, as well as depression and social withdrawal. Still, surgery should be undertaken only when potential benefits clearly outweigh the increased risks associated with elective surgery in the elderly.

Revision surgery is also becoming more common as the population ages. Our approach to revision surgery is similar to that used for younger patients: if indicated, we offer the procedure.

**Patient selection**

Abdominal or pelvic disease, which can present with hip pain, bursitis and concurrent articular disease in other joints or the spine, must be ruled out. Once osteoarthritis of the hip or knee is confirmed, evaluation continues with assessment of the patient's functional status, co-morbidities and cognitive function, often in consultation with geriatricians.

Basic and instrumental activities of daily living are assessed. Co-morbidities, including heart failure, coronary heart disease, chronic obstructive pulmonary disease, diabetes mellitus and chronic renal failure, significantly increase operative risk and potentially complicate the postoperative course and must be carefully evaluated. In most cases, medical conditions can be optimized prior to surgery.

An evaluation of mental status — mood, motivation and cognition — is essential. Successful rehabilitation is dependent on the patient's desire and ability to comprehend and follow the postoperative exercise program. Cognitive impairment poses a greater risk of postoperative delirium.

When the patient's family is very involved, the clinician needs to ensure that motivation to undergo surgery stems primarily from the patient and not just the family. The patient must be the primary decision-maker and be mentally prepared to undergo this major procedure. In addition, expectations must be realistic. The patient must understand the need to participate in therapy and that surgery will probably relieve pain, but will not return him or her to the activity level of youth.

**Surgical procedure**

Surgical technique in the very elderly is similar to that used in younger patients. Anesthetic management, a critical factor, generally involves a spinal or regional block. The choice of porous-coated or non-porous-coated prosthesis and the method of fixation is decided on a case-by-case basis. Cement is avoided in patients with cardiovascular problems because volatile monomer fumes released during the mixing of the cement may cause instability. Unilateral or bilateral replacement can be performed, but recent studies indicate that bilateral procedures are associated with a significantly greater incidence of postoperative cardiovascular complications.

**Postoperative management**

Early postoperative complications included delirium, medical myocardial infarction, pneumonia, deep vein thrombosis and stroke, while infection has been the primary late complication. The likelihood of a smooth postoperative course is increased with meticulous surgical technique and careful postoperative care.

In general, the very elderly need less postoperative narcotics. After an average length of stay of three to five days, most patients are discharged to a subacute rehabilitation facility. Very old patients tend to tolerate rehabilitation very well, in some cases better than their younger counterparts. Their postoperative pain may be minimal because they have often lived with long-term chronic pain. Once the rehabilitation period is complete, we often hear patients say they wish they would have undergone surgery earlier. Nevertheless, the timing must be right and they must be mentally ready for the procedure. In carefully selected elderly patients with manageable comorbidities who are likely to regain independent physical functioning, total joint replacement is a rewarding and cost effective option.

For more information regarding total hip or knee arthroplasty in the elderly, please call Dr. Matejczyk at 216/444-2608.
Team Approach Benefits Kids with Cerebral Palsy
Alan Gurd, M.D., and Thomas Kuivila, M.D.

We’re trying to put ourselves out of business – the cerebral palsy business, that is. And the multidisciplinary cerebral palsy clinic we participate in may help us do just that. The care cerebral palsy patients can receive in a multidisciplinary clinic like ours can improve their conditions enough or prevent enough deterioration to avoid the serious sequelae we orthopedists are often called upon to treat.

Treatment of the lower-extremity complications of cerebral palsy has continued to advance beyond the tendon lengthening and osteotomies to address the problems of spasticity at the level of the central nervous system. In time, as we implement and improve these procedures in our clinic, we orthopedists will become less and less involved in the care of cerebral palsy patients, except when treatment fails and we must do soft-tissue procedures for contractures or reconstructive surgery for hip displacement or scoliosis.

Pediatric neurosurgeon Mark Luciano, M.D., is successfully implementing some of these newer central nervous system therapies, including selective dorsal root rhizotomy and implantation of baclofen pumps. Developed about 18 years ago, selective dorsal root rhizotomy procedures for cerebral palsy were controversial because results were not always satisfying, and the long-term results were unknown. But patient selection has been refined, the techniques to select the dorsal roots for sectioning and intraoperative monitoring have improved. At our multi-disciplinary clinic, one of the few that where this procedure is performed, results have been excellent, effectively diminishing spasticity while maintaining muscle strength and giving the patients better lower-extremity function.

Other than selective dorsal rhizotomy, one of the mainstays of management of spasticity is administration of the antispasmodic baclofen. But, as most physicians who use the oral form to treat spasticity, the medication is a double-edged sword. Doses high enough for an antispasmodic effect diminish alertness. Dr. Luciano is implementing a new route for targeted delivery of this drug with an implantable pump. The self-contained pump with a titanium bellows delivers baclofen into the spinal canal continually in small doses, reducing spasticity without affecting sensorium. The pump needs to be filled with a sterile needle only every few months. Not every patient is a candidate for this therapy. The child must be large enough to accommodate the pump, for example, but those who are candidates do well.

Another therapy that holds promise in reducing spasticity is botulinum toxin (botox) injection, which pediatric physiatrist Douglas Henry, M.D., implements. The weakening of the muscle that results with injections of small doses of botox can allow physical therapy that stretches the muscle to have a larger effect. We are using this procedure with greater frequency.

Assisting all of us in the care of cerebral palsy patients at the clinic are pediatric physical therapists and occupational therapists, nurses experienced in cerebral palsy, and an orthotist who makes lower-extremity and spinal appliances. We bring the team together to see patients once a month and see about 15 patients on our clinic days. This team approach offers significant advantages for the patients and their caregivers. Nearly every patient has multiple problems that need the input of different specialists and staff. This clinic makes all these specialists available to them, allowing them to see the team members they need to in about 3 hours instead of separate appointments. Without a team approach like this, cerebral palsy patients and their caregivers might not see all the specialists and therapists they need to address the patients’ problems.

Here, the team approach provides total care in addition to convenience. The team approach is an important one from our standpoint as health care providers as well. Each subspecialist and staff member has a different focus on what the patient’s problem is and how to take care of it. Bringing all of those different perspectives to the table helps us formulate the best treatment plan possible to improve our patients’ function and quality of life.

Endoscopically Assisted Decompression for Metastatic Thoracic Neoplasms
Robert F. McLain, M.D.

When metastatic spinal lesions must be repaired surgically, the outlook is usually poor. With metastatic adenocarcinoma, morbidity is often high. But by adding endoscopic assistance to a posterolateral approach, our department has been able to change that outlook, dramatically improving the results and reducing intensive care unit (ICU) and inpatient time.

Radiotherapy is the standard of treatment for metastatic spinal lesions, but sometimes the tumors are resistant and produce bony compromise. Those cases require direct surgical repair, and until now, the only viable surgical option has been repair through traditional thoracotomy because results with the alternatives have been poor. Decompressive laminectomy and posterolateral decompression have shown no better results than stabilization alone. The anterior approach, however, is challenging surgically, and morbidity is high. Even though minimally invasive surgery has been tried with thoracoscopy and laparoscopy, the anterior approach with the best endoscopes still requires the surgeon to collapse a lung and keep it fully deflated for a prolonged period. Many older patients and the very ill, especially those with advanced pulmonary disease, cannot tolerate the loss of lung volume that the anterior approach requires. They may be able to tolerate the posterolateral, transpedicular approach quite well, however. Nevertheless, results with posterolateral approaches have also been disappointing. The major difficulties with decompression through a costotransversectomy approach are limited vision and inability to access vertebral elements anterior to the spinal cord without blindly manipulating the cord. Frequently, neurologic injury results, especially in the thoracic region. In addition, because of the limited access to anterior tumors, debridement may not be complete.

Even though some surgeons have used a dental mirror to aid visualization in this approach, results were still poor. We added endoscopic visualization to the posterolateral technique using readily available instruments familiar to most orthopaedic surgeons. In surgery, we take the proximal origin of the rib and any rib invaded by tumor with a standard costotransversectomy approach and take down the pedicle to the back of the vertebral body using a standard transpedicular approach.

That allows the surgeon to debulk the anterior tumor under direct vision until a cavity is formed in the vertebral body. Then, we introduce a standard 4-mm endoscope into the cavity while maintaining suction and irrigating the cavity frequently. Initially, we use a 30° endoscope, which provides light, magnification, and visualization of the posterior vertebral cortex and the tumor and bone immediately anterior to the spinal cord. With Epstein curettes and pituitary rongeurs, the surgeon removes soft tissue and bone fragments from in front of the cord and moves all tissues away from the cord. Then the interval between the posterior longitudinal ligament and the posterior cortex can be examined directly through the endoscope. This allows the surgeon to collapse the posterior cortex into the vertebral cavity without touching the spinal cord. The remaining vertebral body is then removed to the far pedicle. Next, we introduce a 70° endoscope,
Bone Cell Viability: Is Physical Activity the Key?

Melissa L. Knothe Tate, Ph.D.

The Cleveland Clinic Musculoskeletal Research Center Mechanobiology Laboratory is establishing a biophysical basis for mechanotransduction in bone, providing unique insight into the biology underlying processes associated with bone growth, adaptation and repair. Once such basic mechanisms are elucidated, the development of new treatment modalities for acute or chronic problems, such as fracture, osteoporosis and osteomyelitis, will be possible.

Using innovative methods in an ex vivo sheep model, an in vivo rat model and an in vitro model using bone explants, Mechanobiology Laboratory researchers have proven the postulate that mechanical loading drives fluid flow through bone. Furthermore, they have shown that fluid movement resulting from mechanical loading enhances molecular transport from the blood supply to the osteocytes, thus playing an important role in osteocyte viability. This has tremendous clinical implications for healing bones.

In addition, the mechanobiology research team has developed theoretical computer models to predict flow patterns under simulated model conditions. By comparing the predictions of such models with actual experimental results, we have begun to elucidate the relationship between mechanical loading parameters and fluid dynamics in bone. Such parallel studies have been important for understanding, for example, the role of fluid flow in the hypertrophic response of rats to four-point-bending loads.

Furthermore, we are able to link spatial information such as local architecture to distribution of flow and to osteocyte signaling. Recent studies showing the distinct molecular sieving properties of bone implicate a role of mechanical load-induced fluid flow in modulating the distribution of cytokines through the tissue.

These effects are observable in soft tissues of the musculoskeletal system as well. Interestingly, not only strenuous exercise but also normal daily activities promote transport of nutrients and growth factors through bone.

In summary, we are forming a global picture of fluid flow that has tremendous implications for cell viability, cell integrity, as well as the governance of functional adaptation and repair within bone tissue.

How Bone Adapts to Functional Requirements

The ability of bone to adapt to changing mechanical and systemic factors is particularly striking and is indeed essential for long-term survival of the organism. Although cause-and-effect relationships for this functional adaptation in bone have been documented from an a priori perspective, the mechanisms underlying functional adaptation are poorly understood.

Until recently, it was assumed that bone cells were pre-programmed, like a thermostat or, in biomechanical jargon, a “mechanostat,” to expect certain mechanical loads and that deviations from this norm “turned the cells on” to deposit or remove bone until the expected loading regimen could be re-established. Recently, researchers have revisited an idea proposed by Bassett in the 1960s and Plekanski and Munro in 1977 that bone is like a stiff, fluid-filled sponge and that mechanical loading of the solid components of bone (collagen, mineral composite) results in movement of the liquid phase (extracellular fluid as well as fluid within noncellular areas of the matrix). This “load-induced fluid flow” has been implicated as a potential mechanism for mechanotransduction, by which individual bone cells sense and react to loads imparted through physiological activities. This theory provides the foundation for our research efforts. These effects are observable in soft tissues of the musculoskeletal system as well. Interestingly, not only strenuous exercise, but also normal daily activities promote transport of nutrients and growth factors through bone.

Hospital stays now average 4 to 5 days, compared with 10 to 14 days with standard anterior or posterior approaches.

That contrasts with an average 2.5 day ICU stay with traditional approach. Hospital stays now average 4 to 5 days compared with 10 to 14 days with standard anterior or posterior approaches. Since we first developed the procedure, improvements in the camera and endoscopic tools continue to make this surgery faster and more appealing. Surgical time now averages 4.5 hours skin to skin compared with 7.25 hours for our initial experience and 8.5 to 12.0 hours for the combined anterior and posterior procedures.

Overall, experience has continued to be very positive, and patients and their primary doctors have been very pleased to avoid the danger and morbidity of the formal anterior approach. This surgery improves patients’ function and speeds their return to normal activity. I have found that return to function has been significantly quicker when we can avoid the thoracic or thoracoabdominal incision needed for a formal debridement. The patients’ recovery over the long term, of course, depends on their underlying disease. The indications for this surgical approach have now expanded to some cases of fracture and infection, where formal anterior approaches pose specific risks for the patients. In addition, the procedure is being incorporated into the armamentarium of a number of other major medical centers, and recent reports from other centers have verified both the approach and the principles.

Osteocytes are connected to each other, as well as to bone surfaces upon which osteoblasts rest, via the lacunocanalicular network to osteocytes remote to the blood supply. After endoprosthesis implantation, the small canals, through which the cell processes protrude, provide an exquisitely fine network for intra- and extracellular traffic.

In healthy cancellous bone (left), fluid flows from the blood supply of the marrow space through the lacunocanalicular network to osteocyte remote to the blood supply. After endoprosthesis implantation (right), lack of mechanical loading as well as dissection to the blood supply adversely affect fluid flow through cancellous bone, impairing osteocyte viability and threatening tissue survival.

allowing the surgeon to visualize the posterior longitudinal ligament and dura from below and note any areas of residual compression. Any adherent tumor can then be meticulously dissected from the dura. Epidural veins can be visualized and controlled with angled bipolar cautery. A bilateral approach is required. We have now used this approach to determine whether a chest tube is required. We have now used this procedure or a modification of it to treat 15 to 20 patients. All of them recovered completely postoperatively.

There have been no neurologic complications, and no patient has been made worse neurologically. ICU stays now average 1.0 day, and we have avoided ICU stays altogether for 60% of patients. The ability of bone to adapt to changing mechanical and systemic factors is particularly striking and is indeed essential for long-term survival of the organism. Although cause-and-effect relationships for this functional adaptation in bone have been documented from an a priori perspective, the mechanisms underlying functional adaptation are poorly understood.

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The Cleveland Clinic Department of Orthopaedic Surgery in the 21st Century

continued from page 1

Lerner Research Institute
Research at The Cleveland Clinic continues to grow and prosper through recruitment of outstanding new staff, improvement and expansion of facilities, development of extensive infrastructure and support services, and the enhancement of education programs. Besides performing cutting edge research, the Clinic has developed new relationships with scientists in the biomedical business community around the world and has built upon established collaborations with colleagues at nearby academic institutions. The Cleveland Clinic continue to collaborate productively with clinical colleagues to move discoveries from the bench to the bedside as efficiently as possible.

Subspecialty Services Provided at the Cleveland Clinic Department of Orthopaedic Surgery

- Adult Reconstruction
- Foot and Ankle
- General Orthopaedics
- Hand and Upper Extremity
- Musculoskeletal Oncology
- Pediatric Orthopaedics
- Radiology
- Research
- Spinal Surgery
- Sports Medicine
- Trauma

Major areas of inquiry include bone, tendon, ligament, cartilage and peripheral nerve tissue injury and repair, and tissue engineering. The Joint and Body Biomechanics, Prosthetic Design and Performance Section includes research studies in the spine, shoulder, knee and foot and ankle, as well as research programs in whole-body neuromuscular control, gait, locomotion and rehabilitation. Approximately 20 basic science and translational research programs focused on diverse and clinically relevant problems are under way.

Major musculoskeletal research projects

A number of these projects will be highlighted in each issue of Orthopaedic Insights.

- Cartilage and meniscus transplantation and tissue healing for resurfacing arthritic joints and replacement of damaged meniscus tissue.
- Tissue engineered products for rotator cuff repair.
- The effect of tissue tension, stress, relaxation and muscle atrophy on the healing of rotator cuff defects.
- The role of smooth muscle actin and type IV collagen in the pathogenesis and healing of rotator cuff tears.
- The effect of glenoid component malposition and prosthetic strain patterns and glenoid loosening.
- Bone marrow stem cell fractionation for enhanced spine fusions and fracture healing.
- Clinical outcome and biomechanics of anterior and posterior cruciate ligament reconstructions.- Neuro-muscular control patterns and mechanisms that influence falls and recovery from tripping.
- The biomechanics of flatfoot deformity and reconstructive procedures.
- The role of mechanical loads on the biomechanical and biochemical properties of tendons.
- The role of metalloproteinase activity in injury and repair of connective tissues.
- Biomechanics of spinal instrumentation.
- Use of electromagnetic fields and ultrasound in the healing of fractures.
- Use of exogenous glucosamine on chondrocyte function.
- Design of new instrumentation and devices for spinal surgery, fracture fixation and arthroscopic surgery and prosthetics design.

Clinical outcomes

The orthopaedic clinical outcomes center area is developing a comprehensive database and outcome system. The new computerized program allows direct patient clinical data entry and integrates departmental and institutional data into a single database. This database will allow us to study the effectiveness of current and new treatment methods.

Prospective clinical outcome trials

- Evaluation of the results of shoulder, knee and hip prosthetic arthroplasty.
- Spinal instrumentation and kyphoplasty.
- Celebrex vs. placebo treatment of plantar fasciitis.
- Use of platelet gel fractionation for management of postoperative bleeding after total knee studies and the use of EST-321 for the treatment of acute shoulder pain.
- Use of office-based ulcerasonography for the diagnosis and management of rotator cuff tears.
- Long-term clinical results of anterior cruciate ligament injuries and reconstruction.

Educational excellence

The Orthopaedic Department training programs provide excellent experience in clinical as well as research areas. Twenty-four residents, 10 fellows in seven advanced subspecialty areas of orthopaedic surgery, and numerous postdoctoral research fellows from around the world are in training here each year.

We feel it is of utmost importance to the future of orthopaedics to inspire and prepare young physicians to become leaders in the field. Medical students select Orthopaedic Department training program because of their desire to stay in academic medicine and continue their careers in both clinical care and clinical or basic science investigation. As a result, our program is distinguished as one of only a few that seed our profession with future leaders in musculoskeletal care, research and education.

The ability to practice state-of-the-art musculoskeletal care throughout the 30- to 40-year career of an orthopaedic surgeon depends on being able to critically review new concepts and treatment modalities.

Recognizing the growing importance of basic research, The Cleveland Clinic orthopaedic residency has been lengthened from five to six years. All incoming orthopaedic residents spend one year performing basic science research. In addition, the curriculum for all residents, fellows and graduate students now includes an extensive basic science study, emphasizing the principles of the musculoskeletal system and orthopaedic surgery. This allows the graduating surgeon to keep abreast of advances in the basic science of orthopaedic surgery and to better evaluate any changes in treatment options. We also continue to provide more than a dozen continuing medical education opportunities for community orthopaedics.

In addition, department members contributed 68 journal articles and book chapters to the literature in the last year; 345 articles and chapters over the last five years.

As The Cleveland Clinic Department of Orthopaedic Surgery continues to grow, so does our dedication to excellence in research, education and above all patient care. With our diverse, experienced and motivated staff, we will remain committed to our role as a leader in orthopaedic surgery well into the 21st century.
Researchers from the Cleveland Clinic, in collaboration with NASA Glenn Research Center engineers, have developed and patented a novel device to measure small deformations in bone. The new extensometer is less invasive and provides major advances in measurement accuracy over previously available devices.

Understanding small bone deformations experienced during normal daily activities has direct implications in the study of age-related bone loss, postmenopausal osteoporosis, fracture healing and disuse osteoporosis. Improved measurement of deformations will lead to better understanding of how bone adapts to its functional environment.

Electronic or resistance-type strain gages have been used for research purposes in vivo in humans, but the process needed to bond them to bone is invasive and poses limitations. They require degreasing or chemical bonding agents, or bone surface preparation such as drying, sanding and filing.

Development of the new gage began four years ago when the Departments of Biomedical Engineering and Orthopaedic Surgery at The Cleveland Clinic began investigating the relationship between external impact forces and resulting internal deformations of the calcaneus. However, available equipment could not measure small bone deformations adequately. We turned to NASA engineers for assistance. Work was conducted under the Space Act Agreement for cooperative research with NASA Glenn Research Center and supported by a NASA grant.

The new extensometer is far less invasive and uses non-contact capacitive probes as the deformation sensing technique (figures 1 and 2). Three pairs of probes are mounted on acrylic bodies to three intraosseous pins implanted into and protruding from the bone. One advantage of the new device is its ability to distinguish between deformations resulting from bending loads and other forces. Bending loads are thought to better represent normal, in vivo loading regimens than purely axial or torsional loads. The new device also offers advantages over bonded strain gages when access to the specimen is limited; surfaces are rough, porous or cannot be adequately cleaned; strain magnitudes are expected to exceed 100 microstrain; and when relatively low invasiveness is required.

Validation tests in dynamic four-point bending in an acrylic specimen showed excellent agreement between the new extensometer and standard bonded gages. The accuracy of the device depends upon several measured variables, including the distance between bone cortex and sensor planes. Thus, magnetic resonance imaging or fluoroscopy is required (figure 3). Resolution of deformations in the plane of interest can be changed by altering gage length, distance between sensors and distance from outboard sensor to specimen.

Follow-up studies of calcaneal fractures are under way. Funding is from the U.S. Department of Defense, which is concerned with parachuting injuries, and the Aircast Foundation, which focuses on fractures caused by heel contact with the floor pan in automobile accidents. The National Space Biomedical Research Institute also has funded The Cleveland Clinic to test new devices that would allow astronauts to perform jumping exercises in microgravity.
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