IX. Ligaments and Tendons

[*See also pg. 199*]

Affects of Immobilization and Motion in the Injured Tendon (Chicken)

Albert J. Banes
University of North Carolina
Chapel Hill, NC 27514

Sponsor: National Institutes of Health

Purpose — Tendon injuries constitute an increasing proportion of trauma cases reported at our hospital, yet research in tendon healing has been neglected. There is a strong clinical impression that exercise speeds healing in an injured tendon. Early motion of the affected tendon favorably influences collagen synthesis and maturation, particularly the quantity of and types of collagen crosslinks formed. The variety and amount of collagen crosslinks present are directly related to the strength and mobility of the healing tendon. Without the appropriate types of crosslinks in the appropriate locations within collagen molecules, connective tissue would literally fall apart. On the other hand, too many crosslinks in joint tissue or tendon can restrict mobility. Since the tensile strength of tendons is dependent on the nature of the collagen, and physical activity strengthens tendons, exercise must favorably alter the crosslink chemistry of healing tendons. Moreover, a study of how cultures of tendon cells react biochemically to stress *in vitro* will indicate how stress *in vivo* acts to strengthen healing tendons.

Exercise Effects on Tendon Repair (Rabbits, Chickens)

Richard H. Gelberman
University of California
San Diego, CA 92103

Sponsor: National Institutes of Health

Purpose — The objective of this proposal is to evaluate the tendon repair process by means of a multidisciplinary approach. A variety of exercise conditions will be imposed in order to establish the conditions which will maximize the rate and strength of the repair. Preliminary studies will be performed to evaluate the influence of rigid immobilization, cage activity, farm activity, and vigorous daily treadmill exercise on the size and strength of normal tendons and on the strength of insertion sites into bone. We also will evaluate the influence of these exercise factors on the rate of tendon healing. Of particular importance will be studies on the exercise postoperatively after tendon repair. The purpose of this part of the study will be to determine the conditions which will maximize the quality of repair, including the proper duration of immobilizaton, timing onset of the exercise programmed, and the exercise schedule.

A variety of techniques will be used to evaluate the quality of repair. Correlation studies will be performed between morphologic, bioengineering, and biochemical procedures. Video dimension analysis will be performed under various strain rate conditions including high speed motion analysis converted to the video format. It will be possible to study the repair line and the remainder of the tendon composite independently using this approach. This is necessary because the effects of exercise (or its deficiency) are different between various elements of the tendon composite, viz. area of repair, area of tendon proximal and

distal to the repair site and the tendon insertion site. A variety of biochemical techniques also will be used to correlate with the tensile test measurements. These will include estimation of water content, total hexosamine, glycosaminoglycan, total collagen, soluble collagen, and analysis of reducible collagen cross-links. The application of drugs and hormones known to modify connective tissue metabolism will be explored to determine whether the immobilization effects occurring in the early phase of repair can be overcome without impeding the tendon repair process.

The L.T.W. Connective Tendon/Ligament Device

Lutz T. Kynast
VA Medical Center
Hines, IL 60141

Sponsor: VA Rehabilitation Research and Development Service

Purpose — Research laboratories interested in the problems associated with tendon/ligament surgery are often confronted with the difficult task of fastening loads and/or loading instrumentation to the tendons and ligaments of cadavers. Research in this area often necessitates subjecting the intact and repaired sutured tendons and ligaments to biomechanical evaluation, determining the ultimate tensil strength of tendons and ligaments, assessing the tensile parameters of healing tendons and ligaments, and physiologically loading joints.

The measurement techniques require the use of connective devices that clamp onto the end of a ligament or tendon. A cable, linkage, or other instrumentation is then attached to the other end of the connective device. The clamping action of the device often damages (at the clamping/gripping site) the fibers within the tendon or ligament to be tested. Consequently, stress concentration and slippage at the clamping site make it difficult to obtain reliable data.

It is essential to don ligament and the loading instrumentation and to avoid damaging fibers with clamping actions that would influence the tensile strength of the material to be tested, as well as to minimize the creation of new areas of stress concentration. The L.T.W. Connective Tendon/Ligament Device meets these requirements as it allows the loading of joints as physiologically as possible.

Pathokinesiology of Anterior Cruciate Ligament Deficiency

Richard Shiavi, Ph.D.
VA Medical Center
Nashville, TN 37203

Sponsor: VA Rehabilitation Research and Development Service

Progress — The progress has been good after conquering some difficulties transferring theoretical kinematic concepts concerning helical motion into useful software analyses that apply to locomotion. Presently, the knees of 17 uninjured and seven injured subjects have undergone extensive study of their kinematics and EMG control during walking and pivoting.

Preliminary Results — Several helical motion variables, such as direction cosines and helical rotation, easily distinguish the injured and uninjured knees while the standard anatomic angles do not. A presentation of this technique was made at the International Society of Biomechanics Congress in June 1985. A manuscript for journal publication of these results is presently being prepared. Work is continuing to enlarge the data base and to refine the analysis in order to

further distinguish between loose and tight injured knees. A necessary component of this research has developed which was not anticipated. This is the computer graphical presentation of the results that depict the three dimensional motions. It is necessary for fully appreciating the kinematics and for understandable presentation of the results. Supplemental funds to support this endeavor are being sought through the VA Rehabilitation Research and Development Service.

Future Plans — The EMG patterns of several muscles in the patients with the injured knees are extremely different from the normal during both walking and pivoting. A presentation of these results was at the Engineering in Medicine and Biology Conference in late September 1985. A manuscript describing the full results is also being prepared for journal publication. Again, more subjects are scheduled to be studied in order to increase the data base.

Anterior Cruciate Ligament Healing (Dogs, Rabbits)

Wayne H. Akeson
University of California
San Diego, CA 92103

Sponsor: National Institutes of Health

Purpose — The limitations in the healing response of the anterior cruciate ligament (ACL) are well organized. Various reasons have been proposed for the failure of healing of this ligament, particularly mechanical factors and nutritional factors resulting from a limited blood supply. Additional harmful effects to repair the anterior cruciate ligament result from the post-injury synovial fluid which contains numerous proteolytic enzymes harmful to immature proliferating cells and their matrix. In summary, failure of repair is the result of a multifactorial hostile environment.

However, intrinsic repair of flexor tendon in the flexor tendon sheath has been demonstrated in this laboratory when intermittent passive motion is imposed. This environment is seemingly as "hostile" as in the case of the ACL. The blood supply and nutrition are outwardly as limited. Why is intrinsic healing so effective in the case of the tendon, but so limited in the case of the ACL?

These investigators propose a study to evaluate the early ACL healing response and to compare it to the process of flexor tendon healing. A series of descriptive studies are proposed to clarify differences between the ACL and other ligaments of the knee joint, as well as between flexor tendon with respect to routes of nutrition, repair mechanisms, and the influence of activity on repair rate and quality.

Future Plans — Subsequent studies will evaluate the routes of nutrition of tissues used in ACL reconstruction, the potential for augmentation of that nutrition by the anterior synovial fat pad, the collagen turnover rate of ligament autocraft replacements, and the changes in their strength characteristics with time. Nutritional studies will employ labelled collagen precursors (L-5-3H proline) administered by routes chosen to elucidate the questions of nutritional mechanisms. Turnover studies will employ chronic collagen prelabeling. Evaluation of repair mechanisms will employ a variety of morphological, biomechanical, and biochemical techniques.

Evaluation of Tubular Internal Fixation Plate for Fracture Management

Savio Woo, Ph.D.; Richard Coutts; David Amiel; Steven Garfin; and Wayne Akeson
VA Medical Center
San Diego, CA 92161

Sponsor: VA Rehabilitation Research and Development Service

Purpose — The overall objective is to determine whether significant advantages can be obtained from internal fixation of diaphyseal fractures using plates with improved design. Our goal is to test the newly developed design criteria, i.e. moderate bending and torsional plate rigidities needed for early immobilization in order to achieve fracture healing without bone shortening and/or angulation. Low plate axial rigidity is desirable to minimize stress (strain) shielding of the underlying bone during the post-union remodeling process. A new plate with a tubular cross section is made of stainless steel filled with polyethylene. This plate has rigidity characteristics and will be used in a canine unilateral midshaft femoral osteotomy mode. A traditional solid stainless steel plate of identical external geometry will be used in a separate series of animals with similar osteotomy. In addition, it is also our goal to test whether such a low axial rigidity plate can prove to be advantageous to the recovery of full structural properties of the underlying bone following plate removal.

Progress — The evaluation of the bone lying beneath both the traditional solid stainless steel (control) and the new tubular (experimental) plates is being performed now using X-ray, geometric measurements, histomorphometric measurements, and biochemical techniques. A comparison is being made specifically between the actual physical properties of bone and the structural and mechanical properties obtained by biomechanical bending and axial and torsional testing. Histomorphometric data have shown on the average that bone porosity is higher for the control solid stainless steel plate while there is an increase in new bone growth and less porosity for bone lying beneath the experimental hollow plate. This information correlates well with the bioengineering tests performed. With further comparison and study of these test results, we hope to provide more insight into the problem of localized osteopenia with the use of internal fixation plate systems.

Structural and Functional Properties of Normal and Repaired Ligaments

Savio Woo, Ph.D.
VA Medical Center
San Diego, CA 92161

Sponsor: VA Rehabilitation Research and Development Service

Purpose — The objective of this research is to evaluate the ligament repair process in a model synovial joint system. A variety of activity conditions will be used in order to determine which set of conditions will maximize the speed and strength of the repair or healing of ligaments. To achieve this objective, it will be necessary to determine the influence of a wide range of physical factors such as rigid immobilization, cage activity, normal activity, intermittent-controlled passive motion, and rigorous daily exercise programs on the size and strength of normal and repaired/healing ligaments. The timing of the onset of these forces at the repair line and its magnitude and frequency need to be optimized in order to achieve the most rapid and complete remodeling of the repaired/healing ligaments.

Progress — To date, we have studied medial collateral ligament healing with and without surgical repair using a canine model. The evaluation of the quality of ligament healing and repair has included correlative studies using morphologic, biomechanical, and biochemical techniques. Specifically, we have studied healing ligaments subjected to various regimens of repair and early mobilization over a 6-week time period. We have focused on the biomechanical properties of the ligament repair site and the areas of the ligament proximal and distal to the repair. The structural and mechanical properties obtained were compared to the biochemical results and histological appearance of each of these areas.

Future Plans — We are currently performing experiments over a 12-week time period to further define proper clinical regimens that may be used to provide better healing of ligament structures. Our goal is essentially two-fold: to improve the structural integrity of the healing ligament to ameliorate problems of knee joint instability, and to improve the material properties of the healing ligament substance as well.