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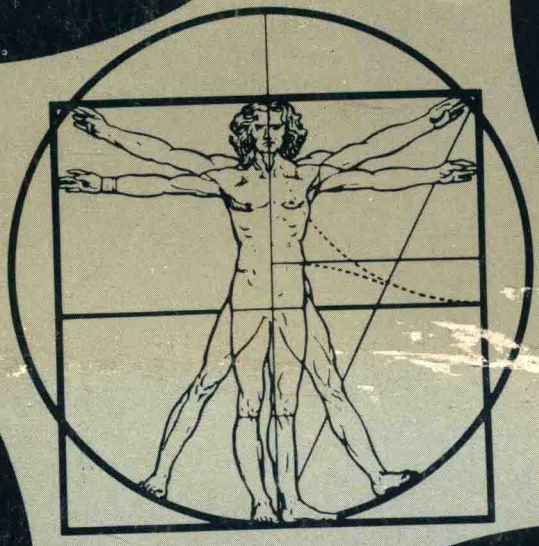

1987 Advances in Bioengineering

edited by
A. G. ERDMAN

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1987 Advances in Bioengineering

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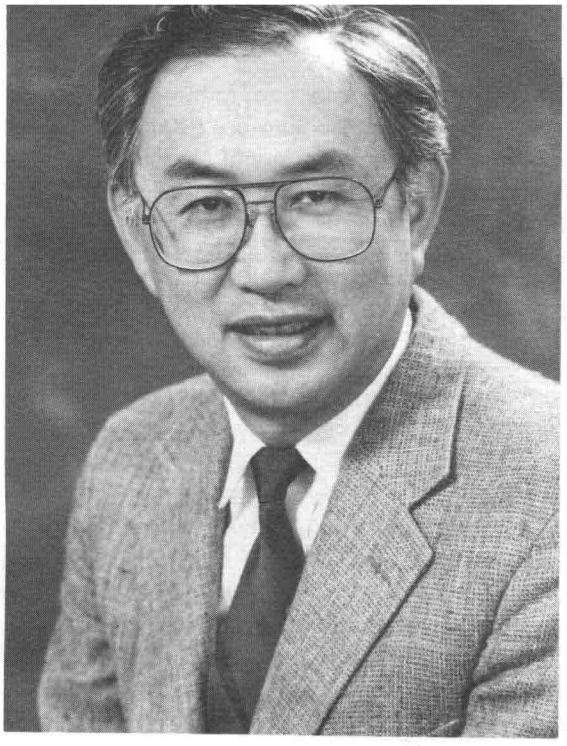

VAN C. MOW, PH. D.

RECIPIENT OF
1987 HERBERT R. LISSNER BIOMECHANICAL ENGINEERING AWARD

The Bioengineering Division of the American Society of Mechanical Engineers is proud to present the 1987 Herbert R. Lissner Award to Dr. Van C. Mow. He is currently Professor of Mechanical Engineering and Orthopaedic Bioengineering at Columbia College of Physicians and Surgeons and Columbia School of Engineering and Applied Science, and Director of the Orthopaedic Research Laboratory at Columbia-Presbyterian Medical Center. Prior to his joining Columbia University on July, 1986, Dr. Mow was the John A. Clark and Edward T. Crossan Professor of Engineering at Rensselaer Polytechnic Institute, a post he held from 1982 to 1986. Dr. Mow received his Ph. D. degree in applied mechanics from Rensselaer in 1966. From 1966 to 1969, he was Post-Doctoral fellow in applied mathematics at the Courant Institute of Mathematical Sciences and Member of Technical Staff at the Bell Telephone Laboratory. In 1969 he returned to join the faculty of Rensselaer as Associate Professor of Applied Mechanics at which time he began his research on biomechanics focusing on diarthrodial joints and osteoarthritis. He was promoted to Professor in 1976. From 1972 to 1986, he held the position of Professor of Orthopaedic Surgery at Albany Medical College and from 1976 to 1977, was a Visiting Professor at the Children's Hospital Medical Center of Harvard Medical School.

To date, Dr. Mow has written 184 articles, chapters, review papers and symposium proceedings contributing to the understanding of biomechanical functions of diarthrodial joints, the biomechanical properties of normal and pathological articular cartilage, rheological properties of biomacromolecules, especially cartilage proteoglycans, and biomechanical factors involved in the etiology of osteoarthritis. He has also delivered over 200 invited and professional lectures at meetings throughout Europe, Asia and North America.

Dr. Mow is currently Chairman of the Editorial Advisory Committee of the Journal of Orthopaedic Research, has served as an Associate Editor for the Journal of Biomechanics and the Journal of Biomechanical Engineering, and served on the Board of Consulting Editors of the Journal of Bone and Joint Surgery. He is currently a member of the Editorial Board of the Mechanical Engineering Series for Springer-Verlag Publishers. As a reviewer, he served on the National Institutes of Health Study Section for Orthopaedic Surgery and Musculoskeletal Diseases and was Chairman of this Study Section from 1982-1984. In 1982, Dr. Mow became the first engineer to be elected as President of the Orthopaedic Research Society.

Dr. Mow has received many honors for his contributions to bioengineering and orthopaedic research. He is the recipient of the American Academy of Orthopaedic Surgeons's Kappa Delta Award for outstanding research in orthopaedics, 1981, and recipient of the American Society of Mechanical Engineers' Melville Medal for outstanding contributions to the engineering literature, 1982. He received the William H. Wiley Distinguished Faculty award in 1981 from Rensselaer, and Honorary Professorships from the Chengdu University of Science and Technology, 1981, Shanghai University of Science and Technology, 1983, and Shanghai Jiao Tong University, 1987. Finally, Dr. Mow is also the recipient of a Fogarty International Senior Fellowship in 1986 and the Alza Distinguished Lectureship of the Biomedical Engineering Society for his contributions to bioengineering in 1987.

PREFACE

The *1987 Advances in Bioengineering* contains extended abstracts of bioengineering papers presented at the 1987 Winter Annual Meeting of the American Society of Mechanical Engineers. The entire bioengineering program consists of twenty-eight sessions included in this volume. The five sessions on biomechanics of normal and prosthetic gait (co-sponsored by the Dynamics Systems and Control Division) are included in a special ASME volume entitled, *Biomechanics of Normal and Prosthetic Gait.* There are five sessions in Biomechanics of Sport (co-sponsored with the Design Division) which make up the publication, *Biomechanics in Sport—A 1987 Update.* Also, there are three sessions in bioengineering aspects of biotechnology included in the volume, *Network Thermodynamics, Heat and Mass Transfer in Biotechnology.* The titles of the papers in these symposium volumes are included in the Table of Contents of this volume in order to have a complete listing here of the 1987 Winter Annual Meeting bioengineering program.

Among the abstracts within this volume are those from several mini symposia. The two session symposium on Rehabilitation Engineering was sponsored by the Solid Mechanics Committee of the Bioengineering Division. Several sessions on bio-fluid mechanics were organized by the Fluid Mechanics Committee, including "Experimental Techniques in Biofluid Mechanics" and "Catheter Tip Intra-Arterial Interventional Techniques." The Fluid Mechanics and the Heat Transfer Committee cooperated in developing sessions on aspects of flow heat and mass transfer in microcirculation and tissue.

The remaining sessions were made up of unsolicited papers in a variety of areas, which formed sessions such as "Soft Tissue Modeling," "Cardio-Pulmonary," Bone Mechanics," and "Spine Mechanics." Session Bio-9A, "Experimental Techniques in Biofluid Mechanics," is being dedicated to the memory of Professor Vaishnav, Fellow, ASME, from the Catholic University of America, who passed away on July 1, 1987. He conducted research on vascular tissue and published a book, *Thermodynamics and Its Role in Disease Processes.*

There are a total of 145 papers, 81 in this publication and 64 longer papers in the other three volumes. The rather large meeting this year, especially following the 1987 Summer Biomechanics Symposium, may indicate increased research and interest in bioengineering topics.

The Bioengineering Division Honors Committee has selected Dr. Van C. Mow as this year's recipient of the H. R. Lissner Biomedical Engineering Award. A tribute to Dr. Mow appears in the front of this volume. This award honors outstanding or unique contributions to the field of biomedical engineering each year.

ACKNOWLEDGMENTS

I wish to acknowledge the tremendous help of Phyllis Peterson in putting together this volume. Her administrative, word-processing, and database expertise has held everything together in developing this large meeting. Her continued help was crucial in satisfying all the deadlines for this effort. I wish also to thank Jack Lewis, the 1987 Bioengineering Division Chairman, for his help and guidance in generating sessions and helping review papers for this meeting.

I also appreciate the assistance of the symposium organizers for both the papers in this publication as well as the other three volumes: E. Dianne Rekow and John Thacker for the Biomechanics in Sport Symposium; Jeff Stein for the Biomechanics of Normal and Prosthetic Gait Symposium; Gerald Miller for the Bio-Fluids Sessions; Ray Vanderby for the Rehabilitation Mini-Symposium; Sheldon Weinbaum for the Microcirculation Symposium; Ken Diller for the Heat Transfer and Biotechnology Symposium; and Paul Stein for the Catheter Tip Intervention Session. All of these individuals went out of their way to develop exciting, integrated sessions and to help in coordination of the meeting.

I would also like to thank past program chairmen, Albert King, Susan Lantz, Noshir Langrana, and the past division chairman, Sevio Woo, for their strong support and advice. Thanks are also due to a variety of people who reviewed abstracts and helped the symposium chairmen in selecting papers for the program.

Finally, I wish to acknowledge the support of the Mechanical Engineering Department at the University of Minnesota for making facilities available for putting together this program.

Arthur G. Erdman

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DE-Vol. 13/BED-Vol. 6, BIOMECHANICS IN SPORT—A 1987 UPDATE
Book Number G00412

PHOTODIODE CAMERA MEASUREMENT OF SURFACE STRAINS ON TENDONS DURING MULTIPLE CYCLIC EXTENSION TESTS

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and

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INTRODUCTION: Using high speed photography, Butler, et al. [1] showed that local surface strains near the bone attachment sites of human patellar tendons were larger than in their mid-region. Strain measurement with high speed photography is laborious and there is potential for error in human judgement during film analysis. Woo, et al. [4] used the Video Dimension Analyzer (VDA) system for measuring surface strain to eliminate the errors introduced by contacting the tissue such as with clip gauges. The VDA is limited in the number of regions in which strain can be accurately measured.

The objectives of this paper are to introduce the use of a photodiode camera for measuring surface strain on soft tissue and to present some representative responses of the tendon.

MATERIALS AND METHODS: Tendon samples were dissected from hind limbs of canines and stored frozen with precautions to prevent tissue drying. Tests were conducted with a computer controlled, servohydraulic Instron testing system. During testing, specimens were immersed in a saline bath at a temperature of 22°C. This saline bath was constructed of clear plastic with clear, flat front (quartz) and rear (plastic) plate windows. The grips were flat plates with waterproof 100 grit silicon carbide abrasive paper in the grip surface. Grip motion was measured with an LVDT mounted in the hydraulic actuator and the load was measured with a submissible Interface load cell (Model SSM-100). The initial specimen length was measured between grips with a micrometer at a preload of 0.13N. Tests were performed at a strain rate of 2% per second with the maximum strain level of 3% in two 21 second long blocks of cycles separated by a rest period (120 second).

A Reticon camera (Model LC 120 V2048/16), which employs a linear 2048 element photodiode array to sense the image, was utilized to measure the surface deformations during cyclic motions. Figure 1 is an illustration of a tendon segment with the scanning line and the 12V-DC fluorescent back lighting system. Two targets of self-adhesive, stiff, and narrow (about 0.5 mm) plastic were glued approximately 10 mm apart with cellulose nitrate [3] to the mid-portion of the tendon specimen. The Reticon camera scanned these targets and grips for measurement of surface deformation during cyclic extensions. It was assumed that there was not target rotation during cyclic extensions in the tendon specimen.

The accuracy of measurement was 17.5 μm within about a 35mm field of view. The field-of-view was imaged by the lens onto the photodiode array, which was electronically scanned to provide both analog and digital outputs to the Reticon RSB6320 camera data formatter and interface unit. The formatted camera data were stored in two toggled 254-word RAM memories on-board the RSB6320. This toggling scheme allowed simultaneous image data storage and computer processing with camera data rates up to 2 MHz. At this rate, a 2048 pixel scan line would take nominally 2 ms. However, the ultimate image data rate was generally dependent upon the number of transitions, complexity of the image, and the computer's ability to accept and process image data. The back lighting system was chosen to make a good uniform light field.

A PDP-11/23 computer was used for test control and data acquisition, storage, and analysis. An Instron Machine Interface Unit and an Instron Machine Driver enabled command and communication between the computer and testing machine. Data were also monitored and stored on a Nicolet digital oscilloscope (Model 201, series 2090).

RESULTS AND DISCUSSION: The empirical results presented here are a small part of work which is completely described in a dissertation [2]. Figure 2 shows the surface strains of the tendon segments for seven extension cycles. The local surface strains near the gripped ends (seg. 1 and seg. 3) were greater than those at the middle segment (seg. 2). The grip effect may cause nonuniform distribution of strains on this tendon specimen. Figure 3 presents the surface strains of the tendon segments with 120 second wait period. Cyclic load relaxation and recovery responses are shown in Figure 4. Comparing Figure 3 and Figure 4, the surface strains in seg. 2 after the rest period is reduced (recovered).

The pattern of larger strain near the grips or the recovery (reduction of strain) phenomena for surface strains during the rest periods are not consistent in all the specimens in this study [2]. Submissions for journal publication which more completely present this work are in preparation.

ACKNOWLEDGEMENT: This work was supported, in part, by grants from the American Osteopathic Association (No. 84- and 85-05-158).

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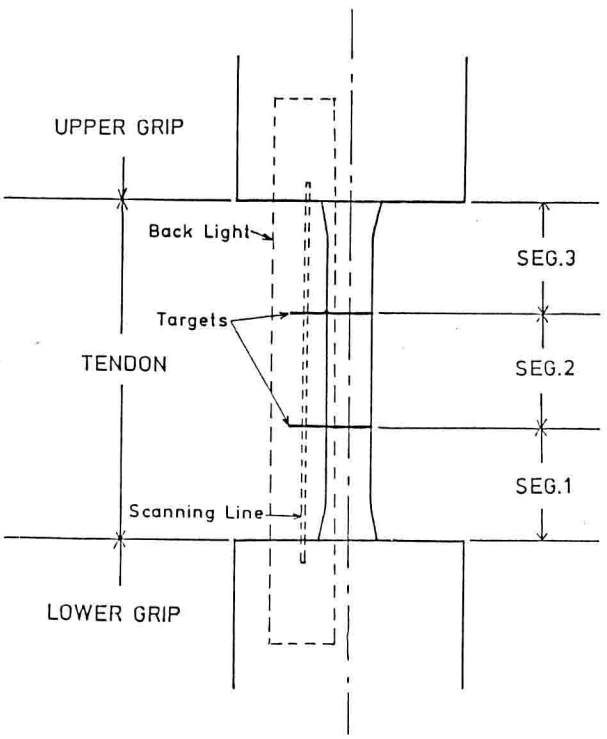

Figure 1 Illustration of tendon segments with the scanning line in the Reticon camera and the back lighting system.

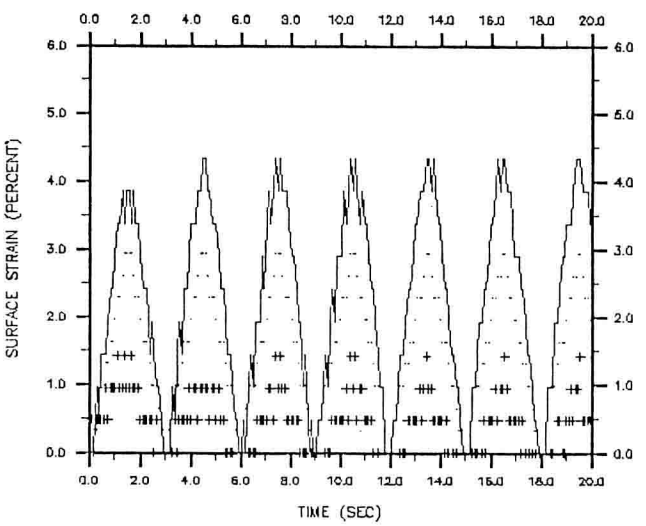

Figure 2 Surface strains of the tendon segments with cycles for a peroneus longus tendon.
(.... : seg.1, ++++ : seg.2, —— : seg.3)

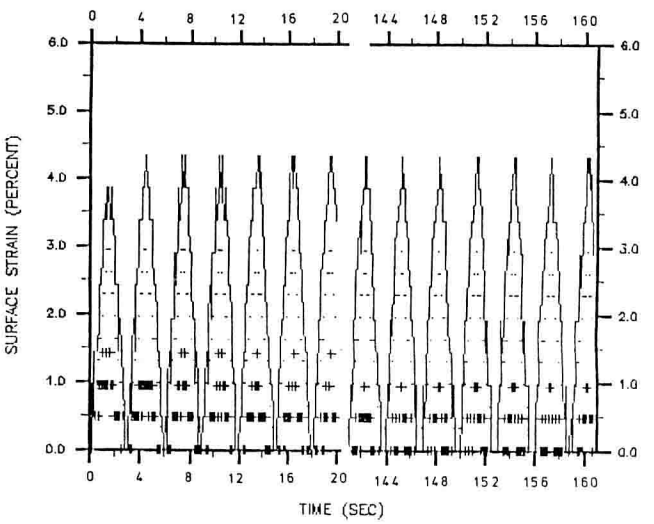

Figure 3 Surface strains of the tendon segments with 120 second rest period for a peroneus longus tendon.
(.... : seg.1, ++++ : seg.2, —— : seg.3)

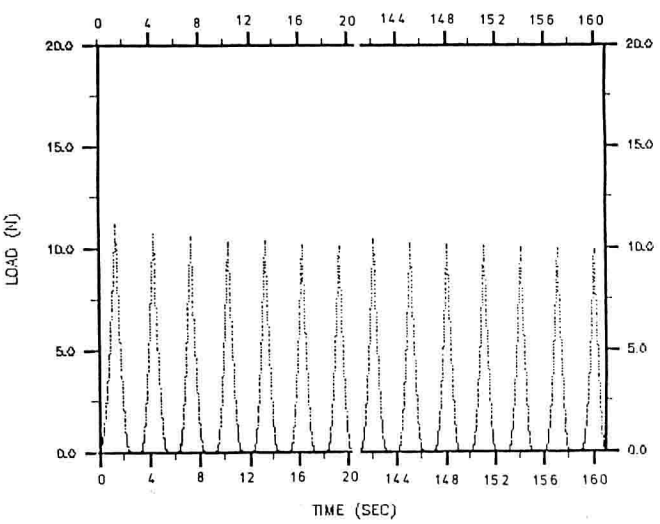

Figure 4 Cyclic load relaxation and recovery with 120 second rest period for a peroneus longus tendon.

TECHNIQUE FOR MEASURING THE 3-DIMENSIONAL CONFIGURATION OF THE HUMAN CRUCIATE LIGAMENTS

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INTRODUCTION: The anterior (ACL) and posterior (PCL) cruciate ligaments are complex structures which serve a multitude of functions in the human knee. As such an understanding of their fiber bundle structure is essential. Traditionally, both ligaments were studied as whole structures. In 1975, Girgis et al [1] described each ligament as having two bands. This has since been confirmed [2]. Others see the ACL as having three distinct portions [3]. To date, however, no studies have further subdivided these structures to determine the lengths and spatial orientations of major fiber bundles.

This investigation was designed to more fully understand the organization of both tissues. Our objectives were as follows;
1) To determine the spatial configurations of representative fiber bundles at three separate depths in the ACL and PCL of one human cadaveric knee, with the knee in several positions of flexion (0,30,60,90 degs.) and internal (10,20 degs.), neutral (0 deg.) and external (10,20,30 degs.) tibial rotation, and 2) To process the resulting ligament data so it could be plotted using color computer graphics. We sought to be able to rotate the knee image to visualize fascicle configurations and insertion sites from different perspectives.

MATERIALS AND METHODS: The specimen under study was a right knee from a 30 year old male taken at autopsy within twelve hours post-mortem. The specimen included six inches of tibia and fibula. All ligaments and capsular structures were kept intact. The specimen was immediately frozen at -15 degrees C. One day before dissection, the knee was removed from the freezer and thawed in its freezer bag at room temperature.

The tibia of the intact knee was potted in an aluminum tube using methylmethacrylate cement and the combination inserted into a tibial sleeve on the testing stage (Figure 1). The femur was fixed at one of four flexion angles (0,30,60, and 90 degs.) using methymethacrylate flexion casts. The tibia was then positioned and pinned in one of six angles of internal (10,20 degs.), neutral (0 deg.) or external tibial rotation (10,20,30 degs.). Anterior or posterior displacement of the tibia was achieved by having the tibial sleeve slide on two 1/2 inch dia. stainless steel shafts. These points were kept constant during digitization using 1/2 inch dia. collars. The initial anterior or posterior drawer force was produced with weights suspended from the end of steel cables acting over pulleys at the front and back of the platform. An Instrumented Spatial Linkage (ISL), mounted either on an anterior or posterior post, was used to collect the data.

Once the flexion angles were set, the femur was split along a midsagittal plane for easy access to the cruciate ligaments. Short lengths of Kirschner wire pins (K-wire) were then drilled into the open, cut face of each femoral half to provide reference bone landmarks. Six K-wire pins were also inserted into the anterior, superior surface of the tibial plateau and another 4 pins placed along the posterior edge. Four additional landmark points were affixed to the medial and lateral surfaces of the tibial tube. These points provided a common reference between the anterior and posterior coordinate systems.

Eight surface bundles were identified around the tibial attachment and traced toward the femur. Once a bundle was located, it was marked with suture at five equally-spaced intervals -- most proximally at the femoral insertion, mid-proximal, middle, mid-distal and most distal or tibial. The most proximal and distal locations were adjacent to the insertion sites of each fascicle, but in some cases, not exactly on the insertion.

During testing, the ISL was used as a 3-dimensional digitizer to determine all ligament markers, insertion site points and bone landmarks. The accuracy of the device was +/- 0.5mm. The order of data collection was as follows: a) the tibial tube reference points with respect to the ISL post; b) the K-wire marker locations along the front edge of the tibial plateau; c) the femoral markers; d) the ACL insertion sites; and e) the specific ACL bundle markers in a distal-to-proximal direction, beginning with the anterior-most bundle.

The locations of the suture points on the ACL were first determined in neutral tibial rotation and zero degrees flexion. For purposes of efficiency, data was collected at the four flexion angles for each tibial rotation angle. Surface bundles on the ACL were digitized with no anterior tibial displacement for all combinations of flexion and rotation angles. The lateral capsule and LCL were then dissected and a four pound anterior drawer force was applied to the tibia and isolated ACL. The entire digitization procedure was then repeated for all surface bundles at all angles of flexion and tibial rotation.

Once all surface bundles were digitized, approximately one third of the radial depth of the ligament was dissected to expose the middle bundles.