SUMMARIES OF SCIENTIFIC/TECHNICAL ARTICLES

The effects of tibial rotation on the patellofemoral joint: Assessment of the changes in *in situ* strain in the peripatellar retinaculum and the patellofemoral contact pressures and areas

Thay Q. Lee, PhD; Bruce Y. Yang, BS;
Matthew D. Sandusky, BS; Patrick J. McMahon, MD

Purpose of the Work. To determine the effects of tibial rotation on the patellofemoral joint biomechanics. **Procedures.** Human cadaver knees were used with a custom patellofemoral joint testing jig that simulates the forces in the knee extensor muscles. Patellofemoral contact and *in situ* strain in the peripatellar retinaculum was quantified with respect to tibial rotation. **Results.** The results suggest that it is the underlying geometry of the patella that causes the patella to rotate and shift with external and internal tibial rotation affecting both the patello-femoral contact and the *in situ* strain in the peripatellar retinaculum. **Relevance to the Veteran Population.** Patellofemoral joint disorders are common and significant problems for the VA patient population. These disorders result from injuries and chronic conditions that alter the patellofemoral joint force system, which is also a function of tibial rotation. This suggests that the physical exams of knee should include the effects of tibial rotation.
Thay Q. Lee, PhD

Design and validation of an instrument package designed to increase the reliability of ankle range of motion measurements

Kelly Weaver, MD; Robert Price, MSME;
Joseph Czerniecki, MD; Bruce Sangeorzan, MD

Purpose of the Work. To evaluate the reliability of the equinometer in measuring ankle dorsiflexion. **Subjects/Procedures.** Ten normal subjects were evaluated with the equinometer on two separate days, and the reproducibility of the measurements was recorded. **Results.** The test retest data obtained showed the equinometer to be a reliable method for evaluating ankle plantarflexion contracture. **Relevance to the Veteran Population.** Equinus contracture is thought to contribute to the development of a number of musculoskeletal conditions observed in the lower limb. Unfortunately, it is clear that measuring contractures of the ankle with standard methods results in data that are poorly reproducible. The equinometer offers improved measurement of equinus contracture and therefore the potential for a better understanding of the contributions of equinus contracture to lower-limb musculoskeletal complaints.
Kelly Weaver, MD

Microstructural characteristics of human skin subjected to static *versus* cyclic pressures

Laura E. Edsberg PhD; Joseph R. Natiella, DDS;
Robert E. Baier, PhD, PE; JoAnn Earle, EMT, HT

Purpose of the Work The purpose of this study was to evaluate microstructural changes occurring in human skin exposed to static versus cyclic pressures. **Procedures.** Static or cyclic pressures were applied to healthy newborn skin. The pressures used simulated those recorded for heels of human subjects on various pressure-relief systems. The skin was evaluated microstructurally after being subjected to pressure. **Results.** Cyclic pressure induced parallel alignment of connective tissue collagen bundles, which themselves became oriented, to various degrees, perpendicular to the surface of the tissue. Static pressure produced alignment of the connective tissue collagen bundles parallel both to one another and to the surface of the tissue. **Relevance to Veteran Population.** The findings of this study suggest that pressure has a direct effect on the microstructure of human skin. Microstructural alignment may be the precursor to pressure ulcer formation. Identification of the earliest pressure-induced microstructural changes in the tissue might aid pressure ulcer prevention.
Laura E. Edsberg, PhD

Pulmonary function testing in spinal cord injury: Effects of abdominal muscle stimulation

W. Edwin Langbein, PhD; Christine Maloney, MS; Franc Kandare, MS, MD; Uroš Stanič, DSc; Bernard Nemchausky, MS, MD; Robert J. Jaeger, PhD

Purpose of this Work Breathing and coughing are often impaired in spinal cord injury (SCI). In this study the effect of electrical stimulation of paralyzed abdominal muscles on pulmonary function test performance was evaluated. **Subjects/Procedures.** Ten individuals with cervical and thoracic level SCI participated. Subjects inhaled as much air as possible then exhaled into a machine that measured the volume of exhaled air in liters and flow in liters per second. Subjects repeated this test three times with and three times without electrical stimulation of the abdominal muscles. **Results.** Subjects were able to exhale significantly more air and faster when receiving stimulation. **Relevance to Veteran Population.** Pulmonary complications like pneumonia remain a serious health problem for individuals with SCI. In this study electrical stimulation significantly improves pulmonary function test performance. A future challenge will be to determine a method whereby stimulation can be provided when needed by the individual.
W. Edwin Langbein, PhD

Influence of training on biomechanics of wheelchair propulsion

Mary M. Rodgers, PhD, PT; Randall E. Keyser, PhD; Elizabeth K. Rasch, MS, PT; Peter H. Gorman, MD; Pamela J. Russell, PhD

Purpose of the Work. The purpose of this study was to determine if a specific therapeutic exercise training program designed for manual wheelchair users changed biomechanics during propulsion. **Subjects/Procedures.** Biomechanical and physiological measures were collected pre- and posttraining during a wheelchair exercise test to exhaustion on 19 manual wheelchair users. Each subject participated in a specific intervention program of supervised therapeutic exercise (strengthening, stretching, and aerobic exercise) for six weeks. **Results.** After training, subjects used less frequent strokes to maintain the same speed. Increases after training were found in maximum elbow extension angle, trunk and shoulder flexion/extension range of motion, handrim propulsive moment, wrist extension moment, and power output. **Relevance to Veteran Population.** This training program increased biomechanical efficiency without increasing shoulder or elbow joint stresses. Training may be important for veteran manual wheelchair users to decrease long-term overuse injuries.
Mary M. Rodgers, PhD, PT

Performance of an intramuscular electrode during functional neuromuscular stimulation for gait training post stroke

Janis J. Daly, PhD, MS; Kathryn Kollar, BME; A. Anna Debogorski, BME; Beth Strasshofer, PT; E. Byron Marsolais, MD, PhD; Avram Scheiner, PhD; Scott Snyder, PhD; Robert L. Ruff, MD, PhD

Purpose of the Work Many patients with stroke are not able to walk normally even after a good rehabilitation program. Problems with walking can lead to falls, joint pain, inability to care for oneself, and inability to normally participate in leisure activities. A promising, innovative method for restoring normal walking is functional neuromuscular stimulation (FNS) that uses implanted electrodes that are placed beneath the skin for retraining multiple leg muscles. The purpose of this study was to quantitatively document the performance of and patient satisfaction with implanted electrodes used in an FNS system. **Subjects/Procedures.** Seventeen subjects with stroke were provided with the FNS system. For this group, the performance of 124 electrodes was quantified for 1,413.8 electrode-months of use. **Results.** There were no infections. There was a 99% electrode survival rate. Patients improved in strength, coordination, walking ability, and functional capability. There was a 100% patient satisfaction rate with the electrodes and the FNS system. **Relevance to the Veteran Population.** FNS is a promising rehabilitation tool for restoring motor control for stroke patients. The system will be practical for use in both clinical and home environments.
Janis J. Daly, PhD, MS

A reusable, self-adhesive electrode for intraoperative stimulation in the lower limbs

Ronald J. Triolo, PhD; Joshua D. Moss, SM; Niloy Bhadra, MD

Purpose of the Work. This work was undertaken to facilitate stimulation of paralyzed muscle for testing

purposes during surgery. As a muscle contracts in response to electrical stimulation, it is difficult for surgeons to maintain a consistent position of the stimulating electrode with respect to the moving muscle and its nerve supply. A suction-based stimulating electrode was designed and fabricated to allow intraoperative testing of lower-limb muscles during routinely scheduled surgical procedures. **Procedures.** A single-chamber suction electrode consisting of a flexible silicon shell, platinum epimysial stimulating disk, vacuum port, and leadwire was designed and fabricated. An analytical model of the device was developed to predict its performance under load as a function of the volume of evacuated air. Predicted performance was compared to experimentally measured values of adhesion force and preliminary animal tests were conducted. **Results.** The suction device can adhere to a small exposure of muscle surface with reproducible contact forces and can maintain its geometric relationship to the underlying tissue for sufficient time to grade the resulting muscle contraction before removal and repositioning. When operated with a 10-cc syringe, the device can generate between 0 and 23 N of contact force; correlation between measured contact forces and those analytically predicted was 0.989. Preliminary animal testing indicates that the reusable device maintains its position over the nerve entry point even during vigorous active contractions of the stimulated muscle. **Relevance to the Veteran Population.** This device may be a valuable tool useful for locating the optimal site for a permanent electrode for functional electrical stimulation (FES) applications, as well as an ideal means of providing accurate and repeatable stimulation in various locations. Use of such a device should make collecting research data easier and more reliable and implanting stimulating electrodes for clinical FES systems more efficient.

Ronald J. Triolo, PhD

Selectivity of intramuscular stimulating electrodes in the lower limbs

Ronald J. Triolo, PhD; May Q. Liu, MS; Rudi Kobetic, MS; James P. Uhlir, MS

Purpose of the Work. Intramuscular (IM) electrodes have been used safely and effectively for decades to activate paralyzed muscles in neuroprosthetic systems employing functional electrical stimulation (FES). However, the response to stimulation delivered by these and any type of electrode can be limited by a phenomenon known as spillover, in which the stimulus intended to produce a contraction in a particular muscle inadvertently activates another muscle, causes adverse sensation, or triggers undesired reflexes. The purpose of this retrospective study was to determine the selectivity of monopolar intramuscular stimulating electrodes implanted in the lower limbs of individuals with motor and sensory complete paraplegia secondary to spinal cord injury (SCI), and to catalog the most common electrode spillover patterns. **Subjects/Procedures.** The performance records of 602 electrodes from ten subjects with motor complete paraplegia who participated in a program of standing and walking with FES in our laboratory over the past decade were examined. The relative frequency of occurrence of spillover and the observed pattern of spillover activity were catalogued and interpreted to assess the selectivity of IM electrodes in the lower limbs. **Results.** Sixty percent (358) of the electrodes examined were "stable" (i.e., stimulated responses were consistent during the first six months post-implant), and 32 percent of all stable electrodes (113) exhibited spillover. Common spillover patterns for eight muscle groups were tabulated and analyzed in terms of their functional implications. The beneficial (activation of synergistic muscles) or deleterious (activation of compromising reflexes, antagonists or adverse sensation) effects of spillover were highly context dependent, with several potentially useful spillover patterns in certain phases of gait becoming undesirable and limiting in others. **Relevance to the Veteran Population.** Knowledge of the selectivity of intramuscular electrodes and the patterns of spillover they exhibit should guide surgeons and rehabilitationists installing lower-limb neuroprostheses during the implantation process, and allow them to better predict the ultimate functional usefulness of the electrodes they choose.

Ronald J. Triolo, PhD

Effects of stimulated hip extension moment and position on upper-limb support forces during FNS-induced standing—A technical note

Ronald Triolo, PhD; Michael Wibowo, MS; James Uhlir, MS; Rudi Kobetic, MS; Robert Kirsch, PhD

Purpose of the Work. This study explores the effects of active hip extension moment produced by electrical stimulation on the support forces the arms must exert through an assistive device during quiet erect standing with Functional

Neuromuscular Stimulation (FNS) in individuals with spinal cord injuries. The overall goal is to define patterns of stimulation that minimize the bodyweight placed on the upper limbs while standing with FNS. **Subjects/Procedures.** A static sagittal plane biomechanical model of human standing was developed to predict the effects of stimulated hip extension moment and sagittal plane hip angle on the arm support necessary to maintain an upright posture. Two individuals with complete thoracic spinal cord injuries (SCI) were then tested while they stood with continuous stimulation to the knee and trunk extensors. The steady-state active extension moment exerted at the hip was varied by activating different combinations of hip extensor muscles with continuous stimulation while steady-state support forces applied to the arms and feet during standing were measured. **Results.** The steady-state support forces imposed on the arms during quiet standing decrease with increased stimulated hip extension moment and are highly dependent upon hip flexion angle, as predicted by the biomechanical simulations. Experimentally, the combination of gluteus maximus and semimembranosus stimulation produced three times more steady-state hip extension moment than did stimulation of the gluteus maximus and adductor magnus. This resulted in a 10-fold decrease in body weight supported on the arms. More vertical postures (smaller hip flexion angles) improve the effectiveness of the hip extensor muscles in reducing the support forces placed on the arms. **Relevance to the Veteran Population.** Veterans are overrepresented in the SCI population and constitute up to 25% of potential users of FNS systems. This study will guide developers of neuroprostheses and clinicians who will apply them to choose stimulation strategies that optimize standing posture by relieving weight on the upper limbs. To minimize the forces applied by the arms on an assistive device for support while standing with FNS, these preliminary results suggest that (a) efforts should be made to assume the most erect postures possible and (b) muscles and stimulation paradigms that maximize active hip extension moment should be chosen.
Ronald Triolo, PhD

Comparison of two computer-automated procedures for tinnitus pitch-matching

James A. Henry, PhD; Christopher L. Flick, BS; Alison Gilbert, MS; Roger M. Ellingson, MS; Stephen A. Fausti, PhD

Purpose of the Work. The present study evaluated new methods for identifying the perceived tinnitus pitch. The objectives were to reduce testing time and to improve test-retest reliability. **Subjects/Procedures.** Two protocols ("Octave" and "Binary") were developed, each of which was patterned after a documented manual-testing procedure. Both protocols used computer-automation to conduct testing, and the protocols differed according to their specific testing algorithms. Twenty subjects with nonfluctuating tinnitus were each tested over two sessions. **Results.** Both protocols could be used to obtain pitch matches within 20–25 minutes. Reliability of responses was good for some subjects but not for others, and the Binary protocol generally provided more reliable results. **Relevance to the Veteran Population.** A standardized clinical protocol for tinnitus pitch matching does not yet exist. Tinnitus is a significant problem for veterans, and these techniques are intended to lead to standardized methods for clinical assessment of the veteran patient who has severe tinnitus.
James A. Henry, PhD

Reliability of hearing thresholds: Computer-automated testing with ER-4B Canal Phone™ earphones

James A. Henry, PhD; Christopher L. Flick, BS; Alison Gilbert, MS; Roger M. Ellingson, MS; Stephen A. Fausti, PhD

Purpose of the Work. This study was conducted to document test-retest reliability of hearing thresholds using our computer-automated tinnitus matching technique and Etymotic ER-4B Canal Phone™ insert earphones. **Subjects/Procedures.** Repeated thresholds were obtained, within and between sessions, to the nearest 1 dB at 1/3-octave frequencies from 0.5–16 kHz. Testing also evaluated for effects of eartip reinsertion at the octave frequencies. Twenty normal-hearing individuals were evaluated with the use of our fully-automated protocol. **Results.** Responses between-sessions differed by an average of 2.5 dB across all 16 test frequencies, and 91.5% of the repeated thresholds varied within ± 5 dB (98.1% within ± 10 dB). Reliability of within-sessions thresholds was also good. There was no effect of eartip replacement. **Relevance to the Veteran Population.** The techniques documented in this study have particular application for tinnitus testing and for ototoxicity monitoring and are intended for eventual clinical use in VA Audiology Clinics. The ER-4B earphones could be used immediately.
James A. Henry, PhD

Modified constraint induced therapy: A randomized feasibility and efficacy study

Stephen J. Page, PhD; SueAnn Sisto, PhD, PT; Peter Levine, BA, PTA; Mark V. Johnston, PhD; Mary Hughes, OTR

Purpose of the Work. Although efficacious, constraint-induced therapy (CIT) may be difficult to implement in some clinical settings. The purpose of this study is to assess the effectiveness of a reimbursable, outpatient, modified constraint-induced therapy (mCIT) in improving affected upper-limb use and function. **Subjects/Procedures.** The Fugl-Meyer Assessment of Motor Recovery After Stroke, Action Research Arm Test, Wolf Motor Function Test, and Motor Activity Log were administered to six patients > 6 months post-CVA exhibiting stable motor deficits and learned nonuse of the affected limb. Two patients then participated in half-hour physical and occupational therapy sessions 3 times/week for 10 weeks. During the same period, their unaffected arms and hands were restrained 5 days/week during 5 hours identified as times of frequent use. Two other patients received regular therapy and two control patients received no therapy. **Results.** Patients receiving mCIT exhibited substantial increases in affected limb use and function, as well as improved ability to perform valued ADLs in their homes. Patients receiving regular therapy and no therapy exhibited nominal changes. **Relevance to the Veteran Population.** mCIT is indeed a promising, efficacious, and clinically practical alternative to CIT. Furthermore, the therapy could be made accessible to a large number of veterans and bring a higher level of function to veterans who have experienced strokes and exhibited learned nonuse in their affected limbs.

Stephen J. Page, PhD