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About the Journal and Scientific Publishing

The publication of this issue of the American Journal of Physical Medicine and Rehabilitation (AJPM&R) coincides with the celebration of the Annual Meeting of the Association of Academic Physiatrists in San Juan, Puerto Rico. At a time when the Association meets to share new information and deliberate about the future of the field, I would like to use this editorial page to comment on several things related to our Journal that may be of interest to the readership.

Some new events and features of the AJPM&R are worth mentioning. In terms of content, a supplement including the papers presented at the Musculoskeletal Research Conference organized by the National Center for Medical Rehabilitation Research, National Institutes of Health, was published together with the first issue of the AJPM&R in 2007. As the field of physical medicine and rehabilitation (PM&R) makes a concerted effort to strengthen its scientific basis, the main objective of the conference was to develop an agenda for musculoskeletal research. The manuscripts included in the supplement summarize the state of the science and identify important gaps in our knowledge as it relates to the diagnosis, treatment, and rehabilitation of musculoskeletal pain and injury. Another important publication is a commentary on the Asian Perspective of PM&R that will be published in the May issue of the AJPM&R in time for the Fourth World Congress of the International Society for Physical and Rehabilitation Medicine. The congress will be held in Seoul, Korea on June 10–14, 2007. Many countries in Asia have a long-standing tradition in PM&R and have contributed significantly to the expansion of the field in that part of the world. Also, many of our colleagues in Asia are submitting their work for consideration by the editorial board of the AJPM&R. Finally, a four-part special series on poststroke and brain injury rehabilitation will be published beginning with the June issue. These papers, two per issue, address clinical problems that may not be getting enough attention from clinicians in this area and discuss novel approaches to the acute treatment and rehabilitation of these conditions. Do we need to increase blood pressure after an acute stroke?

In terms of presentation and process, we have recently started to add more color figures in selected articles to make the publication more visually attractive and to show details in color that may not be seen in black and white images. With the objective of making new information available more quickly to the reader and to clinicians, selected papers are being published early online before print at www.AJPMR.com. In an attempt to simplify the submission process, an email submission option for sending new manuscripts to journal@physiatry.org is now available as described in the new Instructions for Authors. Also, we are offering the option for authors to publish video clips online as support material to printed manuscripts. This new video feature has been launched with the paper by Stein et al. in this issue of the Journal.

Finally, we have made several changes in the composition of the Editorial Board. In 2006, three Members of the Board have been “promoted” to Associate Editors, including James Atchison (University of Florida, Gainesville), Denise Campagnolo (Barrow Neurological Institute), and James Richardson (University of Michigan). Paul Pasquina (Walter Reed Medical Center) was appointed Member of the Editorial Board, and Moon Suk Bang (Department of PM&R, Seoul National University, South Korea) was chosen as International Editorial Consultant.

With the purpose of increasing the number of non-physiatrists participating in the editorial process and augmenting the expertise in the rehabilitation sciences, we have appointed James Ashton-Miller (Professor of Mechanical Engineering and Director of the Biomechanics Research Laboratories, University of Michigan) and Rory A. Cooper (Paralyzed Veterans of America (PVA) Chair and Distinguished Professor, Department of Rehabilitation Science and Technology, and Director of the Human Engineering Research Laboratories, University of Pittsburgh) as Associate Editors. We are also very happy to announce the appointment of Scott Ward (Professor and Chair, Division of Physical Therapy at the University of Utah, and President of the American Physical Therapy Association) as a Member of the Editorial Board. Scientific diversity is needed on the board to make the Journal even better.

In 2006, the very important discussion about scientific misconduct resurfaced. Misconduct is defined at 42 CFR 50.102 as “fabrication, falsification, plagiarism or other practices that seriously deviate from those that are commonly accepted within the scientific community for proposing, conducting or reporting research. It does not include honest error or honest differences in interpretation or judgments of data.” In a recent editorial, Donald Kennedy, editor of Science, summarized an experience by that very prestigious journal that had resulted from the publication and subsequent retraction of two manuscripts.
with fraudulent data. In his opinion, “the environment for science now presents increased incentives for the production of work that is intentionally misleading or distorted by self-interest.” He recommends that special attention be given to the papers that, although small in number, are likely to be visible and influential. Other more clinically oriented journals, such as the New England Journal of Medicine, also have had to deal with the consequences of scientific misconduct. Clearly, not everyone plays by the rules and follows the scientific code of ethics. Although cases of scientific misconduct have not been an issue in our field, we should maintain a high level of suspicion during the review process to make sure it does not happen. Our vigilance will also prevent scholarly ethical dilemmas such as simultaneous submission of the same manuscript to multiple journals.

The topic of conflict of interest in scientific publishing also received some publicity in 2006. The editor-in-chief of one journal resigned because a published manuscript on which he was an author did not disclosed his ties to the manufacturer of a device that was highlighted in the review paper. Further, all other authors of the paper are paid advisers to the company, and the first draft had been written by a professional writer hired by the company. The editor called it an oversight, but the perception of a conflict is enough to raise concerns. The trust of our colleagues, researchers, and clinicians as well as that of the public on the information published by clinical and scientific journals will depend on the quality of peer-review and on the ability of editorial teams to monitor the process.

See you in San Juan!

Walter R. Frontera, MD, PhD
Editor-in-Chief

REFERENCES
Electromyography-Controlled Exoskeletal Upper-Limb–Powered Orthosis for Exercise Training After Stroke

ABSTRACT


Objective: Robot-assisted exercise shows promise as a means of providing exercise therapy for weakness that results from stroke or other neurological conditions. Exoskeletal or “wearable” robots can, in principle, provide therapeutic exercise and/or function as powered orthoses to help compensate for chronic weakness. We describe a novel electromyography (EMG)-controlled exoskeletal robotic brace for the elbow (the active joint brace) and the results of a pilot study conducted using this brace for exercise training in individuals with chronic hemiparesis after stroke.

Design: Eight stroke survivors with severe chronic hemiparesis were enrolled in this pilot study. One subject withdrew from the study because of scheduling conflicts. A second subject was unable to participate in the training protocol because of insufficient surface EMG activity to control the active joint brace. The six remaining subjects each underwent 18 hrs of exercise training using the device for a period of 6 wks. Outcome measures included the upper-extremity component of the Fugl-Meyer scale and the modified Ashworth scale of muscle hypertonicity.

Results: Analysis revealed that the mean upper-extremity component of the Fugl-Meyer scale increased from 15.5 (SD 3.88) to 19 (SD 3.95) ($P = 0.04$) at the conclusion of training for the six subjects who completed training. Combined (summated) modified Ashworth scale for the elbow flexors and extensors improved from 4.67 ($\pm 1.2$ SD) to 2.33 ($\pm 0.653$ SD) ($P = 0.009$) and improved for the entire upper limb as well. All subjects tolerated the device, and no complications occurred.

Conclusion: EMG-controlled powered elbow orthoses can be successfully controlled by severely impaired hemiparetic stroke survivors. This technique shows promise as a new modality for assisted exercise training after stroke.

Key Words: Robots, EMG, Stroke, Exercise, Hemiparesis
More than 700,000 strokes occur each year in the United States, and there are more than 4.5 million stroke survivors in the population at any given time. Of these, approximately 1 million have substantial disability as a result of stroke.\(^1\) Impaired motor function after stroke has been demonstrated to be a primary contributor to poststroke disability.\(^2\) Although existing rehabilitation programs provide significant benefits with regard to functional independence, these programs have had limited impact on the underlying motor impairment. Outcomes for upper-limb function in hemiparesis caused by stroke are particularly poor.\(^3\)

Rehabilitation programs for hemiparesis after stroke provide therapeutic exercises designed to increase functional independence, attempting to stimulate neurologic recovery and teach compensatory techniques. Although most patients regain their walking ability, 30–66% are no longer able to use the affected arm functionally.\(^4\) It has been found that only 5% of individuals who receive intensive therapy for severe upper-extremity weakness after stroke regain functional use of the upper extremity during the course of rehabilitation.\(^3\) The need for effective rehabilitation for the paretic upper limb after stroke remains largely unmet.

In view of the limited success of traditional rehabilitation programs in restoring upper-limb function after stroke, research has focused on facilitating motor recovery through a variety of novel approaches. Both human and animal studies have established that cerebral plasticity plays an important role in motor recovery.\(^5\)–\(^8\) Studies of exercise to influence motor recovery have demonstrated improved motor abilities and associated changes in metabolic activity and excitability in the cerebral cortex.\(^9\)–\(^11\)

For people with stroke, it has been demonstrated that highly repetitive, task-specific exercise training can facilitate cortical plasticity in the brain, with concomitantly improved motor abilities and enhanced functional activity performance.\(^9\)–\(^12\) A number of techniques have been proposed to facilitate the delivery of this type of exercise therapy after stroke, including constraint-induced movement therapy and robot-aided rehabilitation.\(^13\)–\(^15\)

Robotic devices are of particular interest because they can provide exercise therapies in accurate, reproducible dosages, and they can provide assistance during task training for individuals with more severe weakness after stroke. Furthermore, these devices have the potential to ultimately become an economic complement to traditional, labor- and time-intensive neurological rehabilitation. The best-studied robotic devices for providing upper-extremity exercise after stroke are the MIT-Manus robot and the MIME robot.\(^14\)–\(^21\) Improved motor function has been shown with the MIT-Manus robot in patients early after stroke.\(^17\)–\(^18\)

These improvements were maintained at the time of a 3-yr follow-up study.\(^19\) The MIT-Manus robot also has been shown to provide modest improvements in motor function in people with chronic hemiparesis after stroke.\(^14\)–\(^20\)–\(^21\) Both the MIT-Manus and the MIME robots are stationary training devices, and they cannot be directly incorporated into the performance of activities of daily living in a community setting.

Electromyographic (EMG) signals have been used to trigger robot-assisted exercises and to control powered exoskeletal devices to provide assistance with movement.\(^22\)–\(^25\)

Limitations of these systems include control algorithms that have difficulty correcting for co-contraction of antagonist muscles,\(^23\) fixed (stationary) devices that are not inherently mobile,\(^22\)–\(^23\)–\(^25\) and bulky actuators that are not wearable.\(^24\)

**Device Description**

We have developed a novel device, the active joint brace (AJB), which effectively combines an exoskeletal robotic brace with EMG control algorithms (see Fig. 1). The AJB is a noninvasive, lightweight, wearable system that uses surface EMG signals from affected muscle groups to control a powered orthosis to assist with the movement of a paretic limb. The AJB functions by continuously monitoring the surface EMG signals of the user’s flexor and extensor muscles of the elbow joint. These signals are filtered and processed to infer a desired joint torque. The signal processing of the measured surface EMG is accomplished through a system that comprises off-the-shelf EMG sensors, analog signal–processing components, and digital signal–processing components. All digital signal processing is implemented on a PIC microcontroller, with code written in C.

The signal-processing algorithm enables bidirectional control, from a single degree of input, through the use of a unilateral active assist, combined with a competing passive force.
The EMG sensors used were the BL-AE-W from B&L Engineering. The sensors have a gain of 300, bandwidth of 10 Hz to 3.12 kHz, and >100 MΩ of input impedance. The averaged output of three identical sensor channels was used to control the motor. Analog signal processing is accomplished through a combination of linear and nonlinear filtering elements that act as a signal-conditioning front end to a PIC microcontroller. The analog signal conditioning is similar to a power calculation that selects lower order frequency components of the input signal, in addition to performing antialiasing signal conditioning. The digital signal-processing algorithms implemented in the PIC allow adjustment of the bandwidth of the software system and adjustment of the passive extension force.

The parameter of system gain (amount of assistance in the active assist direction) generally varies during the course of a session as the subject fatigues. The base unit for software gain corresponds to 12 V of motor voltage per volt of surface EMG voltage. The parameter for the passive opposing force was generally constant throughout a study session, usually changing slightly from session to session to account for changes in muscle tone. The parameters were set by study staff each session, using the following procedure. The brace was placed on the arm, in a neutral position (90-degree bend in arm). If the device was in bicep assist mode, the spring was increased until the arm reached close to full extension. At that point, the subject was asked to bring a hand to his or her face. While the subject flexed his or her arm, the gain was increased to the lowest level that would enable controlled movement. If the brace was in triceps mode, the procedure was the same, but with the directions reversed.

These data are used to externally apply a proportional torque in parallel with the existing muscle force (via the actuator and drive train) to assist the user in achieving the desired motion. An electric motor is used to power the device through a system of cables attached to the brace (Fig. 2). A brushed 12-V DC motor was used to move the brace. Torque was transmitted through a throttle cable system of steel cables and flexible cable housing. Separate power supplies were used for motor control and signal processing to eliminate noise.

The device provides active assistance with elbow flexion and extension and allows the user to alternate between these movements without the need to change any device settings. The user’s central nervous system is incorporated into the control loop through a combination of kinesthetic, proprioceptive, tactile, and visual sensory feedback. This allows the user to accomplish position control, with the AJB acting as a forward-loop strength amplifier. The treating therapist (typically the patient’s occupational or physical therapist) can adjust the system parameters to alter the amount of assistance that the device provides. Control algorithms are supplemented with hardware and software safety interlocks to ensure that an excessive amount of force is never exerted on the user’s limb. These include physical limitations in range of motion inherent in the modified off-the-shelf elbow brace used (Bledsoe Brace Systems, Grand Prairie, TX), a motor with a stall torque such that the maximum force that can applied at the hand is 10 lbs, and a back-drivable system.

We hypothesized that stroke survivors with persistent weakness after stroke would be able to safely and effectively control the AJB, allowing them to perform exercise training with the device. We report the results of a pilot feasibility study of exercise training with the AJB for individuals with chronic hemiparesis after stroke.

METHODS

Eight subjects with chronic weakness at least 6 mos after stroke were enrolled in the study. Subjects were required to have weakness and loss of motor control sufficient to interfere with functional use of the upper extremity. Individuals with either ischemic stroke or hemorrhagic stroke were...
Subjects were required to have completed their formal physical and occupational therapy programs before study entry. Exclusion criteria included history of more than one stroke, other neurologic conditions that might affect motor abilities (e.g., Parkinson disease), other medical conditions that were likely to interfere with the ability to complete the protocol, active participation in another research study, and cognitive or perceptual deficits or aphasia sufficiently severe to interfere with the ability to follow instructions and complete the protocol. Subjects were asked to refrain from beginning any new interventions for motor rehabilitation (such as physical or occupational therapy for the arm) during the course of their participation in the study.

Electrodes were placed over the center of the biceps and triceps muscles (location determined by visual estimation). One subject dropped out of the study because of scheduling conflicts. A second subject was found to have insufficient surface EMG activity in the target muscles (biceps and triceps) to control the device. This subject had no clinically evident movement at the elbow (manual muscle testing score of 0/5 at elbow flexors and extensors) and an upper-extremity Fugl-Meyer scale of 6. The data on the six subjects who completed the training protocol were analyzed and are reported here.

The subjects’ descriptive data are provided in Table 1. Subjects underwent a baseline assessment of motor function by a physical or occupational therapist before initiating treatment with the device, and at the conclusion of training. Assessments included measurement of upper-extremity motor function using the Fugl-Meyer scale, measurements of active and passive range of motion at the shoulder, elbow, wrist, and hand, and measurements of muscle hypertonicity using the modified Ashworth scale (MAS).26,27 MAS measurements were made at 14 muscle groups in the affected upper limb. For the purposes of statistical analysis, the MAS values were converted from a 0–4 scale (which includes a value of 1+ between scores of 1 and 2) to a 0–5 scale; the resulting values were summated to obtain an overall score ranging from 0 to 70. Clinical scales were assessed by one of two experienced research therapists; the same examiner performed all measurements for each individual subject.

Training consisted of 2–3 hrs of training per week for a total of 18 hrs of exercise training during a 6- to 9-wk period. Each session consisted of approximately 60 mins of exercise training using the AIB. Exercises consisted of a defined set of functionally oriented upper-extremity tasks tailored to each subject’s motor abilities, such as moving blocks from one area to another or turning a light switch on and off. Subjects performed these motor tasks while using the AIB. Tasks were tailored to the subjects’ distal motor abilities because all subjects had significant weakness and impaired motor control in the hand and wrist. The study was conducted in an open-label fashion.

This study was approved by the institutional review boards of both Spaulding Rehabilitation Hospital and the Massachusetts Institute of Technology. All subjects provided informed consent before participation.

STATISTICAL ANALYSIS

Given the preliminary nature of this feasibility study, no a priori power analysis was performed. Outcome measures were found to have a normal distribution and were analyzed using two-tailed paired t tests.

RESULTS

Training with the AIB was well tolerated by all participants, and no complications of treatment occurred. All users were able to successfully control the device to assist them in elbow flexion and extension movements, with the exception of the one subject who was dropped from the study because of undetectable elbow-flexion and elbow-extension motor control. Motor control, as measured by the upper-extremity portion of the Fugl-Meyer scale, showed statistically significant gains, from a mean of 15.5 (±3.88 SD) before treatment to a mean of 19 (±3.95 SD) at the end of treatment ($P = 0.04$) (Fig. 3).

Measurements of muscle hypertonicity, as measured by the MAS, also demonstrate a decrease

<table>
<thead>
<tr>
<th>TABLE 1 Demographic and clinical data on study participants (data provided only for subjects completing the study protocol)</th>
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<td>Number of subjects</td>
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<td>Mean age</td>
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<td>Gender</td>
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<tr>
<td>Male</td>
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<tr>
<td>Female</td>
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<tr>
<td>Mean (range) duration since stroke, yrs</td>
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<tr>
<td>Mechanism of stroke</td>
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<tr>
<td>Infarct</td>
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<tr>
<td>Hemorrhage</td>
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<td>Side of stroke</td>
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<td>Right</td>
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<td>Left</td>
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<td>Anatomy of stroke</td>
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<td>MCA distribution (infarct)</td>
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<td>Internal capsule/basal ganglia (hemorrhage)</td>
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in the summated MAS for the upper limb as a result of the intervention, from a mean of 19 (±5.21 SD) to a mean of 15.17 (±6.31 SD) ($P = 0.04$). The largest decrease in MAS was in the elbow, with the sum of elbow flexor and elbow extensor tone decreasing from a mean of 4.67 (±1.2 SD) to 2.33 (±0.65 SD) ($P = 0.009$) (Fig. 4). MAS values have been converted to a 0–5 scale.

Subjective impressions of the participants were not formally collected, but anecdotally, virtually all participants found training with the device enjoyable and felt that they experienced meaningful improvement in elbow control and use of the upper limb as a result of participation.

**DISCUSSION**

This pilot study demonstrates the feasibility of using an EMG-controlled powered exoskeletal orthosis for exercise training in stroke survivors. It also provides some preliminary evidence suggesting that the AJB system may be efficacious for improving upper-limb motor function in stroke survivors with chronic hemiparesis.
The size of the improvement found in the upper-extremity component of the Fugl-Meyer scale (3.5 points) is modest in absolute terms, although it represents a 23% increase in this severely impaired sample. Although the minimal clinically important difference for the upper-extremity component of the Fugl-Meyer scale has not been established, this degree of improvement is comparable with that found in other studies of robot-assisted exercise for the upper limb after stroke. Similarly, the magnitude of reduction in muscle hypertonicity at the elbow, as measured by the Ashworth scale, seems to be clinically relevant and to be comparable with the degree of improvement stipulated as significant in studies of other treatments for spasticity.

The data obtained regarding efficacy should be interpreted cautiously. This study was an open-label, uncontrolled trial with a small number of subjects; it was not designed to test efficacy. Potential confounders include placebo/nonspecific effects of medical attention and encouragement, and participation in a formal upper-extremity exercise program for individuals who were not previously active in such a program. A larger study with blinded assessors and appropriate controls is needed to further assess efficacy of this training device and program.

The ability of severely hemiplegic stroke survivors to effectively control a powered exoskeletal orthosis using EMG-based control is itself an intriguing finding. Hemiparesis after stroke is typically considered more of an impairment of motor control than of muscle-force generation. Thus, one might assume that the ability to control the paretic limb would not be enhanced using this technique (which relies on the subject’s own motor control) and provide amplification of force generation. We hypothesize that the role of weakness in impairing motor recovery may be underappreciated. Our population comprised a group of individuals with fairly severe motor impairments of the upper limb, and they were unable to generate much force at the elbow at baseline. Such individuals are unable to practice the use of the limb because of the severity of their baseline impairments. This, in turn, may inhibit their motor recovery. The ability of this device to provide a “power assist” to the hemiparetic muscle groups may help close the feedback loop of brain intention and actual limb movement that is believed to be a key component of cerebral plasticity in motor recovery.

Potential concerns regarding the use of a powered EMG-controlled orthosis for patients with spasticity are addressed only partially in this pilot study. We excluded individuals with marked spasticity in order to minimize the risk of amplifying any involuntary movements. Further studies of subjects with greater degrees of hypertonicity are needed, as are studies of individuals who are at risk of flexor spasms at the elbow (e.g., those with cervical spinal cord injuries).

This type of device has the potential for two distinct therapeutic uses. One use is as an aid for exercise training, as demonstrated in this study. This application could be further subdivided into control and training algorithms targeted at training motor control for stroke, traumatic brain injury, and other central nervous system disorders. The device also could be programmed for resistance training for strengthening exercises, as might be appropriate in patients after injury or orthopedic surgery who do not have upper–motor neuron damage.

A second potential application of this type of device is as a powered brace for functional applications. Individuals with chronic weakness (such as those caused by spinal cord injury, peripheral neuropathy, or myopathy) could potentially use this type of device during their daily activities as a power assist. The goal of this use would be to facilitate performance of daily tasks, rather than as exercise therapy. Further research in this application is needed, as is further development of the device to address issues of portability, ease of application, and comfort.

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Scanning Laser-Doppler Imaging of Leg- and Foot-Skin Perfusion in Normal Subjects
Analysis of Age, Gender, Site, and Laser-Type Effects

ABSTRACT

Objectives: To report normal values of skin perfusion in healthy subjects in three age groups using a laser Doppler imager; to determine differences attributable to gender, age, site, and use of red or near-infrared lasers; and to correlate transcutaneous oxygen with laser flux values.

Design: Flux and transcutaneous oxygen were measured at ten sites in the lower extremity in 60 subjects from three age groups. Heated and unheated sites were scanned with red and near-infrared lasers.

Results: Heat hyperemia was prominent at all sites. Small, statistically significant mean ± SD differences were found between heated and unheated sites for the red and near-infrared lasers (P = 0.02). All flux ratios were independent of gender but were higher in the oldest group. Plantar sites demonstrated higher flux in unheated areas and lower flux ratios compared with leg sites. Transcutaneous oxygen did not correlate significantly with flux for either laser type.

Conclusions: Scanning laser-Doppler imaging flux values provide a reference for identifying patients at risk for tissue ischemia and poor healing potential caused by impaired circulatory reserve in the legs and distal feet. The lack of correlation between flux and transcutaneous oxygen in healthy individuals suggests that they measure different physiologic processes.

Key Words: Microcirculation, Laser Doppler Flowmetry, Rehabilitation, Wound Healing
More than 100,000 amputations are performed in the United States per year. Many of these are consequences of critical limb ischemia, especially in patients with arteriosclerosis and diabetes. One of the challenges of amputation surgery is the accurate limb-level selection. Because of poor assessment of blood flow before procedures, surgical wounds fail to heal, and patients may need to undergo revisions at a more proximal site. Therefore, the most successful procedures in these patients require an accurate initial assessment of skin perfusion.

Radioisotope clearance has been used to evaluate skin blood flow. This technique can be expensive, invasive, and time consuming. Laser Doppler flowmetry uses fiberoptic probes to study tissue microperfusion of small single sites at rest and in response to a local thermal challenge. It has been used to assess lower-extremity blood flow, amputation level, and wound healing.

The scanning laser-Doppler imaging (LDI) technique uses the same principles as laser Doppler flowmetry, but it has the advantages of sampling large areas rather than single points without direct skin contact. This technique has been used in dermatology to measure burn depth and the effects of drugs, inflammation, and other skin conditions. However, despite having clear advantages over other methods of measurement, LDI has not been systematically used for the evaluation of peripheral arterial disease (PAD). There is a need to further investigate the usefulness, effectiveness, and validity of scanning LDI to assess blood flow and healing potential in patients with PAD and in patients requiring amputation.

$TcPO_2$ values have a demonstrated use for identifying sites with a good prognosis of healing, sites associated with healing complications, and sites associated with postoperative “failure.” Some investigators have reported both $TcPO_2$ data and laser Doppler data; however, none have correlated the results of the methods in the same sites over extensive sampling of leg and foot sites. The $TcPO_2$ method can be time consuming for the clinician and the patient. LDI scanning is a promising technique for determining prognosis for postoperative wound healing because it is relatively rapid, noninvasive, and painless.

One of the current limitations of using the LDI technique is the lack of reported normal values and method standardization. The purposes of this study are to (1) determine normal values of skin blood flow (flux) in response to skin warming in healthy subjects in three age groups using LDI, (2) determine differences attributable to gender, age, site, and use of red or near-infrared (NIR) lasers, (3) estimate test–retest reliability, and (4) correlate LDI flux with $TcPO_2$ values. The use of LDI as a rapid, noninvasive, and accurate method of assessing skin perfusion would help guide surgeons to make accurate initial decisions regarding amputation level and avoid postsurgical complications and the need for reamputation brought about by poor wound healing.

**METHODS**

**Subjects**

A convenience sample of 60 healthy adults was performed in three age groups of 20 subjects each (20–39, 40–59, and 60–79 yrs old). The 20- to 79-yr-old age range (with three subgroups at 20-yr intervals) was chosen to represent the average adult life span. Written informed consent, approved by the medical center’s institutional review board, was obtained from subjects before their participation in this study. Prospective subjects completed an extensive self-report health survey (see Appendix 1). On the health survey, if subjects reported a history of diabetes mellitus, Raynaud’s or other PAD, leg amputation, skin disease, coronary artery disease, cerebral vascular accident, dyslipidemia, hypertension, smoking, edema, or rest/exercise leg pain, they were excluded from the study. Subjects also were asked to report any medications they were currently taking and were excluded from entering the study if they listed any medications typically used to treat the above conditions, such as hypoglycemic and antiplatelet agents, lipid-lowering drugs, antihypertensives, or antiarrhythmics and cardiovascular medications; they also were excluded if they were on any cardiovascular medications such as antihypertensives or antiarrhythmics or if they reported a history of diabetes mellitus, Raynaud’s or other PAD, leg amputation, skin disease, coronary artery disease, cerebral vascular accident, dyslipidemia, hypertension, smoking, edema, or rest/exercise leg pain. Resting blood pressure was assessed before testing.

**Instrumentation**

A Moor laser Doppler imager (Moor Instruments, Ltd., Devon, England) with red (633 nm) and NIR (830 nm) laser beams was used for measurements of skin perfusion. With this instrument, laser light is projected onto the skin by a computer-controlled mirror in a raster pattern. A portion of the back-scattered laser light is detected as “flux,” representing the product of red cell velocity (calculated from the Doppler shift of the back-scattered light) and the red cell concentration (often referred to as blood volume). Flux is expressed in arbitrary perfusion units and is calculated using the first moment of the power spectral density. Five identical $TcPO_2$ monitors were used to heat skin...
and monitor TcPO₂ (TCO₂M, model 860, Novametrix Medical Systems, Wallingford, CT).

**Testing Procedures**

Each subject was brought to an environmentally controlled testing room. Subjects were offered safety goggles before laser scanning to prevent damage to their eyes from stray laser radiation. Ten sites in either the right or the left lower extremity (leg randomly selected by a coin toss) were designated as follows:

1. plantar surface over the first metatarsophalan-geal (MTP) joint,
2. plantar surface over the fifth MTP joint,
3. dorsal surface over the first MTP joint,
4. dorsal surface over the fifth MTP joint,
5. lateral surface over the leg at a site two thirds of the distance from the fibular head to lateral malleolus (lateral distal leg),
6. lateral surface over the leg at midpoint between the fibular head and the lateral malleolus (lateral middle leg),
7. lateral surface over the leg at one third of the distance from the fibular head to lateral malleolus (lateral proximal leg),
8. anterior surface over the leg at a site two thirds of the distance from the fibular head to lateral malleolus (anterior distal leg),
9. anterior surface over the leg at midpoint between the fibular head to lateral malleolus (anterior middle leg), and
10. anterior surface over the leg at a site one third of the distance from the fibular head to lateral malleolus (anterior proximal leg).

Probes on leg sites were placed anteriorly over the tibialis anterior and laterally over the peroneal and lateral gastrocnemius muscles. On the foot, probes were placed on flat areas from which probes would not easily detach. The sites were arbitrarily chosen for accessibility to TcPO₂ and LDI evaluation and for their broad topographic distribution (proximal–distal leg; medial–lateral and dorsal–plantar foot).

Initial skin temperatures (before probe was applied) and final skin temperatures (immediately after probe removal) were measured at each site with a handheld infrared thermometer, because skin perfusion is known to increase nonlinearly with an increase in skin temperature, especially with temperatures above 33°C.23

Skin sites were cleaned with alcohol wipes, skin hair was shaved with a razor when necessary, and the TcPO₂ probes were placed tightly on the skin site to provide an airtight seal using specially designed adhesive rings. Subjects rested in the semirecumbent posture on a hospital bed for foot and anterior leg measurements and side-lying posture for lateral leg measurements. Then, each skin site was warmed with TcPO₂ probes to 44°C (111°F). While waiting for the TcPO₂ probe to warm up the skin surface, the LDI laser head was aligned perpendicularly to the skin sites. The area to be scanned was outlined by the laser beam before actual laser Doppler scanning to be certain that all the probes were contained in the scanning area.

TcPO₂ values were recorded every 2 mins. Immediately after TcPO₂ readings reached a steady state (defined as unchanged values for two consecutive measurements), the probes were removed. The surface temperature measured and the site including the heated and surrounding unheated areas was scanned using the red and NIR lasers of the LDI. The length of time for TcPO₂ to reach steady state ranged from 11 to 117 min, varying by site and region. The region over plantar surfaces took significantly longer to reach steady state in comparison with all other regions on the leg and foot. The time lapse between the removal of the probes and the completion of the LDI scanning averaged 1 min. The typical area scanned in the foot measured 8 × 4 cm and, in the anterior and lateral leg, 14 × 4 cm. The distance between the LDI laser head and the skin sites was adjusted from 30 to 50 cm to provide the area necessary for scanning.

**Retesting**

To assess the test–retest reliability of LDI measurements, 15 subjects (five from each age group) were retested. Retest subjects were randomly chosen by paper lots. Each lot identified the name of the subject, and, together, they formed a pool of all study participants. As each lot was drawn blindly by the pool by an investigator, it was assigned a number from 1 to 60 in order of its draw and was then placed into one of the study’s three age groups reflecting the age of the selected subject. After all lots had been drawn and assigned, from each age group, the first five subjects determined by the order of their draw were selected for retesting. If, for any reason, a subject was unavailable for retesting, the next subject in order of assignment from the same age group was selected, until five subjects from each age group were retested. Time elapsed between test and retest ranged from 2 wks to 6 mos. Skin perfusion was assumed to be a stable physiologic phenomenon in our healthy subjects.

**Data Analysis**

Each site was scanned with the heating probe on the skin and immediately after the heating probe had been removed from the skin. To determine flux values, the image produced by LDI was viewed on a computer monitor. LDI software pro-
duced a color-coded image of skin perfusion and a black and white image of optical density that was used to identify the limits and position of the heating probes. A polygonal region of interest (ROI) (greatest diameter = 10 mm) was manually drawn around the probe image, saved, and then used on the perfusion image to collect perfusion data (mean of all pixels’ flux values within the ROI) at the heated site (location of the heating probe) and at three adjacent nonheated sites (Fig. 1). Images with streaks of high flux values within nonheated areas, presumed to be blood vessels, were avoided. Flux ratios were calculated as the mean flux in the heated ROI divided by the mean flux in the three adjacent unheated ROIs. As such, the flux ratios represent the number of multiples of perfusion resulting from maximal vasodilation of skin above the nonheated condition.

In Figure 1, the measurement of flux in the heated zone may seem to be inaccurate as the image is clearly saturated over the heated region. The Moor LDI system frequently displays the pixels within the heated area as “white,” representing the highest range of flux values. However, the heated area consists of numerous pixels of varying flux magnitudes; therefore, white areas are not necessarily fully saturated.

Because this study aimed to determine normal values of skin flux in response to skin warming, TcPO₂ electrodes were used to topically heat the skin to 44°C (111°F). Heating to 44°C causes a temperature-dependent microstructural change from solid to liquid of the lipid phase of the stratum corneum,

![FIGURE 1 Laser Doppler image showing a heated region of interest (center) and three nonheated regions of interest.](image)

Alternative stressors might also include exercise or ulceration that increase the metabolic and circulatory demand on the skin tissue, but topical heating is the safest and most feasible.

Statistics

The statistical software NCSS (Number Cruncher Statistical System 2001, NCSS, Inc., Kaysville, UT) was used for all calculations, and alpha was preset at 0.05 for all statistical hypothesis testing. Descriptive statistics (mean ± SD) were calculated for flux of heated and nonheated sites, flux ratios, and TcPO₂. For the dependent variables of mean flux of heated and nonheated areas and flux ratio, a four-factor mixed-model analysis of variance (ANOVA) and post hoc Tukey–Kramer multiple comparison tests were used to determine the main effects and interactions for skin site (ten sites), laser wavelength (red vs. infrared), age group (ages 20–39, 40–59, and 60–79) and gender (male vs. female). Additionally, separate three-factor mixed-model ANOVAs for each laser (red vs. NIR wavelength) were used to determine main effects of skin site, age, and gender, with Tukey–Kramer tests. For the dependent variable of TcPO₂, a one-factor repeated-measures ANOVA was used to determine differences among sites.

Two approaches were used for assessing test–retest reliability of flux ratios and TcPO₂ values: (a) linear regression and Pearson correlation of paired values of tests 1 and 2, and (b) Bland–Altman plots of the difference between values obtained in tests 2 and test 1 as a function of the average of both tests. Group values for each site were used in the regression analysis and individual values of tests for the Bland–Altman approach. In addition, the NIR laser mean flux ratios from both tests were compared, using paired t tests.

RESULTS

Demographics

Subjects’ mean age and age ranges for each of the three groups and the breakdown of subjects by
age group, gender, and ethnicity are shown in Table 1. More female participants were found in group 3 in comparison with the other two, younger-aged groups. Caucasian females comprised the largest subject pool (35%; n = 21); the second largest were Asian males (17%; n = 10).

**Flux Data**

ANOVA indicated significant effects of the skin site and laser wavelength on the mean flux of unheated and heated skin areas and on flux ratios. Age was also a significant factor, with mean ± SE flux ratio values of the 60- to 79-yr-old group (8.9 ± 0.17) significantly higher than the 20- to 39-yr-old (8.1 ± 0.17) and 40- to 59-yr-old (8.1 ± 0.17) groups. The mean flux ratio for all sites and groups measured with the NIR laser (8.6 ± 0.14) was significantly higher than with the red laser (8.1 ± 0.14). No significant effect of gender on mean flux of unheated areas or flux ratios was detected. However, mean flux for heated areas for females was significantly higher ($P < 0.004$) than for males (males: 300.4 ± 5.9 for males vs. 324.3 ± 5.4 for females).

Mean flux and flux ratio values from all subjects in each of the ten measured sites are depicted in Table 2 for the red laser and in Table 3 for the NIR laser types. For both laser types, plantar first MTP and fifth MTP sites showed significantly higher unheated means in comparison with all leg sites. Because the heated flux values of plantar sites were not significantly greater than for any of the leg sites, plantar flux ratios were significantly lower than the ratios for the leg sites. No significant differences were found among flux ratios of the six leg sites. Mean ± SE flux ratios measured with the NIR laser for the three age groups are depicted in Figure 2.

Initial and final skin temperatures at test sites showed significant ($P < 0.05$) differences among the ten skin sites. Before and after heating, foot temperatures (unheated means 29.3–30.0°C; heated means 34.9–36.4°C) were slightly lower than leg temperatures (unheated means 30.1–31.1°C; heated means 37.3–38.0°C). Unheated flux and skin temperature before heating correlated significantly but weakly ($r = 0.226$, $P = 0.000$), supporting previous findings that skin temperature is nonlinearly related to

### Table 1 Subject demographics

<table>
<thead>
<tr>
<th>Age Group, yrs</th>
<th>20–39</th>
<th>40–59</th>
<th>60–79</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Age, yrs</td>
<td>32.4</td>
<td>49.8</td>
<td>66.7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Numbers of subjects per gender, age group, and ethnic group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
</tr>
<tr>
<td>--------</td>
</tr>
<tr>
<td>Caucasian</td>
</tr>
<tr>
<td>African American</td>
</tr>
<tr>
<td>Asian</td>
</tr>
<tr>
<td>Pacific Islander</td>
</tr>
<tr>
<td>Hispanic (non-Caucasian)</td>
</tr>
<tr>
<td>Total per gender</td>
</tr>
<tr>
<td>Total per age group</td>
</tr>
</tbody>
</table>

### Table 2 Mean (±SD) red laser fluxes and ratios by sites for all subjects

<table>
<thead>
<tr>
<th>Site</th>
<th>Unheated Mean Flux</th>
<th>Heated Mean Flux</th>
<th>Mean Flux Ratios</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plantar first MTP</td>
<td>80.6 (79.0)</td>
<td>320.1 (197.7)</td>
<td>5.1 (2.54)</td>
</tr>
<tr>
<td>Plantar fifth MTP</td>
<td>75.4 (67.4)</td>
<td>273.1 (187.2)</td>
<td>4.6 (2.46)</td>
</tr>
<tr>
<td>Dorsal first MTP</td>
<td>59.0 (32.9)</td>
<td>418.0 (166.2)</td>
<td>8.5 (4.0)</td>
</tr>
<tr>
<td>Dorsal fifth MTP</td>
<td>53.1 (30.2)</td>
<td>345.1 (156.0)</td>
<td>7.6 (3.7)</td>
</tr>
<tr>
<td>Lateral distal leg</td>
<td>37.8 (18.1)</td>
<td>324.3 (122.5)</td>
<td>9.5 (3.5)</td>
</tr>
<tr>
<td>Lateral middle leg</td>
<td>44.1 (21.0)</td>
<td>333.7 (120.6)</td>
<td>8.4 (3.2)</td>
</tr>
<tr>
<td>Lateral proximal leg</td>
<td>48.6 (22.5)</td>
<td>370.9 (153.7)</td>
<td>8.5 (3.7)</td>
</tr>
<tr>
<td>Anterior distal leg</td>
<td>41.0 (28.5)</td>
<td>356.8 (156.2)</td>
<td>10.3 (3.8)</td>
</tr>
<tr>
<td>Anterior middle leg</td>
<td>40.8 (25.3)</td>
<td>320.0 (121.2)</td>
<td>9.1 (3.4)</td>
</tr>
<tr>
<td>Anterior proximal leg</td>
<td>44.6 (31.1)</td>
<td>320.6 (115.5)</td>
<td>8.6 (3.3)</td>
</tr>
</tbody>
</table>

Unit of measurement for flux is arbitrary perfusion unit (PU). MTP, metatarsophalangeal joint.
perfusion. Heated flux and skin temperature after heating did not significantly correlate \((r = -0.017, P = 0.684)\). Hence, flux was not dependent on skin temperature after heating.

**TcPO₂ Data**

The mean values of the steady-state TcPO₂ before LDI scanning for each site are listed in Table 3. No differences were found in these values among leg sites, but mean values of the two plantar sites in the foot were significantly lower than any other site, and below those values given as a reference for detection of critical limb ischemia. Moreover, 14 and 18 out of 60 subjects had a TcPO₂ of zero over the first MTP and the fifth MTP sites, respectively. Linear regression comparison of the last recorded mean TcPO₂ to mean heated flux magnitude showed no significant correlations for either laser type at any site, except for the dorsal first MTP site \((r = 0.268, P = 0.044)\).

### Reliability

Five subjects (25%) of each group \((n = 15)\) were selected randomly for reliability analysis. One subject’s retest data were invalid because of technical difficulties, so the retest sample size was \(n = 14\). Regression analysis indicated high Pearson correlation coefficients between the first and second tests (flux ratio = 0.96; TcPO₂ = 0.98). The regression slope was not significantly different from one, and the regression ordinate intercept was not significantly different from zero. The Bland–Altman approach indicated a lack of dependence of differences between tests 2 and 1 on the average of tests 2 and 1, with differences clustering around zero for both variables (Figs. 3 and 4). Paired \(t\) tests to

<table>
<thead>
<tr>
<th>Site</th>
<th>Unheated Flu</th>
<th>Heated Flux</th>
<th>Flux Ratios</th>
<th>TcPO₂ (mm Hg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plantar first MTP</td>
<td>63.6 (48.2)</td>
<td>308.0 (195.8)</td>
<td>5.6 (2.9)</td>
<td>13.7 (18.1)</td>
</tr>
<tr>
<td>Plantar fifth MTP</td>
<td>63.8 (54.4)</td>
<td>271.7 (189.5)</td>
<td>4.8 (2.1)</td>
<td>9.8 (13.1)</td>
</tr>
<tr>
<td>Dorsal first MTP</td>
<td>50.9 (26.1)</td>
<td>358.6 (131.2)</td>
<td>8.1 (3.7)</td>
<td>56.7 (13.8)</td>
</tr>
<tr>
<td>Dorsal fifth MTP</td>
<td>42.1 (19.6)</td>
<td>285.3 (111.8)</td>
<td>7.6 (3.5)</td>
<td>51.1 (11.4)</td>
</tr>
<tr>
<td>Lateral distal leg</td>
<td>30.8 (11.7)</td>
<td>283.5 (85.3)</td>
<td>10.1 (3.7)</td>
<td>57.9 (12.1)</td>
</tr>
<tr>
<td>Lateral middle leg</td>
<td>35.7 (13.7)</td>
<td>294.5 (78.1)</td>
<td>9.3 (3.6)</td>
<td>58.1 (12.2)</td>
</tr>
<tr>
<td>Lateral proximal leg</td>
<td>37.6 (12.9)</td>
<td>309.9 (85.8)</td>
<td>9.0 (3.3)</td>
<td>55 (10.5)</td>
</tr>
<tr>
<td>Anterior distal leg</td>
<td>29.4 (11.3)</td>
<td>297.5 (94.7)</td>
<td>11.0 (3.6)</td>
<td>55.8 (16.2)</td>
</tr>
<tr>
<td>Anterior middle leg</td>
<td>29.4 (11.7)</td>
<td>263.1 (68.4)</td>
<td>9.7 (2.8)</td>
<td>51.7 (14.0)</td>
</tr>
<tr>
<td>Anterior proximal leg</td>
<td>29.4 (10.1)</td>
<td>262.6 (80.8)</td>
<td>9.5 (3.1)</td>
<td>50.1 (14.5)</td>
</tr>
</tbody>
</table>

Unit of measurement for flux is arbitrary perfusion unit (PU). MTP, metatarsophalangeal joint.

![FIGURE 2](image)
compare means of the first and second tests for each skin site indicated no significant differences for any of the sites or variables.

**DISCUSSION**

To date, normal value parameters for the lower extremity using the scanning LDI have not been published. In our study, no consistent differences between leg sites in heated or unheated skin flux or ratios were found, but lower flux ratios were found for the plantar and dorsal foot sites compared with the leg sites. This was attributed to higher mean flux values of unheated areas obtained on the plantar and dorsal sites coupled in a ratio calculation with mean flux values after heating that were comparable with those for the leg sites. This observation could be explained by known pressure-induced vasodilatation that is higher at the plantar areas of the foot; this has been recently reported as a protective response to mechanically induced pressures in the human skin.26

Few studies comparing laser wavelengths and perfusion values have been published to date. The Moor LDI is capable of measuring flux using red and NIR simultaneously. Bray et al.27 report that red and NIR wavelength photons provided similar blood-flow information in 20 patients with hypertrophic burn scars. Their study reportedly repre-

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**FIGURE 3** The differences in flux ratios (near-infrared laser, NIR) between tests 1 and 2 are plotted against the means of both tests for each site in 14 subjects in the reliability study. The slope and ordinate intercept of the linear regression of differences on means for all data points (solid line) were not significantly different from zero. The two dotted lines represent two SDs above and below the mean difference for all data points.

**FIGURE 4** The differences in TcPO2 between tests 1 and 2 are plotted against the means of both tests for each site in all 14 subjects in the reliability study. The slope and ordinate intercept of the linear regression of differences on means for all data points (solid line) were not significantly different from zero. The two dotted lines represent two SDs above and below the mean difference for all data points.
sents multiple ethnicities and quantifies color differences in burn scars.

Our study shows a significant overall difference between measured flux values for red and NIR wavelengths. We did not include subjects with any skin diseases, scarring, edema, or lesions in our ROI. The NIR laser consistently showed lower mean flux values at unheated and heated areas. This gave overall higher values for flux ratios in most sites except for the dorsal foot. However, within each laser type, the flux ratio trends were sustained for each site. Even though subjects from several ethnic groups were represented in our study, there was a preponderance of Caucasians and Asians. Previous studies on laser Doppler flowmetry and race have shown no significant differences when comparing Caucasians with Hispanics, or Caucasians with blacks. Skin pigment was not quantified in our study, but most of the participants had fair skin. Our data suggest that either laser would be adequate for the evaluation of skin perfusion, provided that the corresponding normal values are used for comparison. We have thus provided normal values for red and NIR laser types. Indications for a particular laser type for a clinical situation have not been determined, and further studies evaluating effects of skin pigmentation on flux values are warranted.

We anticipated a decrease in heat vasodilation, as measured by flux ratio, with advancing age. However, only some sites showed statistically significant differences in flux ratios among the three age groups. Although the differences were small, the older group in each case had the highest values. These results suggest that healthy aging per se may not be a contributing factor to impaired cutaneous circulation. Previous studies also support this finding. Age may have an effect in slowing vasodilation, but this was not evaluated in our study.

Previous research regarding gender has shown men to have slightly higher skin microcirculation than women, but this has been controversial and incompletely studied. In this study, no significant differences in flux ratios between genders were observed. There were more women in our study than men because of the predominance of women in the highest age group of 60–79 yrs. The younger two age groups were closely matched for gender.

Repeat testing on 25% of our total subject sample showed no significant difference in mean flux ratios or TcPO2 values between two tests. Although repeat tests were completed weeks to months after initial testing and by different testers, values were consistent across all ten sites. This provides confidence that the data presented are independent of intertester variation. The results we obtained with TcPO2 evaluated with the Bland–Altman approach are remarkably similar to those previously obtained by de Graaff et al.

In this study, attempts were made to control for circulatory variations that could have been caused by physical and mental stressors that disturb metabolic and circulatory steady states. It is conceivable that subjects had subclinical or undiagnosed diseases that were not reported on their intake questionnaires. However, no compensation was associated with participation, making it unlikely that information would have been manipulated for secondary gain.

Other limitations to this study include the small subject sample, which was relatively more homogeneous than the population at large. Most of our subjects were women of Caucasian and Asian ancestry and were under the age of 60. If prospective subjects were not aware of or honest about their health status, it was also possible that some subjects with subclinical PAD may have been included in the sample.

It is interesting to note that in many subjects, TcPO2 levels approached zero at the two plantar foot sites, and the means of TcPO2 in these sites were below the level generally considered an indication of severe ischemia. This observation invalidates the use of TcPO2 for the study of ischemia on the plantar surface of the foot, the most frequent site of lower-extremity ulceration in PAD. In contrast, LDI flux of unheated areas was highest in the plantar sites, and the ratios were always positive. LDI flux determination could replace TcPO2 in the study of skin blood flow of the feet.

LDI values did not correlate with TcPO2 values in healthy subjects at any of the ten tested sites. This contradicts findings in studies of subjects with PAD, and it may be explained by the fact that local blood flow correlates with TcPO2 only at low levels of skin perfusion. The variations observed in TcPO2 values in our results could be attributable to diffusion factors rather than perfusion levels. The low TcPO2 levels recorded at the plantar foot surface could be explained by the greater thickness of the epidermis in this area, averaging 0.5–1.4 mm compared with 0.04–0.1 mm for the leg.

The perfusion values reported in this study from healthy adults indicate that the variability associated with each mean value is large, with coefficients of variability ranging from 29 to 52% for LDI flux ratios and from 29 to 134% for TcPO2. Therefore, comparison of these values against those from a specific patient with compromised lower-limb perfusion may be problematic. More meaningful normal values may be those measured on the clinical patient near heart level. Within the same patient, these values should only be compared with more distal compromised values, provided that the same type of laser was used in both
measurements. Although our results do not specify the normal perfusion values for PAD patients, statistical norms for healthy adults are presented. Our results suggest that LDI flux ratios > 2 SDs below the mean may indicate statistical abnormality. Further research is necessary to correlate clinically the signs/symptoms and severity of PAD with the magnitude of LDI flux ratio.

CONCLUSION

Normative values for hyperemic skin blood-flow responses to thermal stress derived from 60 healthy adults in three age groups were presented as mean flux and mean flux ratios for ten lower-extremity sites. Flux ratios at all sites were independent of gender, but they were higher in the 60- to 79-yr-old age group. The leg presented higher flux ratios and lower baseline flux values than the plantar and dorsal foot sites. Consistent and small differences between red and NIR wavelength lasers at the leg sites indicate that either laser may be clinically acceptable if contrasted to respective normative values. The results from this study provide a reference of normal values that can be compared and contrasted with findings from future studies of patients with known PAD in the legs and feet. This study also shows that there is no correlation between flux and TcPO$_2$ values in healthy individuals, indicating that the source of variance for the two methods may be based on different processes. Thus, TcPO$_2$ cannot be used as an estimate of perfusion in subjects without ischemia. Because the values of flux of heated areas recorded by LDI in the group with a maximal heating time of 15 mins was not different from longer times, a period of 15 mins is considered appropriate for evaluation of skin perfusion with this methodology. More research is needed to determine LDI values in patients with ischemia, if such data can help determine levels of amputation consistent with successful wound healing and rehabilitation outcome.

ACKNOWLEDGMENTS

We gratefully acknowledge the Physical Medicine and Rehabilitation Service at the VA West Los Angeles Healthcare Center for use of facilities, staff, and supplies.

REFERENCES

APPENDIX 1.

LASER-DOPPLER HEALTH INTAKE SURVEY

Contact Information

Name: ____________________________ SSN: ____________________________ Date: ____________________________
Home Address: ____________________________ Fax: ____________________________ Email: ____________________________
Phone: ____________________________ In case of emergency, contact: ____________________________ Phone: ____________________________

Demographic Information

Date of Birth: ____________________________ Age: _______ Race/Ethnicity: ____________________________ Sex: ____________________________

Highest Education: Level (check one):

___< High School Diploma/GED
___High School Diploma/GED
___Vocational Certificate
___Associate Degree
___Baccalaureate Degree
___Doctoral Degree

Annual Gross Income Category:

___< $10,000
___$10,000-$25,000
___$25,000-$50,000
___$50,000-$75,000
___$75,000-$100,000
___> $100,000

Medical Information

Estimated Height (inches): ____________________________ Estimated Weight (lb.): ____________________________

Do you have any of the following? (Please check all that apply. Please ask a member of the research team if you have any questions about these conditions.)

___High blood pressure
___High cholesterol
___Stroke
___Peripheral vascular disease
___Ankle/leg swelling
___Amputation: If Yes, please describe: ____________________________
___Raynaud’s disease
___Pain in leg at rest or during walking/exercise
___Skin disease. If Yes, please describe: ____________________________
___History of smoking. If Yes, when was the last time you smoked?

Please list any other medical problems: ____________________________

________________________________________

________________________________________

________________________________________

Please list any medication(s) that you are currently taking:

________________________________________

________________________________________

________________________________________

April 2007

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Recovery Preference Exploration
Analysis of Patient Feedback After Imagined Scenarios

ABSTRACT

Objective: To present a new assessment approach, referred to as recovery preference exploration (RPE), for exploring the personal meaning of functional loss and recovery. RPE determines how people would choose to recover from profound disability if they could control that recovery.

Design: Twenty-six patients with a variety of medical conditions and one or more limitations in the functions being addressed were recruited from an inner-city ambulatory care clinic. The patients imagined recovery from 15 functional limitations, beginning with severe problems in all functions and ending with complete independence. Individual-specific preferences for recovery in each function were calculated relative to the other 14 and were submitted for principal components analyses.

Results: Imagined difficulty in toileting and with depression were most troubling. Principal components analyses identified trade-off choices among domains of physical, psychological, and social functioning. Some people valued physical independence above psychological well-being or social abilities. Others had opposite patterns. Patients’ narrative explanations, when triangulated, were consistent with their preferences.

Conclusion: RPE makes visible the highly personal nature of feelings about ability and disability. Our results may help guide the selection of rehabilitation interventions in ambulatory care.

Key Words: Rehabilitation, Quality of Life, Decision Support Techniques, Physician–Patient Relations
The medical anthropologist Gay Becker writes, “Discontinuities in life force individuals to reconstruct their biographies... a health biography includes highly personal and particularized memories, conceptions and meanings of events, pain, and discomfort, experiences of past illnesses, and health-care experiences. Identity is fluid, not static... different illnesses have different effects on identity.” The biomedical model places its highest value on those scientifically reproducible outcomes that are perceived as most useful for guiding practice. However, complete reliance on such data may disconnect care from patients’ perspectives and values. There is insufficient time during the typical patient encounter to extract health biographies. Consequently, standardized measures of function and health-related quality of life (HRQL) have emerged to quantify the influence of illness on overall well-being. Such measures typically express a patient’s level of physical, mental, and social functioning.

Measuring physical, mental, and social functioning alone is insufficient when attempting to understand implications to well-being. A man can describe moderate difficulties moving inside his home, but this says nothing about how he sees such an experience influencing his quality of life. Theoretically, each HRQL domain has both objective (status related) and subjective (value laden) qualities. Although objective status is commonly addressed in rehabilitation practices and research, the subjective meaning of that status is typically not addressed because it is intrinsically more abstract. Subjective meaning is described, but it is left unmeasured.

We introduce an innovative procedure called recovery preference exploration (RPE) as a process for visualizing the subjective meaning of functional status. RPE works by inducing a state akin to decentering. Decentering applied in social psychology and family therapy is a technique through which a person is encouraged to set aside his or her own point of view and take the point of view of someone else in a completely different circumstance. In family therapy, decentering is intended to help one member understand and empathize with another member of the family. In contrast, with RPE, the patient is asked to keep his or her own point of view but to imagine what life would be like if he or she had complete disability according to a specified set of functional activities. This process of partial decentering is intended to inspire empathy—not necessarily for others, but for oneself. After imagining complete disability, the patient ranks each activity according to how he or she would want to recover and provides rationale for the rankings.

We address the following questions through RPE: do the value-laden constructs of meaningfulness reflect the classical physical, psychological, and social status–related domains of HRQL? To what degree are concepts of meaningfulness unique to each individual? Finally, we discuss how RPE might be applied to enhance the depth of discussion about therapeutic decision making in general ambulatory care and rehabilitation practices.

**METHODOLOGY**

**RPE Procedures**

**Theoretical Framework**

Reality is constituted by attributing meaning to life experiences, partly through interacting with others. As authoritative figures, physiatrists and other rehabilitation professionals are, rightly or wrongly, in a position to influence a patient’s reaction to the functional sequelae of illness. Informed by clinical training and practice, the clinician’s viewpoint may be at odds with the patient’s view. By increasing the depth of discourse between patients and clinicians, the exploration of recovery preferences moves outside professional concepts to extract the implications of functional loss and recovery from the patient’s vantage point.

RPE is an emerging therapeutic tool with a foundation in concepts of phenomenology. It is intended to clarify the meaning of disability and symptoms as phenomena experienced or observed in the lived and highly personal state. RPE is derived from the first part of the two-part Features Resource Trade-Off game, which was developed originally as a research tool. The original game adopted concepts from economic theory and applied them to discover how groups of people sharing some trait would want to recover, assuming complete disability and the ability to control the trajectory of their recoveries. The set amount of recovery allowed at any point in the procedure is analogous to the number of dollars available for spending, assuming limited resource availability and the need to make choices between items. The alternative functions or symptoms listed for imagining recovery among functions as diverse as toileting and making friends, yielding utilities for alternative functional states. In contrast to the Features Resource Trade-Off game, RPE is being designed for application by single individuals and for clinical applications. Through the clinician-administered RPE procedure, the patient displays his or her preferred recovery choices. It is intended for application with any set of health status, functional status, or symptom-related questions.
Measures of Functional Status

Applicable to any ordinal functional status or health status measure, RPE is applied here to 15 questions derived from the National Health Interview Survey.16,17 These questions were selected because they are self-reported, applicable to a variety of chronic health conditions, intended to be relevant for person dwelling in the community (appropriate to outpatient care), and because they describe functional concepts that are generally accepted as important. They include a series of six physical, five psychological, and four social functions fundamental to HRQL (see Fig. 1 for questions).

Each function was addressed according to the following levels of difficulty: total assistance/severe, a lot of difficulty/frequent problem, some difficulty/occasional problem, and no difficulty/no problem. Originally dichotomous, response levels for some of the psychological and social functioning domains were expanded so that all measures would include four levels.

Subjects

We enrolled an ambulatory care population with disabilities related to chronic illness in an effort to gain insight into the meaning of disability among those living in the community. Subjects were approached during routine visits to an inner-city ambulatory care clinic and were screened for inclusion. Inclusion criteria were chronic health condition(s) causing at least one functional limitation or symptom (see Table 1) to be addressed and the ability to read and understand simple written instructions. The project was approved by the University of Pennsylvania institutional review board. All patients signed and dated an informed consent document.

### TABLE 1 Perceived functional limitations among study patients

<table>
<thead>
<tr>
<th>ACTIVITY / SYMPTOM</th>
<th>Level of Difficulty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Using the TOILET</td>
<td>Start</td>
</tr>
<tr>
<td>Getting in and out of CHAIRS/BEDS</td>
<td>Start</td>
</tr>
<tr>
<td>MOVING inside the home</td>
<td>Start</td>
</tr>
<tr>
<td>DRESSING</td>
<td>Start</td>
</tr>
<tr>
<td>EATING</td>
<td>Start</td>
</tr>
<tr>
<td>BATHING or showering</td>
<td>Start</td>
</tr>
<tr>
<td>DEPRESSION OR ANXIETY</td>
<td>Start</td>
</tr>
<tr>
<td>CONCENTRATING on a task</td>
<td>Start</td>
</tr>
<tr>
<td>CONFUSION</td>
<td>Start</td>
</tr>
<tr>
<td>Phobias or strong FEARS</td>
<td>Start</td>
</tr>
<tr>
<td>LEARNING new things</td>
<td>Start</td>
</tr>
<tr>
<td>Making or keeping FRIENDSHIPS</td>
<td>Start</td>
</tr>
<tr>
<td>GETTING ALONG with other people</td>
<td>Start</td>
</tr>
<tr>
<td>COMMUNICATING with FAMILY</td>
<td>Start</td>
</tr>
<tr>
<td>COMMUNICATING OUTSIDE family</td>
<td>Start</td>
</tr>
</tbody>
</table>

FIGURE 1 Game board: patients demonstrate their preferred patterns of recovery by sequentially numbering the open squares.

ADL, activities of daily living; IADL, instrumental activities of daily living.
The RPE Procedure

Patients were given verbal and written definitions of the 15 limitations and were asked to record their status according to each function. They were then provided an RPE board (Fig. 1). The board listed the 15 functions along its left side, with decreasing severity levels moving from left to right across the top. The RPE procedure was administered by a physician and several assistants to groups of five to eight subjects. It took about 30 mins.

Patients were asked to “imagine that you have a serious health condition that makes it impossible for you to get to and use the toilet, get in and out of a chair and bed, move inside the house, etc.” (All items were read.) “Recovery will be complete but will take many years. How would you choose to recover if you could control how you recover?” Essentially, patients were instructed to pretend initially that they were completely disabled in all 15 National Health Interview Survey questions. When deciding on what recovery choices to make, patients were asked to “make moves in a way that would maximize your ability to perform the activities that you see as most essential and reduce the symptoms that are most troubling.”

After this introduction, patients were instructed: “Starting on the left-hand side, select that limitation or symptom you would most like to reduce. Place a ‘1’ in the first column next to that item in the ‘moderate’ difficulty column. This indicates imagined improvement from ‘severe to moderate difficulty.’” After the patient had selected the first move, the investigator stated, “now, imagine that you still have moderate difficulty with (the selected function), and you still need total assistance in all the other functions. Select the function you would next like to recover. You may choose to imagine more recovery in (the first function), or select a different function. Place a ‘2’ in the corresponding box . . .” This continued until all functions were imagined as being no problem. The patient expressed his or her desired sequence of recovery by numbering the items and levels on the board. At the conclusion of the ranking procedure, each patient was asked to explain why he or she had chosen that particular recovery sequence.

Preference Weights

A preference weight is calculated from the move numbers and represents the relative value the individual places on recovering a particular function compared with the other 14 functions. For each function, the unit of measurement was improvement in one level (i.e., one move). There were 45 moves or choices. Preference for each function was the inverse sum of the move numbers for that item, multiplied by 100. This yielded a set of 15 weights corresponding to each item for each individual. An attribute for which points were spent early in the procedure is assumed to have more value than one left for later. For example, an item with move numbers 1, 7, and 8 would be more valuable than one with move numbers 6, 12, and 23.

Exploring the Individual Nature of Meaning

We plotted the 15 preference weights for each function. The distribution of each person’s preference weights across the 15 conditions is referred to his or her “value ruler.”

Physical, Psychological, and Social Domains of Functional Meaning

Principal components analysis using SAS was applied to see whether simplified summary indices of preferences could be derived from the 15 individual preference weights. Principal components analysis was applied to discover the broad underlying dimensions of meaningfulness. We expected meaningful and interpretable principal components reflecting the physical, psychological, and social constructs of HRQL. Principal components analysis is a multivariable statistical technique that linearly transforms an original set of variables into a substantially smaller set of uncorrelated indices that capture most of the variance (and covariance) present in the original items. Its goal is to reduce the dimensionality of the original data without substantial loss of information, making it easier to discern important patterns in the observed data. A set of three indices would provide a simpler summary of preferences that might be easier to understand than the set of 15 individual utilities. The first principal component of a multi-

<table>
<thead>
<tr>
<th>TABLE 2 Patient characteristics</th>
<th>n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age, yrs</strong></td>
<td></td>
</tr>
<tr>
<td>18–44</td>
<td>3 (12)</td>
</tr>
<tr>
<td>45–65</td>
<td>13 (52)</td>
</tr>
<tr>
<td>65–69</td>
<td>2 (8)</td>
</tr>
<tr>
<td>70–74</td>
<td>2 (8)</td>
</tr>
<tr>
<td>75+</td>
<td>5 (20)</td>
</tr>
<tr>
<td><strong>Gender</strong></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>16 (61.5)</td>
</tr>
<tr>
<td><strong>Race</strong></td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>10 (38.5)</td>
</tr>
<tr>
<td>Black</td>
<td>15 (59.7)</td>
</tr>
<tr>
<td>Other</td>
<td>1 (3.9)</td>
</tr>
<tr>
<td><strong>Perceived health</strong></td>
<td></td>
</tr>
<tr>
<td>Excellent</td>
<td>1 (3.9)</td>
</tr>
<tr>
<td>Very good</td>
<td>4 (15.4)</td>
</tr>
<tr>
<td>Good</td>
<td>12 (46.2)</td>
</tr>
<tr>
<td>Fair</td>
<td>4 (15.4)</td>
</tr>
<tr>
<td>Poor</td>
<td>5 (19.2)</td>
</tr>
</tbody>
</table>

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The variate vector is simply the linear combination with maximum variance. The second principal component is the linear combination, orthogonal (i.e., uncorrelated) to the first that maximizes residual variance, and so forth. Because principal components reflect maximum variance in a multi-dimensional space, they are ideally suited to display location in a high (e.g., 15 dimensional) space using a reduced number of dimensions (e.g., the anticipated three dimensions). This analysis was used to develop the typology trade-off space that theoretically makes it possible to see how the individual patient’s preferences are balanced across the physical, psychological, and social domains.

RESULTS

The majority of patients were adults younger than 65 yr of age. More than half were African American (Table 2). Diagnoses listed by the patients included heart failure, short-bowel syndrome, stroke, multiple myeloma, diabetes, thyroid disorders, osteoporosis, end-stage renal disease, lower-extremity amputation, Parkinson disease, legal blindness, manic depression, paranoid schizophrenia, depression, blood clots, bowel resection, asthma, chronic obstructive pulmonary disease, and others. All had difficulties with the instrumental activities of daily living. Most had physical limitations, and many described psychological difficulties (Table 1).

The Individual Nature of Meaning

Figure 2 superimposes all 26 patient value rulers connecting each patient’s pattern of desired recovery as a series of confusing interconnected points. It illustrates complex and wide scatter, highlighting the individual nature of meaning. Functions with relative values above ten represent the most valuable, and those below five represent the least valuable. Discordance between patients’ preferred recovery sequences and physiologically plausible recovery patterns highlights the distinctions between status and the value placed on achieving that status. Independence in toileting, absence of depression, and communication with family members were the most valued, and learning new things, making new friends, and getting along with people were the least valued among the physical, psychological, and social functions. Nearly all patients considered communication with family members more important than communication with people outside the family. In sharp contrast to Figure 2, Figure 3 shows “value rulers” that represent two separate patients’ utilities for each of the items.

Physical, Psychological, and Social Domains of Functional Meaning

When subjected to principal components analysis, the 15 preference weights expressed two components (Table 3). The first component reflected...
trade-offs between social and physical function. Social function items had large negative weights, and physical functions had large positive weights.

The second component reflected trade-offs between psychological and social function recovery. Psychological function items had predominantly negative weights, and social function items had large positive weights. Together, these two linear combinations produce scores that express individuals’ preferences relative to their desires to be able to perform physical, psychological, and social functions.

We computed summary scores from the principal components analysis for each patient. As a consequence of the forced trade-offs, each principal component index reflected the degree of preference for recovery in one domain vs. another. Each patient’s scores were plotted producing a “preference trade-off space” that showed the relative degree to which he or she would value one type of recovery over a different type (Fig. 4). This space is a two-dimensional display translating the 15 functional items into two axes representing trade-offs (and thus relative preferences) between social (−) and physical functions (+) along the y-axis; and trade-offs between psychological (−) and social functions (+) along the x-axis. This translates into recovery preference across the three dominant dimensions.

FIGURE 3  Value rulers demonstrating extreme patterns. The two patients’ value rulers demonstrate opposite preferences. Patient U would choose to recover the physical functions before the psychological and social, whereas patient P would prefer psychological and social recovery.

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Principal Components</th>
</tr>
</thead>
<tbody>
<tr>
<td>Toileting</td>
<td>0.341</td>
</tr>
<tr>
<td>Transferring</td>
<td>0.342</td>
</tr>
<tr>
<td>Moving</td>
<td>0.343</td>
</tr>
<tr>
<td>Dressing</td>
<td>0.323</td>
</tr>
<tr>
<td>Eating</td>
<td>0.258</td>
</tr>
<tr>
<td>Bathing</td>
<td>0.353</td>
</tr>
<tr>
<td>Depression</td>
<td>−0.053</td>
</tr>
<tr>
<td>Concentration</td>
<td>−0.097</td>
</tr>
<tr>
<td>Confusion</td>
<td>−0.194</td>
</tr>
<tr>
<td>Fears</td>
<td>−0.125</td>
</tr>
<tr>
<td>Learning</td>
<td>−0.194</td>
</tr>
<tr>
<td>Making friends</td>
<td>−0.295</td>
</tr>
<tr>
<td>Getting along with others</td>
<td>−0.210</td>
</tr>
<tr>
<td>Communication with family</td>
<td>−0.261</td>
</tr>
<tr>
<td>Communication with others</td>
<td>−0.226</td>
</tr>
</tbody>
</table>
in the following way: physical preference is highest at the point in the trade-off space where the y-axis is +3 and the x-axis is 0. Psychological preference is highest at the point where the x-axis is −3 and the y-axis is 0. Social preference is highest at the point where the y-axis is −3 and the x-axis is +3.

A patient’s location in this space reflects his or her individual recovery strategy anchored on complete disability. The closer the plotted value is to the origin (0, 0) of the coordinate axes, the more balanced the preferred recovery. Cases d, s, n, and j within the inner circle show the most balanced patterns. Patients whose plotted preferences are beyond the outer circle are outliers demonstrating extreme preferences. The space suggests a continuum of recovery preference across the three dimensions. Patients’ verbal descriptions of strategies for imagined recovery were compared against their plotted position. The narrative content explaining choices provided by patients with the most divergent preference patterns (those furthest from the origin) were consistent with spatial position. For example:

Patient u, a white female in her 60s who rated her health as good, described having some difficulty with heavy work around the house, washing windows, walking a quarter of a mile, climbing ten steps, or standing for 20 mins. She showed the most dominant physical preference within the preference trade-off space (Fig. 4) desiring the recovery of physical activities of daily living consistently over all types of function. This individual consistently traded imagined recovery of social and psychological well-being for physical independence, stating, “if you are physically independent, you can then go to work on other things. Independence and quality of life are most important.”

Patient p, a woman with glaucoma and breast cancer in her 70s who rated her health as very good, described having difficulty doing heavy housework, lifting 10 lbs, reaching with her arms, and occasional forgetfulness. She showed a pattern opposite that of patient u (Fig. 4), valuing psychological and social functioning almost equally and placing relatively less value on physical functioning. On the basis of experience with relatives, this woman stated, “if I can communicate, I can tell them the physical things I need. Moving is no good if you can’t have a purpose. My brother . . . with Alzheimer disease can move fine. Doesn’t know where he’s going.” On the basis of her experience with relatives, she was impressed with how little physical abilities matter when psychological capacity “is adrift.” She stated, “my mother, aunt, and mother-in-law went to nursing homes. My mother was physically fit with dementia. When my aunt went in, she had physical problems but was completely alert. My mother-in-law was physically fit and alert but had attitude problems. She didn’t want to be there. My aunt is the one I would like to model. If I can communicate, I can tell them the physical things I need.”

Patient h, a woman in her 50s with diabetes, arthritis, hypothyroid, manic depression, panic attacks, and renal damage, described her health as poor. She noted some difficulty with getting in and out of bed, preparing meals, managing money, shopping, doing housework, washing windows, doing
light cleaning, lifting 10 lbs, climbing ten steps, standing for 20 mins, and bending down to pick up an object. She also noted some difficulty with concentration, stress, forgetfulness, confusion, fears, and communicating with others. She showed a dominant psychological pattern (Fig. 4). She stated, “clear thinking is essential. Before you can do anything about these basic tasks, confusion has to be straightened out. Those phobias and fears keep you in, undermine everything.”

Patient z, a man in his 60s who had quadruple bypass surgery, operations on his knees, a number of small strokes, uvula extraction, congestive heart failure, carotid endarterectomy, a hearing aid, and renal failure, valued physical and social functions more than psychological functions. He described having some difficulty eating, getting in and out of his bed, managing money, doing heavy housework, washing windows, and picking up an object from the floor. He also noted some difficulty with concentration, stress, confusion, and forgetfulness. His narrative discussed the social implications of being able to function physically. He stated, “if you can’t move, how can you let friends in? When you are very sick, it is your family that is most important.”

DISCUSSION

We present preliminary evidence that constructs of meaningfulness reflect the classical physical, psychological, and social domains of HRQL. This suggests that metrics of value can be reported alongside metrics of status.6 Within the physical, psychological, and social functioning domains, patients’ preferences for recovery from limitations in activities are highly personal and are relevant to individual life contexts and experiences. The differences in relative meaningfulness assigned to the same functional activities by individuals suggest why some people with devastating disabilities perceive a high quality of life, whereas others fall into states of hopeless despair. The meaning a person assigns to particular patterns of functional loss or recovery is distinct from his or her measured status. As value-laden quantities, recovery preferences are driven by the contexts of a person’s life. Personal feelings, such as need for privacy and personal pride, often drive the value of being able to use the toilet without help. These drivers of meaning and utility are distinct from the physiologic drivers that determine return of the physical movements, coordination, and cognitive responses necessary to accomplish independent toilet use. Consequently, at times, the sequence of recovery preferences selected by patients within or across domains will seem clinically incoherent and physiologically impossible.

The RPE procedure yields metrics distinct from functional status, questions about subjective quality of life,20 and preference-based scores such as those obtained from the Health Utility Index.23 Functional status includes directly observable exteriorized signs of the individual.22 Global questions about quality of life ask how the individual views life as a whole. The Health Utility Index, currently being translated into many languages, embodies community preferences, under the assumption that preference-based scoring functions are robust across populations. In contrast to recording observable, exteriorized signs of functional status, RPE assays the internalized representation of those exteriorized signs. Rather than addressing how the individual views life as a whole, RPE focuses on feelings about specific functional or health states relative to others. Instead of embodying community preferences, RPE operates under the assumption that credible estimates of person-level subjective HRQL must reflect the individual viewpoint rather than population summaries.

RPE also differs from and complements other measures and procedures that are designed to include the patient’s perspective in the rehabilitation process, such as the Participation Objective, Participation Subjective and the Canadian Occupational Performance Measure. In performing Participation Objective, Participation Subjective, the patient rates 26 activities according to these activities’ importance to the patient’s perceived well-being.23 The value of each separate item is rated independently of the value of the others. Rather than being tied to specific activities, the patient RPE is a procedure that can be applied to any set of questions or functional status measures of relevance to the population being studied. In the Canadian Occupational Performance Measure, the therapist performs a semistructured interview with a patient to identify the problems in daily activities that are most troubling to the patient, and then the patient ranks these activities according to how important they are to him or her.24 In contrast, RPE ranks named activities taken from any available functional measure to yield a hierarchy of activity preferences instead of ranking patient-generated concepts.

Developing standard approaches to incorporating the patient’s perspective in care is important. There is tension in medicine between the pursuit of facts about disease and its resulting disabilities, and an understanding of the individual’s subjective personal responses. Physicians and other clinicians record the patients’ state of pathology and its functional consequences according to empirically delineated concepts. Facts about functional difficulty are devoid of meaning. For people with chronic disabilities, the normal condition may no longer be a meaningful or realistic standard. Consequently, loss of “normalcy” typically requires a shift in self concept. To reestablish a sense of well-being after disability, the individual must experience a process of embodiment25 by which different facets of his or
The experience of partial decentering in the performance of RPE could facilitate embodiment. As the patient thinks about alternative recovery choices from the point of view of pretending complete disability, he or she weighs the implications of the disabilities he or she has, along with those disabilities he or she might have had if the condition were much more severe. As a standardized procedure, we believe RPE uncovers value-laden ideas and attitudes that could accelerate the patient's process of reconstructing his or her identity. Additionally, the process of partial decentering tends to reduce embarrassment by having the patient pretend he or she has disabilities he or she does not have. Not having to admit particular disabilities, the patient can talk more freely about how he or she feels about different aspects of functioning.

The structured patient–clinician discourse that accompanies RPE encourages deep thought about the consequences of functional loss and recovery. The content essence is taken to represent the essential meaning of functional abilities and disabilities within the patient's life contexts at a particular moment in time.13

The approach to treating disease and disability can either be salutogenic (seeking the origins of health) or pathogenic (seeking explanations for causes).27 We hope that exploring recovery preferences will encourage a salutogenic approach to rehabilitation and medicine by providing a cogent explanation of personal hopes for the avoidance of particular disabilities and desired patterns of recovery. RPE is being designed as an interdisciplinary tool that we believe will have applications in multiple settings.

RPE has many potential clinical applications. Patients' exploratory recovery preferences may be expressed either as separate utilities for each activity, or broadly, through the summary physical, psychological, and social indices. Graphic displays of individual utilities on a value ruler (Fig. 2) show how a patient valued each activity compared with all others. Alternatively, utilities expressed as physical, psychological, and social indices plotted within the typology trade-off space (Fig. 4) provide a way to compare a patient's values against those of a larger population. A highly ranked activity on the patient's value ruler for an activity he or she has difficulty with can identify an important therapeutic target. Such value ruler patterns might be applied through a person-centered planning approach28 to better understand the patient's aspirations and attitudes about disability recovery. Patient p, for example, reported occasional forgetfulness. According to her value ruler (Fig. 3), she identified reducing confusion as the most important priority if she were to become completely disabled. Discussing strategies for enhancing organization and memory might prove meaningful.

In contrast to the value ruler, a patient's position within the typology trade-off space identifies the broader domains of function he or she most values and provides insights into his or her reasoning. Patient u (Fig. 3) valued physical ability over other types of abilities. She saw the maintenance of physical independence as essential to achieving well-being in other areas. Although she was able to perform all the basic physical activities included in this RPE procedure, she described difficulty with more challenging activities, such as climbing steps. Formal functional evaluation with the development of a home exercise program to enhance endurance and improve current function would represent a reasonable approach to lifestyle planning and enhanced well-being.

Utilities from RPE are not intended to supersede professional judgment. However, they can help with the process of individualizing recovery plans by revealing those aspects of functioning that are most important to the patient. For example, a man with a spinal cord injury might have walking as his highest utility. Although the physiatrist knows that walking may be an impractical recovery goal, he or she can use the knowledge of how important mobility is to this patient to set other rehabilitation goals. For example, the patient's rehabilitation plan may focus on teaching him to use mobility aids early in the rehabilitation process or on helping him identify home environment modifications that will allow him to regain mobility within his environment. By using utilities from RPE in combination with professional judgment, it may be possible to create rehabilitation plans that focus on those activities or skills that are most meaningful to the patient.

Summary physical, psychological, and social indices and individual item utilities established through RPE can also be used to assess patient progress by weighting the importance of improvements in various functional skills. For example, in goal attainment scaling, a goal attainment scaling score is calculated using the weights assigned to each goal area and the attained score for each goal area.29 Recovery in an area with a higher weight would have a greater effect on the goal attainment scaling score than an equal amount of recovery in an area with a lower weight.

Because only a small number of patients have experienced RPE to date, findings must be considered exploratory. Future work should test the stability of the physical, psychological, and social domains of functional meaningfulness as well as the degree to which recovery preferences are relatively stable vs. fluctuating.30 It will be key to address the degree to which meaningfulness constructs vary across different health and functional status measures applied in various rehabilitation settings such as the Functional Independence Measure, the
standard assessment used in the inpatient rehabilitation setting.\textsuperscript{3,1} Future work might also explore how patient circumstances and status, including variables such as age, diagnoses, and disability, influence preferences.

We believe that RPE will prove particularly therapeutic for people being rehabilitated in the inpatient setting after the sudden onset of severe disabilities. The capacity to imagine greater disability and to set priorities depends on the ability to think abstractly. Consequently, it may be necessary to derive a less demanding procedure for those with strokes or other conditions that cause cognitive impairment.

RPE, a procedure in its infancy, acknowledges that people with similar functional manifestations of illness may experience them differently. Optimally, the practice of medicine, like qualitative research, is individual and context rich.\textsuperscript{32} There is a plethora of quantitative tools to aid the practice of medicine, but few of these tools assay the inner worlds of patients. We believe that RPE could emerge as a clinical tool with the potential to help patients make more sense of their loss of function and to guide them toward new positive life trajectories, thus instilling the rehabilitation process with even greater meaning and enhanced outcomes.

ACKNOWLEDGMENTS

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REFERENCES


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Pathological Changes of Human Ligament After Complete Mechanical Unloading

ABSTRACT


Objective: To investigate the pathologic changes with a time sequence among patients with injured ligaments after complete mechanical unloading, based on a human anterior cruciate ligament (ACL) model.

Design: Pathologic examinations were done on remnants of completely ruptured ACLs at various times up to 14 wks after injury on 31 patients and on normal ACLs from five cadaver donors. Testing variables included fibroblast density, crimp amplitude, and crimp nuclear shape.

Results: Sequential changes were observed: Fibroblast density significantly increased within 5–6 wks of unloading. By 7–8 wks, crimp amplitude significantly decreased, accompanied by formation of irregular fiber patterns and fragments. This was followed by crimp wavelength and nuclear shape change within 9–14 wks.

Conclusions: These pathologic findings suggest that the ACL undergoes significantly deleterious changes from 5 to 6 wks after mechanical unloading. This study may emphasize the important concept of early implementation of mechanical force in rehabilitation programs for patients with injured ligaments.

Key Words: ACL, Mechanical Unloading, Dynamic Change, Basic Science

A challenging yet controversial question in the management of complete mechanical unloading of joints after injury concerns the optimal timing for physical rehabilitation activity. Joint immobilization promotes healing of fractured bones or injured soft tissues. However, prolonged immobilization, such as joint disuse, may have deleterious effects on normal tissues because of stress deprivation, leading to degeneration, weakening, or disorganization of ligament structures. On the other hand, early rehabilitation may interfere with the
healing process. It has been shown that accelerated rehabilitation protocols result in increased incidence of synovitis after ligament injury. The results show that the degradation of collagen was increased in canine ligament after mechanical unloading for 12 wks. However, rates of collagen synthesis and degradation were affected by mechanical unloading, and results varied depending on the type of animal model used, the type of ligament, and the duration of mechanical unloading. On the other hand, mechanical unloading, resulting in decreased load force on the ligaments, varied in different models. The patterns of mechanical unloading—such as with the knee fixed in full flexion, or external fixation—and the exact amount of reduced force also differed. In animal models, investigations reported that mechanical unloading could induce synthesis of the collagen and collagen crosslinks and could result in random arrangements or fixation of the fibers that further inhibited movement. Degenerative changes with necrosis of cells at the central area of rabbit anterior cruciate ligaments (ACLs) were also noted after 6 wks of immobilization. The clear limitation in these animal studies is the species difference between human and animal models; the information from these studies cannot be translated directly to human beings. However, these studies still offer important information regarding the effects of mechanical unloading.

This study presented a human ACL model to evaluate the mechanical unloading effects on the histologic changes of ligament tissue over time. The objective was to provide pathologic information for investigating the dynamic effects for people with ligament injury after mechanical unloading.

METHODS
Experimental Model
The human in situ ligament mechanical unloading model was designed using remnants of completely ruptured human ACLs with a large sample size at various times after injury. Ruptured ACLs were obtained from 35 athletes undergoing ACL reconstruction using the protocol approved by the institutional review board at Baylor College of Medicine. The ruptured sites often occurred in the middle parts of ACLs. Remnant sites that were more than 6 mm from the rupture ends were included. The more distal remnant ACLs resemble the histology of intact ACLs, and the explanted samples were referred to as having come from the normal zones. The ACLs were transected at their insertion area with a scalpel by a surgeon, and all specimens were obtained from the normal zones. Thirty-one samples were included on which the crimp morphology was measurable. Four samples were excluded because of unreadable crimp arrangement. Five intact ligaments were obtained from five cadaver donors. Informed consent was obtained from each subject with a ruptured ligament, and the procedures followed were in accordance with the ethical standards of the institutional review board.

To observe the histologic changes across different time periods, the samples were divided into five groups according to the mechanical unloading time (or the time between ACL rupture and reconstruction): 1–2, 3–4, 5–6, 7–8, and 9–14 wks. Control ACL ligaments were taken from five normal, physically functional cadaver donors using the same procedures as for the ruptured ligaments. These ACLs were harvested within 48 hrs after death, and they were classified as the 0-wk group. The patient characteristics including age range, mean age, gender, and time from rupture are listed in Table 1.

Tissue Preparation and Staining
Tissue samples for histologic examination were taken from normal human ACLs. They were fixed in 10% buffered formalin at room temperature for 48 hrs and were then embedded in paraffin. The specimens were cut into five-micrometer-thick longitudinal sections and stained with hematoxylin and eosin stain. Histologic slides of longitudinal sections were evaluated under microscopy with normal and polarized light.

<table>
<thead>
<tr>
<th>Groups</th>
<th>Sample Size</th>
<th>Age</th>
<th>Gender</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>5</td>
<td>32.0 (20–41)</td>
<td>M: 3</td>
</tr>
<tr>
<td>1–2 wks after injury</td>
<td>7</td>
<td>22.7 (15–57)</td>
<td>M: 5</td>
</tr>
<tr>
<td>3–4 wks after injury</td>
<td>5</td>
<td>17.6 (16–20)</td>
<td>M: 2</td>
</tr>
<tr>
<td>5–6 wks after injury</td>
<td>7</td>
<td>31.8 (16–53)</td>
<td>M: 3</td>
</tr>
<tr>
<td>7–8 wks after injury</td>
<td>5</td>
<td>36.4 (20–53)</td>
<td>M: 1</td>
</tr>
<tr>
<td>9–14 wks after injury</td>
<td>7</td>
<td>23.7 (13–35)</td>
<td>M: 1</td>
</tr>
</tbody>
</table>
Measurements of Variables
Crimp amplitude, crimp wavelength, nuclear density, and nuclear shape of fibroblasts were used for measurement assays.

Crimp Wavelength and Amplitude
The morphological variables of ACL fibers were observed according to histologic changes. First, the collagen fascicle morphology and architecture to describe the crimp of the wavelength and amplitude was based on Yahia’s model. In brief, changes of the collagen fibers exhibited a sinusoid wave periodically into two dimensions and ran continuously along the ligament (Fig. 1). They played an important role in maintaining ligament morphology and strength to resist tensile force. Crimp wavelength and amplitude decreased in an immobilized ligament status. In this study, measurement of crimp wavelength and amplitude were calculated with a calibrated scale under light microscopy. Ten locations along the length of each specimen were randomly evaluated, and mean crimp wavelength and amplitude were determined and used for analysis.

Fibroblast Density and Nuclear Shape
Parameters of fibroblasts were also included and analyzed by a second researcher. The fibroblast density was calculated at four independent areas under a microscopic field. Ten nuclear shapes in each specimen were included in the calculation of ratios. The fibroblast nucleus form was described according to the ratio of nuclear length and width. A nuclear ratio >4 was classified as spindle. A ratio <4 was defined as ovoid.

Characteristics in Atomic Force Microscopy
The characteristics of the single-fibril microstructure of ACLs were viewed, and atomic force microscopy (AFM) (Synergy ESPM, Novascan, Ames, IA) was employed. The AFM generates images by an interaction force between the cantilever tip and the molecules of the specimen rather than the photon or electron for optical microscopy or electron microscopy. This approach can generate magnification nearly similar to that of electron microscopy; however, the specimen can be viewed under more natural conditions with the AFM. The specimen process for optical microscopy can be directly used for AFM observation after the specimen is deparaffined. It is an ideal instrument to investigate the detailed fibril ultrastructure of the ACL. Therefore, the same slide observed by optical microscopy was processed for AFM evaluation. The fixed paraffin slides were heated to 60°C on a hot plate, then they were deparaffined with xylene and ethanol alcohol and allowed to air dry for AFM observation. A morphology of a single fibril was taken using the tapping mode of the AFM. A silicone tip with a cantilever length of 130 μm and a resonance frequency of 145 KHz was used (NSC12, Mikromasch USA, Portland, OR). The image was recorded with a 1-Hz scan rate and 512 × 512 resolution. The measured test dimension was calculated using Image Analysis software.

Data Analysis and Statistics
A Kruskal–Wallis test was used for statistical analysis in time sequence. Bonferroni correction testing was performed to compare each study group with the control group. Differences were considered significant at the \( P < 0.05 \) level.

RESULTS
Histologic changes in the ACLs were significantly noted after 5–6 wks of mechanical unloading compared with the control group, and a sequence of development was found to be continuous (Table 2).

<table>
<thead>
<tr>
<th>Groups</th>
<th>Cell Density, no./mm²</th>
<th>Fibril Amplitude, μm</th>
<th>Fibril Distance, μm</th>
<th>Nuclear Aspect Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>303.8 ± 45.3</td>
<td>5.1 ± 0.4</td>
<td>25.0 ± 1.8</td>
<td>4.4 ± 1.5</td>
</tr>
<tr>
<td>1–2 wks after injury</td>
<td>322.3 ± 19.7</td>
<td>5.2 ± 0.2</td>
<td>26.0 ± 1.8</td>
<td>4.6 ± 1.3</td>
</tr>
<tr>
<td>3–4 wks after injury</td>
<td>342.8 ± 32.8</td>
<td>5.0 ± 0.2</td>
<td>25.3 ± 1.2</td>
<td>4.4 ± 1.1</td>
</tr>
<tr>
<td>5–6 wks after injury</td>
<td>472.8 ± 80.3</td>
<td>4.7 ± 0.3</td>
<td>25.6 ± 2.0</td>
<td>4.4 ± 1.5</td>
</tr>
<tr>
<td>7–8 wks after injury</td>
<td>590.8 ± 103.2</td>
<td>4.0 ± 0.3</td>
<td>25.4 ± 1.6</td>
<td>4.2 ± 1.4</td>
</tr>
<tr>
<td>9–14 wks after injury</td>
<td>826.3 ± 187.4</td>
<td>3.2 ± 0.2</td>
<td>22.6 ± 1.0</td>
<td>3.8 ± 1.2</td>
</tr>
</tbody>
</table>
The cell density was first significantly changed, followed by the crimp amplitude, nuclear shape, and crimp wavelength.

**Fiber Morphology**

Irregular fiber arrangements and decreased crimp amplitude were markedly apparent after 7–8 wks (Fig. 2A–F). Fibers were closely packed and well arranged longitudinally, and the crimp patterns were clearly present in the first 4 wks of mechanical unloading. The AFM image from longitudinally cut normal ACLs from the control group showed regular arrangement of fibrils and their periods (Fig. 2G). In some areas, the fibrils from the study group were not well aligned in the same direction, and some smaller fibrils oriented vertically to larger parallel fibrils after 7–8 wks of mechanical unloading (Fig. 2H).

**Fibroblast Density**

Fibroblast density increased, especially from 5 to 6 wks after mechanical unloading, compared with the control group ($P < 0.01$). The cellularity also significantly increased at 7–8 and 9–14 wks (Fig. 3). The fibroblast density presented a tendency to increase from 322.3 to 342.8 fibroblasts per squared millimeter during the first 4 wks of mechanical unloading, but there was no significant change ($P > 0.05$).
Crimp Amplitude and Wavelength

Fiber amplitude was found to decrease with time, showing significant change from 7 to 8 wks onward, compared with the control group \( P < 0.01 \) (Fig. 4). Fiber wavelength slightly increased during the first 8 wks but significantly decreased during weeks 9–14 compared with the control group \( P < 0.01 \) (Fig. 5).

Nuclear Shape

The nuclear ratio of the fibroblast was significantly decreased at 9–14 wks after mechanical unloading compared with the control group \( P < 0.05 \). The results showed a spindle form in the first 8 wks and significantly changed into ovoid form from 9 to 14 wks onward (Fig. 6).

DISCUSSION

This study showed that the significantly disordered changes of human ligament occurred from the fifth week of complete mechanical unloading and that changes in the fibroblast and fibers were continuous. After 5–6 wks, the fibroblast density increased remarkably compared with the initial 4 wks, as noted in Figure 3. Although an ACL study showed that fibroblast density was increased after 6 wks,13 samples for the study were harvested from the rupture ends of the ligament. Living tissues demonstrate an ability to...
respond to mechanical loading, and this condition is very important for living tissues to maintain tendon structures. Fibroblast transformation within the ligaments after mechanical unloading offers signals to the homeostatic response of ligaments. Therefore, the fibroblasts are first responsible for experiencing the changes of the external mechanical force or motion and transferring signals into a cellular response to adjust the synthesis or regeneration of the ligament.

The dynamic change that took place in the extracellular matrix was progressive deterioration, as seen in Figure 4. Crimp amplitude significantly decreased in complete mechanical unloading at 7–8 wks. The mechanism of decreased crimp amplitude was related to the biomechanical phenomenon. After the proliferation of fibroblasts in a completely immobilized status, this signal could trigger the production of collagen precursors in the extracellular matrix. Therefore, an increase in the amount of newly synthesized collagen occurs, and less mature fibers may decrease the resistance to tensile load. The crimp wavelength was also significantly changed at 9–14 wks, as seen in Figure 5. This meant that the deterioration of the fibroblasts and fibers might not occur simultaneously. Another finding in this study was inconsistent with those in other animal model studies.
The fragmentation of collagen fibers appeared after 6 wks of mechanical unloading in a canine study. These significant differences implied that the changes after complete mechanical unloading in human beings were not similar to those of animal models. However, they presented common dynamic and continuous changes in ligaments after mechanical unloading.

The changes of the nuclear shapes indicated that fibroblasts underwent a new configuration. Further changes in the amounts and the function of intracellular organelles might occur. The fibroblasts in the control group in the early stages were spindle shaped. They became ovoid shaped after 9–14 wks of complete mechanical unloading, as seen in Figure 6. Fibroblasts took on the configuration from ovoid shaped to spindle shaped in a rabbit ACL study after 9–14 wks of complete mechanical unloading. Nuclear adaptation to the influence from the extracellular matrix seemed dissimilar between human and animal environments.

Fibers were found in an irregular arrangement after a period of complete mechanical unloading in this study. Widening of the intervals between crimp bundles was markedly obvious after 7–8 wks of complete mechanical unloading (Fig. 2). The fibrils were found to be arbitrarily organized (Fig. 2H). Collagen degeneration and significant decreases in collagen-fiber density after a period of mechanical unloading resulted in decreased stiffness of ligament. Collagen fibrils have been known to provide resistance to mechanical loading. If this resistance is decreased, the ligament is impaired.

The concepts regarding the effect of complete mechanical unloading on morphological changes of the ligament are clinically important. According to the literature, physical loadings provide an important stimulant source for maintaining the normal structure and function of ligament tissue. Prolonged mechanical unloading has adverse effects on ligaments. According to one study, disused muscle atrophy started immediately, and the characteristics were significant within 1 wk. In another study of internally immobilized knees, development of surface irregularity and degeneration of articular cartilage was found. Ligament substance weakness was also found in the insertion site and was attributed to osteoclastic resorption of bone after mechanical unloading. However, the criteria of the complete mechanical unloading duration have not been determined. Future studies exploring these criteria could provide important information about ligament histologic change under complete mechanical unloading.

Some limitations in this study need to be addressed. First, ruptured ACL tissues obtained during ACL reconstruction were provided as an ideal human model because of complete mechanical unloading. ACL properties may not represent those of other ligaments under complete mechanical unloading. Second, histologic changes may not be the sole indicator for clinical applications. For example, biochemical activities of fibroblast synthesis may occur at different points of time. These are topics to be further investigated in the near future.

**CONCLUSION**

This study introduced a human ACL model with which to evaluate complete mechanical unloading. The result provides morphological evidence explaining the altered structure–time period relationship in ACLs under mechanical unloading. It also emphasized that implementation of a rehabilitation plan for patients with ligament injury should take mechanical force into consideration in the early stages of rehabilitation.

**ACKNOWLEDGMENTS**

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Effects of Glossopharyngeal Pistoning for Lung Insufflation on Vital Capacity in Healthy Women

ABSTRACT


Objectives: To determine whether healthy women could be trained to perform glossopharyngeal pistoning (GP) to insufflate the lungs to volumes exceeding maximum inspiratory capacity (IC), whether such insufflation caused discomfort, and the immediate and long-term effects on vital capacity (VC).

Design: A randomized controlled trial. Twenty-six healthy women were randomly assigned to a training group (TG, n = 17) or to a control group (CG, n = 9). The TG performed 15–30 deep inspiratory efforts supplemented by GP to lung volumes exceeding IC, three times per week for 6 wks. Pulmonary function and chest expansion were measured before and after the 6-wk period. The TG was retested again 12 wks after the end of the training period.

Results: One of 17 women had difficulty performing GP and was excluded. Temporary symptoms (while performing GP) were reported in 44% of subjects in the TG. After 6 wks of training, subjects in the TG had significantly increased their VC (P < 0.001). VC did not change in the CG. The increase in vital capacity of the TG was still evident after 12 wks without performing GP. Chest expansion increased significantly with GP.

Conclusion: The women in the TG were able to perform the technique, and it did not cause major discomfort. VC increased significantly in the TG, and the increase was still present after 12 wks without GP.

Key Words: Chest Expansion, Glossopharyngeal Breathing, Pulmonary Function, Respiratory Physiotherapy
Glossopharyngeal breathing (GPB) is a procedure in which the glossopharyngeal muscles are used to piston boluses of air past the vocal cords into the lungs to lung volumes exceeding inspiratory capacity; this has been called gulping. GPB can increase alveolar ventilation for patients with respiratory muscle paralysis, and it can be used for greater cough volumes.\textsuperscript{1–8} GPB was first described by Dail in 1951\textsuperscript{9} in patients with poliomyelitic paralysis. Patients have reported that the ability to cough increases, voice volume increases, and the chest wall becomes more mobile, when the amount of air in the lungs is increased by glossopharyngeal pistoning (GP) to lung volumes exceeding inspiratory capacity (IC).\textsuperscript{1,5,6,8,10} The technique, however, is not frequently taught to patients by physiotherapists or by respiratory therapists.

The lung volume added to IC by GP can be denoted the “glossopharyngeal pistoning lung insufflation volume.” The volume exhaled by a subject in a complete exhalation after performing GP is the glossopharyngeal pistoning lung insufflation volume + vital capacity (VC), or VC\textsubscript{GP}. This is similar to the VC supplemented by GP, called the glossopharyngeal maximum single-breath capacity,\textsuperscript{8} described for patients with reduced VC.\textsuperscript{5} Breath-hold divers use the extra volume obtained by GP to boost diving performance.\textsuperscript{11,12} These divers also use GP on dry land as a stretching maneuver to improve the flexibility of the chest and diaphragm (personal communication between divers and Lindholm 2002). Large lung volumes have been reported in competitive breath-hold divers,\textsuperscript{11} but no one has studied whether this is a result of genetically gifted individuals being overrepresented in the population of competitive breath-hold divers or whether it is a result of performing GP for many years.

It is unclear whether the performance of GP has any long-term effects on VC. Most studies have focused on patients with reduced VC, who try to achieve a volume closer to their predicted VC using GPB.\textsuperscript{1,2,3,10,13–15} To our knowledge, no study has investigated the long-term effects of GP on pulmonary function in the general population.

We hypothesized that 6 wks of performing GP would increase VC in healthy women. The aims of this study were to determine whether the subjects could be trained to perform the technique, whether such training would cause discomfort, and the immediate and long-term effects of GP on VC.

**MATERIALS AND METHODS**

**Subjects**

Subjects were recruited among female physiotherapists working at a university hospital. Criteria for inclusion were adults younger than 60 yrs, healthy, and nonsmoking. Twenty-six subjects agreed to participate. Subjects were randomly assigned either to a training group (TG, n = 17) or to a control group (CG, n = 9). Table 1 summarizes the subject characteristics. The research ethics committee at Karolinska Institutet in Stockholm, Sweden approved the study, and it was conducted in accordance with the Helsinki Declaration. All subjects gave their written informed consent before participation.

**Performing Glossopharyngeal Pistoning**

Subjects were trained to carry out GP. The subjects first carried out a maximal inhalation and then performed GP using as many gulps of air as possible without discomfort from lung hyperexpansion. Finally, they relaxed the larynx, and the air (volume = VC\textsubscript{GP}) was passively expelled. Subjects performed GP via the mouth; some subjects used a nasal clip to avoid air leakage.\textsuperscript{2,5,8}

Each subject in the TG received individual instruction in GP from a physiotherapist. The subjects watched an instructional video and then learned the technique together with the instructor. Subjects also received written information.

The TG performed GP three times a week for 6 wks. They carried out a short warm-up program with stretching exercises for the chest, and then they performed 15–30 repetitions of GP. Each session took about 20 mins. The instructor supervised at least one session per subject per week. The CG did not perform GP.

**Pulmonary Function Tests**

Static and dynamic spirometry was performed by a blinded independent technician using a body plethysmograph (Master Screen Body, Jaeger) in accor-
dance with American Thoracic Society standards.\textsuperscript{16} All subjects of both groups were tested at baseline and after 6 wks. Reference values from Quanjer et al.\textsuperscript{17} were used. The coefficient of variance for test–retest intrareliability of the measurement of VC (\(n = 50\)) was 1.1\%. The TG was reexamined after another 12 wks without performing GP.

A portable spirometer (infrared interruption flow sensor; SpirobankG, MIR, Rome, Italy) was used to measure VC in both groups every week during the 6-wk period. In the TG, the \(V_{CGP}\) and VC after performing GP were also measured each week during the weekly supervised session. We ensured that the subjects in the TG carried out GP correctly at each session.

### Chest Expansion

Chest circumference was measured at baseline and after 6 wks, at the fourth costae and at the level of the xiphoid process. It was measured with a tape measure, and both the upper and the lower rib cage were measured. The subjects were instructed to perform a maximal exhalation and then a maximal inhalation, with chest expansion being the difference between the two.\textsuperscript{18} Chest expansion was also determined using GP. The coefficient of variance for test–retest intrareliability of the tape measurements at the level of the xiphoid process was 0.8\%, and it was 0.4\% for measurements at the fourth costae (\(n = 50\)).

### Other Assessments

The subjects in the TG graded the perceived tension in the chest using the Borg CR-10 scale\textsuperscript{19} at baseline (Table 1). The subjects in the TG graded the perceived tension in their chest during the GP maneuvers at a median score of 4 (range 1.5–8) on the Borg CR-10 scale. Five subjects used nasal clips during GP, and no subjects brought in air via the nose. Seven subjects (44\%) experienced often temporary symptoms, including light-headedness, hacking cough, headache, and yawning. None of the subjects fainted during the GP maneuvers.

There were no significant differences between the two groups in any of the measured parameters at baseline (Table 1).

### Statistical Analysis

Descriptive statistics are presented as mean ± SD and range. The results were analyzed using parametric statistics. The significance of differences between baseline and after training was assessed by Student’s paired \(t\) test. The significance of differences between the TG and the CG was determined by repeated-measures ANOVA. A statistical significance level of \(P < 0.05\) was accepted.

All analyses were performed using Statistica 7.0 (Stat Soft, Inc, Tulsa, OK).

### RESULTS

One subject in the TG was not able to perform the GP with or without a nasal clip. This subject was excluded from the study, and the number of subjects in the TG was thus 16. Compliance with the protocol was 84\%, as determined by examining the subjects’ records. Subjects performed an average of 19 GP cycles (range 15–30), with an average of 10 gulps per GP cycle (range 2–42). Subjects graded the perceived tension in their chest during the GP maneuvers at a median score of 4 (range 1.5–8) on the Borg CR-10 scale. Five subjects used nasal clips during GP, and no subjects brought in air via the nose. Seven subjects (44\%) experienced often temporary symptoms, including light-headedness, hacking cough, headache, and yawning. None of the subjects fainted during the GP maneuvers.

There were no significant differences between the two groups in any of the measured parameters at baseline (Table 1).

### Pulmonary Function Tests

Table 2 shows the results obtained from the body plethysmograph; VC increased after the 6-wk period by 0.13 liters (\(P < 0.001\)) in the TG, whereas it did not change in the CG (Fig. 1). The statistical comparison between the groups indicated that there was a significant increase in the TG compared with the CG (\(P < 0.01\)). The increase in the VC in the TG persisted for at least 12 wks after the study (4.47 ± 0.6 liters).

Table 3 shows \(V_{CGP}\) during the 6 wks, and the corresponding values of VC before and after performing GP.

### Table 2: Lung volumes at baseline and after 6 wks

<table>
<thead>
<tr>
<th>Subjects, (n)</th>
<th>Baseline</th>
<th>After 6 wks</th>
<th>(P)</th>
<th>Between-Groups (P)</th>
<th>Baseline</th>
<th>After 6 wks</th>
<th>(P)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TG</td>
<td>16</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VC, liters</td>
<td>4.36 ± 0.55</td>
<td>4.49 ± 0.60</td>
<td>&lt;0.001</td>
<td>4.19 ± 0.43</td>
<td>4.19 ± 0.48</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td>TLC, liters</td>
<td>6.13 ± 0.68</td>
<td>6.21 ± 0.69</td>
<td>NS</td>
<td>5.92 ± 0.55</td>
<td>5.94 ± 0.59</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td>RV, liters</td>
<td>1.77 ± 0.29</td>
<td>1.72 ± 0.34</td>
<td>NS</td>
<td>1.73 ± 0.30</td>
<td>1.75 ± 0.31</td>
<td>NS</td>
<td></td>
</tr>
</tbody>
</table>

Values are presented in liters as mean ± SD. TG, training group; CG, control group; VC, vital capacity; TLC, total lung capacity; RV, residual volume. \(P\) values are given for differences between baseline and after 6 wks and between groups. Measurements were made with a body plethysmograph.
Chest Expansion

Chest expansion was greater at the level of the xiphoid process (1.0 ± 0.7 cm, P = 0.001) and at the level of the fourth costae (1.0 ± 0.7 cm, P < 0.001) with GP than it was during normal maximum inhalation. The mean chest expansion without GP did not increase significantly after the 6-wk period.

DISCUSSION

All women in the TG were able to perform GP for 6 wks without any major discomfort. The main findings were that the VCGP was 14.6% (significantly) greater than VC and that chest expansion also increased significantly with GP.

Some subjects learned GP immediately, whereas it took a few training sessions for others. Proper instruction and motivation are important for learning.20 The portable spirometer was useful as a teaching tool, giving direct quantitation of efficacy.

From our data, and from an extensive review of the literature, it does not seem that GPB increases the risk of pulmonary trauma.4,5,8,10,15,21,22 The increase in intrathoracic pressure by GP may cause orthostatic syncope attributable to the reduction in venous return, especially if the subject is standing upright. Forceful straining (e.g., in labor) has been shown to cause pneumomediastinum with subcutaneous emphysema in some individuals,24 and it is possible that GP may cause pneumothorax in susceptible individuals from the increased stress on the pulmonary tissue.

Our data show that the chest may expand to a larger volume than the volume achieved using ordinary inspiratory muscles. The exact mechanism for the increase in VC is not known, although this may be a result of an increase in pulmonary compliance that results from stretching, enabling the inspiratory muscles to inhale to a greater lung volume.14

The mean VC of the subjects in the TG increased by 3% after the 6-wk period. Other authors have also shown a small increase in the mean VC of healthy subjects25,26 after inspiratory muscle training. However, the training in our study differs from that described by other authors in that our training consisted of conventional inhalation to maximum inspiratory capacity, followed by GP. This may result in a stretching effect rather than an increase in muscle power. With lobectomy, the remaining pulmonary tissue expands.27 This suggests that lung volume in healthy subjects is limited either by the magnitude of chest-wall expansion or by resistance to diaphragm movement. The period of GP sessions in this study was brief, and the question remains whether a longer period might affect VC more.

Some of the breath-hold divers that have been studied11 have been using this technique for many years. For these divers, VCGP can be 30–40% greater than VC, whereas this figure was 14.6% for our subjects.

ACKNOWLEDGMENTS

This study was supported by the Swedish National Centre for Research in Sports and the Health Care Sciences Postgraduate School.

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April 2007

Glossopharyngeal Pistoning in Women 293

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Lung Inflation by Glossopharyngeal Breathing and “Air Stacking” in Duchenne Muscular Dystrophy

ABSTRACT


Objective: To compare the use of glossopharyngeal breathing (GPB) and air stacking to increase lung volumes and cough peak flows (CPF), and GPB to increase ventilator-free breathing ability (VFBA), for patients with Duchenne muscular dystrophy.

Design: A case series of all referred patients with declining vital capacity (VC). Seventy-eight patients underwent training in and monitoring of the efficacy of air stacking (retaining consecutively delivered volumes of air delivered via manual resuscitator and held by glottic closure) to maximum insufflation capacity (MIC). GPB also was demonstrated to all 78 patients, and 32 were formally trained and prescribed GPB as their VCs decreased below 400 ml. To be successful, the MIC or GPB maximum single-breath capacity (GPmaxSBC) had to exceed VC.

Results: Seventy-four (94.9%) of the patients could air stack (MIC > VC), and, thus far, 21 (27%) are able to GPB. Fifteen could GPB sufficiently to delay onset of daytime ventilator use and, later, to require 1.9 fewer ventilator assisted breaths per minute. For the 47 patients with multiple data points, as VC deteriorated from 1080 ± 870 to 1001 ± 785 ml, MIC increased from 1592 ± 887 to 1838 ± 774 ml. For 21 patients, GPmaxSBC significantly exceeded VC (824 ± 584 vs. 244 ± 151 ml, respectively, P < 0.001). The ability to increase lung volume by air stacking (MIC) was better retained than was the ability to increase lung volume by GPB (GPmaxSBC). Air stacking also permitted assisted CPF to exceed unassisted CPF: 289 ± 91 and 164 ± 76 liters/m, respectively (P < 0.001).

Conclusions: GPB and air stacking can increase lung volumes and, thereby, cough flows. GPB also can be used in many cases to delay and decrease daytime ventilator use.

Key Words: Glossopharyngeal Breathing, Cough, Duchenne Muscular Dystrophy, Respiratory Therapy, Noninvasive Mechanical Ventilation, Life Expectancy
The key to the successful long-term use of noninvasive mechanical ventilatory support is in effectively expelling airway secretions when necessary. To do so, the augmentation of lung air volumes can be crucial to optimize cough peak flows (CPF). In 1981, it was reported that 47 Duchenne muscular dystrophy (DMD) patients reached a maximum (plateau) vital capacity (VC) between ages 10 and 12 (range 9–16); in the general population, VC plateaus at age 19. Subsequently, VC decreases by 5–10% per year in patients with DMD. This contributes to the decrease in unassisted CPF. Two methods of lung-inflation therapy that can result in increased cough flows are air stacking and maximum-depth glottopharyngeal breathing (GPB).

Air stacking involves the use of a manual resuscitator or volume-cycle ventilator to deliver volumes of air that are consecutively held by glottic closure until no more air can be retained. The maximum lung volume that can be held by air stacking is the maximum insufflation capacity (MIC).

Dail first described GPB as gulping air into the lungs for the purpose of providing deep lung volumes to increase the cough flows of five postpolio-lungs for the purpose of providing deep lung volume that could be retained. The maximum lung volume that can be held by air stacking is the maximum insufflation capacity (MIC).

Dail first described GPB as gulping air into the lungs for the purpose of providing deep lung volumes to increase the cough flows of five postpolio-myelitis patients. Use of GPB for ventilator-free breathing has been reported for high-level traumatic tetraplegia patients and poliomyelitis patients, but not for DMD patients. Indeed, DMD patients who are not taught and equipped with respiratory muscle aids to avoid respiratory failure often undergo tracheotomy before they are able to benefit from GPB for ventilator-free breathing ability (VFBA).

The VFBA is considered limited when patients need intermittent positive pressure ventilations to supplement unassisted minute ventilation to prevent distress and to maintain baseline blood-gas levels. When absent, cessation of ventilator use results in immediate distress and blood-gas deterioration.

Advances made during the last two decades in noninvasive mechanical ventilatory support and mechanically assisted coughing have greatly improved survival without resort to tracheotomy. This makes air stacking and GPB increasingly important in the autonomous augmentation of cough flows, voice volume, and VFBA. GPB mastery also can eliminate fear of ventilator dysfunction or disconnection. Thus, we prospectively determined whether the ability to air stack and GPB could improve with practice and result in improved VFBA and cough flows.

**MATERIALS AND METHODS**

This work was approved by the hospital ethics committee. Seventy-eight consecutive males who had visited a clinic since 1996 were studied after VC plateau. The initial appointment for 16 patients had been before 1996. The diagnosis was based on clinical, enzymatic, electromyographic, and biopsy assessments. Gene-deletion studies were positive for 54 of 70 patients. All except one lost the ability to walk by age 11. Four of the 78 patients had taken glucocorticoids.

All patients were trained in air stacking and were given a demonstration of GPB after the plateauing of the VC. The age and magnitude of the plateau was documented by pre- and post-VC measurements below a maximum (plateau) for 24 patients, or it was assumed for the others because of their age and because subsequent data points were lower than the initial VC measurement. All 74 self-directed patients mastered air stacking when initially introduced to it (MIC > VC) and were asked to practice it two to three times per day, 10–15 maneuvers each time, from then on. Air stacking was performed by the patient receiving consecutively delivered volumes of air from a manual resuscitator or a volume-cycled ventilator via a mouthpiece, nasal, or oral–nasal interface and retaining as much as possible with a closed glottis (MIC). The volume was then measured spirometrically to determine MIC.

Each patient was asked about his practice efforts at every visit. Thirty-one of 47 who returned for at least one follow-up visit reported performing it at least twice daily.

GPB was demonstrated after VC plateau at every clinic visit, and each patient was screened for the ability to exceed VC by GPB. Once a patient demonstrated mastery (maximum single-breath capacity [GPmaxSBC] > VC), he was asked to practice it three times a day. If he had not mastered GPB by the time his VC had decreased to 400 ml (the point at which many patients with DMD begin to use daytime ventilatory assistance), a demonstration videotape was dispensed, and GPB practice was formally prescribed. GPB practice was considered optional before this point because it could not be used for VFBA early on, and air stacking was easier to master and the ability easier to retain over time for deep lung expansion, as typified by the patient record in Figure 1.

GPB was taught by having the patient take a deep breath and hold it, then imitate the clinician and take 15–20 gulps, and then blow the volume into a spirometer. The GPmaxSBC was the maximum volume that could be gulped in. Training was facilitated by monitoring gulp efficiency, which was defined as (GPmaxSBC – VC) ÷ (number of gulps to a maximum insufflation) in milliliters per gulp. If initially unsuccessful, the patient’s nostrils were sealed to demonstrate to him the need for the soft palate to seal off the nasopharynx. Even then, nine patients could not master the glottic movements necessary for successful GPB. On obser-
vation, they did not have as much rostral–caudal
cal movement of the glottis as did patients whose GP-
maxSBC exceeded VC, nor did they have the glottic
closure gulp (click) that is heard with successful GPB.
VC, MIC, and GPmaxSBC were measured spirometri-
cally (Mark 14 spirometer; Ferraris Development and

Assisted CPF are defined as CPF augmented by
an abdominal thrust that is timed to glottic open-
ing after air stacking or GPB to deep lung inflation.
Unassisted and assisted CPF were measured by Ac-
cess Peak Flow Meter (Health Scan Products Inc,
Cedar Grove, NJ) at every visit.

The maximum of four or five measurements
was recorded for the initial (post-VC plateau) VC,
MIC, and GPmaxSBC; and the most recent data.
A standard oral–nasal mask was used
for spirometry and CPF measurements.

Diminished VFBA was defined by lack of au-
tonomous ability to breathe without using GPB, or
by a difference in need for mouthpiece intermittent
positive-pressure ventilations during 5-min periods
when using GPB vs. periods when it was not used,
with no change in end-tidal carbon dioxide or oxyhe-
omoglobin saturation. Patients took these assisted
breaths to avoid dyspnea. Delayed onset of daytime
ventilatory assistance was recognized when patients
who normally used GPB throughout waking hours
became dyspneic and hypercapnic when breathing
without it, to the extent that only resumption of GPB
or deep, ventilator-assisted breaths could maintain
them.

**Statistical Analysis**

Descriptive statistics included mean and stan-
dard deviations. Comparisons between mean
values of MIC and GPmaxSBC with VC at the initial, plateau,
and most recent evaluations were made by t test
using the Bonferroni correction for six comparisons.
This warranted a P value <0.008 for statistical sig-
nificance.

**RESULTS**

All 78 patients cooperated for VC measure-
ments, but four were too cognitively impaired to
learn lung-inflation techniques. Twenty-four DMD
patients' VCs plateaued at mean age 12.7 ± 3.1 (range
10.5–16.1) yrs, at 2026 ± 555 (940–2510) ml.
The 74 remaining self-directed patients (mean
age 20.6 ± 3.1 yrs) were taught air stacking after
their VC was on the decline. Their mean initial VC,
and MIC by air stacking, were 987 ± 631 and 1501 ±
618 ml, respectively, and unassisted and assisted
CPF were 145 ± 112 and 250 ± 84 liters/m, re-
spectively. The VC, MIC, and CPF changes over
time for the 47 patients with multiple data points
during a 7- to 169-mo follow-up are illustrated in
Figure 2. For 31 of the 47 patients who reported
practicing air stacking at least twice a day, the MIC
increased over time despite diminishing VC. For
these 31, MIC plateaued at 21 ± 18 (2–51) mos
after initial training. Eight of the 47 patients' post-
plateau VCs increased by 35–70 ml for one or more
follow-up visits after practicing lung-insufflation
therapy. Two patients lost the ability to air stack
(MIC < VC) at ages 26 and 38.

Ten patients had mastered GPB on their own
and presented with GPmaxSBC >VC. Twenty-two
others were formally taught GPB. The VC and GP-
maxSBC changes over time for 19 of the 32 pa-
tients who mastered GPB and had two or more data
points are illustrated in Figure 3. Eighteen of the
19 reported using GPB daily. For 11 of the 19,
GPmaxSBC increased with practice and plateaued
13 ± 16 (range 3–49) mos after initial mastery.

**FIGURE 1 Graphic for a patient with 20 data points. VC, vital capacity; MIC, maximum insufflation capacity; GPmaxSBC, glossopharyngeal maximum single-breath capacity.**
(Figure 4). Gulp capacities were from 8 ± 9 to 70 ± 34 ml, depending on whether GPB was being used for normal minute ventilation or for maximal lung inflation, with the latter gulps being much smaller.

Fifteen patients eventually used GPB throughout daytime hours such that respiratory distress and hypercapnia developed when ceasing GPB. Thus, GPB delayed the need for daytime ventilator use. At the most recent evaluation, these 15 required 5.3 ± 1.7 mouthpiece intermittent positive-pressure ventilations per minute (1200 ml each) when not using GPB and 3.4 ± 1.7 ventilations per minute when using it. All used volume-cycled ventilators on assist/control mode with delivered volumes of 850–1500 ml and a backup rate of 10–12 per minute. Nine of the 32 patients did not master GPB, and two had GPmaxSBC exceed VC by 80 and 240 ml at initial mastery but have not yet returned.

Whereas 74 of 78 (95%) patients with DMD mastered air stacking, only 21 of 78 (26.9%) have mastered GPB thus far, and at least nine are likely to never master it. Some of the remaining 42 may master it as their VCs decrease below 400 ml. Thus, for at least 27% of DMD patients, GPmaxSBC can exceed VC, and for most of these, it can delay the need for daytime ventilator use. For the 74 patients as a whole, and for the patients in Figures 2–4, the MIC and GPmaxSBC values significantly exceeded VC and assisted CPF exceeded unassisted CPF ($P < 0.008$).

The mean age of beginning nocturnal noninvasive ventilation was 19.1 ± 3.3 yrs. Although all of our GPB users lost the ability to breathe unaided by ventilator use, none have tracheostomy tubes. Six patients died during the course of the study:
five from overt cardiac failure, and one, who had no assistance at home, from respiratory failure during a respiratory tract infection.

**DISCUSSION**

The VC plateau that we found for 24 patients occurred months later than the figure reported previously. The fact that 4 of our 24 patients received glucocorticoid therapy may be one of the reasons for this.

In a previous study, it was reported that three DMD patients used GPB to inflate the lungs to two to three times VC. The authors did not report any effect on cough flows or on VFBA. The delayed need to use daytime ventilatory support and, subsequently, the fewer assisted breaths required when using GPB than when not using it, provided some security to the patients because they could survive longer by using GPB in the event of ventilator failure, and GPB saved them some effort in having to rotate the neck and grab the mouthpiece as much as would have been necessary otherwise. Also, because 90% of episodes of respiratory failure and death for conventionally managed DMD patients occur as a result of ineffective coughing during intercurrent upper-respiratory tract infections, and because cough flows correlate with (pre-) cough volumes, it is important for patients to be able to autonomously increase lung volumes when they need to cough. Lung-inflation therapy also helps maintain both dynamic and static pulmonary compliance. GPB, like air stacking via a volume ventilator, permits this. Because both GPmaxSBC and MIC can improve and plateau over a wide range of time (2–51 mos) despite declining VC, both should be monitored regularly, and practice should be encouraged. Pressure-cycled ventilators such as BiPAP machines do not permit air stacking and should not be used for these patients.

The slight, temporary increase in VC for eight patients was probably attributable to an improvement in pulmonary compliance brought about by regular lung-expansion therapy. Although we only measured the effect of deeper lung volumes and abdominal thrusts on assisted coughing, deep lung insufflations and abdominal thrusts have been separately shown to increase CPF almost equally, with the greatest increases when they are combined. The GPmaxSBCs and gulp volumes in DMD patients tend to be lower than those reported for postpolio and spinal cord–injured patients, who often have gulp capacities over 100 ml, GPmaxSBCs over 3000 ml, and many hours of VFBA despite having little or no VC. This is because bulbar-innervated muscles tend to be spared for the latter but become increasingly dysfunctional in DMD. Thus, although DMD patients are usually able to speak clearly, take food by mouth, and maintain good vocal-fold mobility and glottic closure even after 40 yrs of age, they lose the ability to close the glottis tightly enough to hold deep lung volumes. Whereas most patients with bulbar amyotrophic lateral sclerosis lose the ability to air stack, and GPB and cough become physically impossible for them, we have observed losses of air-stacking ability in only 2 of 74 DMD patients, despite some being over age 40.

When air stacking and GPB are suboptimal, lung-insufflation therapy can still be performed using a manual resuscitator with the expiratory valve blocked, by delivering high volumes from a volume-cycled ventilator, or by using the CoughAssist machine (J. H. Emerson Company, Cambridge, MA) at insufflation pressures of 40 cm H2O or more via an oronasal interface. Indeed, as assisted CPF and air-stacking ability decrease, our patients use CoughAssist machines for both mechanically assisted coughing and for maximal lung insufflations. No complications have been associated with this therapy for the >1000 patients with neuromuscular diagnoses who have been treated in this manner in the last 28 yrs.

Comparing GPmaxSBC and MIC permits the evaluation of oropharyngeal muscle groups. When the GPmaxSBC is greater than the MIC achieved by air stacking via a mouthpiece (as often occurs in postpoliomyelitis patients), then the glottis is sufficiently intact to hold deep lung volumes, but the lips and buccal muscles are too weak to permit air delivery past the vocal fold. Some such patients can air stack better via nasal interfaces. Likewise, when MIC is greater than GPmaxSBC, as for these DMD patients, the hypopharyngeal musculature is weakened and laryngeal mobility is impaired. Some patients can only GPB or air stack with the nose plugged because the soft palate is unable to seal off the nasopharynx.

Although we and others strongly recommend that GPB be taught to patients with neuromuscular disorders, few clinicians are familiar with the technique. Some patients learn it on their own. This is probably a consequence of cerebral imprinting of the phylogenetic distribution of lung-ventilation mechanisms. Aspiration breathers, like mammals, ceased GPB shortly after aspiration breathing had evolved. Indeed, at least four of our patients who learned it on their own and used it spontaneously were hypercapnic and hypoxic. It is possible that the mechanism for GPB is the same as that observed in experimental studies in lunged amphibians for whom buccal pumping activity increases during hypoxia and hypercapnia. Lung packing by GPB is used by many breath-hold divers to increase lung air volumes by up to 5.6 liters over VC to permit longer submersion, and by many competitive swimmers to increase thoracic volumes and buoyancy. The transpulmonary pressures generated by maximal-depth GPB in swim-
mors have been reported as high as 80 cm H₂O. These are similar to the pressures we use for maximum-depth air stacking. Despite such high pressures, no barotrauma or other complications have been reported.

Many postpolio, spinal cord–injured, and DMD patients can use GPB instead of a ventilator for ventilatory support when awake. With deteriorating inspiratory and bulbar-innervated muscle function, however, DMD patients eventually use GPB to take fewer ventilator-assisted breaths. Once a DMD patient’s VC is inadequate to breathe without continuous ventilator use (VC <200 ml), bulbar-innervated musculature is inadequate to use GPB for complete ventilator-free breathing.

GPB has been included among the techniques that are not well adapted to producing bronchial clearance, because “it cannot be mastered by all patients.” However, it seems that this is rarely even attempted. The clinician should at least identify those patients who already perform it and should help them improve their technique by spirometric feedback. With training and practice, many DMD patients can exceed their VC’s three- to tenfold (Fig. 4)—increases comparable with those of spinal cord–injured and postpolio patients.

Both air stacking and GPB can improve with practice, even when VC is deteriorating. GPB provides a vital advantage for those who master it. It should no longer be ignored for patients with DMD.

REFERENCES


300 Bach et al.
Air Doping
An Exposé on “Frog” Insufflation in Competitive Sports

ABSTRACT


Key Words: Pulmonary, Glossopharyngeal Breathing, Insufflation, Respiratory Therapy, Noninvasive Ventilation, Swimming, Sports

Whereas athletes who “blood dope” add intravascular volume for a competitive advantage in endurance sports, other athletes attain intrapulmonary volumes that exceed maximum inspiratory capacity to yield equally impressive competitive advantages. The article by Nygren-Bonnier et al., entitled “Effects of Glossopharyngeal Pistoning for Lung Insufflation on Vital Capacity in Healthy Women,” describes a little-used technique that provides important benefits for certain athletes as well as for patients who are too weak to breathe or cough.

Frogs do not have diaphragms. Frogs ventilate their lungs by using glossopharyngeal muscles to piston boluses of air past their glottises into their chests. Because ontogeny recapitulates phylogeny, it is likely that humans perform a similar ventilation technique in utero. Although we apparently forget it long before we are born, Nygren-Bonnier et al. demonstrate that we can relearn it. They demonstrate that the great majority of a sample of 26 people in the general population were able to master glossopharyngeal pistoning (GP) to increase lung volumes to 15% greater than VC and to increase unassisted vital capacity (VC) by about 130 ml. This means that many people with functioning bulbar-innervated musculature can potentially benefit from GP. Like patients with neuromuscular weakness, air bolus volumes average 60–200 ml per gulp. We, too, have observed that the majority of unaffected family members of patients with neuromuscular disease can learn GP along with the patients and supplement inspiratory capacity by about 500 ml in this manner on initial attempts. The GP is most easily taught by simply imitating the instructor.

GP must always be done to provide lung volumes that exceed maximum inspiratory capacity, or else it is irrelevant and unmeasurable. Thus, patients with little or no VC perform it to provide greater tidal volumes than they could accomplish autonomously to normalize alveolar ventilation. In this regard, it has been referred to as “glossopharyngeal breathing” or “frog breathing.” The majority of patients with little or no VC or respiratory muscle function other than for very functional bulbar-innervated muscles can master the technique and use it for ventilator-free breathing. In this way, it can provide security in the event of sudden ventilator failure or ventilator-interface disconnection for
patients using noninvasive mechanical ventilation. Indeed, some patients with no measurable VC have awakened in the middle of the night breathing glossopharyngeally before realizing that their respirators are no longer operating. This ability is one of the main reasons that most patients with tracheostomy tubes and functional bulbar-innervated musculature, whether using respiratory support or not, should be offered decanulation to noninvasive mechanical ventilation as part of their rehabilitation.  Although it can be used somewhat effectively by some patients with capped tracheostomy tubes, for the majority of such patients, too much air leaks around the tube and out the ostomy for it to be very useful.

Patients with reduced VCs also perform GP and other techniques such as air stacking to maximum lung volumes to raise their voices, cough more effectively, and expand their lungs.  This has been shown to result in lung volumes that are often as much as 3 liters greater than VCs (glossopharyngeal maximum single-breath capacity), mild increases in non-GP-assisted VC, and pulmonary compliance for patients, normals, and athletes.

Another paper that is currently in press reports that elite competitive swimmers use GP to increase both VC and chest expansion.  Sprints of 50 m are often done without taking a breath. Holding a breath at lung volumes that exceed maximum inspiratory capacity results in increased buoyancy that might increase speed. In another paper, it was shown that water submersion could be increased from 309 secs with a deep breath (to maximum inspiratory capacity) to 346 secs with a deep breath supplemented by GP. These athletes added 1.95 liters of lung air volume to their VCs by GP. It should be noted that to increase lung volumes beyond total lung capacity, lung and chest-wall recoil pressures must be overcome by GP. The mean mouth-relaxation pressure at total lung capacity supplemented by GP was 65 ± 19 cm H2O; at times, it exceeded 90 cm H2O. These pressure levels are comparable with those seen in patients with neuromuscular disorders who perform air stacking to maximum insufflation capacities or maximum lung insufflations with mechanical in- and exsufflators three times a day to maintain pulmonary compliance. These pressures have not been associated with barotrauma in the normals, patients, or athletes.

Is this not legal “air doping”? For GP to be effective, the soft palate must close the nasopharynx off to air leakage out of the nose. Swimmers (and patients, for that matter) with incompetent soft palates could use nose clips to seal the nose and, thereby, perform GP effectively, but that would mean requiring a foreign device. Individuals whose GP is ineffective despite the use of a nose clip could fill the lungs to volumes over inspiratory capacity by air stacking. Most simply, this would involve the use of a manual resuscitator to deeply inflate the lungs. Although this would be quicker than GP, racing officials would probably look askance at air doping in this manner.

Yet another use for GP is by breath-holding deep-sea divers. For this application, GP can be used for insufflation, and reverse GP can be used for exsufflation to lung volumes below residual volume. The latter must be strictly a human endeavor, because it is doubtful that any frog would ever have reason to attempt such a thing. For five deep-sea divers, GP increased lung volumes from a VC of 6.2–9.5 liters to maximum GP lung volumes of 7.8–11.9 liters. The greater the lung volume of air, the more oxygen is present to support longer submersion. The increased volume of gas also better equalizes lung pressure at great depths. Deep-sea divers also master reverse GP to lung volumes below residual volume. The five deep-sea divers in the study by Lindholm and Nyren exhale to residual volumes of 1.37–2.4 liters without GP and to 1.16–1.77 liters using reverse GP. Because air cannot be exhaled (to the mouth, for example) using expiratory muscles from lungs compressed at depths to as much as 73 m, reverse GP for exhalation is critical for equalizing pressures in the inner ear and sinuses at great depths. Using GP for deep lung inflation, then reverse GP for exsufflation, one individual with a VC of 5.5 liters was able to expel 11.1 liters of air.

Thus, GP can be critical for ventilator-free breathing ability and for coughing and speech for patients unable to breathe and cough effectively unaired, for successful breath-hold deep-sea dives, and, quite possibly, for competitive swimming. Besides being tasty, frogs also have a lot to teach us.

REFERENCES


ABSTRACT


Magnetoencephalography (MEG) is a sensitive technique that can detect and map cortical electrophysiologic activations with high spatial (mm) and temporal (msecs) resolutions. We used 148-channel whole-head MEG to record the activation sequence for the somatosensory and motor cortical network during cued hand movements in a healthy 39-yr-old subject. The complex sequence and topography of cortical activations were superimposed onto the subject’s brain magnetic resonance images. Frontal premotor and supplementary motor and cingulate areas activated well before the primary motor area and again repetitively from 200 msecs onward with activations alternating repeatedly between frontal and parietal areas. The network’s very close functional integration of supplementary motor areas suggests how brain injury that is localized to these regions, but not to the primary motor area itself, can disrupt integrity of movement, and why preservation of functional integrity of some areas traditionally viewed as extramotor may be necessary for recovery from neurologic disability.

Key Words: Magnetoencephalography, MEG, Brain Mapping, Cortical Activation, Neurophysiology

Magnetoencephalography (MEG) is a sensitive neuroimaging technique that combines high spatial (mm) and temporal (msecs) resolutions of functional brain activity. This study seeks to use the advantages of MEG to pinpoint and functionally map the human cortical network mediating voluntary movement. Previous MEG studies have mapped and validated the reliability of localizing the cortical sources of the major latency events corresponding to the major visible peaks in the event-related, signal-averaged magnetic waveform associated with intentional movement. In this study, we seek to evaluate whether magnetic dipole localizations can be obtained for cortical activations occurring throughout an event-related period without limitation to the major visible latency peaks. If the technical
feasiability of this concept could be established, then exhaustive mapping of cortical activations mediating intentional movement would be routinely available. Such capability could be used to illuminate network components and their relationships in greater detail than has been previously reported. Such deepened information regarding the functional organization of human cerebral cortex could then be applied to understanding healthy and neurologic disease (or injury) conditions.

METHODS

A healthy, 39-yr-old, left-handed male subject gave informed consent to participate in this study. The subject was instructed to respond to a sensory cue with a brisk full-hand extension and then active flexion of the wrist back to the original resting position. A brief practice session was performed to ensure optimal performance (i.e., adequate and consistent response timing). The sensory stimulus was a painless tactile cue consisting of a 15-psi airpuff of 30-msec duration applied at the skin surface of the tip of the index finger of the hand to be moved. The stimulus was applied with an inter-stimulus interval of 2 secs. Three hundred stimuli (trials) were applied to the right hand, and then 300 stimuli were applied to the left hand. Headshape digitization using anatomic and electrode (electrooculogram) fiducial points was imported into the MEG software. MEG activity was recorded continuously throughout the entire 600 trials by a Magnes 2500 whole-head system with 148 channels (4D NeuroImaging Technologies, Inc., San Diego CA) inside a sound-damped and magnetically shielded room. Signal acquisition was conducted at a sample rate of 678.17 Hz with a band-pass filter of 0.1–100 Hz. Data postprocessing for the offline analysis included digitization, filtering (0.1–40 Hz), and signal averaging (300 trials).

A single equivalent dipole model was used (equivalent-current dipole) to calculate the spatial localization of the neuronal currents. The dipole-fit algorithm selection criteria were (1) amplitude or global field power of each magnetic response >400 fT (expressed as the root mean square of magnetic flux integrated over all sensors), (2) strength of the magnetic moment had to be <400 nAm-m in amplitude so that the current density would be consistent with a focal source, (3) correlation >0.90 between the recorded measurements and the values expected from the dipole estimate from the forward equation, (4) goodness of fit >0.90 for agreement of the observed measurements and the resulting dipole fit with the model, and (5) 95% confidence that the real dipole fell in a volume less than 15 cm³, on the basis of a comparison of signal strength and the background noise as measured in an interval before the trigger.

Whole-head isocontour maps of the magnetic field strengths were evaluated visually for the presence of dipoles and were also explored algorithmically using the equivalent-current dipole software, with selection stringency set at the dipole-qualification criteria described above. The isocontour maps and magnetic dipole solutions were evaluated by scrolling millisecond by millisecond through 1000 msecs (0–1000 msecs after stimulus) of the event-related averaged waveforms. Magnetic resonance imaging (MRI) of the brain was performed according to routine clinical protocol on a General Electric Signa 1.5-T system using contiguous 1.0-mm T1-weighted slices. MRI was imported into the MEG software in Digital Imaging and Communications in Medicine format. Anatomic landmarks were visualized on the MRI T1 axial plane. The MEG dipole localizations were overlaid onto magnetic resonance images by coregistration of MEG fiducial points and MRI anatomic landmarks using Spatio Temporal Analysis/Review software. Di- poles in the hemisphere contralateral to the hand movement were counted and portrayed graphically, and a schematic summary was made of the temporal predominance of the motor- vs. somatosensory-area dipole generators produced in contiguous 50-msec epochs (predominance was defined as >80% of epochal dipoles). Good replicability of the technique has been demonstrated in a similar pneumatically cued hand-flexion study design, which showed close similarity of MEG waveforms across three different days and close proximity of dipolar sources computed at the peak of each component. Such MEG-derived localizations of primary sensory and motor cortex have also been verified using invasive recordings during surgery.

RESULTS

Signal averaging of the 300 trials in each hand yielded event-related waveforms corresponding to somatosensory- and motor-evoked fields. The equivalent-current dipole calculations pinpointed magnetic dipoles (cerebral activations) from cortical sources throughout the period from the time of the central receipt of the stimulus to the completion of the wrist movement. All magnetic dipole source activations localized to a radius less than 1 cm.

Figure 1 shows the sequence of the time frames and the changing loci of cortical activations from 0 to 200 msecs after the stimulus. This sequence of time frames is the cortical representation of a physiologic event, with the limits of each interval (time frame) based on the latencies of the first and last dipoles of every group anatomically located in the MRI. It can be seen from Figure 1 that the spatiotemporal pattern of cortical activation unfolds similarly for either right- or left-hand movement (in their contralateral hemispheres, re-
spectively). In particular, the operation of the pre-
motor activations identifiable within the supple-
mentary motor area (SMA) and prefrontal motor
(53–63 msecs) and cingulate areas (65–108 msecs)
precedes primary motor cortex activation (130–
185 msecs) in a similar manner, regardless of
which hemisphere is engaged.

In each hemisphere, contiguous epochs of 50-
msec duration from 200 to 1000 msecs, coincident
with the actual extension–flexion wrist movement,
were evaluated for predominance of motor vs.
somatosensory activations. Epochs were defined as
predominantly motor or predominantly somatosen-
sory when more than 80% of epochal dipoles
localized to the motor area or the somatosensory
areas, respectively. Epochs were defined as simul-
taneous motor and somatosensory when epochal di-
poles localized approximately equally to the motor
area and the somatosensory areas. The schematic
presentation in Figure 2 uses these conventions to
illustrate the sequence of changing predominance
of cortical activations between the motor and sen-
sory areas. This pattern of reciprocating predomi-
nance between the motor and somatosensory areas

FIGURE 1 Cortical dipole source representations of hand movement task during the first 200 msecs after
stimulus. The left panel shows the spatiotemporal phases of the left-hemisphere activations (corre-
sponding to the right-hand task), and the right panel represents right-hemisphere activations
(corresponding to the left-hand task). Five discrete sequential topographies (phases) of somatosensory
and motor response are evident in the cortical areas of each hemisphere. The limits for each interval
(time frame) represent the range of latencies for each cortical phase according to the latencies of the
first and the last dipoles of every group anatomically located in the MRI.
during contralateral hand movement seem to be structured with a similar physiology (in locations and timing), regardless of which hemisphere is being activated.

**DISCUSSION**

Our findings establish the technical feasibility of the use of MEG to map the instantaneous trajectory of brain cortical processing during a cued movement. In the current study, this approach was used to generate a sample operation, from a single, healthy individual, of a model cortical network. The results in this single subject unify and corroborate a large body of reported latency events corresponding to select major peaks in the signal-averaged waveform across a large number of subjects. On the basis of these results, we suggest that MEG mapping of the instantaneous operations of the cortical networks on a millisecond-by-millisecond basis can now be applied to larger populations. Methodological refinements such as self-triggered movements would help to isolate the pure volitional and motor planning components without the influence of any external stimuli. In principle, mapping the instantaneous trajectory of cortical processing could be used to explore the organization and operational status of any desired cortical network.

The key correspondences between the model somatomotor network and known latencies and their cortical origins can be summarized in phases. In the first phase, from 16 to 51 msecs, the primary somatosensory response forms predominantly in the postcentral gyrus, consistent with other MEG studies reporting 20–40 msecs. In the second phase, between 53 and 63 msecs, cortical activation predominates in the frontal areas for movement preparation (SMA, prefrontal motor, etc.). This is in agreement with previous descriptions of the activation of these areas during the preparation and execution of simple and sequential voluntary movement. Functional MRI, a technique of lower temporal resolution, shows that the activation of these areas precedes M1. We show that M2 (premotor and supplementary motor activity) precedes M1 by 70–100 msecs, in close agreement with MEG studies that have shown that this SMA and prefrontal motor activation precede M1 by 80–120 msecs.

In the third phase, from 65 to 108 msecs, the secondary somatosensory areas, supramarginal gyrus, posterior cingulate cortex, and insula are all activated; others have shown between 90 and 100 msecs. This activity has been interpreted as related to movement preparation through the transmittal of sensory information to the premotor cortex. The posterior cingulate cortex is activated by sensory stimulation that can be seen with functional MRI and MEG. In the fourth phase, from 130 to 185 msecs, the primary motor cortex becomes activated along the precentral gyrus (M1) in agreement with neuroimaging techniques and MEG. In the fifth phase, from 169 to 198 msecs, the areas for the secondary somatosensory areas, supramarginal gyrus, posterior cingulate cortex, insula, superior temporal gyrus, and,
less intensively, the SMA, are all activated. This activation is described around 200 msecs and is interpreted as being related to the planning and execution of movement. In the follow-on activity between 200 and 1000 msecs, corresponding to the actual extension and flexion movements, M2 and the secondary somatosensory areas, as well as other parietal areas, become activated with similar latencies in both hemispheres, as has been reported from MEG.

The correspondence between our findings and these results from many studies across many subjects suggests that the present model network is generally valid. Larger studies are needed to produce model refinements and validation within and across selected populations, and to obtain normative ranges for the overall trajectory and its component-activation latencies and locations. An important limitation of the technique and, thus, the present model network, is that it identifies and incorporates only a subset of all activation events. This limitation exists because MEG is believed to detect primarily sulcal events, being insensitive to events localized within the convexities of the cortices (surface of the brain) because of differing orientation of the magnetic fields generating from these sites. Therefore, contributions to network processes from cortical neurons at the crowns of the gyri might not be registered using the MEG technique. This spatial gap in mapping cortical network components might be complemented by the use of other functional neuroimaging techniques such as functional MRI. However, no functional neuroimaging technique other than MEG provides the fine-scale temporal resolution needed to precisely identify when a particular gyrus activates in relation to the activation of other network components.

The present findings present a sample of a model cortical network. This network mediating intentional movement operates through dense reciprocating communications among frontal supplementary motor, premotor, cingulate, and somatosensory areas. First, there is a relatively concentrated period of cortical processing in the prefrontal motor and SMA and cingulate gyrus, antecedent to M activation by 70–100 msecs. This processing likely corresponds to movement planning and preparation. We have recently confirmed this through a related MEG study of imagined movement conducted in the same subject. The mental plan for movement was mediated predominantly at M2 (76–91% of frontal motor area activations, left and right hemispheres, respectively). Additionally, it was also shown that the somatosensory stimulation alone does not elicit any M2 activation. Second, there is the reciprocating flow of information between these frontal areas and parietal lobes during movement execution. This likely corresponds to a position-checking or proprioceptive function. We surmise, from the very close functional integration of these structures within the network, that damage to the supplementary motor, premotor, or cingulate areas might impede both pre-M1 movement preparation and proprioceptive integrating functions during movement execution. This close functional integration may explain why even small, discrete lesions localized to these regions can produce substantial motor disability, such as immediate paresis and dysarthria after neurosurgical resections of brain tumors localized only to the SMA. The model’s close integration of the supplementary motor, cingulate, and insula also explains why the level of functional integrity of each of these areas seems to affect the degree of impairment and recovery of motor function after stroke.

The model network presented here, based on a single equivalent-current dipole technique for dipole localization, provides insight that is useful for evaluating and investigating a broad range of motor-associated disabilities. For example, MEG could be used to quickly and easily screen symptomatic individuals to identify the level of integrity or loss of network-component functions, possibly enabling early classification of capacity for recovery. This information is greatly needed during the earliest stages of brain injuries, including stroke, head injury, or treatment of brain tumor. This principle has been explored using MEG to monitor a unique-latency event and site, where a change in the source strength of the first motor-evoked field component (postmedian nerve stimulation) of the motor cortex and postcentral gyrus after stroke was shown to correlate with the extent of recovery of sensorimotor function. The present approach using MEG monitors all detectable cortical activations with their instantaneous trajectories across all gyri and throughout the full span of event-related latencies. This more comprehensive approach vastly expands the capability to investigate and relate focal and global brain plasticity to clinical outcomes. In particular, the advantages of such an approach could lead to the development of objective quantitative indices that are highly prognostic regarding a patient’s individual capacity for recovery from neurologic disability.

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Introduction to Musculoskeletal Diagnostic Ultrasound
Examination of the Upper Limb

ABSTRACT

With recent advances in computer technology and equipment miniaturization, the clinical application of diagnostic ultrasonography (U/S) has spread across various medical specialties. Diagnostic U/S is attractive in terms of its noninvasiveness, lack of radiation, readiness of use, cost-effectiveness, and its ability to make dynamic examinations possible. Dynamic imaging deserves special emphasis because it is useful in differentiating full-thickness from partial-thickness tendon tears, muscle tears, and tendon and nerve subluxations or dislocations. It is also a quick and easy avenue for side-to-side comparisons. When appropriately used, diagnostic U/S can be considered as an extension of one’s physical examination. However, there are limitations of U/S, which will be discussed in this review article. This is part 1 of two articles; this first part will focus on the ultrasound examination of the upper extremity, using selected examples relevant to musculoskeletal medicine. Part 2 will cover common pathologies of the lower extremity.

Key Words: Musculoskeletal, Ultrasound, Upper Limb

Ultrasoundography (U/S) is an imaging modality that uses sound waves in the higher frequency range of >20,000 Hz, which normally cannot be heard by human beings. Ultrasound travels as a longitudinal wave, and images are generated when pulses of ultrasound from the transducer produce echoes at tissue or organ boundaries. Some of the waves are absorbed by the tissues, and the extent to which the ultrasound is absorbed or reflected gives information about the structures scanned, as illustrated in Figure 1. Resolution is defined as the smallest distance that can be discriminated in the image. Better resolutions are attained with higher frequencies. But, in doing so, signals are attenuated, decreasing the depth of field. For example, a 7.5-MHz transducer would produce imaging depths of up to 8 cm with an average resolution of 0.20 mm, whereas a 10.0-MHz transducer would produce imaging depths of 6 cm or less, with a sharper resolution of 0.15 mm.

Between pulse transmissions, the transducer serves as a detector of echoes, which are processed to form an anatomic image. For most musculoskeletal diagnosis, the most useful frequency ranges for the transducer are between 7.0 and 12.0
MHz. This article will review the ultrasound appearance of normal tissues in the upper limb and will use clinical examples to demonstrate pathologic changes as they appear on ultrasound.

TERMINOLOGY AND EQUIPMENT CONSIDERATIONS

Interpretation of ultrasound images depends on the echogenicity: the brightness of the image, depending on the degree of reflection of the ultrasound waves. Terms used include hyperechoic, isoechoic, hypoechoic, and anechoic. The images are also described in terms of the plane on which the sonogram is viewed, which is usually longitudinal or transverse in relation to the structure scanned. Common terminology used in musculoskeletal ultrasound is defined in Table 1. Correct selection and configuration of equipment is critical for musculoskeletal U/S. The choice of transducer used depends on the size and location of the musculoskeletal structure to be imaged. Generally, linear transducers are used with high-frequency transducers (7.5–20 MHz) that have higher-resolution imaging but poorer tissue penetrance, making them ideal for small, superficial structures. Low-frequency transducers (<7.5 MHz) have poorer resolution but excellent tissue penetrance; these are preferable for larger, deeper structures. Images in this review were attained from the HDI 5000 (Advanced Technology Laboratories, Bothell, WA) and Xario (SSA 660A, Toshiba Corporation, Japan) with variable-frequency transducer probes between 5 and 20 MHz.

NORMAL AND PATHOLOGIC U/S APPEARANCE OF THE TENDON

Assessment of tendon integrity is one of the best applications of musculoskeletal U/S.3–5 Tendons are recognized by parallel and fine fibrillar patterns on U/S in the longitudinal view, as shown in Figure 2. The parallel fascicles of collagen fibers produce hyperechoic lines, whereas the interfascicular ground substance produce anechoic lines in between.6 In the transverse view, tendons appear as round or oval hyperechoic structures. Anisotropy is a characteristic feature of U/S of tendons and ligaments, where echogenicity of the structure changes depending on the angle of the U/S beam, as illustrated in Figure 3. The image appears hyperechoic when the beam is perpendicular to the tendon and hypoechoic when the beam is oblique, which may lead to misinterpretation.7 This characteristic is useful in identifying the scanned structure as either a tendon or ligament.

<table>
<thead>
<tr>
<th>TABLE 1</th>
<th>Terminology in musculoskeletal ultrasound</th>
</tr>
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<tr>
<td>Term</td>
<td>Definition</td>
</tr>
<tr>
<td>Echogenicity</td>
<td>Capacity of a structure in the path of an ultrasound beam to reflect back sound waves.</td>
</tr>
<tr>
<td>Hyperechoic</td>
<td>The structure examined in the ultrasound image shows a high reflective pattern and appears brighter than the surrounding tissue.</td>
</tr>
<tr>
<td>Isoechoic</td>
<td>The structure demonstrates the same echogenicity as the surrounding soft tissues.</td>
</tr>
<tr>
<td>Hypoechoic</td>
<td>The structure examined in the ultrasound image shows a low reflective pattern, manifesting as an area where the echoes are not as bright as the surrounding tissue.</td>
</tr>
<tr>
<td>Anechoic</td>
<td>The image of the structure shows no internal echoes (e.g., simple fluid).</td>
</tr>
<tr>
<td>Longitudinal</td>
<td>Scan is lengthwise and parallel to the long axis of the structure, organ, or body part.</td>
</tr>
<tr>
<td>Transverse</td>
<td>Scan is crosswise and at right angles to the long axis of the structure, organ, or body part.</td>
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The extent and mechanisms of tendon injury can be demonstrated by U/S through passive or resisted dynamic examination. Tendon degeneration on ultrasound is seen as irregularities of fibrillar appearance, such as thickening and fragmentation, focal hypoechoic areas, and calcifications. In tendons with synovial sheath, chronic tendinosis is characterized by widening of the tendon sheath, loss of normal fibrillar echotexture, and loss of definition of tendon margins. In tendons without synovial sheath, the pathology is characterized by focal or diffused thickening of the tendon, with loss of fibrillar echotexture and patches of hypoechoogenicity. Tendon ruptures, which can range from partial to complete to massive, appear as fragmented, contiguous fibrils. It is difficult to draw the distinction between tendon degeneration and intrasubstance tears in the absence of hematoma. This is especially so because the two conditions are not mutually exclusive. Complete tears of the tendon are characterized by retraction of torn edges, with hypoechoic hematoma or granulation tissue. Passive movement to accentuate the tendon interruption is a useful maneuver in U/S examination of a suspected tendon tear. In tendons with synovial sheath, fluid can collect in the space between the retracted ends of the tendon. Partial-thickness tears present with a combination of intact and retracted ruptured portions of the tendon, often accompanied by hematoma.

FIGURE 3  Anisotropy of normal biceps tendon. a, Transverse sonogram of hyperechoic biceps tendon (arrow) when the ultrasound beam is perpendicular to the tendon. b, Hypoechoic biceps tendon (open arrow) when the ultrasound beam is not perpendicular to the tendon.

FIGURE 4  Lateral view of the right shoulder, showing the rotator cuff muscles.

FIGURE 5  Sequence for rotator cuff ultrasound. 1) Ultrasound transducer placement for imaging the biceps tendon, with the forearm resting in a supinated position on the thigh. 2) Ultrasound transducer placement for imaging the subscapularis, with the arm externally rotated. 3) Ultrasound transducer placement for imaging the supraspinatus, with the hand in a back pocket, palm toward the gluteal muscles, and the elbow directed posteriorly. 4) Ultrasound transducer placement for imaging the infraspinatus, teres minor, and posterior glenohumeral joint, with an arm across the chest and the hand on the opposite shoulder.
Rotator cuff disease is common and is one of the most common reasons for using U/S. Matsen and coworkers\textsuperscript{14} have suggested diagnostic U/S as a primary imaging technique for soft-tissue injuries of the shoulder. The main advantages are its ability to perform dynamic examinations and to conduct side-to-side comparisons on the spot. Many studies report excellent sensitivity and specificity of ultrasound in diagnosing rotator cuff tears.\textsuperscript{15–20} U/S diagnosis of full-thickness rotator cuff tears has an overall accuracy of up to 96%.\textsuperscript{21} Recently, Teefey and colleagues\textsuperscript{22} found comparable accuracy of diagnostic ultrasound and magnetic resonance imaging for diagnosis and measurement of rotator cuff tears. Iannotti and coworkers,\textsuperscript{23} in their evaluation of office-based U/S by orthopedic surgeons measuring full-thickness rotator cuff tears, have yielded similar findings. However, several studies have reported less than satisfactory results in terms of accuracy.\textsuperscript{24–26} Interstudy comparison is difficult because of a lack of standardization of technique, clinical experience of different operators, and changes in equipment over time.

Understanding the anatomy of the rotator cuff is essential for successful shoulder U/S examination, because the overlying bony structures create obstacles to ultrasound imaging. The rotator cuff consists of the supraspinatus, subscapularis, infraspinatus, and teres minor tendons. The relations of the rotator cuff are illustrated in Figure 4. The long head of the biceps runs in the interval between the supraspinatus and the subscapularis tendons from the superior glenoid tubercle. These muscles provide dynamic stability to the inherently unstable, extremely mobile glenohumeral joint. The subscapularis originates anteriorly from the scapula and inserts into the lesser tuberosity of the humerus. The supraspinatus originates posteriorly from the scapula above the scapular spine and inserts into the anterior aspect of the greater tuberosity. The infraspinatus originates posteriorly from the scapula below the scapular spine and inserts into the greater tuberosity of the humerus posteriorly to that of the supraspinatus. The teres minor arises posteriorly from the scapula and inserts posteriorly and inferiorly to that of the infraspinatus at the greater tuberosity. The three posterior muscle tendons have a common insertion into the greater tuberosity and are difficult to distinguish.

**Standardized Technique in Examination of the Shoulder**

The shoulder is an important, yet complicated, joint to examine. Proper positioning of the patient is important for successful U/S of the shoulder. Typically, the patient is seated upright on a revolving stool. The examination should be systematic, with predetermined structures scanned step by step. U/S of the shoulder begins with the long head of the biceps tendon, which is often used as a reference landmark. The biceps tendon is examined in the longitudinal and transverse planes with the patient’s forearm or hand resting in a supinated position on the thigh. Moving from the biceps tendon medially is the subscapularis, which is best examined with the patient’s arm in external rotation. The tendon is traced from the bicipital groove and lesser tuberosity. Imaging of the supraspinatus is obstructed by the overlying acromion. The maneuver for exposing the supraspinatus beneath the acromion anteriorly is to have the patient put a hand in his or her back pocket with the palm toward the gluteal muscles while keeping the elbow directed posteriorly. The tendon is examined in perpendicular planes, bearing in mind that the axis of the tendon is approximately 45° between the sagittal and coronal planes of the body. The poste-
rior glenohumeral joint, infraspinatus, and teres minor are examined by putting the patient’s arm across the chest with his or her hand on the opposite shoulder. The posterior cuff is examined by tracing from the bony landmark of the spine of the scapular and moving the transducer inferiorly to the infraspinatus and then laterally to visualize the posterior glenohumeral joint.

Because the cuff tendons inserting into the greater tuberosity are relatively indistinct from each other, it is difficult to distinguish them. One way to tell them apart is by sequential measurements. The supraspinatus forms approximately 1.5–2 cm of width on the transverse plane, starting from the edge of the biceps tendon, and the infraspinatus forms the next 1.5 cm posteriorly. Figure 5 illustrates the sequence of ultrasound examination of the shoulder.

Supraspinatus Tendon Pathologies

The normal longitudinal ultrasound appearance of the supraspinatus resembles a parrot’s beak. The transverse view of the supraspinatus shows the parallel convexity of the subacromial–subdeltoid bursa above and the humeral epiphysis below, as illustrated in Figure 6.

Supraspinatus Tendinosis

The term “tendinosis” (or “tendinopathy”) has superseded the term “tendonitis” as studies have shown the absence of active inflammation in these conditions. Tendinosis appears as focal or diffuse, poorly demarcated hypoechoic regions accompanied by swelling. Confusion often occurs here because partial tendon tears may appear hypoechoic. The presence of an internal fibrillar pattern and the lack of tendon atrophy differentiate tendinosis from partial tears. A markedly echogenic appearance with posterior acoustic shadowing arising from the tendon substance can occur in calcific tendinopathy, as shown in Figure 7.

Full-Thickness Supraspinatus Tear

Rotator cuff tears are characterized by the degree of tear (i.e., either partial or full thickness), the amount of tendon retraction in the longitudinal plane, and the width of the defect in the transverse plane. Full-thickness tears can present with nonvisualization of the rotator cuff, where there is total absence of the supraspinatus tendon on U/S. This feature can be seen in massive rotator cuff tears, which are associated with a high-riding humeral head on radiographs. The fluid collection between the deltoid and humerus may be mistaken as the supraspinatus. In the absence of the supraspinatus tendon, compression with the ultrasound probe will obliterate this space, as illustrated in Figure 8. In addition to compressibility, the fluid should not be mistaken for cuff tissue, because there is no internal fibrillar echotexture of the fluid.

The edge of the tendon stump can be tapered off to fibrosed synovium. This produces a contour
alteration in that the normal outer convex border of the rotator cuff is flattened or becomes concave. The most common ultrasound feature of full-thickness tears of the supraspinatus is the hypoechoic defect, which appears as sharp demarcations from the bursal to the articular surface of the tendon. Shoulder effusions and bursal fluid have been shown to correlate strongly with rotator cuff abnormalities. It distributes within the glenohumeral joint, to the tendon sheath of the long head of biceps, to the subacromiodeltoid bursa through the tear and through the acromioclavicular joint to produce the geyser sign, as illustrated in Figure 9. The loss of tendon causes the deltoid at the bursal surface to sink into the gap to produce the deltoid herniation sign, and accompanying exaggeration of articular hyaline cartilage produces a double-cortex appearance as well as cortical irregularities. These features can be seen in Figure 10.

Partial-Thickness Supraspinatus Tear

A partial-thickness tear appears as a hypoechoic area within or at the bursal or articular aspect of the tendon, usually located at the critical area over the anatomic neck of the humerus. Differentiating between partial tears and severe localized degeneration of the tendon can be difficult using U/S, which is less sensitive in such cases than it is for detecting full-thickness tears. The intrasubstance tears are hypoechoic areas within the tendon substance with intact articular and bursal surfaces. Articular-surface tear can be seen as a hypoechoic defect that continues to the articular surface of the tendon. Cortical irregularity is a common finding at the articular extension of a tendon tear. In bursal-surface tears, the hypoechoic defect is in continuity with the bursal surface of the tendon. Ultrasound appearance of both

![FIGURE 9](image1.png)

a. Normal acromioclavicular joint. b. Acromioclavicular joint effusion demonstrating the geyser's sign, as shown by arrows. Acr, acromion; Clav, clavicle.

![FIGURE 10](image2.png)

Full-thickness tear of the supraspinatus tendon. a. Longitudinal sonogram depicting a focal hypoechoic defect (open arrow) with deltoid muscle (Del) herniation from above. Exaggeration of cartilage reflection is seen here in the absence of an overlying tendon. Cortical irregularities are seen at the greater tuberosity (GT). b. Transverse sonogram showing double-cortex sign (arrows), representing the articular hyaline cartilage above and the cortex of the humeral head below.
articular- and bursal-surface partial tears of the supraspinatus are illustrated in Figure 11.

Although most partial tears occur in the critical zone of the supraspinatus tendon, some tears, commonly known as rim rent tears, involve a small, articular surface avulsion adjacent to the greater tuberosity. This type of tear appears as a small, hypoechoic defect with a central hyperechoic line on the articular surface. The transverse view appears as a bull’s eye lesion, with central punctuate echo surrounded by a hypoechoic halo of fluid or edematous tendon.

**Biceps Tendinosis**

The long head of the biceps tendon is kept in place within the groove by the transverse humeral ligament and coracohumeral ligaments. A full-thickness tear is represented by complete discontinuity of the fibrillar pattern of the tendon, whereas a partial-thickness or intrasubstance tear of the biceps tendon produces a hypoechoic defect. Surrounding tenosynovitis is commonly seen in bicipital tendinosis, as shown in Figure 12. The tendon can subluxate or dislocate out of the groove when the integrity of the transverse humeral ligament is breached in association with supraspinatus or subscapularis tendon tears. Biceps tendon subluxation out of the groove can be demonstrated by internal and external rotation of the shoulder; this usually occurs medially. An empty bicipital groove can be seen when the biceps tendon is completely dislocated or torn. Complete biceps tendon tears are differentiated from dislocations by tracing the muscle belly, which will also be absent but only visualized distally because of muscle retraction.

**Tennis Elbow, Lateral Epicondylitis**

Tennis elbow, or lateral epicondylitis, is the most common soft-tissue injury affecting the elbow joint. It is thought to arise from chronic repetitive injury. The lateral epicondyte is the origin of the common extensor tendons of the wrist and hand. Tendons of the extensor carpi radialis brevis, extensor digitorum, extensor digiti minimi, and extensor carpi ulnaris fuse to form the common extensor tendon origin.

In lateral epicondylitis, the tendon origin appears thickened and hypoechoic on ultrasound. There may be hypoechoic linear clefts within the tendon, representing intrasubstance tears—a common occurrence in tendinopathy. As seen in Figure 13, chronic epicondylitis is associated with tendon thickening, calcification, and cortical irregularity, or spur formation of the epicondyle.

**De Quervain Tenosynovitis**

De Quervain tenosynovitis is an idiopathic condition involving the abductor pollicis longus and extensor pollicis brevis tendons in the first extensor compartment at the level of and proximal to the radial styloid. Pain is usually brought about by thumb movements or, specifically, by the
Finkelstein test, in which the patient makes a fist with his or her fingers over the thumb, with the wrist adducted. The tendon sheath appears thickened with hypoechoic fluid on ultrasound, as shown in Figure 14. A hypoechoic or anechoic ring surrounds the hyperchoic tendon in peritendineal effusion of tenosynovitis, giving the appearance of a target sign.

NORMAL AND PATHOLOGIC U/S APPEARANCE OF THE MUSCLE

U/S is an effective assessment tool for diagnosis of acute muscle injury, such as muscle contusions, strains, tears, and hematoma, as well as chronic lesions such as fibrous scars. U/S can be helpful for predicting the expected recovery period, and it is ideal for serial assessment to document muscle healing and recovery. Muscle fibers are grouped into fascicles and are separated by septa of fibroadipose tissue. The whole muscle is enclosed in a fascial sheath. On ultrasound, muscle appears hypoechoic with hyperechoic septations, as illustrated in Figure 15. The intramuscular septations appear as hyperechoic dots combined to form a reticular pattern on a hypoechoic background in the transverse view. In the longitudinal view, the intermuscular septa appear markedly hyperechoic, and the intramuscular septa appear as parallel hyperechoic striae. The characteristic feature of muscle is that its alignment varies with contraction of the muscle.

Muscle strains can be classified into grade 1, which is a strain injury with no macroscopic tissue disruption; grade 2, which is a partial-thickness tear with associated partial loss of muscle strength; and grade 3, which is a full-thickness tear with complete loss of muscle strength and which may be associated with a retraction of ruptured muscle ends. Grade 1 muscle strains often appear normal, but the muscle may have an increased echogenic appearance because of perifascial fluid buildup. Grade 2 muscle strains are represented by disruption of echogenic parallel striae of the muscle, with associated fluid collection. In grade 3 muscle strains, complete disruption, with retraction of muscle fibers, surrounded by hypoechoic hema-
toma, is the characteristic feature. Other acute muscle injuries include blunt injuries to muscle (contusions), in which the ultrasound appearance depicts an ill-defined hyperechoic region in the muscle, with associated hypoechoic hematoma. In recurrent or chronic injuries, fibrous scar formation can occur, which appears on ultrasound as a hyperechoic lesion that is unchanged with muscle contraction.

**NORMAL AND PATHOLOGIC U/S APPEARANCE OF THE BURSA**

**Subacromial Bursa**

The subacromial bursa lies between the deltoid and the rotator cuff and is not easily seen in normal conditions. The opposing sides of the bursa should be no more than 2 mm apart. The bursa may swell in association with supraspinatus impingement or tears. Supraspinatus impingement can be demonstrated on ultrasound by pooling of fluid in the subacromial–subdeltoid bursa with active arm elevation. Fluid inside the subacromial bursa usually collects in its caudal portion and can be found both in superficial and full-thickness tears of the rotator cuff. The bursa is best evaluated at the lateral aspect of the shoulder between the supraspinatus tendon and the deltoid muscle. Effusions can distend along this deltoid shelf, which is the point of least resistance. It produces the teardrop sign, as seen in Figure 16. Apart from chronic repetitive or inflammatory conditions, bursitis can result from trauma.

**NORMAL AND PATHOLOGIC U/S APPEARANCE OF THE NERVE**

Peripheral nerves have a fascicular pattern in the longitudinal plane, as shown in Figure 17. It demonstrates a speckled appearance in the transverse plane as the neuronal fascicles appear hyperechoic with hyperechoic connective stroma.

**Carpal Tunnel Syndrome**

The diagnosis of carpal tunnel syndrome is usually made on the basis of clinical features and is then confirmed by nerve conduction studies. Carpal tunnel syndrome can also be diagnosed with U/S by demonstrating an increase in the cross-sectional area of the median nerve at the level of the pisiform bone, as shown in Figure 18. The advantages of U/S are that it is painless and allows visualization of other underlying causes, such as a mass lesion. The reported cross-sectional area for diagnosis of the condition varied mostly between 9 and 11 mm². U/S seems to be a promising tool for the diagnosis of carpal tunnel syndrome. In one study comparing U/S diagnosis of carpal tunnel syn-

![Figure 15](image_url)

**Figure 15** Normal biceps brachii muscle. a, Longitudinal sonogram showing intramuscular septations (arrows) seen as hyperechoic lines separating hypoechoic muscle bundles. b, Transverse sonogram showing the intramuscular septations (arrows) that appear as hyperechoic dots on a hypoechoic background. Bic, biceps brachii muscle; Brach, brachialis muscle; H, humerus.

![Figure 16](image_url)

**Figure 16** Longitudinal sonogram depicting a distended subacromiodeltoid bursa, demonstrated by the teardrop sign (arrow). SST, supraspinatus; GT, greater tuberosity of the humerus.
drome with nerve conduction studies, the sensitivity was found to be 70 vs. 98%, and specificity 63 vs. 19%, respectively. Further research is needed to gain further insight into the possible additional value of this diagnostic modality.

OTHER APPLICATIONS OF U/S

In musculoskeletal medicine, treatment with injections into joints, bursae, or tendon sheaths are carried out for various pathologies. In addition to diagnosis of pathologies, ultrasound can be used to monitor needle position during the injection procedure. U/S has been shown to be an accurate, safe imaging modality for guiding musculoskeletal injections. Actual techniques for ultrasound-guided procedures are not within the scope of this paper. But, to mention a few applications, ultrasound can be used for guiding glenohumeral joint injections, subacromial injections, aspiration of calcific tendonitis, and elbow joint and carpal tunnel injections.

LIMITATIONS IN DIAGNOSTIC U/S

The limitations of U/S stem from operator dependence for this diagnostic procedure. This diagnostic tool lacks uniformity because of the dynamic nature of musculoskeletal examinations. The mobile nature of joints (in combination with random probe placements), gives rise to unlimited permutations in image variations. This is best illustrated by ultrasound examination of the rotator cuff in the shoulder, where clinical accuracy depends heavily on the scanning technique. To be able to correctly employ the diagnostic procedure and interpret findings, there is a long learning curve.

CONCLUSION

Musculoskeletal ultrasound has multiple advantages as a primary diagnostic modality. It is portable and highly accessible. An important feature of ultrasound is its ability for dynamic imaging. In addition to making side-to-side comparisons, it allows clinicians to correlate their patients’ symptoms directly with anatomic visualization. The main disadvantages are operator dependence and the long learning curve. Nevertheless, with proper use as an adjunct diagnostic tool, it can become a valuable extension to one’s physical examination.
ACKNOWLEDGMENTS

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Synovitis of the Sternoclavicular Joint: The Role of Ultrasound
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A 55-yr-old right hand–dominant female presented to clinic with a 1-yr history of right sternoclavicular joint (SCJ) pain. The pain was focal, dull, nonradiational, and increased with any upper-limb activity. She reported no history of trauma or other joint complaints. The pain started while the patient was working in a factory; it eventually resulted in early retirement and a switch to a nonmanual labor job. Rheumatologic work-up was unremarkable. Prior treatments had included numerous medications, extensive physical therapy, icing, and a non–image-guided intra-articular SCJ steroid injection, all without any appreciable change in symptoms.

Physical examination revealed obvious swelling over the right SCJ, where palpation produced significant tenderness reproductive of her usual pain. All other joints were normal.

Radiographs revealed mild degenerative changes at the right SCJ. Chest computed tomography revealed only minimal irregularity and narrowing of the right SCJ compared with the left, with moderate amounts of adjacent soft-tissue swelling. Prior bone scan was normal at the SCJ.

Because of the perception of synovitis on examination, we performed an ultrasound (US) examination of the right SCJ with comparison views of the left SCJ (Fig. 1). The exam revealed remarkable capsular hypertrophy, a small amount of anechoic intra-articular fluid, and a moderate amount of hyperechoic, intra-articular tissue exhibiting increased power Doppler flow, consistent with synovitis (Fig. 2). The visualized bony margins were only minimally irregular.

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US-guided right intra-articular SCJ aspiration and injection were then performed. A small amount of yellowish fluid of slightly reduced viscosity was obtained. A 1-ml mixture of methylprednisolone and 1% lidocaine were then slowly injected under direct US guidance (Fig. 3). The patient tolerated the procedure well with no complications.

This case illustrates numerous advantages of using musculoskeletal US in a physiatric practice. Despite prior unremarkable radiographs, computed tomography scan, and bone scan, the use of US with Doppler confirmed SCJ synovitis and ensured accurate needle placement for aspiration and therapeutic injection. Accurate needle placement is particularly crucial when fluid must be obtained for analysis or when target structures are close to neurovascular structures. Finally, this procedure was easily accomplished in the office during a single patient visit.

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After reviewing the multivariate regression models, we found that strength, odds ratio (OR) 1.21 (1.04–1.40), was more predictive than velocity OR 0.96 (0.82–0.12) of higher static balance status. In contrast, velocity was consistently more predictive of higher performance on all measures of dynamic balance with odds ratios of 1.26 (1.03–1.54), 1.34 (1.11–1.71) and 1.84 (1.37–2.47) for the BERG, POMA and DGI respectively. Discussion: The major finding of our study was that of the two components of muscle power, limb strength was a significant predictor of better static balance performance, while limb velocity was a significant predictor of better dynamic balance performance. Mechanistically, this dichotomous result can be explained by looking at the dominant activities involved in these two types of balance measures.
The three dynamic balance tests, the BERG, POMA, and DGI, require the subject to perform a variety of different tasks, most of which mimic activities performed in daily life. A large number of these tasks are timed and require the subject to perform such activities as walking, rising from a seated position, and transferring between chairs. As such, the BERG, POMA, and DGI may be broader measures of mobility, rather than just “tests of balance." When considered as broader tests of mobility, the association of limb velocity with better performance is fully consistent with the earlier report by Sayers et al. This result does not negate the utility of the BERG, POMA, and DGI as tests of dynamic balance, but instead emphasizes the link between balance and mobility. As a result, it seems likely that training programs that aim to improve limb velocity may positively affect both balance and mobility.

Conversely, the nature of activity required for the UST is quite different from those involved in the dynamic tests. The UST is a measure of static balance that is dependant on the ability of the individual to support their weight on one leg. Since this activity does not involve movement and only requires maintenance of a static position, it is not necessarily surprising that strength plays a more dominant role than limb velocity.

A limitation of this study is that limb strength and velocity were not measured within muscle groups other than the hip and knee extenders. The study design did not consider the relationship between balance and strength or velocity at the ankle, trunk, or hip abductors, all of which include muscle groups that are potentially important in the maintenance of balance. Additional training, our study was a cross-sectional analysis evaluating older adults with mobility limitations. A broader longitudinal study including both healthy older adults and those with a significant fall history may allow us to better understand these relationships. Nevertheless, our results are of relevance given the increased fall risk in our studied population on the basis of their low SPPB scores.

The results presented in this paper highlight the importance of emphasizing enhancements in limb velocity in rehabilitation. Clinical experience suggests that most rehabilitative therapists will emphasize strength training as components of balance rehabilitation. However, despite intervention studies suggesting the benefits of limb power enhancement, use of high-velocity training among older adults is relatively rare.

In conclusion, our study has demonstrated that higher leg press velocity is associated with better performance on BERG, POMA, and DGI measures and that higher leg strength is associated with better UST performance. These findings underscore the importance of training both leg strength and velocity of movement when considering balance rehabilitation among older adults at risk for falls. Further investigation of these relationships through future longitudinal studies is warranted.

Resident

CARPAL TUNNEL SYNDROME SYMPTOMS IN INDIVIDUALS WITH SPINAL CORD INJURY WHO USE MANUAL WHEELCHAIRS

Jennifer Yang, MD; Michael L. Boninger, MD; Trevor A. Dyson-Hudson, MD; Robert Price, MSME; Bradley G. Impink, MS; Rachel Cowan, MS

Introduction: Due to the repetitive motion involved in wheelchair propulsion and transfers, individuals with spinal cord injury (SCI) who use manual wheelchairs are at risk for carpal tunnel syndrome (CTS). CTS is usually diagnosed based on symptoms with physical examination and nerve conduction studies providing additional information. Research on individuals with paraplegia has directly linked the severity of median nerve electrodiagnostic abnormalities to subject weight, wheelchair stroke propulsion pattern, wheelchair weight and wrist position. Symptomatic CTS is well-documented in the medical literature and was recently reviewed in the clinical practice guidelines for preservation of upper limb function following SCI. Symptom surveys by Subbarao, Schroer and Pentland, and Twomey showed a 40-48% prevalence of wrist pain. Separate studies by Sie and Gellman have noted a prevalence of CTS by history and physical examination ranging from 49 to 66%, with the prevalence increasing in the duration of SCI. Gellman in 1985 noted that individuals with paraplegia had increased pressures within the carpal tunnel while the wrist was in neutral and in extension, as compared with those without paraplegia. Studies in the general population have also shown that other risk factors that increase the likelihood of carpal tunnel syndrome include female gender, increased BMI, age and symptoms in the dominant hand.

The object of this study was to investigate the prevalence, common symptoms, and impact of CTS symptoms in a cohort of manual wheelchair users with SCI. In addition, we wanted to examine the relationship between symptoms and subject characteristics such as weight, gender, and years with SCI. Methods: We conducted a multicenter cross-sectional study. Individuals 18 yrs old and older with traumatic spinal cord injury levels T2 through L4 were recruited from three SCI model system centers with large databases across the United States. To be included in the study, participants had to use a manual wheelchair for over 40 hrs/wk and not have upper limb trauma affecting their report of symptoms. After written informed consent was obtained for the study, subjects were administered a questionnaire on CTS symptoms such as numbness, tingling/electric sensation and pain with wheelchair propulsion, whether they sought medical help for their symptoms, whether these symptoms curtailed their activity and the duration that they curtailed activity. Demographic data collected included gender, age, handedness, level of injury, length of time since injury, weight, and stature (height). BMI was calculated as weight/height squared. Demographic and clinical information were entered into a database constructed for this study using Microsoft Access and analyzed using SPSS. Subjects were dichotomized based on symptoms. The two groups were then compared using the Student t test for continuous variables the Mann-Whitney U test for ordinal variables, and the χ² test for categorical variables. Results: Data were collected on 118 subjects, 23 women and 95 men, aged 23–76 yrs (40.9 ± 11.8 yrs), with length of time since injury from 1.2 to 34.1 yrs (13.1 ± 8.8 yrs). Among those who experienced symptoms (88.1%) were right-handed and 14 (11.9%) were left handed. The most frequent level of injury was T12 (16.1%), followed by T10 (14.4%) and T4 (11%). Patient weight had a range of 43.1–132.8 kg (79.2 ± 17.1 kg), stature ranged from 1.5–1.9 m (1.7 ± 0.1 m) and BMI ranged from 14.9 to 40.6 (25.6 ± 5.2).

Among the subjects, 57.6% had symptoms consistent with CTS. Among those who experienced symptoms, numbness was most frequently reported (45.8%), followed by electric sensation or tingling (39%) and pain with wheelchair propulsion (27.1%). Of the subjects with symptoms, 35.2% had one symptom, 26.6% had two symptoms, and 38.2% experienced three symptoms. Among these subjects, 54.5% experienced symptoms in their dominant hand (53.5% of right-handers and 13.1% of left-handers). Among the subjects, 41.5% had symptoms in both hands, regardless of handedness. Subjects were not found to have significantly more symptoms in their dominant hand.

36.8% of our subjects with symptoms consulted a physician and 33% were told they had CTS. Of the symptomatic subjects, 41.3% underwent nerve conduction studies. Of the symptomatic individuals, 25.4% curtailed their activity due to the symptoms. Subjects with a greater number of symptoms were more likely to curtail activity (P = 0.001). No significant differences in demographic characteristics were noted between persons who did and did not report CTS symptoms.

Subjects reporting any symptoms were significantly younger (mean 38.7 yrs) than subjects who reported no symptoms (mean 43.8 yrs, P = 0.019). However, when comparing groups who were and were not given the diagnosis of CTS, a trend was found showing subjects with a CTS diagnosis were older (mean 44.3 yrs, vs. 39.8 yrs, P = 0.089). Discussion: This study examines CTS symptoms in individuals with spinal cord injury and their relationship to subject activity and demographics. Numbness was the most common complaint, consistent with what is found in the general population. Most reports in the literature combine numbness and tingling under the category “paresthesia”; our study agrees with this as these were the two most common symptoms reported by our subjects.

Unlike the general population we did not find CTS to be more common in the dominant hand. This may be related to the nature of our subjects, as they most likely use both hands equally in wheelchair propulsion and transfers.

Our data shows that although younger subjects are more likely to report their symptoms, older subjects are more likely to have a diagnosis of CTS. It is possible that older subjects, presumably having had symptoms for a longer period of time, have learned to live with their symptoms, are less concerned about them and thus do not report these symptoms.

Symptoms of CTS in the wrist and hand seem to be an important factor in limiting subject function. The magnitude of this problem can be seen in the number of subjects who consult a physician for these symptoms, as well as those who curtail their activity due to symptoms. However there is also a population that did not seek consultation with a physician nor curtail their activities, and these subjects may be at risk of...
further injury. This highlights the need for patient education regarding preservation of upper limb function.

These findings provide further insight into symptoms of CTS in subjects with SCI who use manual wheelchairs. Some limitations to this study must also be noted. As it has been shown in the literature that females in the general population are more likely to have symptoms of CTS, we would expect this in the SCI population as well. Due to the small number of women in our study, we may not have had enough power to detect this difference. Although not statistically significant, it should be noted that 69.6% of our female subjects reported symptom of CTS compared with 54.7% of our male subjects.

We did not find a relationship between prevalence of CTS and duration of symptoms. In the absence of symptoms or if patients choose to ignore symptoms, median nerve function may worsen with time. By design this report has focused on symptoms. Future reports will be more comprehensive, including both physical examination and electrodiagnostic data, both of which can assist in the diagnosis of CTS.

Fellow

NEW MODEL OF SCI-INDUCED OSTEOPOROSIS: ACUTE CONTUSION SPINAL CORD INJURY IN RATS TRIGGERS RAPID BONE LOSS
Leslie Morse, DO, Dou Yu, MD, Wei-Li Liao, MD, Kimberly Newton, Ricardo Battaglino, PhD, Philip Stashenko, DMD, PhD, Yang Teng, MD, PhD

Background: Limited understanding of the mechanism governing SCI-induced bone loss has led to inadequately few treatment options. As this condition carries significant morbidity and mortality, a need exists to advance the general knowledge regarding its pathophysiology. Mechanistic studies are limited by the lack of a rodent model and difficulties associated with obtaining bone biopsies from patients with spinal cord injury. In this work we present an experimental model of SCI-induced osteoporosis in rats that is rapidly occurring, reproducible and similar in nature to the bone loss experienced by individuals immediately following complete spinal cord injury. Methods: Rat Model of Severe SCI: Adolescent male Sprague-Dawley rats (200 g) were anesthetized with intraperitoneal ketamine (75 mg/kg) and xylazine (20 mg/kg). A severe T10 contusion injury was produced utilizing the New York University (NYU) impactor (10 g × 50 mm) as previously described. The control group consisted of naive, age-matched male Sprague-Dawley rats. Animals were euthanized on day 10 postinjury for subsequent analyses. Confirmation of Severe Neurological Impairment: The well-established BBB hind limb locomotor rating scale was used to determine hindlimb functional deficits on day 1 and 7 postinjury. Only severely injured animals (defined as BBB score of 4 or less i.e., only very limited hindlimb reflexes without locomotion observed at day 7 post injury) were used for all subsequent studies. In vivo Assessment of Bone Mineral Density: Before sacrifice all animals were anesthetized and bone mineral density (BMD) was measured in vivo using PIXimus Scan and software version (1.A.4X). Animals were positioned on their stomachs with the hindlimb externally rotated. The hip and knee were flexed to 110 degrees with the ankle in neutral. The femoral shaft was externally rotated. Two regions of interest were analyzed, one (16 × 17 pixel) at the distal femoral metaphysis and one (11 × 13 pixel) at the distal radius/ulna. Micro-Computed Tomographic Imaging (μCT): To assess bone microarchitecture, fixed femoral shafts were acquired at the Institute for Biomedical Engineering, ETH and University Zuerich, using a compact fan-beam-type tomograph (μCT 20, Scanco Medical AG, Bassersdorf, Switzerland). Samples were located in an airtight cylindrical sample holder filled with formalin. The sample holders are marked with an axial alignment line to allow for consistent positioning of the specimens. For each sample, approximately 200 micro-tomographic slices with an increment of 17 μm were acquired, covering the entire width of the bone. Three-dimensional analyses were performed to calculate morphometric indices including total volume (TV), bone volume (BV), marrow volume (MV), bone mineral content (BMC), bone surface (BS), bone thickness (Th), and various ratios including density BV/TV, trabecular thickness [Th.Tb = 2 × BV/bone surface (BS)], trabecular number [Tb. N = (BV/TV)/Th. Tb], and trabecular separation [Th. Sp = (1/Th. N) Th. Tb]. Static and Dynamic Histomorphometry: Naïve and severely injured animals were injected with calcein, a dye which intercalates into growing bone, on day 2 and day 7 postinjury. Hindlimbs were resected and sent to the histomorphometry core facility at Mayo clinic for dynamic (appositional growth) and static histomorphometry analysis. Summary of Results: We found a significant relative bone loss at the distal femoral metaphysis by PIXimus scan in the injured animals compared with naïve controls at 10 days postinjury. We found no significant change in the forelimb BMD (skeletal site used as a supraspinalional control). MicroCT analysis of the femoral metaphysis showed a significant alteration in bone microarchitecture due to severe SCI. We detected a 48% decrease in trabecular bone mineral content with associated decrease in trabecular thickness, number and connectivity at the femoral metaphysis in the injured animals when compared with the naïve controls. The cortical bone mineral content was also decreased by 35%. The ratio of bone surface to bone volume was increased in both compartments indicating increased bone resorption. Appositional growth studies demonstrated decreased new bone formation in the injured animals with an abnormal labeling pattern suggesting a mineralization defect in the injured animals. Static histomorphometry studies demonstrated no difference in osteoclast or osteoblast numbers at distal femoral metaphysis. However, there was decreased osteoid production in the injured animals suggesting impaired ability to form new bone at that site. Conclusions: The femoral metaphysis was chosen as this is the site of greatest fracture frequency in individuals with spinal cord injury and therefore has high clinical relevance. We have demonstrated that our experimental model of severe SCI in rats causes a rapid, severe bone loss at the femoral metaphysis. This loss is detectable 10 days postinjury. In animals with severe injury (BBB score less than 4), there is little variability in the degree of bone loss that occurs. Furthermore, we have demonstrated abnormal bone microarchitecture due to severe SCI with decreased trabecular and cortical bone. These findings indicate increased bone resorption due to osteoclast activation following SCI. We have also demonstrated impaired bone formation suggestive of osteoblast dysfunction. Based on studies of markers of bone turnover following acute spinal cord injury, it is widely believed that bone formation is normal with abnormal bone resorption. Therefore, these findings are the first to report both osteoclast and osteoblast dysfunction in the development of osteoporosis following spinal cord injury. This model has enormous potential for mechanistic studies that are currently lacking and greatly needed to advance the understanding of SCI-induced bone loss. Furthermore, this model can be used to test therapeutic interventions aimed at prevention of osteoporosis following neurological injury.

RMSTP PRESENTATIONS

FORCE CONTROL STRATEGIES WHILE DRIVING ELECTRIC POWERED WHEELCHAIRS WITH ISOMETRIC AND MOVEMENT-SENSING JOYSTICKS
Brad E. Dicianno, MD; Donald M. Spaeth, PhD; Rory A. Cooper, PhD; Shirley G. Fitzgerald, PhD; Michael L. Boninger, MD; Karl W. Brown

Innovations to control interfaces for electric powered wheelchairs (EPWs) could benefit 220,000 current users and over 60,000 individuals who desire mobility but cannot use a conventional motion sensing joystick (MSJ). We developed a digital isometric joystick (IJ) with sophisticated signal processing and two control functions. In a prior study, subject’s driving accuracy with our IJ was comparable with using an MSJ. However, we observed subjects using excessive force on the IJ possibly because its rigidity provides no positional feedback. Thus, this study examines the time-series data recorded in the previous study to characterize subjects’ force control strategies since fatigue and weakness are common impairments of individuals who need improved interfaces, and also because studies that compare MSJs and IJs could be biased if force control is not taken into account. Eleven EPW users with upper limb impairments drove an EPW to floor targets using an IJ with two different control functions and an MSJ in a FITTS’ law paradigm. Subjects relied upon positional feedback from the MSJ and used appropriate force. In contrast, subjects using the IJ with either control function applied significantly higher force than necessary (p < 0.0001 and P = 0.0058). Using higher average force was correlated with quicker trial times but not associated with accuracy. Lack of positional feedback may result in use of excess isometric force. Modifying control functions, adjusting gain, or providing additional training or feedback might address this problem.
RELATIONSHIP BETWEEN FINGER INDIVIDUATION AND SHAPING THE FINGERS TO OBJECT CONTOURS
Preeti Raghavan, MD; John Krakauer, MD; Marco Santello, PhD; Andrew Gordon, PhD

Grasping objects is an essential component of one’s daily activities, and involves accurate coordination of finger movements to approximate the size, shape, and number of object before grasping. However, defects in deficit functions may contribute to limited or deficient dexterity. Finger individuation is a key component of dextrous hand function. In the initial in vitro studies, disk explants and chondrocytes overexpressing hBMP-7 was 25% higher than the control (AdGFP) group. Conclusions: We have demonstrated, for the first time, that rabbit articular chondrocytes overexpressing hBMP-7 can survive in a rabbit disk explant where they stimulated matrix production in the NP. Furthermore, we have shown that the transplantation of chondrocytes over-expressing hBMP-7 improves disk tissue proteoglycan production and disk height in the rabbit. Our encouraging findings suggest that chondrocyte transplantation may replenish degenerating disks with vital cells and provide appropriate trophic factors; this is a promising strategy for the treatment of symptomatic disk degeneration.

SCIENTIFIC PAPER PRESENTATIONS
ROOM A

VITAMIN D DEFICIENCY AND OPIOID ANALGESIC USE AMONG CHRONIC PAIN PATIENTS
Michael Turner, MD; Jennifer L. Kerkvliet, MS; W. Michael Hooten, MD

Introduction: Hypovitaminosis D is a prevalent vitamin deficiency among patients with chronic pain. Seemingly unrelated, the use of opioid analgesics for treatment of noncancer pain is increasing. The objective of this study was to determine the association between vitamin D deficiency and opioid analgesic use among a heterogeneous group of chronic pain patients undergoing multidisciplinary pain rehabilitation. Methods: Serum vitamin D levels were collected at admission from 162 consecutive patients admitted to the Mayo Clinic Pain Rehabilitation Center from February to April, 2007. Admissions were converted to oral morphine equivalents. Patients with vitamin D deficiency (< 20ng/ml) were compared with patients with levels >20ng/ml on oral morphine equivalents, demographics, pain duration, pain severity, and body mass index. Continuous variables were compared using two-sided t tests with a significance level of <.05. Results: The mean age was 48 yrs (SD = 13). Seventy-nine percent (n = 128) were female and 92% (n = 138) were Caucasian. The mean pain duration was 10.5 yrs (SD = 12.0). The mean vitamin D serum level was 29.2 ng/ml (SD = 12.0) and hypovitaminosis D was found in 24.7% (n = 40) of patients. Sixty-three percent (n = 102) of patients were using opioids upon admission. The mean morphine equivalent dose was 55.2 mg/day. The mean morphine equivalent dose among patients with vitamin D deficiency was 140.2 mg/day and the mean dose among nondeficient patients was 67.8 mg/day (P = 0.015). No significant differences were found in demographics, pain duration, pain severity, or body mass index were identified between the two groups. Conclusions: In this consecutive series of chronic pain patients, hypovitaminosis D was associated with higher daily doses of opioids compared with nondeficient patients. While opioids do not directly impede vitamin D metabolism, use of higher opioid dosages among chronic pain patients may be indicative of dietary habits and impairments in physical functioning that increase the risk of developing hypovitaminosis D. Further research is needed to clarify the risk factors and clinical correlates of vitamin D deficiency among patients with chronic pain.

CURRENT PARTICIPATION AND INTEREST IN RESEARCH TRAINING FOR PHYSICAL MEDICINE AND REHABILITATION (PM&R) FACULTY AND RESIDENTS
Scott M. Paul, MD; Frederick P. Ognibene, MD; N. Lynn H. Gerber, MD

Objective: To determine the current experience and interest in formal research training in PM&R faculty and residents in a major metropolitan area, to help with planning the offering of formal didactic research education. Design: World Wide Web Based Survey. Participants: Faculty and residents affiliated with 11 PM&R training programs in the New York City metropolitan area. Results: Over the one month survey period 156 responses (46% overall response rate) were received. Respondents included 107 residents (54% response rate) and 49 faculty physicians (35% response rate). Responses were received from persons affiliated with 9 of...
11 programs. Fifty-four percent reported current involvement in PM&R research, and 65% reported having some formal research training. Although a majority of respondents reported some training in epidemiology, ethics and regulation of human subjects, most reported no training in motor control or action observation. Residents who were interested in improving their knowledge of the principles and practice of clinical research. Most are willing to commit significant time and effort to obtaining that knowledge, although they may be unable to participate for an extended period of time. Given the limited resources for research training, offering a centrally located course, available to members of all training programs in a geographic area, may be an effective way to increase research knowledge in PM&R. Plans are underway to provide such a course in the New York metropolitan area and study its impact.

CORRELATION OF CLINICAL EXPERIENCES AND CAREER PLANS OF GRADUATING RESIDENTS DURING THE 2004–2005 ACADEMIC YEAR

Vishwa S. Raj, MD; Diana H. Rintala, PhD

The purpose of this survey was to collect data from graduating physiatry residents during the 2004–2005 academic year and correlate clinical experiences during residency with future career goals. Residents were asked to complete a survey pertaining to 11 of the primary educational objectives outlined by the SAE examination, as well as answer open ended questions regarding fellowship and/or professional plans. Out of 386 surveys distributed, 93 responses were returned in confidential manner. Based on preliminary results of the survey, residents planned to pursue the following areas of specialization: interventional-based procedures (43); musculoskeletal medicine (32); general physiatry (17); sports medicine (9); spinal cord injury medicine (6); electromyography (4); traumatic brain injury and stroke (2); and industrial rehabilitation (2). Of the residents pursuing general physiatry, 11.8%, compared with 66.7% pursuing all other career goals, planned to pursue fellowship (exact significance 2 sided: < 0.001 with Forward Exact Test). Of the residents pursuing interventional pain management, 95.3%, compared with 22.4% pursuing other career goals, also planned to pursue fellowship (exact significance 2 sided < 0.001 with Forward Exact Test). Compared with residents not pursuing interventional pain fellowship, residents pursuing interventional pain fellowship spent less months training in traumatic brain injury (7.45 vs. 4.10 mos; t test: 4.898; P value with equal variances assumed = 0.001), spinal cord injury (5.33 vs. 3.45 mos; t test: 2.784; P value with equal variances assumed = 0.008), and medical rehabilitation (7.64 vs. 4.83 mos; t test: 2.274; P value with equal variances assumed = 0.027). Compared with residents not pursuing musculoskeletal fellowship, residents pursuing musculoskeletal fellowship were less prepared for physiatric therapies (4.28 vs. 3.88; t test: 2.176; P value with equal variances assumed = 0.034), less confident in writing prosthetic and orthotic prescriptions (3.69 vs. 3.00; t test: 2.468; P value with equal variances assumed = 0.017), less confident in writing physiatric therapeutic prescriptions (4.25 vs. 3.69; t test: 2.573; P value with equal variances assumed = 0.027), less confident in performing interventional physiatric procedures (3.00 vs. 2.13 mos; t test: 2.250; P value with equal variances assumed = 0.029), and less confident in performing botulinum toxin injections and/or phenol injections (4.25 vs. 3.69; t test: 2.409; P value with equal variances assumed = 0.020). These results indicate trends in career goals of graduating residents. In addition, when considering residents pursuing interventional pain fellowship or musculoskeletal fellowship, certain characteristics were noted with respect to months of training in different subspecialties and confidence and/or preparedness levels when dealing with specific skill sets.

ACTION OBSERVATION IMPROVES THE EFFECTS OF MOTOR TRAINING IN STROKE PATIENTS

Pablo Celnik, MD; Brian Webster, BS; Davis Glasser; Leonardo G. Cohen, MD

Background: Training represents the goldstandard in neurorehabilitation of motor disabilities following stroke. Similar to healthy older adults, the ability to encode memory by motor training is reduced in chronic stroke patients. Observation of another individual performing a motor action, action observation (AO), results in activation of various areas in the motor network and could play a role in neurorehabilitation. Hypothesis: Action observation will enhance the beneficial effects of motor training (MT) on motor memory formation in patients with chronic stroke. Methods: Eight chronic stroke patients (mean age 58.7+/−13.3) participated in a crossover, randomized and counterbalanced experimental study testing 3 interventions on different days. The endpoint measure of the study was the ability to encode a motor memory following: MT (practice of voluntary thumb movements performed in a specific direction for 30 min at 1 Hz), MT+AO INCONGRUENT (synchronous MT and observation of another subject performing MT in identical direction), MT+AO CONGRUENT (similar to MT+AO, but the movements observed are in a direction opposite to the trained movements). Motor evoked potentials (MEP) to TMS were recorded from muscles mediating movements in the training/observed (MEP AGONIST) and in the baseline (MEP ANTAGO-NIST) directions. Data were analyzed using ANOVAR with factors INTERVENTION (MT, MT+AO CONGRUENT, MT+AO INCONGRUENT) and TIME (Pre-, Postintervention), and post hoc with Forward PLSD. Results: Attention, fatigue and motor training kinematics did not differ across sessions. ANOVAR showed a significant TIME × INTERVENTION interaction (F2,12 = 4.2 P < 0.05) on the ability to encode a motor memory. Posthoc testing showed that the effects of MT+AO CONGRUENT were more pronounced compared with MT (3.4 + 2.6% vs. 3.0 + 5.4%, P < 0.017, mean+SEM; P < 0.001 with Forward Exact Test). Of the residents pursuing interventional pain fellowship, residents pursuing interventional pain fellowship planned to pursue fellowship (exact significance 2 sided: < 0.001 with Forward Exact Test). Of the residents pursuing interventional pain management, 95.3%, compared with 22.4% pursuing other career goals, also planned to pursue fellowship (exact significance 2 sided < 0.001 with Forward Exact Test). Compared with residents not pursuing interventional pain fellowship, residents pursuing interventional pain fellowship spent less months training in traumatic brain injury (7.45 vs. 4.10 mos; t test: 4.898; P value with equal variances assumed = 0.001), spinal cord injury (5.33 vs. 3.45 mos; t test: 2.784; P value with equal variances assumed = 0.008), and medical rehabilitation (7.64 vs. 4.83 mos; t test: 2.274; P value with equal variances assumed = 0.027). Compared with residents not pursuing musculoskeletal fellowship, residents pursuing musculoskeletal fellowship were less prepared for physiatric therapies (4.28 vs. 3.88; t test: 2.176; P value with equal variances assumed = 0.034), less confident in writing prosthetic and orthotic prescriptions (3.69 vs. 3.00; t test: 2.468; P value with equal variances assumed = 0.017), less confident in writing physiatric therapeutic prescriptions (4.25 vs. 3.69; t test: 2.573; P value with equal variances assumed = 0.027), less confident in performing interventional physiatric procedures (3.00 vs. 2.13 mos; t test: 2.250; P value with equal variances assumed = 0.029), and less confident in performing botulinum toxin injections and/or phenol injections (4.25 vs. 3.69; t test: 2.409; P value with equal variances assumed = 0.020). These results indicate trends in career goals of graduating residents. In addition, when considering residents pursuing interventional pain fellowship or musculoskeletal fellowship, certain characteristics were noted with respect to months of training in different subspecialties and confidence and/or preparedness levels when dealing with specific skill sets.

ROOM B

EXAMINATION OF SELECTED RISK FACTORS FOR PNEUMONIA DURING STROKE REHABILITATION

Christina Marciniak, MD; Alexander Korutz, MS-3; Emily Lin, MS-3; Elliot Roth, MD; Linda Lovell, BS

Introduction: Nosocomial pneumonia is a frequent complication among stroke survivors, with up to 30% of acute stroke patients developing lower respiratory tract infections within 3 mos following stroke. Previous studies have suggested that the use of H2 receptor antagonists (H2RAs), proton pump inhibitors (PPIs), tracheotomy tubes, and feeding tubes are associated with increased risk of pneumonia. Conversely, several studies have suggested that ACE inhibitors may serve a protective role due to their tussigenic effect. Although many stroke patients are placed on these medications or devices, studies examining the role each of these factors in the development of pneumonia in the poststroke period were few. The purpose of this study was to examine the risk factors associated with pneumonia during stroke rehabilitation. This study investigates the effects of H2RA’s, PPI’s tracheotomy tubes, feeding tubes, and ACE inhibitors in the development of pneumonia in hospitalized stroke patients. Methods: In this case-matched, controlled study, a database containing a prospective cohort of patients admitted for stroke rehabilitation was queried for poststroke patients hospitalized during a 5-year period, and whose rehabilitation stay was completed. Subjects identified were matched with 36 controls stroke patients admitted during the same period. Matching was performed on the basis of age, gender, side of stroke, depth of stroke (cortical vs. noncortical), and NISS score. Dysphagia severity, the presence of a tracheotomy or feeding tube, and the use of H2RAs, PPIs, or ACE inhibitors were recorded from a subsequent chart review. Results: McNemar’s test of paired data revealed that patients on PPIs or H2Blockers had an increased risk of developing pneumonia with an odds ratio of 3.3 [95% confidence interval (CI) 1.0–13.7]. Univariate analyses also revealed that significantly higher risk of pneumonia was also found in patients with a tracheotomy tube [Odds ratio: 10; 95% CI 1.4-434], any feeding tube [Odds ratio: 3; 95% CI 1.4-27.0], and those with dysphagia [Odds ratio: 15; 95% CI 0.2-157. 2.3631]. A conditional logistic regression to adjust for the effects of conventional risk factors, however, did not find that these were independently associated with pneumonia risk, including decreased risk with ACE inhibitors. However, when all factors were entered into a multivariable conditional logistic regression, none of the factors proved to be statistically significant.
Conclusions: Though the individual risk factors evaluated may not independently increase the likelihood of poststroke pneumonias in acute rehabilitation, the presence of the above four risk factors is associated with a significantly increased risk. In our population, the use of ACE inhibitors and proton pump inhibitors (PPI) or H2 Blocker use, tracheostomy, feeding tube, and the presence of dysphagia. However, none of these factors demonstrated an independent association with pneumonia on multivariate analysis.

**AMPETEUE BONE DENSITY EVALUATION FOR COMPETITIVE SPORTS (RUNNING) CLEARANCE**

Maj Derek J. Stocker, MD; Col Paul Marin; LtC Aaron L. Stack; Maj Brandon J. Goff; LtC Paul F. Pasquina

Introduction: Advances in body armor have lead to a higher rate of surviving amputees in the current conflicts in Iraq and Afghanistan. Young and active service members are aggressively recovering from their injuries and progressing rapidly toward pursuing increasingly vigorous sports activities, to include competitive running. As a result, many of these individuals are receiving specially adapted running prostheses as early as 4–6 mos after their amputation based on the clinical recovery of the patient. There have been cases of residual limb bone fractures during participation in the competitive running rehabilitation program attributed to osteopenia. As a result, beginning in September 2005, it has been the policy of our center to obtain a dual x-ray absorptiometry (DEXA) study of all amputees being evaluated for enrollment into our sports running program. A protocol used to perform these studies included obtaining bone density assessments of both hips and the whole body. This prospective study analyzed these studies to determine the degree of bone loss in an effort to help determine the fracture risk encountered by these patients. Methods: Between September 2005 and May 2006, nineteen patients with unilateral amputations received DEXA studies. The intact limb as a surrogate baseline, the comparative bone density decrease was determined for the amputated limb at the level of the femoral neck and total hip. In addition, whole body comparisons were also obtained. Results: The DEXA results of 19 patients were reviewed. One patient had retained shrapnel, limiting the measurement of the lower extremity and total hip assessments. The patients were aged 29 ± 1.9 yrs, predominantly male (18/19), and had undergone a unilateral amputation 9 ± 1 mos before the study. Etidronate and Calcitonin were administered to 6/19 (32%) of these patients during their rehabilitation period for heterotopic ossification prophylaxis. Significant bone loss was seen in all evaluated sites and these patients were not cleared for the sports running program. At the hip, femoral neck, and whole body regions DEXA scans shows BMD differences of -0.1545/-.0232, and -0.2876/-0.1562 with P < 0.0005. We are not aware of any recurrent fractures in these patients during our screening program. Conclusions: Rapid bone loss of the proximal amputated limb seems to occur following traumatic amputation despite early ambulation and bisphosphonate use. Our policy of clearing amputees for aggressive sports running based on proximal amputated limb bone densities as proxies for more distal sites seems to be justified as it is presumed that bone densities at the more distal sites are likely to be more severely affected. A prospective study on the natural course of amputated limb osteoporosis and the identification of distal limb bone density reference values is currently underway.

**IMPLEMENTATION OF AN ULTRASONIC BLADDER SCANNING PROTOCOL FOR ASSESSMENT AND MANAGEMENT OF URINARY RETENTION IS ASSOCIATED WITH A REDUCTION IN URINARY TRACT INFECTIONS IN AN ACUTE INPATIENT REHABILITATION HOSPITAL**

Kate W. Paylo, DO; Heather Cosner, RN; Alan Alfano, MD; Lori Aylor, RN; Mary Bryant, MD; Jonathan Evans, MD, MPH

Background: Urinary retention (URs) common among hospitalized patients undergoing acute inpatient rehabilitation and may arise in the setting of a variety of clinical conditions that are common in this setting, including acute stroke, brain tumor, spinal cord injury, prostatic enlarge-ment, and drug therapy. In addition to functional dependence, UR is also associated with significant morbidity, related to both renal failure and urinary tract infection (UTI). The evaluation and management of UR is therefore an important rehabilitation goal. Intermittent catherization (IC) of the bladder has been a mainstay of evaluation, monitoring, and treatment of UR. Unfortunately, IC may itself be a cause of UTI and bacteremia. Consequently, strategies which minimize the use of IC in evaluation and monitoring of UR are desirable in an effort to reduce infection risk. Objective: To evaluate the effect of a hospital-wide ultrasonic bladder scanning protocol on reducing the incidence of hospital-acquired UTI in an acute inpatient rehabilitation hospital. METHODS: Design: Intervention study (pre/post design). Intervention: Implementation of a bladder scanning protocol for evaluation and management of UR in all adult patients for whom assessment of postvoid residual urine volume is clinically indicated. Setting: A 50-bed academic acute inpatient rehabilitation hospital. Main outcome measures: Rates of hospital-acquired UTI per 1000 patient-days before and after implementation of the clinical protocol. Results: UTI rates fell significantly from 7.13–3.88 per 1000 patient-days over a 2-year period, despite an increase in severity of clinical illness (“case-mix”) over the same time period. There was also a significant reduction in the number of intermittent catherizations performed. Discussion: Implementation of a hospital-wide bladder scanning protocol was associated with a clinically meaningful overall reduction in the incidence of urinary tract infections. Since IC was also associated with a significantly increased risk. Conclusions: It is plausible to conclude that UTIs are a direct result of avoidance of IC, particularly for diagnostic purposes. Reduction in hospital acquired UTI is a desirable outcome, irrespective of the mechanism by which it was achieved. Nevertheless, there are several other potential explanations for the reduction in UTIs. Reported rates of hospital acquired urinary tract infection are confounded by asymptomatic bacteriuria. Consequently, reduction in IC is expected to reduce the rate of testing for UTI, which in turn reduces the rate at which asymptomatic bacteriuria is identified. Moreover, the implementation of this protocol may have resulted in other changes in physician behavior, leading to a reduction in testing for urinary tract infection even among patients without UR.

**DOES METHYLPHENIDATE ENHANCE COGNITION AFTER MODERATE TO SEvere TBI?**

Harvey Levin, PhD; L. Corwin Boake, PhD; Sureyia Dikmen, PhD; Nancy Temkin, PhD; Maya Troyanskaya, MD; Gerard Francisco, MD

Experimental animal models have implicated dopaminergic receptors in prefrontal cortex (PFC) in the mediation of working memory. With established efficacy of methylphenidate (MPH) in the treatment of attention deficit hyperactivity disorder and the widespread administration of this drug to treat cognitive impairment after traumatic brain injury (TBI), we completed a two center randomized, placebo-controlled double-blind clinical trial comparing the effects of MPH given in a dose of 15 mg twice a day for 28 days to placebo on mitigating working memory deficit in patients enrolled between 3 and 12 mos after moderate to severe TBI. Prospective recruitment of participants with working memory deficit included at least one of two screening tests (Paced Auditory Serial Addition, Self-Ordered Pointing Test) yielded 74 patients who were randomized to MPH (n = 38; mean Glasgow Coma Scale score = 6.9, SD = 3.5; mean age at study = 27.4 yrs, SD = 10.3; 18.4% female; mean education = 1.8 yrs, SD = 2.0; mean postinjury interval = 10.2 mos, SD = 4.3) or placebo (n = 36; mean Glasgow Coma Scale score = 6.9, SD = 3.5; mean age at study = 29.2 yrs, SD = 11.5; 33.3% female; mean education = 12.2 yrs, SD = 2.3; mean postinjury interval = 11.0 mos, SD = 4.6). A separate randomization was performed at each center. Cognitive tests were given on three occasions: pretreatment baseline, final day of treatment, and 1 mo follow-up. A visual N-back working memory task for letters, including 1-, 2-, and 3-back conditions, was the primary outcome measure. Secondary outcome measures included the verbal selective reminding, consonant trigram distractor memory, and symbol digit modality tests. There were no significant group differences in patient features or pretreatment cognitive performance. Net accuracy of working memory averaged across 1-, 2-, and 3-back conditions did not differ between groups F(1,60) = 0.19, P = 0.665, and there was no significant group difference by occasion, F(2,60) = 0.28, P = 0.757. Significant between-group differences in the posttreatment results were found on only one of the secondary cognitive measures. On the 30-min delayed recall of the selective reminding test there was a significant between group difference in improvement from baseline to 1 mo (χ2 = 6.14, P = 0.046). MPH treated patients had improved delayed recall from baseline (mean = 6.54, SD = 3.53) to 1 mo (mean = 7.73, SD = 3.15) (χ2(1) = 9.13, P = 0.003), whereas delayed recall
by patients in the placebo group did not significantly change from baseline (mean = 7.40, SD = 3.36) to 1 mo (mean = 7.20, SD = 3.61) (t(1) = 0.27, P = 0.603). However, total recall of words across trials of the selective reminding test did not differ between groups. Our findings show a lack of consistent evidence for MPH efficacy in mitigating working memory deficit after TBI and only an isolated effect in other cognitive domains. These results differ from a previous crossover study in which MPH improved response speed on reaction time measures of attention in moderate to severe TBI patients enrolled at least 3 mos postinjury. We postulate that MPH may have short-term effects that diminish over long periods of treatment. In summary, the results of this randomized, placebo-controlled clinical trial offer sparse support for the efficacy of MPH in treating cognitive impairment in patients 3–12 mos following moderate to severe TBI.

ROOM C

PREVALENCE OF ROTATOR CUFF TEARS AND TENDONOPATHIES IN PAINFUL HEMIPLEGIC SHOULDER

Sepideh Haghpanah MD; Rajiv Shah MD; John Chae MD

Objective: Assess the age adjusted prevalence of rotator cuff tears and tendinopathies among stroke survivors with painful hemiplegic shoulder. Method: Shoulder MRI scans of 76 chronic stroke survivors with shoulder pain of ≥4 on a 0-10 numeric rating scale (Brief Pain Inventory Question 12) was reviewed by a single radiologist for presence of rotator cuff tears, rotator cuff tendinopathies, subacromial bursa fluid and labral ligamentous complex abnormalities. Results: The mean age of the patients was 57 ± 11 (SD)-yrs at a mean time from stroke onset of 66 ± 84 mos. Rotator cuff tears were present in 54% of patients. The Supraspinatus was the most commonly torn (29%) followed by Infraspinatus (12%), Subscapularis (3%), and Teres Minor (1%). At least 1 tear was present in 11% of patients less than 50-yrs old, 31% in age group 50–59-yrs, 42% in age group 60–69-yrs and 50% in age group older than 69-yrs. Overall prevalence of any tendinopathy was 57%. The Supraspinatus was the most commonly involved (51%) followed by Infraspinatus (21%) and Subscapularis (12%). Tendonopathy was present in 51% of patients less than 50-yrs old, 52% in age group 50-59-yrs, 58% in age group 60-69-yrs and 60% in age group older than 69-yrs. Labral complex abnormality was found in 8% of patients, and subacromial bursa fluid in 25%. Linear regression showed that rotator cuff tears, rotator cuff tendinopathy, subacromial bursa fluid and labral ligamentous complex abnormality were not related to degree of hemiplegic shoulder pain. Conclusions: Rotator cuff tears and tendinopathies are common in painful hemiplegic shoulder. The prevalence of rotator cuff tears is age dependent, but the prevalence of tendinopathies is not. However, these abnormalities do not seem to be related to the severity of hemiplegic shoulder pain.

FRACTURE OF HETEROTOPIC OSSIFICATION IN A YOUNG TRAUMATIC AMPUTEE: A CASE REPORT

Allison J. Franklin, DO; Donald A. Gajewski, MD

Heterotopic ossification (HO) is the formation of mature lamellar bone in the soft tissues and periacicular areas. HO is clinically significant in only 10–20% of reported cases and the reported incidence ranges from 11–76%. Heterotopic ossification is most commonly reported after elective joint surgery, burns, and spinal cord injuries, but may also be seen in traumatic amputees. These lesions tend to be asymptomatic. Our patient was a 22-yr-old male with a traumatic right transfemoral amputation secondary to a blast injury. He had developed asymptomatic heterotopic bone formation in his residual limb. Five months after his injury date he fell on his residual limb when downhill skiing. This resulted in immediate and severe pain. A hard, tender, mobile nodule was present within the HO. Radiographs demonstrated a fracture through the existing heterotopic bone. He was treated conservatively and quickly returned to his prefracture activity levels. To our knowledge, this is the first report of fractured heterotopic ossication in an amputee.

“BLIND-SIDE” TRAINING WITH FORCED-CHOICE TASKS FOR HOMONYMOUS HEMIANOMA

Yonghua Tai, MD, PhD

Objective: To develop discriminative visual functions in the blind field by training target detection and localization with forced-choice tasks. Design: Case series study. Thirteen patients with homonymous hemianopia or quadrantopia caused by tumor, arteriovenous malformation, traumatic brain injury, or stroke were recruited 12–144 mos beyond the acute stage. All patients’ visual fields were confirmed to be stable by serial Humphrey perimeter and SLO macular perimeter. They were also screened by the Sunnybrook Depression Battery, and all had normal trials per session. Each subject underwent 6 wks of computerized training of target detection on screen. In each trial, a transient target (200 msecs) randomly appeared in the four quadrants at 20-degree eccentricity from center fixation cross. The subjects were prompted to guess the target location. The home blindsight training comprised 150 trials per session, 2 sessions daily. The subjects responded with pressing a specific key corresponding to the target locations. In-facility training comprised 100 trials per session per week. The subjects responded with saccadic eye movement toward the target or verbal reporting target location. Feedback was provided to the subjects during the training. Each subject was tested for the above tasks. They were also tested for discriminating presence vs. absence of a target. Results: Laser scanning ophthalmoscopy confirmed that the visual functions developed in the blind field was not a result of scotter light detected by the normal side retina. Comparing with the pretrained performance, there were significant improvements in saccadic hit rate (P < 0.01), verbally expressed detection rate (P < 0.05), saccadic localization rate (P < 0.01), and verbally expressed localization (P < 0.01). Conclusions: Nonveridical vision is a true function of the blind side, rather than scatter light onto the normal retina. Patients with homonymous hemianopia have nonveridical vision in verbalized discrimination, oculomotor accuracy performing saccades to targets in the blind visual field after training with forced-choice tasks. Residual vision in the perimetric blind field was present in cortical and subcortical homonymous hemianopia. Nonveridical vision developed after training with forced-choice tasks in blind field in a period of just weeks, even years after brain injuries.

FUNCTIONAL OUTCOME AFTER SUBTHALAMIC NUCLEUS DEEP BRAIN STIMULATION TO TREAT PARKINSON DISEASE: A LONGITUDINAL STUDY

Keith M. Robinson, MD

Introduction: As many as 50% of individuals who have PD can be labeled as medically refractory. Surgical interventions including subthalamic nucleus deep brain stimulation (STN-DBS) have been viewed as efficacious based on short-term (<1 yr) and long term (>1 yr) studies using impairment based outcome measures. This longitudinal study which assesses integrative functional outcome following STN-DBS has reached the 18-mo postsurgery point. Methods: Thirty-two subjects have been assessed at three points: presurgery, 6 mos postsurgery, and 18 mos postsurgery. A final assessment will occur when subjects reach the 3-yr postsurgery point. Subjects were recruited from among PD patients referred regionally for STN-DBS. Criteria for inclusion included: diagnosis of idiopathic PD; disease severity of at least Hoehn and Yahr stage 2; a history of being levodopa responsive; persistent disabling dyskinesias or rapid motor fluctuations when using dopaminergic medications; stable on medications at least 1 mo before surgery; age < 84-mos. Heterotopic ossification is most commonly reported after elective surgery, burns, and spinal cord injuries, but may also be seen in traumatic amputees. These lesions tend to be asymptomatic. Our patient was a 22-yr-old male with a traumatic right transfemoral amputation secondary to a blast injury. He had developed asymptomatic heterotopic bone formation in his residual limb. Five months after his injury date he fell on his residual limb when downhill skiing. This resulted in immediate and severe pain. A hard, tender, mobile nodule was present within the HO. Radiographs demonstrated a fracture through the existing heterotopic bone. He was treated conservatively and quickly returned to his prefracture activity levels. To our knowledge, this is the first report of fractured heterotopic ossication in an amputee.
subscale of the FIM (F1.28 = 3.5; P = 0.038), the Communication subscale of the FIM (F1.28 = 8.6; P = 0.001), and the functional reach forward (F1.28 = 5.9; P = 0.005). Pairwise comparisons (using Bonferroni adjustments) of scores showed that performance improved more noticeably for the first postoperative (six months) time period, although the difference was significant only for the functional reach forward. Conclu-

sion: Early evidence indicated STN-DBS may serve to improve basic functional status and balance during the initial six months postsurgically, and that functional status and balance stabilized thereafter until 18 mos. Gait and cognition did not seem to be influenced either positively or negatively by STN-DBS at 6 and 18 mos postsurgically.

RELATIONSHIP BETWEEN STRENGTH AND MUSCULAR AREA DIFFERS WITH OBESITY: INTERIM ANALYSIS
Neil A Segal, MD; James Torner PhD; Morgun Brubaker BS; Bret Goodpaster PhD; Bridgett Zimmerman PhD

Objective: To assess the relationship between knee extensor strength and muscle mass in normal weight and obese subjects, age 50–59 yrs; 2) To determine whether lower limb lean body mass (LBM) or lean cross-sectional area (CSA) of the knee extensor strength and muscle cross-sectional area (CSA) or lean body mass. Results: A total of 106 subjects have been enrolled to date (51 male, 55 female). Two hundred eleven lower limbs were studied; 56 in normal weight, and 155 obese individuals; 62 with knee OA and 149 without knee OA. Mean ± SD peak IK knee extensor torque did not significantly differ between normal weight (108.1 ± 42.2) and obese (116.7 ± 46.7) subjects, nor between nonknee OA (116.0 ± 43.8) and knee OA (110.4 ± 49.6) subjects, whether unadjusted or adjusted for age and sex matching. After scaling to adjust strength for body size, peak IK knee extensor torque did not significantly differ between groups (normal weight 110.4 ± 5.28N, and obese 117.5 ± 3.7N). A linear model with scaled peak IK knee extensor force as the response and quadriceps muscle CSA (cm²) as the independent variable was fit for normal weight and obese individuals. In males, a significant difference was detected comparing the relative relationship between strength and CSA in obese (slope = 1.61 ± 0.34), but not in normal weight subjects, whether unadjusted (P = 0.0126) or adjusted for knee OA status (P = 0.0006). In females, there were no significant differences between slopes of these relationships. In females, the y-intercepts significantly differed, with obese having more strength (41.9N) than normal weight subjects (23.4N) at any level of CSA. Scaled knee extensor strength correlated better with quadriceps muscle CSA (r = 0.67, P < 0.0001) than with thigh LBM (r = 0.24, P = 0.0006). Conclusions: Results of this interim analysis suggest that there is an altered relationship between muscle strength and bulk in obese relative to normal weight females, possibly due to a qualitative deficit in muscle function with obesity. However, a similar altered relationship was not detected in males. Further recruitment of normal weight subjects will be necessary achieve adequate power to test these relationships more fully. Quadriceps CSA is a more robust means of normalizing strength independent of body mass than use of LBM.

AAP Annual Meeting Poster Grand Rounds

Thursday, April 12, 2007

COMPARING MOTOR RELATED CORTICAL POTENTIALS AND REACTION TIME BETWEEN HEALTHY CONTROLS AND PATIENTS WITH TRAUMATIC BRAIN INJURY
Henry L. Lew, MD, PhD; Max Gray, BA; Darryl Thomander, PhD; John H. Poole, PhD

This study investigated the effectiveness with which: (i) response-locked motor related cortical potentials (MRCP) and reaction time (RT) measures separated traumatic brain injury (TBI) patients from healthy con-

trols, and (ii) how the effectiveness changed as the ecological relevance of the stimulus was increased. We also examined the relationship between the RT and waveform morphology. Methods: Eleven patients (mean age 25.9 yrs) who had recovered from severe TBI (average 15.5 mos postsurgically) were recruited from one university affiliated hospital. Eleven age-matched volunteers served as healthy controls.

Each participant performed four different discrimination tasks (two con-

ventional tasks, and two other tasks in the same modalities, but designed to be more ecologically relevant). The two conventional tasks were: visual color (VC) and auditory tone (AT) discrimination. The ecologically relevant tasks were: visual facial affect (VFA) and auditory word category (AWC) discrimination. Neuronal (El Paso, TX) hardware and software systems were used for task presentation, and collection of electroencephalo-

gram (EEG) and behavioral measures.

Epochs (~1000 to 50 msecs) were time-locked to the button press for the target trials after conventional EEG processing. Averaged waveforms were digitally filtered (band pass 2–10 Hz) and baseline to each participant’s mean 100-msec prestimulus interval. The motor peak (MP) of the preresponse negativity was measured relative to the baseline interval at electrode C3, defined as the maximum negativity in the −200–

to 0-msec interval. RT and MP data were concurrently collected. The Coefficient of Variation (CoV) for RT was used as an index of within-

participant consistency. One-tailed Wilcoxon signed ranks tests were used to determine significant group differences for all measures, and effect size was used to determine effectiveness of the MRCP and RT measures in discriminating controls from TBI individuals. Results: Response-locked MP amplitude was significantly different (P < 0.05) between participant groups for VC, AT, and AWC (Z = 2.67, 2.31, 1.69), but not for VFA (Z = 1.25, P = 0.11). Latency of the MP did not distinguish the two groups in any condition (all Z < 1.38, all P > 0.08). Mean RT was significantly different (P < 0.05) between healthy participants and TBI patients in all four conditions (VC, AT, VFA, AWC: Z = 2.97, 2.3, 2.2, 2.5, respectively). CoV measures related to RT, there was no statistical difference between the two groups (all P > 0.08). During inspection of individual waveforms, we noticed an interesting pattern that divided the participants into two groups according to their RT measures. The faster responders had more closely synchronized preresponse negative peaks, while the slower responders showed a more dispersed pattern. Conclu-

sions: When simple conventional stimuli were used, more complex and ecologically relevant tasks were: visual facial affect (VFA) and auditory word category (AWC) discrimination. The ecologically relevant tasks were: visual facial affect (VFA) and auditory word category (AWC) discrimination. Neuronal (El Paso, TX) hardware and software systems were used for task presentation, and collection of electroencephalo-

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sions: More complex and ecologically relevant stimuli were used, the trend was reversed. Also, the observed difference in morphology for the preresponse negativities suggests different underlying

response execution mechanisms that deserve further research.

WHEELCHAIR USE, SOCIAL INTEGRATION, AND MOBILITY AMONG ADULTS WITH SPINA BIFIDA
Anna Gaines, BS; Brad E. DiCianno, MD; Diane M. Collins, PhD

Objective: Over 70,000 Americans have Spina Bifida (SB), and many use wheelchairs to increase mobility and independence both at home and in the community. However, adults with SB are often socially isolated despite using mobility devices. Little research has been done to characterize the use of mobility devices in adults with SB and whether such use impacts mobility or social integration. Since the cognitive consequences of hydrocephalus, which is common among individ-

uals with SB, and the isolating effects of depression may also impact community involvement, evaluating the relationship among these factors is vitally important.

The purpose of this study was to evaluate the association between wheelchair use, mobility status, and the extent of social integration in adults with SB. We hypothesized that, overall, social integration and community mobility, as measured by the Craig Handicap Assessment Reporting Technique – Short Form (CHART-SF), will be lower for individ-

uals who use manual wheelchairs (MWC) or power wheelchair (PWC) users. Results: The groups did not differ significantly in age, gender, race, or BDI total scores. They did differed significantly in shunt history (P = 0.000), with 55.6% of ambulators, 90.9% of MWC users, and 95.2% of PWC users having history of at least one shunt. We found associations April 2007

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between shunt history and Physical Independence (P = 0.027) and Mobility (P = 0.017) CHART-SF scores but not with the other domains. Groups differed significantly in Physical Independence (P = 0.000), Mobility (P = 0.005), Occupation (P = 0.002), and Cognitive Independence (P = 0.000), with post hoc analyses revealing ambulators had significantly higher scores than both MVC and PWC groups in all of these domains, even when shunting was used as a covariate. Mobility groups did not differ in the CHART-SF domains of Social Integration or Economic Self-sufficiency. Conclusions: Ambulators were more physically independent and, as hypothesized, more mobile in daily and community activities than those who used wheelchairs. However, reduced Mobility scores across all three groups suggests lower than average daily and community activity levels even for ambulators. The functional discrepancy between ambulators and wheelchair users with respect to Physical Independence and Mobility raises the question of whether better wheelchair provision may help to alleviate these significant differences.

Reduced cognitive independence and occupation scores among wheelchair users support earlier studies that demonstrate these individuals often have nonverbal and organizational deficits and high rates of unemployment. Despite other differences, mobility groups were surprisingly not significantly different in social integration scores, which were

ULTRASOUND IN THE DIAGNOSIS OF MENISCAL TEARS OF THE KNEE

Gi-Young Park, MD, PhD; Jong-Min Kim, MD; Sung-Moon Lee, MD; Michael Lee, MD

Methods: Twenty-seven knees of twenty-two patients (16 female, 6 male; age range, 14-74 y; mean age, 50.4 y) with meniscal tears on MRI were studied. In the 54 menisci of 27 knees, twenty-nine meniscal tears of the knee (medial 22, lateral 7) were found. Twenty eight menisci (medial 14, lateral 14) of 14 volunteers (7 females, 7 males; age range, 23-68 y; mean age 43.4 y) without tear and 25 normal menisci (medial 5, lateral 20) of 22 patients formed a control group.

All patients and volunteers were prospectively examined with MRI and ultrasound. A Musculoskeletal radiologist blindly evaluated the presence and location of meniscal tears on MRI and ultrasound. In MRI, meniscal tear was diagnosed by the high signal in the meniscus extending to its articular surface, gross distortion of the normal shape, or truncation of the meniscus. In ultrasound, it was diagnosed by the appearance of a discrete hypoechoic or anechoic cleft extending to articular surfaces or a defect in the hypoechoic meniscus. Results: Of the 22 medial meniscal tears on MRI, 20 tears (90.9%) involved in the posterior horn and 2 tear (9.1%) in the middle zone. Ultrasound showed that 18 tears were located in the posterior horn, 1 tear in the middle zone, and 1 tear in the anterior horn.

Of the 22 medial meniscus diagnosed with tear on MRI, tears were detected on ultrasound in 20 menisci (90.9%) and no tear in the other 2 menisci (9.1%). Of the 19 meniscal lesions without tear on MRI, tears were detected on ultrasound in 4 menisci (21.1%) and no tear in the other 15 cases (78.9%). The sensitivity and specificity of ultrasound in the diagnosis of medial meniscal tear was 90.9% (20 of 22 menisci) and 78.9% (15 of 19 cases), respectively.

Of the 7 lateral meniscus diagnosed with tear on MRI, tears were detected on ultrasound in 6 menisci (85.7%) and no tear in 1 meniscus. Of the 34 lateral meniscal lesions without tear on MRI, tears were detected on ultrasound in 4 cases (11.8%) and no tear in the other 30 cases (88.2%). The sensitivity and specificity of ultrasound in the diagnosis of lateral meniscal tear was 85.7% (6 of 7 cases) and 88.2% (30 of 34 cases), respectively. The overall sensitivity, specificity, accuracy, positive predictive value, and negative predictive value of ultrasound for the detection of meniscal lesions of the knee were 89.7%, 84.9%, 86.6%, 76.5%, and 93.4%, respectively.

Conclusion: Ultrasound appeared to be an accurate imaging technique for the diagnosis of meniscal tears of the knee, which strongly suggesting that it can be a useful screening imaging technique before MRI.

Friday, April 13, 2007

RACIAL DISPARITIES IN ACCESS TO INPATIENT STROKE REHABILITATION AMONG RURAL NORTH CAROLINA AMERICAN INDIANS

Patricia C. Gregory, MD; Euna Han, PhD; Kim Faurot, MPH

Objective: Prior studies have shown an urban rural disparity in access to inpatient stroke rehabilitation. This study investigated among rural stroke patients the association between American Indian race and discharge to acute inpatient stroke rehabilitation. Design: A total of 17,019 patients who reside in rural counties of North Carolina and were admitted to the hospital with an acute stroke (ICD codes 430-434.9 and 436) were evaluated using the North Carolina Hospital Discharge Dataset. Outcomes evaluated included discharge to acute inpatient rehabilitation (vs. discharge to home. Factors associated with this outcome included:

- age (<60 yrs vs. 60+ years), race (American Indian vs. white), sex, insurance status (insured vs. uninsured), days 1 day in ICU vs. ≥3 days, number of therapy days, and mobility status (self vs. home vs. home assistance). Results: Male patients and those with mobility limitations were more likely to receive rehabilitation than those without. The overall likelihood of rehabilitation was 21.1% (95% CI 1.11, 5.68). After controlling for age, sex, and socioeconomic status (inpatient characteristics), mobility limitations were significantly associated with rehabilitation (OR = 1.16; 95% CI 1.11, 5.68). After controlling for age, sex, insurance status, poverty level in the patient county, physical therapy charges, and ICU charges white race was still independently associated with discharge to acute inpatient stroke rehabilitation (OR = 1.16; 95% CI 1.11, 5.68). Conclusions: Rural American Indian stroke survivors are less likely to access inpatient stroke rehabilitation. Differential utilization of rehabilitation services among American Indian stroke survivors deserves further exploration to identify ways to eliminate these disparities.

GEOGRAPHIC VARIATIONS IN EPIDURAL STEROID INJECTION USE

Janna Friedly MD; Leighton Chan MD; Richard Deyo MD

Objectives: Epidural steroid injection (ESI) rates have been increasing dramatically over time with equivocal data to support their use for various low back pain disorders. Therefore, we sought to evaluate geographic variations in epidural steroid injection use for low back pain within the United States. We also sought to determine if epidural steroid injection rates are correlated with lumbar surgery rates or regional numbers of physicians performing injections. Methods: We used 2001 Medicare Physician Part B claims to examine geographic variations in the use of) epidural steroid injections. Current Procedural Technology (CPT) codes were used to identify the number of procedures performed as well as the percentage of procedures which were fluoroscopically guided. Injection rates were compared with lumbar surgery rates. Procedure rate variations were analyzed using stratified analyses. State, United States Census Bureau definitions of regions (Northeast, South, Midwest and West) and Dartmouth Atlas of Health Care's previously defined health referral regions (306 regions). Results: In 2001, there was a 5.7 fold injection rate difference between the state with lowest rate (Hawaii at 11.5/1000 Medicare beneficiaries) vs. the state with the highest rate (Alabama at 65.5/1000). Five of the ten states with the highest injection rates are in the Northeast and six of the ten states with the highest injection rates are in the South. Nine states had injection rates greater than 25% above the national average. The variation among smaller health referral regions was even larger, with a 27-fold difference from 4.7/1000 in Owensboro, KY to 126.4/1000 in Palm Springs, CA. Seventy-one of the 306 health referral regions had injection rates greater than 25% above the national average. Fluoroscopy use varied dramatically between states as well as health referral regions. Only 0.5% of injections performed in Vermont were fluoroscopically guided vs. 88% of injections in Wyoming. Nationally, 42% of injections were performed using fluoroscopy. Statewide epidural steroid injection rates were positively correlated with lumbar surgery rates (Pearson correlation coefficient = 0.299, P = 0.033). There was also a strong correlation between statewide and regional injection rates and the percentage of patients with low back pain receiving injections (Pearson correlation coefficient = 0.828, P = 0.000) as well as the percentage of patients receiving both epidural steroid injections and lumbar surgery during the study period (Pearson correlation coefficient = 0.389, P = 0.005). There were no correlations between statewide epidural steroid injection rates and nor-
A COMPARISON OF POST–ACUTE CARE DESTINATION FOR AMPUTEE PATIENTS BEFORE AND AFTER IMPLEMENTATION OF THE 75% RULE
Laura Lee, MD, MBA

While the 75% Rule has been notable for excluding several patient populations that have been treated in inpatient rehabilitation facilities (IRFs) in the past, this regulation may also affect the postacute referral patterns of populations that are included in the 75%. Patients with amputations are included within the 75% quota, but have not usually been referred to IRFs in high proportions. We hypothesized that relatively more acute care patients would be referred to an IRF after implementation of the 75% Rule.

All patients at an academic medical center who had a trans-tibial, trans-femoral, or hip disarticulation amputation during 2002 and 2005 and survived to be discharged from the acute care hospital were included. The results are in table form below. Overall, a higher percentage of patients discharged to an IRF than in 2002 (15% vs. 27% in 2005). Patients who went to an IRF tended to be older than the ones who went home (both routine discharges with outpatient follow-up and those who went home with home health services) but younger than the ones who went to a subacute nursing facility. Level of amputation did not affect discharge disposition, although more transtibial amputees went to an IRF and more trans-femoral amputees were discharged to an SNF in both 2002 and 2005. More traumatic amputees tended to go home than to IRF or SNF. Lastly, comorbidities such as age, diabetes, congestive heart failure, renal failure and diabetes were examined to determine relationship to discharge disposition, with PVD demonstrating a significant correlation (please see table below).

THE RELATIONSHIP OF MOOD AND LIFE SATISFACTION TO PHYSICAL FUNCTION AND DEPRESSION IN CHRONIC SPINAL CORD INJURY/DISEASE
Mobeen Choudhri, MD; Chetan Malik, MBbs; T. M. Srikrishnan, MD; Carl V. Granger, MD

Objective: To study the relationship of Mood and Life Satisfaction to Physical Function and Depression in chronic spinal cord injury/disease.

Study Design: Cross-sectional study of a convenience sample of 28 out-patient clinic attendees at Buffalo VAMC – SCI clinic. Persons with spinal cord injury duration of injury greater than 3 mos were selected for the study. Patients were classified based on the ASIA scale into paraplegics and quadriplegics. Informed consent was obtained. Demographic data were obtained. Physical function was measured with FIM™, BMC and Limitation. Mood as evaluated by Placid. Life satisfaction was measured using Satisfaction measure. BDI Fast Screen was used to assess for depression. SSPS was used for statistical analysis. t test was used to compare means and logistic regression was used to calculate Odds ratio.

Participants: Twenty-eight chronic spinal cord injury patients (15 paraplegics, 13 quadriplegics), 27 participations were males. Mean age was 53 yrs (range 20–85). Interventions: Not applicable. Results: Patients with presence of depression had worse mood and life satisfaction as opposed to patients with absence of depression (Placid 90 vs. 55), the relationship persistent, when adjusted other variables including paraplegia. The adjusted Odds ratio 0.26. Quadriplegics patients also had worse mood and life satisfaction than patients with paraplegia, however the relationship did not persist when adjusted for depression. There was no difference in the patient’s mood or life satisfaction in relation to FIM (cognitive or motor or total). BMC, and limitation scores. Paraplegic subjects had higher motor function (BMC), and FIM (motor) scores compared with quadriplegics. Conclusions: It seems that mood and life satisfaction is related the presence of depression and not BMC, FIM motor, or degree of disability (paraplegics vs. quadriplegics).

LONG-TERM OUTCOMES AFTER TRAUMATIC BRAIN INJURY IN VETERANS: SUCCESSES AND CHALLENGES
John H Poole, PhD; Marie N. Dahdah, MS; Karen Schwab, PhD; Henry L. Lew, MD PhD; Deborah L. Warden, MD; Elaine S. Date, MD

Background: To identify the rehabilitation needs of a new generation of veterans with traumatic brain injury (TBI), research is needed on the course of recovery from TBI and challenges encountered by previous veterans. We recently reported on continuing problems during the first two years after TBI. We now present initial findings on functional outcomes and clinical needs of veterans with TBI, five or more years postinjury.

Participants:

Date, MD
Henry L. Lew, MD PhD; Deborah L. Warden, MD; Elaine S. Date, MD

Study Design:

Cross-sectional study of veterans five or more years postinjury.

Results:

Not applicable.

Conclusions:

Not applicable.
Methods: Subjects were 50 patients, currently 22–68 yrs old (median age 39), who sustained TBI 5–15 yrs ago (median 10 yrs ago). All had moderate to severe TBI, and two thirds were in coma for more than 7 days. Following emergence from coma, all received multidisciplinary inpatient rehabilitation in our university-affiliated veterans medical center for an average of 4 wks. As part of an ongoing study, most subjects had one to three follow-up evaluations during the first 2 yrs, with 40% receiving additional rehabilitation. For the present study, we conducted a comprehensive telephone interview developed by the Centers for Disease Control, supplemented with the Disability Rating Scale (DRS) and the Community Integration Questionnaire (CIQ). Results: Forty-five percent of the patients attended college classes post injury, with 25% completing a 2-yr college degree or higher. Forty percent are currently employed, with 27% working at least 30 hrs/wk. Twenty percent became married or engaged. Patient’s current disabilities range from DRS = 0 (absent) to 16 (severe), and average 2.7 (partial disability). Two-thirds view themselves as having a disability and report significant continuing problems in the following areas (in descending order): Cognitive Deficits in 91% of patients (mainly memory, concentration, processing speed, organization, grasp of concepts, and accident proneness); Emotional Problems in 80% (irritability/anger, disturbed mood, suicidal ideation); Physical Symptoms in 71% (balance, gait, hearing, headaches, fatigue); Social Problems in 58% (relationship with spouse, work difficulties); Independent-ADL Problems in 42% (driving, money management, meal preparation); and Basic-ADL Problems in 36% (mobility, dressing). Eighty percent of this veteran sample report that they currently have health coverage. However, the majority cite unmet needs that they attribute to lack of information about available services, lack of transportation, and difficulty organizing services for themselves. Conclusions: (1) A sizable minority of patients with moderate to severe TBI attain higher education, gainful employment, and marital relationships. Even after rehabilitation and follow-up in the first two years postinjury, the majority continue to report persisting cognitive, emotional, physical and social problems during subsequent years. Due to the cognitive and emotional consequences of brain injury, many patients have difficulty organizing and obtaining services to address these issues. (2) These findings highlight the importance of continuing follow-up for patients with TBI throughout their lives. Thus, it is vital that the next generation of TBI programs, now being designed, include treatment plans and a systematic schedule of follow-up appointments that are initiated and monitored by service providers.