UD Center for Biomedical Engineering Research

Biomechanics Research Symposium

May 12, 2006

The Center for Biomechanical Engineering Research at the University of Delaware is pleased to host the 3rd annual CBER research symposium. The motivation for this symposium is to highlight the outstanding and varied biomechanics related research taking place at the University of Delaware.

Poster and podium presentations will be led by young researchers with awards presented for the best undergraduate student poster, the best graduate student poster and for graduate student and post-doc presentations.

Our keynote lecture will be given by Dr. Milos Popovic, director of the Rehabilitation and Engineering Laboratory in the Institute of Biomaterials and Biomedical Engineering at the University of Toronto. Dr. Popovic's research is focussed on developing advanced rehabilitation systems, neuroprostheses and sophisticated man-machine intefaces.

The keynote lecture will be delivered at 10:30 AM in CCM 106. Posters will be on display in the morning (2nd floor Spencer Lab) and podium presentations will be held in the afternoon in CCM 106. Lunch will be served.

Schedule of the Day

Time		What	Where
8:00	9:00	Poster set-up & Breakfast	2nd floor Spencer Lab
9:00	10:00	Poster Session 1 (Odd #'s)	2nd floor Spencer Lab
10:10	11:10	Keynote: Dr. Steven Kautz	CCM 106
11:15	12:15	Poster Session 2 (Even #'s)	2nd floor Spencer Lab
12:15	1:15	Lunch	2nd floor Spencer Lab
1:15	2:30	Podium Session 1	CCM 106
2:30	2:40	Break	
2:40	3:55	Podium Session 2	CCM 106
3:55	4:00	Awards	CCM 106

Podium Presentations

Session 1

		Abstract #
1:15 - 1:30	Philip Crowell	37
1:30 - 1:45	Becky Avrin Zifchock	38
1:45 - 2:00	Trisha Kesar	39
2:00 - 2:15	Daniel Bassett	40
2:15 - 2:30	HeHe Zhou	41

Session 2

		Abstract #
2:40 - 2:55	Clare Milner	42
2:55 - 3:10	Daniel Ramsey	43
3:10 - 3:25	Vijaya Krishnamoorthy	44
3:25 - 3:40	Peter Barrance	45
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Keynote Lecture

Coordination of hemiparetic locomotion

Steve Kautz, PhD
VA Brain Rehabilitation Research Center & University of Florida

The overall goal of my research is to construct a scientific foundation for understanding locomotor coordination deficits in persons with post-stroke hemiparesis in order to provide a rational scientific basis for therapeutic interventions. The underlying theoretical framework is based on neurophysiological and biomechanical control principles that are elucidated by combined experimental and simulation analyses.

A primary impairment of locomotion post-stroke is a reduced ability to sufficiently recruit the muscles of the more affected (paretic) leg. Thus, it is crucial to understand mechanisms by which patterned muscle activity emerges in the paretic leg in order to develop rehabilitation interventions that ultimately facilitate paretic leg muscle recruitment during walking. Hemiparetic gait is often profoundly asymmetric, but the extent to which asymmetry may represent an abnormal influence of CL sensorimotor activity on the ipsilateral motor pattern, as opposed to either a functional compensation or a unilateral control deficit, is not known. We believe that aspects of observed dysfunction in the paretic leg during locomotion may have a genesis in the sensorimotor state of the non-paretic leg, and vice versa.

We have developed a human motor performance laboratory that has several unique tools for studying the coordination of human locomotion, including a novel pedaling apparatus that allows investigation of the bilateral coordination of rhythmic locomotor behavior in ways that are not possible in walking paradigms. Each leg is connected to its own crank, which is connected to a servomotor that can be programmed to apply a load independent of, or dependent on, the kinematic and kinetic state of the CL leg. A set of experiments was performed on persons with hemiparesis and age-matched neurologically healthy subjects. Specific hypotheses tested included:

1. The motor pattern of the paretic leg is inappropriately influenced by the sensorimotor state of the CL leg (e.g., muscular activity and afference related to loading and movement).

2. There is an increased propensity for ipsilateral rhythmic motor activity to induce locomotor-like rhythmic motor activity in the contralateral leg in persons with post-stroke hemiparesis.

3. The induced contralateral limb activity differs with the severity of hemiplegia as assessed using the Brunnstrom stages (e.g., dependence on abnormal synergies).

Our first study found that the normal suppression of interlimb influences may be disrupted during hemiparetic pedaling. We suggest that the coupling of pattern generation between the two legs may result in greater, albeit more impaired, paretic leg motor output during bilateral pedaling than during unilateral pedaling. Following up on this result, our second study found that unilateral pedaling can activate a complete rhythmic locomotor pattern in the non-pedaling leg in persons with post-stroke hemiparesis (in either a stationary or moving paretic leg or in a moving non-paretic leg), but not in the contralateral leg of non-disabled control subjects. Most remarkably, the induced rhythmic locomotor pattern in the paretic leg can even be of similar magnitude to the pedaling pattern for the lowest functioning group of hemiparetic subjects (Brunnstrom stage 3, those dependent on limb synergies), both when the paretic leg is stationary and when it is moving. We suggest that excitatory pathways associated with contralateral pedaling that act on the ipsilateral biomechanical functions in control subjects are up-regulated in both legs in persons with hemiparesis, and to an increasing degree as impairment level increases. We further suggest that these interlimb pathways are of functional importance in the more impaired subjects, and since a complete motor pattern of similar amplitude to the voluntary, bilateral pattern could be activated in the paretic leg by contralateral pedaling in these subjects that they may be responsible for a substantial portion of the locomotor output of the paretic leg. Thus, these interlimb pathways may be a potent target for therapeutic interventions for increasing the output of the paretic leg.

Poster Presentations

1 Examining Neuropsychological Test Performance In Different Age Groups Of Female Interscholastic Soccer Players

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Neuropsychological (NP) testing has become an important tool in the management of sport-related concussion. Objective: The purpose of this study was to compare scores on measures of reaction time and attention/ concentration in a group of female interscholastic soccer players. Design and Setting: A factorial design was utilized to examine the NP measures across five different age groups of female interscholastic soccer players. All NP testing occurred in a quiet, undisturbed setting. Subjects: A total of 218 female, high school soccer players participated in this study. The girls were divided into five distinct age groups; fourteen (29), fifteen (66), sixteen (67), seventeen (39), and eighteen (17) years old (YO). Measurements: Throughput scores, providing a measure of accuracy and speed, were derived from the Automated Neuropsychological Assessment Metrics (ANAM – National Rehabilitation Hospital) computer program. Specifically, the sub-test scores from the simple reaction time (SRT) and continuous performance test (CPT) were compared between the five groups. The SRT sub-test is a measure of reaction time, while the CPT sub-test is a measure of attention/concentration. Results: There were no significant differences ($P > .05$) in throughput scores for either SRT or CPT sub-test measurements between the 5 different age groups examined. SRT scores ranged from 116.69 – 271.26 (200.55±24.67), while the CPT scores ranged from 34.02 – 138.92 (97.15±17.41). Conclusions: The results of this study suggest that the two sub-tests of the ANAM NP test battery are quite consistent between the ages of 14 and 18, in this population of interscholastic female soccer players.

2 3d Real-Time Feedback To Decrease Torsional Loads And Improve Medial Foot Pain

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Excessive twisting moment acting on the leg (free moment) may contribute to a variety of lower extremity injuries, including medial foot pain. PURPOSE: to investigate the influence of training using real-time motion analysis feedback to change running mechanics and resolve patient medial foot symptoms. METHODS: The subject for this case was a 16 y.o. female soccer/track athlete who complained of pain under her left first metatarsal for over a year. The symptoms increased with activity and had not resolved with previous physical therapy. Visual inspection of her running mechanics revealed significantly increased in-toeing during stance. We hypothesized that increased in-toeing would generate greater torsional loads between her foot and the ground which, over repeated exposures, may contribute to her medial foot pain. Prior to gait retraining, running mechanics were recorded at 3.7 (±0.2) m/s as the subject ran along a 25 m runway. The subject next participated in 13 sessions of real-time biofeedback training during treadmill running. Session length increased to 30 minutes over the first 8 visits. To facilitate motor learning, the last five visits included progressively less feedback during the 30 minute training sessions. Running mechanics were again recorded at the conclusion of the retraining sessions. RESULTS: Medial foot pain decreased from 7.5/10 to 3/10 during activity. The subject displayed a 6.7º decrease in foot progression angle excursion and a 6.9º decrease in foot abduction angle excursion during stance after training. Additionally, the subject decreased their peak free moment and net angular impulse by 74% after training. CONCLUSION: The results of this case study suggest that gait training using real-time feedback to adjust running mechanics may reduce torsional loads to the foot and decrease patient complaints.

3 Quadriceps Strength, Laxity, and Function After Acute Isolated ACL Rupture: Relationship to Dynamic Stability

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Objective: The objectives of this study were to prospectively classify the entire population of highly active individuals diagnosed with acute, ACL rupture in the practice of a single orthopedic surgeon using classification algorithm for acute anterior cruciate ligament (ACL) rupture soon after injury (Fitzgerald et al.2000) to determine the role quadriceps weakness, laxity and functional tests play in the development of dynamic stabilty of the ACL injured knee. Methods: 300 consecutive patients with acute isolated ACL injury from the practice of a single orthopaedic surgeon underwent a screening examination including clinical measures, laxity, quadriceps strength, hop test and patient self-report an average of 6 weeks after injury when impairments were resolved. Results: ANOVA was used to determine differences in salient variables between non-copers and potential copers and linear regression was used to evaluate the predictive strength of the variables in the development of dynamic stablity.There was no difference in laxity between groups (5.6 vs 5.9 mm) but the non-copers quadriceps were significantly weaker and contributed substantially to the variance in their functional abilities as measured by four hop tests and patient self-report. In contrast, the portential copers had stronger quadriceps, no instability and no strong relationship between quadriceps strength the functional measures. Laxity had no relationship to the functional measures in either group. Conclusions: Non-copers are much weaker than potential copers in this consecutive sample of physically active individuals with acute isolated ACL injuries. Quadriceps weakness was a strong predictor of functional measures and self-report of function in the non-copers only. Laxity was not a predictor of functional measures, nor did it differ between those who were dynamically stable and those who were not.

References:

1. Fitzgerald et al.Knee Surg Sports Traumatol Arthrosc. 2000;8(2):76-82.

4 One Year After Total Knee Arthroplasty

Yuri Yoshida and Lynn Snyder-Mackler
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A strong positive relationship between quadriceps strength and kinematic characteristic during gait after knee surgery has been reported. Research has indicated that inadequate quadriceps strength contributed to altered gait patterns following anterior cruciate ligament reconstruction[1]. In a previous study in our lab, the patients 3 months after unilateral total knee arthroplasty (TKA) have been reported to have an "asymmetric pattern" in the kinematic data and that is related to the asymmetric quadriceps strength between the legs [2]. Therefore, this study investigated whether the gait pattern is changed at a longer period after surgery in these same patients one year after TKA and compared to an age-matched control group. Nine individuals who underwent TKA and ten healthy subjects as the control group participated in the gait analysis. The knee excursion during weight acceptance was no longer significantly different between sides in the TKA group (p= 0.4), and the knee excursion was also not significantly different from the control group (p= 0.2). The relationship between the symmetry index of knee excursion and the symmetry index of quadriceps strength is significant (p=0.003, r2=0.17). The gait pattern of the patients one year after TKA becoming more symmetrical and more like the control group, but still strongly depends on symmetry of the quadriceps strength.

1. Lewek, M., et al., The effect of insufficient quadriceps strength on gait after anterior cruciate ligament reconstruction. Clin Biomech (Bristol, Avon), 2002. 17(1): p. 56-63.
2. Mizner, R., Snyder-Mackler, L. Altered loading during walking and sit-to-stand is affected by quadriceps weakness after total knee arthroplasty. In Press, Available online 30 March 2005

5 Hip strength and hip kinematics during prolonged running in runners with patellofemoral pain.

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Patellofemoral joint pain (PFP) may be related to muscle weakness of the hip abductors and hip external rotators. These weaknesses may predispose the knee to a more valgus position during stance. No studies have examined the relationship between hip strength and hip motion throughout a prolonged run, when muscles may become exerted. PURPOSE: To examine the relationships between hip strength and hip kinematics during prolonged running in runners with and without PFP. METHODS: Twenty recreational runners with PFP and 20 uninjured runners were evaluated. Isometric muscle strength testing for hip abduction (HABDS) and hip external rotation (HERS) were performed using hand-held dynamometery. Subjects then performed a prolonged run on a treadmill at a self-selected speed. After the run, subjects were retested for HABDS and HERS. Peak hip adduction (HADD) and hip internal rotation (HIR) angles were calculated during stance. Group differences were determined using independent t-tests ($p<0.05$). Correlation coefficients were calculated for HADD and HABDS, and for HIR and HERS. RESULTS: Strength was significantly lower in the PFP group at the beginning for both HABDS (15.2, 17.0) and HERS (5.5, 6.2), and at the end for HABDS (13.5, 15.4). The PFP group displayed a smaller peak HADD angle at the beginning (8.7, 11.8) and end (8.8, 12.0), while no differences were observed for peak HIR. No correlations were observed at the beginning of the run. The PFP group displayed a strong correlation at the end of the run between HADD and HABDS (-0.74). CONCLUSION: Runners with PFP appear to have weaker hip abductors and hip internal rotators. However, only at the end of the run do these weaknesses appear to be related to increased hip motion, with weak hip abductors resulting in increased HADD.

6 A Numerical Method for Determining Ideal Camera Placement

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Camera positioning is important to ensure accurate coordinate data and to minimize camera drop-out. Camera drop-out occurs when a marker fails to be imaged by a camera. The purpose of this study is to describe the conceptual framework for a numerical method of determining where video cameras, if placed, would have an occluded or a merged view of the markers. The ray projection method is best described by considering two markers within a motion capture volume, which is a subspace of a larger laboratory volume; both of which are defined by 4 walls, a floor and a ceiling. The apex of a cone is set at one marker, opening in the direction of the other and encircling its perimeter exactly. The cone continues outward, intersecting the walls, floor or ceiling of both volumes. A camera placed within this cone will have an occluded or merged view of the markers. This idea can be expanded to every possible marker pairing and at every point in time to map out potentially bad camera locations. Regions of intersection are shaded gray to indicate the frequency a camera if placed in that location would fail to see one or more of the markers. Two sets of walking data were collected using a 3 camera motion capture system. The distance between markers and the ankle joint angle were computed for each set of trials. The first set of trials had a camera positioned in a location for which there was significant camera dropout. The camera was moved to a more favorable location (i.e., minimal drop-out) for the second set of trials. The improved location was determined using the ray projection method. Differences between inter-marker distances and the ankle joint angle were noted when the camera was moved from the bad to the improved location. The ray projection method is an objective and practical solution that can be used to assist traditional data piloting to minimize errors associated with camera placement.

7 Effects Of Unilaterally Reduced Ankle Motion On Intrasubject Gait Variability

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People with a unilateral, lower-extremity pathology who favor the healthy limb during walking may predispose the non-affected limb to premature joint degeneration. Decreased variability in movement may be an influence on this joint degeneration by continuously stressing one area of the joint. PURPOSE: To examine the effects of unilaterally reduced ankle motion on the variability of ankle, knee, and hip angle during stride, moments during stance, and vertical ground reaction forces (GRF) in able-bodied subjects. METHODS: Ten able-bodied subjects (Mage = 22.4 ± 2.6 yrs; Mheight = 167.9 ± 10.2 cm; Mmass = 63.9 ± 11.3 kg) walked overground under two randomized conditions: 1) a normal walking condition (NORM), and 2) a unilateral ankle brace condition (BRACE) created by the subject wearing a restrictive ankle brace that reduced plantar flexion range of motion of one limb. Preferred walking speed was controlled (± 5%) between conditions. Three-dimensional position and ground reaction force data were sampled at 60 and 480 Hz respectively. Knee and hip extensor moments were calculated using an inverse dynamics approach. For each condition, 18 trials were collected for kinematic data and 3 trials were collected for kinetic data. All dependent variable curves were normalized to a length of 100 points. The variability of the curves was defined as the average of standard deviations about each point. RESULTS: A repeated measures ANOVA indicated a significantly greater ($p<.05$) average standard deviation of hip extensor moment in the normal and unbraced limbs compared to braced limbs. Ankle angle variability was significantly ($p<.05$) less in braced limbs than ankle angle variability in other limbs. No other significant differences were discovered.

8 The Effect Of Foot Progression Angle On The Knee Adduction Moment During Walking, Stair Ascent And Descent In Individuals With Medial Knee Osteoarthritis

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Progression of medial compartment knee OA is associated with the magnitude of the external knee adduction moment. Treatments to reduce the adduction moment are therefore indicated for patients with knee OA. Regression analyses have shown that the adduction moment is smaller for subjects that walk with a greater degree of toe-out (i.e., foot progression angle -FPA). No study has examined the effect of asking subjects with knee OA to walk with a greater degree of toe-out than their self-selected FPA. Moreover, the effect of increasing FPA while climbing stairs has not been examined in this population. PURPOSE: The purpose of this study was to examine the effect of increasing FPA by 15 degrees on the knee adduction moment during walking, stair ascent and descent in subjects with knee OA. METHODS: 10 subjects (4 female, 6 male; mean age = 63 ± 5 years, weight = 81.8 ± 12.7 kg, height = 1.68 ± 0.08 m) performed 5 trials each of walking, stair ascent and descent. The tasks were performed with a self-selected FPA and an increased FPA of 15 degrees. Motion data were collected using 6 video cameras (Qualisys) and an AMTI force platform. Visual3D was used to compute the external knee adduction moment, normalized to bodyweight and height (%BW*Ht). Dependent t-tests were used to determine if increasing FPA changed the magnitude of the first and second peak adduction moments. RESULTS: Increasing FPA did not change the 1st peak adduction moment during walking, but it did reduce the magnitude of the 2nd peak from 2.27 ± 0.63 %BW*Ht to 1.37 ± 0.53 %BW*Ht. A strong trend ($p=0.051$) towards a smaller 2nd peak with greater FPA was noted during stair ascent. The benefit of a reduced 2nd peak was offset by a significant increase in the 1st peak with greater FPA (3.14 ± 1.03 %BW*Ht & 3.51 ± 1.01 %BW*Ht). No differences in peak adduction moments were found for stair descent. CONCLUSION: The effect of increasing FPA was shown to reduce the magnitude of the 2nd peak adduction moment during walking. This is clinically relevant because the adduction moment is considered an indirect measure of knee joint loading. This simple strategy of increasing FPA during walking can reduce knee joint loading.

9 Curvilinear Relationship of CAR Masks Magnitude of Impairment after Total Knee Arthroplasty

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INTRODUCTION: A curvilinear relationship exists between CAR and %MVC resulting in an overestimation of CAR in outcomes after TKa. The purpose of the study was to recalculate CAR using the curvilinear model to discern the true magnitude of impairment in strength and CAR 1 year after TKA. METHODS: Data were collected on 91 subjects (mean age=65.2±8.4yrs, mean BMI=30.0±4.1kg/m2) 1 year after TKA. Quadriceps strength (MVIC) and CAR were measured using a burst superimposition technique. If CAR was <0.94, the curvilinear model was used to recaluclate CAR. Paired-samples t-tests were used to determine differences between limbs. RESULTS: 10 uninvolved and 8 involved knees achieved full activation and 32 uninvolved and 51 involved knees had a CAR>0.94. Mean involved MVIC was 599±231N and mean uninvolved MVIC was 663±280N. Mean involved CAR was 0.85±0.18 and mean uninvolved CAR was 0.79±0.18. Involved MVIC was significantly smaller than uninvolved MVIC (t=3.32, p<0.01). Involved CAR was significantly greater than uninvolved CAR (t=-3.40, p<0.01). Prior to recalculating CAR, a mean involved CAR of 0.91±0.11 and a mean uninvolved CAR of 0.88±0.11 was observed. Recalculation of CAR resulted in lower activation in both the involved (t=7.10, p<0.001) and uninvolved (t=10.49, p<0.001) limbs. CONCLUSION: The results of this study demonstrate inter-limb differences in quadriceps strength persist 1 year after TKA. Surprisingly, the involved quadriceps had a greater level of muscle activation than the uninvolved quadriceps although both limbs were lower than muscle activation levels of healthy, older adults (CAR=0.87). This suggests other factors (i.e. CSA) may be more critical to force-generating capacity. Using the linear equation, as consistently used in the literature, overestimates true CAR, masking activation deficits.

10 The effect of in-shoe lateral wedging on gait mechanics in patients with medial knee osteoarthritis

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INTRODUCTION: Knee osteoarthritis (OA) is the most common form of OA. In-shoe wedged orthoses have been offered as a non-surgical treatment for knee OA. These devices indirectly realign the knee by adjusting foot alignment. PURPOSE: The purpose of this study was to assess the effect of laterally wedged orthoses and neutral orthoses in patients with medial knee OA on knee mechancis over a one-year period. It is hypothesized that there will be increases in knee adduction angle, adduction angle excursion, and external adduction moment in the control condition compared to the wedged condition. METHODS:18 subjects with physician-confirmed medial knee OA were recruited and split into two groups, matched by OA severity, gender, and BMI. Wedged subjects (n=9) were fitted with wedged orthoses and control subjects (n=9) with neutral orthoses. 3D gait analysis was performed two weeks later and one year after the initial gait analysis. For both analyses, five walking trials were averaged. The variables of interest were peak knee adduction angle, knee adduction angle excursion and external knee adduction moment. RESULTS: Over the course of one year, external knee adduction moment increased in the controls compared to the wedged subjects. Peak knee adduction angle increased in both groups, but moreso in the control group. Adduction angle excursion increased for the controls but had minimal to no change for the wedged subjects. DISCUSSION: Knee adduction angles, excursions and moments were generally increased in the control group compared to the wedge group at a one-year follow-up. These results suggest that wedged orthoses are more successful at managing changes in knee mechanics that occur as a result of knee OA compared to a neutral orthoses. These changes may slow the progression of the disease.

11 Perception-action coupling in children with and without Developmental Coordination Disorder when performing an auditory signal matching task

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Introduction. Children with DCD are at risk for poor academic achievement, socio-emotional difficulties, and long-term health problems due to their lack of participation in physical activities. This research focuses on differences in perception-action coupling among children with and without DCD and adults in a gross motor coordination task (clapping while marching) when a task-relevant driving sensory signal is present. Method. 28 participants (10 DCD, 8 TD, 10 adult) simultaneously clapped while marching to an auditory beat in the following conditions: (a) 0.8 Hz (b) 1.2 Hz (c) 1.6 Hz (d) 2.2 Hz. Participants received 4 trials for each condition for a total of 16 trials. Trials occurred in 4 blocks, with each block containing 4 trials of each condition presented in a random order. Mean (MRP) and variablity (VRP) of relative phase were calculated and compared with repeated measure ANOVAS (alpha <.05). Results. Statistically significant differences in MRP occurred for coupling, frequency and group. There were no significant interactions in MRP. Post hoc analysis indicated that the adult group differed from both the DCD and TD groups. There were significant main effects for coupling and group in VRP. Post hoc analysis revealed that the DCD group differed from the adult and TD groups (who did not differ from each other). Further, there was a significant interaction between group and frequency. Conclusions. Children with DCD are less stable than TD or adults in their perception-action coupling.

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12 New strategies for stimulation frequency and intensity modulation for FES: A pilot study

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Functional electrical stimulation (FES) is the use of electrical stimulation to restore functional movements of paralyzed muscles. Rapid muscle fatigue, however, occurs and limits the application of FES. Stimulation intensity is usually modulated to overcome muscle fatigue when applying FES. Although not currently used by commercially available stimulators, stimulation frequency can also be increased to overcome muscle fatigue. Interestingly, no previous studies have compared the effectiveness of modulating the stimulation intensity, frequency or the combination of the two on muscle performance. The purpose of this study was to explore the best stimulation strategy to maintain force output during repetitive, electrically elicited contractions. Five protocols were tested, including: frequency modulation, intensity modulation and 3 protocols that used both frequency and intensity modulation. These 3 combination protocols used starting frequencies of 20, 30, and 40Hz. Stimulation trains were delivered to 3 healthy subjects' quadriceps muscles once every second. For each protocol, the frequency or intensity was increased when muscle force output dropped below a preset targeted force level. Our results showed that (1) frequency modulation performed similar to intensity modulation for 2 subjects, but outperformed intensity modulation for the third subject. (2) The combination protocol with a starting frequency at 30Hz outperformed all 4 other protocols for all 3 subjects. The results of this study will be used to help design future studies exploring the effects of modulating stimulation frequency and intensity during the application of FES.

13 The Effects of Small Changes in Walking Velocity on Sagittal Plane Kinematics and Kinetics

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Lower extremity kinematics and kinetics change as a result of walking speed, however most studies compare extremes of walking speeds. The effect of small changes in walking speed on kinematics and kinetics is important in designing studies in which walking speed needs to be controlled. The purpose of this study was to determine the effect of small changes in walking speed on muscle activation patterns and sagittal plane kinematics and kinetics of the hip, knee and ankle, in order to determine how precisely walking speed must be controlled during laboratory testing We hypothesized that few differences would appear when speeds varied by 5% of the self-selected free speed. Data were collected on 12 uninjured subjects who walked at four speeds (free speed, 5% slower, 5% and 10% faster speeds). Peaks in sagittal plane kinematics and kinetics at the hip, knee and ankle joints were compared across conditions. EMG timing (onset, peak and termination) and integrals across pertinent points in the gait cycle were compared across conditions. The results show little effect of 5-10% changes in walking speed on joint kinematics; however, kinetic data were sensitive to small changes in walking speed with differences appearing between all four conditions in the hip, knee and ankle joint moments and power. EMG data were less sensitive to speed changes, with differences appearing across 10% speed increments. The results indicate that walking speed should be maintained within less than 5% of the self-selected speed when kinetic patterns are being investigated. Given that even small changes in walking speed can affect some movement analysis data care must be taken in interpreting data in studies in which speed is not tightly controlled;differences in groups that walk a different speeds may be due to changes in walking speed rather than group differences.

14 Effect Of Skin Movement Artifact On Knee Kinematics During Gait And Cutting Motions Measured In-Vivo

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Skin movement artifact limits the ability to accurately 3D tibio-femoral kinematics using non-invasive techniques. The purpose of this study is to measure the effect of skin movement artifact on the reporting of knee joint kinematics during gait and cutting. Intra-cortical bone pins were transcutaneously implanted under local anaesthetic into the proximal tibia and distal femur of eight healthy male subjects. Reflective markers were attached to each bone pin (3) and on the skin of the tibia and thigh (4 respectively). RSA was used to determine the anatomical reference frame of the tibia and femur. Knee joint motion was recorded at 120Hz during walking and cutting using infra-red cameras. Skin and pin marker data were recorded simulatneously. The kinematics derived from the bone-pin markers was compared with that of the skin markers. Rotational errors of up to 4.4 and 13.1 degrees and translation errors of up to 13.0 and 16.1 mm were noted for the walk and cut respectively. Although the skin marker derived kinematics could provide repeatable results this was not representative of the motion of the underlying bones. A standard error of measurement is proposed for reporting 3D knee joint kinematics.

15 Interaction of footwear and arch type on running mechanics

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High and low arched runners are at a greater risk for lower extremity injuries than normal runners. The increase in injury rates is believed to be due to increased shock in high arched runners and increased rearfoot motion in low arched runners. Running shoes are designed to complement arch types in order to reduce the risk for lower extremity injuries sustained during running. Twenty high (HA) and twenty low arched (LA) recreational runners (>10mpw) were recruited for the study. Subjects were determined to be high or low arched by being 1.5 standard deviations above or below a gender specific arch height index value. 3D kinematic and kinetics were collected as subjects ran at 3.5 ms-1+/- 5% down a 25 m runway. Subjects performed the protocol in two separate footwear conditions. The motion control shoe (MC) evaluated was the New Balance 1122 and the cushioning shoe (CT) evaluated was the New Balance 1022. Five acceptable trials were processed for each condition. Joint kinematics and kinetics were analyzed using Visual 3D software and discrete values were averaged to establish mean values. Repeated measures ANOVAs were used to determine if LA and HA runners responded differently to MC and CT shoes. A significant interaction was observed in the instantaneous loading rate such that each foot type had a lower ILR in the recommended footwear condition. Significant shoe main effects were observed for peak positive tibial acceleration, peak to peak tibial acceleration, peak eversion, eversion excursion, and average loading rate. These results suggest that MC shoes controlled motion better than CT shoes and CT shoes attenuated shock better than MC shoes. However. these benefits did not differ between foot type with the exception of instantaneous loading rate which was observed to be reduced in the recommended shoe condition.

16 Motor Equivalent Postural Responses Revealed By The Ucm Approach

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The goal of this work was to determine the extent to which successful restoration responses to postural perturbations caused by support surface translations represent examples of motor equivalence and whether the strength of motor equivalent responses is related to the contribution of hip, knee, and ankle motion to the response. The uncontrolled manifold (UCM) concept may provide an operation definition of motor equivalence. Nine subjects were perturbed by backward surface translation at 7 different amplitudes of 275 ms duration. Based on a geometric model relating joint motion to the position of the body's center of mass (CM), we computed the null space of the Jacobian matrix defining the subspace of postural adjustments leaving the horizontal CM invariant. Markers were placed on body segments sampled at 120 Hz and used to compute joint kinematics. Multiple linear regression approach is used to evaluate the contribution of hip, knee, and ankle joint excursion to prediction of a motor equivalent (ME) index after accounting for repeated trials and perturbation magnitudes. For the low perturbation magnitude condition, ankle excursion accounted for 76.3% of the variance of the ME index while ankle and hip excursion accounted for 78.9% of the variance of the ME index during the high perturbation magnitude condition. This result coincides with previous studies that have identified two distinct strategies for the control of posture, i.e. ankle and hip strategies. In addition, we also found that knee excursion accounted for 65.8% of the variance of the vertical CM position across all perturbation magnitudes. This suggests that it might be a third posture control strategy, which can lower down the CM vertical position by bending the knee joint in order to maintain the stability of balance.

17 Relationships Among Factors Associated with Medial Knee Osteoarthritis

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Osteoarthritis of the tibiofemoral joint is the most prevalent type of arthritis is tne United States (Buckwalter, 2000) and is most common in the medial compartment (Dearborn, 1996). Despite high incidence of the disease, relatively little is known about the complex interplay of impairments associated with medial knee OA. The presence of mediolateral laxity is well-documented in persons with OA (Sharma, 1999; Lewek, 2004) and quadriceps strength is repeatedly shown to influence function (McAlindon, 1993). However, little information is known regarding the influence of laxity on function. Recent work suggests that self-reported knee instability, no passive laxity, along with quadriceps strength may be the best predictors of function (Lewek, 2004; Fitzgerald, in press). Others have found that in the presence of knee laxity the relationships between quadriceps strength and knee function is not as strong (Sharma, 1999). Knowing the relationships between knee alignment, strength, laxity and self-reported knee instability with overall knee function is vital in the development of treatment programs that target the appropriate impairments. Methods: The standing knee alignment, passive medial knee laxity, maximum quadriceps force output and knee function were assessed on 32 patients with medial knee OA. Results: Our data are consistent with recent work that suggests that a majority of patients with knee OA report knee instability (21/32) and 15/32 subjects report that it interferes with completion of daily tasks. Our data are consistent with reports that quadriceps strength predicts physical function. Our data suggest that laxity does not relate to self-reported knee instability and that self-reported knee instability and quadriceps strength, not laxity, predict overall knee function.

18 Variability of Gait Parameters in Patients with Multiple Sclerosis

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Patients with Multiple Sclerosis (MS) often complain of fluctuation in symptoms and movement patterns that they frequently attribute to fatigue. In order to determine the efficacy of treatments to improve movement coordination, it is necessary to understand the variability of motor function associated with the disease. The purpose of this study was to determine the within- and between-day variability of gait mechanics in subjects with MS compared to healthy controls. We hypothesized that MS subjects would be more variable than healthy controls and that there would be within- and between-day differences in variability. Five gait analysis sessions were performed on each of 20 MS subjects (age 43.0 ± 9.6 yrs, height 166. 6± 9.0cm, mass 79.7 ± 19.3kg) and 8 healthy controls (age 40.9 ± 8.6yrs, height 167.4 ± 14.6cm, mass 72.6 ± 14.2kg). Three data collections took place in the morning and afternoon of one day (AM1, PM Fresh, PM Fatigue) and the two collections took place one week later in the morning only (AM2 Fresh, AM2 Fatigue). Gait cycles for each condition were time normalized to the stride cycle (100 data points). Standard deviations (SDs) of 15 stride cycles for kinematic data were calculated for each point and then averaged to determine the measure of variability for the sagittal plane ankle, knee, and hip angles. For kinetic data, the SDs of three gait cycles were calculated and the average during stance was used as the variability measure for vertical ground reaction forces and sagittal plane moments and powers at the ankle, knee and hip. Two-way ANOVAs (group x condition) with repeated measures were used to assess variability differences. Kinematic and kinetic gait variability were not different across conditions for the MS group. The MS group had greater joint angle variability ($p<0.05$) than the control group at the hip (1.85 ± 0.45 vs. 1.62 ± 0.32 deg), knee (2.59 ± 0.69 vs. 2.19 ± 0.35 deg), and ankle (1.48 ± 0.35 vs. 1.30 ± 0.21 deg). Kinetic variability was not different between groups. In general, MS subjects have greater kinematic variability than healthy control subjects.

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19 Estimation Of Corrective Changes In Muscle Activation Patterns For Post-Stroke Patients

Qi Shao and Thomas S. Buchanan, Center for Biomedical Engineering Research

INTRODUCTION: Functional electrical stimulation (FES) has been used to treat the movements in stoke patients. We have created a biomechanical model of the ankle to estimate the corrective increases in muscle activation patterns that would enable post-stoke patients to walk normally. METHODS: During isokinetic and gait trials we collected EMGs from four different muscles, joint position and reaction forces (from the ground or dynamometer) from healthy and post-stroke subjects. Forward dynamics, using EMG and joint position data, was used to estimate the ankle joint moments, which was verified by comparison with the inverse dynamics calculation. From a healthy subject's gait trials, we determined the corrected joint angles and desired joint moments for each post-stroke patient. We then optimized the EMG to produce the desired joint moment using the verified forward dynamics model. Different cost functions were used, minimizing combinations of the EMGs, muscle forces and muscle stresses. RESULTS AND DISCUSSION: Through this optimization model, we found changes in the muscle activations for the post-stroke subjects that would correct their gait pattern so that they matched the healthy gait patterns. The joint moment calculated from the new EMG and desired joint moment were compared, and gave R-squared values of 0.99, and RMS errors of 1.60 N-m. To produce the correct joint moment, different patterns of electrical stimulation should be added on the four muscles to increase their activations. CONCLUSION: The model determined corrective increased in muscle activation for stroke patients. These could be implemented in an FES protocol to improve post-stroke gait.

20 Asymmetry of Muscle Morphology in the Lower Extremities of Athletes

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Purpose: The purpose of this study was to determine if side-to-side muscle morphology showed asymmetries within subjects for two different groups of athletes. One group of athletes participated in sports involving kicking or pivoting while the other group of athletes only participated in running or swimming. A second aim was to describe lower extremity muscle morphology in young athletes and compare these with previously reported values. Methods: Axial spin-echo T1-weighted MR images were obtained from the level of the ankle mortise to the iliac crest in 24 athletes (age 19.0 ± 2.6 yrs). Each subject's three-dimensional anatomy was then digitally reconstructed and muscle volume, peak CSA, and length were calculated for 10 muscles. Results: The muscle volumes and CSAs for the current sample of athletes were generally larger than the values reported by previous researchers (primarily from cadaver studies of non-athletes). Significant differences in side-to-side muscle morphology were observed in several muscles in the group of athletes who participated in sports involving kicking or pivoting, but not in the runners and swimmers. For the pivoting group, the vastus medialis muscle was consistently larger in the dominant leg, whereas the vastus lateralis muscle was larger in the non-dominant leg. Despite these differences, side-to-side total quadriceps muscle volume was similar in both groups. Conclusions: Our findings suggest that the act of pivoting and kicking in sports causes an asymmetry in muscle morphology that is not consistently seen in runners and swimmers. The data presented should improve the accuracy of biomechanical modeling in athletes.

21 Gait Detection from Knee Brace Integrated Kinematic Sensors

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Currently a Smart Knee Brace (SKB) is being developed for stroke patient gait rehabilitation. The specific function of the SKB is to regulate hemiplegic walking by providing support in the stance phase, while allowing free knee motion in the swing phase. The SKB has led to the need for a real-time gait phase detection algorithm based solely on sensors which can be directly attached to the brace. Kinematic data from accelerometers, gyroscopes, and a knee angle potentiometer were examined to develop an algorithm that can detect hemiplegic stance and swing phases. The algorithm utilizes the periodic shape and quantity variation of the kinematic measurements to determine gait phases and transitions. Preliminary studies have validated the algorithm in normal and abnormal gait, showing strong reliability, high accuracy, and wide adaptability to different walking patterns.

22 A Passive Assistive Device for Sit-to-stand Tasks

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A sit-to-stand assist device can serve the needs of people suffering from muscle weakness due to age or other disabilities that make sit-to-stand a difficult functional task. The objective of this work is to design a passive gravity-balancing assist device for sit-to-stand motion to help the elderly and others with muscle impairment. The device will be specifically designed to transfer the weight of a patient safely during standing. In our preliminary studies, we have considered the human body to have three degrees-of-freedom in the sagittal plane during sit-to-stand. In such an activity, the required joint torque is due to gravity, passive muscle forces, and inertia. As expected, since STS movement is relatively slow, the joint torque due to gravity is the most dominant. This motivates the proposal for a gravity balancing assist device during STS motion. A demonstration prototype with the underlying principles was fabricated to test the feasibility of the proposed design.

23 Characterization of articular cartilage under static compression

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The purpose of the study is to understand how diffusion in the articular cartilage of a mouse is affected by mechanical loading. Because of anisotropic, non-homogeneous nature of the cartilage, cellular scale measurements are necessary to characterize the relationship between diffusion and strain of the cell structure. With a mechanical loading device developed to load a murine humeral head while imaging the tissue using a multi-photon/confocal microscope, diffusivity is calculated using the fluorescence recovery after photobleaching method and nuclei displacement was calculated using a three-dimensional, cross-correlation technique by tracking chondrocyte cell nuclei between three static loads. This characterization can aid understanding the development of osteoarthritis and contribute to the tissue engineered cartilage research.

24 Design of a Two Degree-of-freedom Ankle-Foot Orthosis for Robotic Rehabilitation

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An ankle-foot orthosis (AFO) is commonly used to help subjects with weakness of ankle dorsiflexor muscles due to peripheral or central nervous system disorders. Both these disorders are due to the weakness of the tibialis anterior muscle which results in lack of dorsiflexion assist moment. The deformity and muscle weakness of one joint in the lower extremity influences the stability of the adjacent joints, thereby requiring compensatory adaptations. An innovative ankle-foot orthosis (AFO) was designed to allow two degree-of-freedom motion, while serving to maintain proper foot position for subjects is presented in this chapter. The prototype AFO would introduce greater functionality over currently marketed devices by means of its inversion-eversion degree-of-freedom in addition to flexion-extension. The flexion-extension is controlled with the help of an actuator and inversion/eversion with a spring and a damper. This device will be eventually be used for training of subjects to restore a normal walking pattern.

25 Finite Deformation Study on Fibril-reinforced Poroelastic Model of Articular Cartilage

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The mechanical characteristics of articular cartilage play important role in determining its response to normal activities. To understand its function, it is essential, therefore, to study the stress-strain behavior under physiologic loads where large strain occurs; thus a finite deformation model is a prerequisite. Existing fibril-reinforced biphasic models can simulate behavior of articular cartilage very well but only under infinitesimal strain; their application to finite strain has not yet met with success. The objective of this study is to develop a fibril-reinforced poroelastic model applicable to finite strain, and to validate the model by experiments. The finite deformation theory includes an isotropic hyperelastic solid matrix, a nonlinear fibrillar network, and a strain-dependent permeability. The unconfined compression stress-relaxation experiments of bovine humeral head cartilage were performed on Instron materials testing machine. We optimize the model parameters for best fit to experimental data, to obtain the material properties of the cartilage. The model simulations compare very well with experimental results. The stress analysis of the model was also performed.

26 Modeling Falls on the Human Femur

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More than one-third of people over the age of 65 fall each year. The greatest number of deaths, and most severe health problems, along with reduced quality of life from fall-related injuries are the result of hip fractures. Medical costs, reduced functionality, and increased pain, make hip fractures an enormous liability for fall victims, especially the elderly. With an increasing elderly population, there is a greater need for effective hip protection then ever before. Currently, there are various companies that manufacture hip protective garments, but no standards or tests exist to evaluate their effectiveness. Recently, tests have been conducted using a hip impact testing device (developed by the University of Delaware and Dupont), giving a more thorough understanding of the dynamics of a hip fall and impact. To aid in the design and evaluation of new protective devices, and to extrapolate the results from the physical tests on the hip impact device, a computer model of the hip region is being developed. After assigning average physical properties, the solid model makes it possible to simulate the fall and impact of the hip accurately using Finite Element Analysis in ALGOR®. Results from the simulation are being validated with test results obtained under similar loading conditions using the hip impact testing device. Future computer modeling will simulate and assess the impact of the hip with models of various hip protective garments to determine if the protection will reduce the likelihood of fractures.

27 Finte Elements Based Approach to Nutrient Transport in Articular Cartilage

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Articular cartilage is a tough, elastic tissue that covers the ends of bones in joints and helps the bones glide easily past each other during motion of the joint. About 90% of the tissue volume is extracellular matrix, which is composed of two key structural components: collagen fibers and proteoglycans. Since adult articular cartilage is avascular, the only way chondrocytes may receive nutrients and macromolecules is by diffusive and/or convective transport across the artcular surface. An understanding of nutrient transport under different types and intensities of mechanical loading and for different size solute is essential, therefore, to our appreciation of the biological activities occurring in the cartilage. In this study, we derive a three - dimensional formulation of the problem of nutrient transport in articular cartilage based on mixture theory, and utilize the commercial finite element code ABAQUS to study it numerically. Under appropriate circumstances the equations derived here reduce to the classical convection/diffusion equation and the equations of the biphasic cartilage model.Our results reinforce and refine previously published studies. The rate of diffusion of neutral solute is reduced under static compression, due to the strain dependence of the diffusion coefficient: an increase in static compression leads to a decrease in the rate of transport of solutes of all sizes. Dynamic loading, on the other hand, augments solute transport due to convection, this augmentation depending on nutrient size.

28 Reducing the Potential for Hearing Damage with New Impact Tool Designs Using Engineering Polymers

Janelle Konchar and James L. Glancey, Department of Mechanical Engineering

Hearing damage is an occupational injury of increasing concern. Hand struck tools are a common source of noise, and unfortunately, their use is essential in a number of industries worldwide. Tools are often a source of vibration, producing unwanted sound that can result in temporary and eventually permanent hearing loss. Unlike many other sources of unwanted sound, impact tools produce very high sound pressure levels over relatively short durations; the effects of this type of noise on the ear are still not well understood. To begin to understand and ultimately reduce the noise and associated hearing damage from these types of tools, an experimental study was conducted to measure sound emission from conventional hand held, manually struck chisels. In addition, an assortment of new, commercially available polymer capped chisels were evaluated. Results showed that the addition of a polymer cap to a hand struck tool significantly reduces chisel noise emission, especially at higher frequencies where the ear is most susceptible to damage.

29 The Effects of Hydrostatic Loading on a Bioengineered Cartilage Tissue Equivalent

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An active area within tissue engineering involves improving the mechanical and biochemical properties of tissue-engineered articular cartilage through mechanical stimulation. In this study, using our previously described novel method [1], chondrocytes were grown at high density in suspension culture in poly-HEMA coated culture wells. Cells grown in this manner quickly form a mass that has been shown to be characteristically cartilage-like and biocompatible and contain no foreign scaffolds. Hydrostatic pressure was selected as the mechanical stimulation because it mimics a physiological situation; it did not restrict the growth of the cartilage tissue equivalent (CTE) and provided a uniform stress throughout. The objective of this study was to determine if cyclical hydrostatic pressure applied to CTE specimens during growth altered or improved their cartilage like characteristics, as well as the biochemical and molecular changes that occur over time after loading. One dimensional confined compression stress relaxation experiments based on the biphasic model [5] were performed to quantify the material properties. Material properties of the pressurized CTE were compared with unloaded control culture specimens, and an increase in aggregate modulus and decrease in permeability was observed between the two groups. Due to the small sample size, significant differences were unobtainable. The results are encouraging for improved material properties of tissue engineered cartilage grown under hydrostatic pressure.

30 Mature v. Immature Rabbit Articular Cartilage: A Developmental Study

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OBJECTIVE: To analyze and interpret changes in specific biomarker levels and biomechanical changes within bone and articular cartilage of New Zealand White Rabbits at various developmental stages in a temporal fashion. METHODS: Hind limbs from young (0-3 months), juvenile (3-6 months), and adult (12 months and over) New Zealand White Rabbits were dissected, fixed in a 4% (v/v) paraformaldehyde solution, and cut into 4 distinct portions: medial femoral, lateral femoral, medial tibial, lateral tibial. Samples were then decalcified in 5% formic acid, paraffin embedded or frozen in O.C.T., and then sectioned. General histological and immunohistological staining then was performed. RESULTS: Particular attention is paid to developmental changes in the formation of the superficial, transitional, radial, and calcified cartilage zones and concomitant temporal changes in biomechanical properties are being examined. All juvenile rabbit knee sections contain a residual growth plate that is not present in any of the adult specimens. This particular area is populated with cell nuclei and is high in proteoglycan and GAG content. Additionally, juvenile rabbit knee sections appear to have more cell division and therefore a greater cell density within the zone of articular cartilage and also have less bone development then the adults, which was expected. Perlecan, heparanase, and collagen-II expression is underway. CONCLUSIONS: The residual growth plate found in the juvenile rabbit knees may be critical in producing and secreting certain extracellular matrix proteins and growth factors that can direct cartilage healing. Eventually we plan to compare the results of this developmental study to the results of a subsequent study that will examine parallel processes that occur in development and during healing of a rabbit model of experimental osteoarthritis.

31 TiO2-Polyethylene Composites for Reduced Wear in Orthopedic Implants

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Total joint replacement for the repair of diseased and injured hips and other joints has increased over the years. A major concern with these devices is the long-term durability of the materials in younger and more active patients. The common use of Polyethylene for the acetabular cup lining, contributes to implant loosening and failure due to wear debris-induced bone osteolysis. A previous study conducted at the University of Delaware addressed the wear in the acetabular cup lining, using Carbon Nanotube/High Density Polyethylene (CNT/HDPE) composites. The creation of these composites sought to improve the material and tribological properties of HDPE. The conclusions of this study indicated improved mechanical properties of HDPE, increased wear resistance, and minimaleffects on the fracture toughness of the material. Using this previous investigation as background information, the current study will investigate the manufacturing and testing of Titanium Dioxide/High Density Polyethylene (Ti02/HDPE) composites. Ti02/HDPE composites will be processed through a mixing and extruding process. Materials will be created with varying weight percentages of Ti02 (0%, 1%, 3% and 5%) and then molded and machined to form samples for punch testing, block-on-ring wear testing, and fracture testing. Mechanical tests will be conducted for the varying volume percentages of Ti02 content with pure PE as the control. Motivation for the use of

Ti02stems from its lower cost compared to CNT, and the possibility that Ti02 will produce a better dispersion within HDPE. Increased dispersion can lead to further increases in material properties of HDPE, augmented wear resistance properties, and an enhanced effect on the fracture toughness of the material.

32 Preparation of PlnDI/collagen II fibrils substrate used to promote chondrogenic differentiation of mesenchymal cells induced by BMP-2.

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Extracellular matrix (ECM) molecules in cartilage, including perlecan (Pln) and collagen II fibrils (COL-II), cooperate with growth factors, such as FGF-2 and BMP-2, to regulate chondrogenic differentiation and cartilage development. OBJECTIVE: To prepare a self-assembled substrate of recombinant Pln domain I (PlnDI)/COL-II fibrils, and to explore BMP-2 binding and chondrogenic properties of this substrate. METHODS: Chondrogenic differentiation and cartilage-like tissue formation was investigated after C3H10T1/2 cells, a murine mesenchymal stem cell line, were plated onto different subsrtrates with 2D (6 days) and 3D (21 days) cultures. Substrates and scaffolds containing different combinations of PlnDI, COL-II, and BMP-2 were utilized for both general histological and immunohistological staining. RESULTS: PlnDI/COL-II substrates bound more BMP-2 than COL-II alone, and sustained BMP-2 release. The PLA scaffolds coated with the substrate for PlnDI/COL-II fibrils also immobilized more BMP-2 then either PLA alone or COL-II-coated PLA scaffolds. Micromass cultures grown on BMP-2/PlnDI/COL-II substrates demonstrated intense alcian blue staining, and expressed elevated levels of Sox9, aggrecan, and COL-II mRNA. Safranin O staining indicated that cartilage-like tissue was formed on BMP-2/PlnDI/COL-II-coated PLA scaffolds, but not on other scaffold combinations. Indirect immunofluorescence revealed that aggrecan, Pln, tenascin and collagen X were expressed in the cartilage-like tissue. CONCLUSION: These findings suggest that use of PlnDI/COL-II to create biomimetic material improves BMP-2 immobilization in scaffolds, and that these modified scaffolds facilitate chondrogenic differentiation of mesenchymal stem cells.

33 Spectral and Coherence Analyses of Respiratory Outputs During Eupnea and Anoxia in Decerebrated Rats

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Vitaliy Marchenko & Robert F. Rogers, Electrical & Computer Engineering

Currently, there are many unresolved questions about the comparative autospectra (AS) and cross-coherence (Coh) characteristics of respiratory outputs (phrenic and hypoglossal nerves; Ph, XII) in unanesthetized animal models during normal eupnic breathing and anoxia-induced gasping. Experiments were performer on 9 peripheral chemo- and baro-denervated, decerebrated rats. Anoxia was applied by shutting down artificial ventilation. AS of respiratory nerves and Coh between them were estimated from their electroneurograms (gated FFT algorythm was applied). Our data shown three main spectra bands: 5 - 50 (low; LFO), 50 - 110 (middle; MFO) and 110-205 (high; HFO) Hz frequency bands for Ph and 8-45 (LFO) and 45-265 (MFO/HFO) Hz broad spectrum for XII respectively. In Ph, HFO is much stronger then MFO in the first third of inspiration, they are relatively equal in the second third and MFO is significantly stronger in final third. In XII, the peak of the MFO/HFO band is located around 97-112 Hz during the pre-inspiratory (pre-I) phase and is shifted to the 173-196 Hz range during inspiratory phase. LFO for both nerves is relatively week through all phases. Coh between left and right Ph is significantly higher for HFO (0.34, $p<0.05$), and is relatively equal for all bands and peaks between left and right XII. Weak (0.123-0.167) but significant Coh was observed between Ph and XII in LFO band. During anoxic gasps only LFO and MFO are prominent in the Ph AS, and LFO in XII AS with residual peaks in the MFO-HFO band. Weak (.07-1.6 range) but significant Coh was observed between all nerves in the LFO band and in MFO band between ipsilateral Ph and XII. No pre-I activity was observed in XII during anoxic gasping. All nerves changed their bursting patterns from incrementing (eupnea) to synchronized decrementing (anoxia). These data imply a central respiratory network reconfiguration during the transition from eupnea to anoxia.

34 Testing An Isometric Muscle Force Model On The Ankle Muscles Of Individuals With Hemiparesis

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Footdrop is a common complication that limits the independence in activities of daily living of individuals with hemiparesis following stroke. Although functional electrical stimulation (FES) of the ankle dorsiflexor muscles can be used as a neuro-prosthesis to assist in the management of footdrop, FES has not gained widespread use by stroke patients. One limitation of current FES systems is the lack of ability to precisely control movements. Mathematical models can help in the development of more sophisticated systems that use closed-loop feedback to modulate muscle forces. Stimulation frequency and pattern are two of the parameters that can be varied to control muscle force output during FES. We have developed a mathematical model system that predicts the effects of stimulation frequency and pattern on the force output of quadriceps femoris muscles of healthy individuals. With minor modifications, our model also successfully predicted muscle forces for quadriceps femoris muscles of individuals with spinal cord injury. The aim of this study is to validate and test our isometric muscle force model on ankle dorsiflexors and plantarflexor muscles of individuals with hemiparesis following stroke. The model has been tested on four individuals. Results show that our model predicted very well the peak force and force-time integrals produced in response to stimulation trains of different frequencies (10-80 Hz) and patterns (constant, doublet and variable-frequency trains). 77% of comparisons for peak force and 74% of comparisons for force-time integral between experimental and predicted data were within ±15%. The successful testing of our mathematical model on ankle muscles of individuals with stroke suggests its potential use in predicting suitable stimulation parameters during FES for footdrop.

35 Optical Imaging of Respiratory Rhythmogenic Neural Activity in the Medulla of an Artificially-Perfused Rat Preparation

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Dept. of Electrical and Computer Engineering

The lower brainstem contains the neural circuitry for respiratory rhythm generation in mammals, revealed by numerous microsectioning and selective lesioning studies. Respiratory neurons distributed within these regions have been identified by their firing patterns at different phases relative to the onset of inspiration. Conventional electrophysiology techniques have limited investigation of the spatial organization of these respiratory neurons, due to the nature and tedium of serial recordings of single neurons. Optical imaging techniques offer the potential of monitoring the spatiotemporal activity in large groups of neurons simultaneously. Using high-speed voltage-sensitive dye imaging and spatial correlation analysis in a bloodless, arterially-perfused, decerebrate rat preparation (that is still connected to the musculature and skeleton), we were able to determine the spatial distribution of respiratory neurons in the ventrolateral respiratory group (VRG) during spontaneous respiratory-related neuronal activity. This is the first optical imaging of a near fully-intact preparation exhibiting clearly eupnic respiratory activity. Our findings indicate that there are spatially restricted subregions that contain neural activity that is well correlated with firing patterns of individual neurons observed in vivo. Unlike previous calcium imaging studies on brainstem slices, or voltage-sensitive imaging on brainstem-spinal cord block preparations, our approach combines the technical advantages of optical imaging with the scientific advantages of a physiologically-relevant, relatively intact preparation. We anticipate using these methods to uncover the spatiotemporal network activity during various respiratory behaviors, including gasping and coughing.

36 Biomechanics and Medical Imaging: Determination of Kine Angles and Translations During Standing MRI

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In order to determine the kinematics of the knee in an upright, weight-bearing condition, a Phonar stand up MRI machine was used. Previously, it has been difficult to study the knee under realistic circumstances such as standing or squatting because most MRI machines require sunjects to be laying in a non-weight bearing position. In our study, the test subject stood with varying degrees of knee flexion, having the angles measured with a goniometer. A detailed 0° flexion sagittal scan was taken along with several axial scans taken during knee flexion. These scans were digitized using IMOD imaging software, and the data points obtained were compiled into 3-D models using Matlab. Bones in each model of knee flexion were "matched" with bones from the standing sagittal model to determine the translation and rotation each underwent during the flexion of the knee. This was made possible by the implementation of the Trimmed Iterative Closest Point Algorithm developed in Matlab. The algorithm makes a compromise of using the most data points vs. finding the smallest distance between the points it uses. If the distance between two points to be matched was too great, the algorithm ignored that point and based the transformation on the most closely matched points. The algorithm output the relative transformation matrix and the translation and rotation were determined. The method proved to be both practical and accurate, and is a good way of determining in vivo joint mechanics.

Podium Presentations

37 Short-term Retention Of Gait Changes After Real-Time Feedback To Reduce Tibial Shock

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Previous studies of runners have established that higher than normal tibial shock, vertical loading rate, and vertical impact peak are related to stress fractures. If runners who have high values for these variables can be trained to reduce them, it may reduce their risk of stress fractures. Purpose: To determine if runners can use real-time visual feedback from an accelerometer to reduce their tibial shock and loading. Methods: This is a preliminary study in which data have been collected from five subjects. An accelerometer was attached to the distal tibia of each subject. Subjects ran on a force measuring treadmill at a self-selected pace (5.4 – 5.9 mph). Tibial shock and ground reaction force data were collected after a 5 minute warm-up, 10 minute session of visual tibial shock feedback, and 10 minute session without feedback. These periods were consecutive, and they were followed by a cool-down period. Results: Three of the five subjects showed large reductions (between 25 and 48%) in their peak tibial shock, average loading rate, and impact peak at the end of this very brief training session, and short-term retention occurred after feedback was removed. The mean results for all five subjects show that at the end of the 10 minute feedback session: peak tibial shock, average loading rate, and impact peak were reduced 15% to 17%. After the 10 minute session without feedback, peak tibial shock, average loading rate, and inpact peak were reduced 16% to 26%. Conclusion: This preliminary study provides evidence that some runners can use real-time feedback to achieve short-term reductions in their tibial shock and ground reaction forces.

38

Kinetic Asymmetry in Female Runners With and Without Retrospective Tibial Stress Fractures

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The tendency for a runner to become injured on a particular side is not well understood. It has been suggested that it may be due, in part, to asymmetry in their mechanics. The purposes of this study were (1) to compare the levels of kinetic asymmetry in runners who have previously sustained a tibial stress fracture (TSF) and those who have not (CON) and (2) to compare loading parameters between the involved and uninvolved sides of the TSF runners. Twenty-five CON subjects who had never sustained a running injury, and 24 TSF subjects who had sustained one or more tibial stress fractures on a single side of their body were included in the study. Subjects ran along a 25 meter runway at a speed of 3.65 m/s (± 5%), striking a force platform at its center. Five trials were collected at 960 Hz for both the left and right sides. Peak medial, lateral, braking, vertical impact, and vertical ground reaction forces, average and instantaneous vertical loading rates, and peak shock were measured in each subject. Symmetry Index (SI) was used to quantify asymmetry: SI = (XL - XR)/0.5*(XL + XR). A 1-tailed, independent t-test was used to compare SI values between the TSF and CON groups. A 1-tailed, dependent t-test was used to compare loading values between the involved and uninvolved sides of the TSF group. SI values were not significantly different between the CON and TSF groups for any of the parameters. The peak vertical impact ground reaction force and peak shock were both significantly higher on the involved side in the TSF subjects ($p = 0.04$ and 0.02 respectively). These results indicate that while CON and TSF subjects have similar levels of asymmetry, those in the TSF group may have elevated loading values, bilaterally, that predispose them to injury.

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Effects Of Frequency And Intensity On Skeletal Muscle Fatigue During Repetitive Electrical Stimulation

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Both stimulation intensity and frequency can be modulated to compensate for any decline in force generating ability of the muscle due to fatigue during functional electrical stimulation (FES). However, most current FES systems only vary the intensity to control muscle force. This study compared the fatigue produced during repetitive stimulation of quadriceps femoris muscles of 5 healthy subjects using 5 different protocols. Three of the 5 protocols consisted of stimulation with trains of a constant frequency and intensity throughout the protocol (no-modulation protocols). The 3 no-modulation protocols used 3 different combinations of frequency and intensity: (1) low-frequency, high-intensity, (2) medium-frequency, medium-intensity, and (3) high-frequency, low-intensity. Two of the 5 protocols involved a stepwise increase of either frequency (frequency-modulation) or intensity (intensity-modulation). All 5 fatigue protocols produced the same initial peak force. The dependant variables were percent decline in peak forces (PF) and force-time integrals (FTI) produced during each fatigue protocol. The results showed that each of the 2 modulation protocols produced smaller declines in PF and FTI compared to the 3 no-modulation protocols; frequency-modulation produced smaller declines in PF and FTI than intensity-modulation; the low-frequency, high-intensity no-modulation protocol produced smaller declines in PF and FTI than the high-frequency, low-intensity protocol. Although frequency-modulation is not commonly used during clinical FES, it appears that clinicians should consider this strategy to optimize muscle performance.

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Predicting Ankle Moments In Healthy And Neurologically Impaired Gait

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INTRODUCTION: Biomechanical models are important for the study of muscle stimulation, prototype design, and limb control. We have created a biomechanical model of the ankle designed to predict joint moments in both unimpaired subjects and those who have had neuromuscular disorders. METHODS: Three types of data were collected on normal and post-stroke subjects during isokinetic and gait trials: EMG from the tibialis anterior, medial gastrocnemius, lateral gastrocnemius, and soleus, joint position, and reaction forces (from the ground or dynamometer). Forward dynamics, using EMG and joint position data, was used to estimate the joint moments. This was verified by comparison with the inverse dynamics calculation. RESULTS AND DISCUSSION: The joint moment calculations (from forward and inverse dynamics) were compared and gave r-squared values of 0.96 for abnormal gait and 0.98 for unimpaired subjects. and RMS error of 3.87 N-m and 3.57 N-m respectively. Muscle forces and fiber lengths were consistent with literature, indicating the model is potentially a valuable tool to deliver realistic joint moment predictions. The differences noted between subject groups were in the muscle activations and force. According to the model, an unimpaired person produces insignificant torque contribution with the tibialis anterior. Whereas a post-stroke patient compensates for the enlarged moment generated by the gastrocnemii and soleus with an antagonist tibilalis anterior moment. The discrepancy can be explained by the fact that an individual who has spasticity due to a stroke has increased triceps surae forces. CONCLUSION: The model predicted joint moments in novel normal and impaired gait trials with reasonable accuracy.

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NON-UNIFORM FINITE STRAIN FIELDS IN THE SUPRASPINATUS DURING SHOULDER ELEVATION

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Intratendinous shear strains in the supraspinatus tendon have been believed to be an important initiator of the rotator cuff tears. However, there is no data available investigating the deformation in the supraspinatus in dynamic and in vivo situation. A novel method based on the cine phase contrast MRI (CPC-MRI) was proposed to measure the mechanics in the supraspinatus muscle from 15° to 45° dynamically, non-invasively and in vivo. Fine triangular meshes at the sub-pixel resolution were constructed to represent the supraspinatus muscle continuously. A general form was derived to calculate the Lagrangian finite strains from the displacements of nodes computed with CPC-MRI velocity data. Non-uniform maximum principle strains and maximum in plane shear strains were found in the different layers at the insertion side of the supraspinatus. These data proved that the intratendonous shear strains of the supraspinatus muscle play an important role in the elevation of the shoulder joint, which might directly connect with the nonhomogeneous mechanical properties in the supraspinatus tendon.

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Is Dynamic Hip and Knee Malalignment Associated with Tibial Stress Fracture in Female Distance Runners?

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It has been suggested recently that running injuries in females may be related to dynamic hip and knee malalignment in the frontal and transverse planes during stance. This may predispose a runner to injury by changing load distribution. Since tibial stress fractures (TSF) are load-related injuries, differences in alignment may contribute to injury risk. The aim of this study was to determine whether TSF is associated with this dynamic malalignment. It was hypothesized that runners who had sustained a TSF previously would exhibit increased HADD, HIR and KABD and altered axial rotation at the knee (KIR, KER), compared to runners with no history of fracture. The utility of foot abduction

angle (FTLAB) as a simple surrogate measure was also tested. Healthy runners who had sustained TSF previously (HTSF; n = 22) and an age and mileage matched control group (CTRL; n = 22) participated. Gait data were collected at 120 Hz as subjects ran at 3.7m/s on a 25m runway. Data from five trials were averaged. Independent t-tests were used to investigate the hypothesized differences (one-tailed for HADD, HIR and KABD). These data support our hypotheses that HTSF had higher frontal plane HADD (10.8º vs. 7.2º, p = 0.03) and KABD (-5.7º vs. -4.1º, p = 0.03) angles. In the transverse plane, only KIR (4.3 vs. -0.6, p = 0.01) showed an increase. There were no differences in HIR (7.2º vs. 7.4º, p = 0.47) or KER (-8.9º vs. -10.7º, p = 0.35) between groups. Based on these data, dynamic hip and knee malalignment may play a role in stress fracture injuries in female runners. FTLAB (-5.0º vs. -4.1º, p = 0.62) did not differ between groups, so is unsuitable as a surrogate measure of proximal joint alignment. In conclusion, HADD, KABD and KIR were increased in HTSF compared to CTRL. Prospective studies are needed to determine whether these increases are predictive of stress fracture injury.

43 Anatomical Realignment and Muscle Function During Gait in Patients with Medial Knee OA

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INTRODUCTION: To examine the effect of joint realignment on normalization of muscle and movement patterns in patients with medial compartment osteoarthritis (MKOA).
METHODS: Nine subjects with MKOA and genu varum were tested prior to (PRE) and one year following (POST) progressive opening wedge-high tibial osteotomy (OW-HTO). Nine healthy age and gender-matched subjects (NORM) were compared. Knee alignment and laxity was measured from radiographs. Quadriceps strength was assessed with a KinCom Dynamometer. Motion analysis was used to assess kinematic and kinetic patterns. Simultaneous muscle activity was recorded from the medial hamstrings (MH), vastus medialis (VM), and medial gastrocnemius (MG). Co-contraction indices were derived by integrating the linear envelope. RESULTS: Following OW-HTO, knee adduction angles and moments were significantly reduced during stance. Medial laxity was significantly reduced (p = 0.024) and was comparable to the NORM group. Quadriceps strength remained significantly lower than controls (PRE: p = 0.013 and POST p = 0.005). Knee flexion excursions remained unchanged (PRE vs. POST) but were significantly lower than NORM (PRE: p = 0.019 and POST p = 0.042). VMMG co-contractions were lowered 26%. PRE and POST VMMG cocontractions were 33% and 10% greater than NORM respectively. Stronger quadriceps were associated with greater flexion excursions and weaker quadriceps with higher VMMG cocontractions. DISCUSSION: OW-HTO corrected varus malalignment, significantly reduced knee laxity, instability, and adduction angles and moments. Medial muscle co-contractions were lowered. However, quadriceps weakness and reduced knee flexion excursions persisted. Quadriceps weakness interferes with the muscles' ability to absorb shock at the knee and flexion excursion is reduced, which coupled with excessive joint compression from muscle co-contraction could lead to further joint destruction in the long term.

44 Muscle Synergies In The Upper Extremity During Stabilization Of Balance In Sitting

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In this study, we attempted to identify hypothetical control variables called M-modes from the activity of larger sets of muscles in the upper extremity and tested the hypothesis that they form synergies to stabilize the moment about the center of mass (COM) of the body when sitting on an unstable chair that is stabilized by the hand's grasp of a handle. EMGs from nine muscles of the wrist, elbow and shoulder of the right side were recorded and analyzed while subjects performed two tasks. First, they sat on a stable chair, grasped a handle with their right hand and matched a template on the computer screen in front of them by pushing forward or backward to match the prescribed step-change in the torque about the frontal axis of the transducer. For the second task, subjects sat on a chair mounted on a rocker board, making it unstable in the anterior-posterior (AP) direction. They were instructed to pull (push) strongly with the left hand another handle while keeping the chair stable by exerting a counter moment with their right hand. The left hand force was then released at a self-selected time and anticipatory adjustments by the right side muscles immediately prior to release were quantified. Principal component analysis was used to identify M-modes from the first task. The relationship between the M-modes and the moment about the frontal axis of the transducer produced by the right hand was obtained using multiple regression approach. Uncontrolled manifold (UCM) analysis was then performed to determine the extent to which variance of the M-modes acted to stabilize the moment about the frontal axis of the transducer. Three M-modes were identified and formed M-mode synergies that stabilized the moment about the transducer and consequently COM of the body over the unstable chair. The results support our hypothesis that the M-modes work together as a synergy to stabilize a desired moment about the transducer.

45 ACL-deficient Knees Exhibit Elevated Contact Surface Velocities During Motion

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Disruption of the ACL increases knee joint laxity, and changes in relative velocity between joint contact surfaces may contribute to the development of arthritis in these patients. The purpose of the current study was to determine whether differences in contact velocities exist in the tibiofemoral joints of these patients during active exercise. Methods: Cine phase contrast MRI data were acquired while subjects performed a repeated, active knee flexion/extension exercise within the bore of an MRI scanner. A high resolution static 3D scan of each knee was also acquired, and 3D models were created from serial digitizations. Rigid body tracking was used to simulate trajectories of the models of the femur and tibia and optimize correspondence with the cine-PC data. The instantaneous velocities of midpoints between the bones were calculated, after which the velocity of the tibia relative to the femur was calculated from the vector difference of these velocities. Sixteen athletic subjects (age=25.8+/-11.1 yr) who had sustained a complete isolated unilateral ACL rupture less than 6 months prior to testing were enrolled in this study. A further 16 subjects (age=22.1+/-6.9 yr) were uninjured control subjects, matched by activity and age to the ACL-deficient group. Results: Group mean maximum slip velocity magnitudes were similar between sides in the control group (41.8+/-14.2 mm/s, 43.4+/-12.2 mm/s), whereas in the injured group the ACL injured knees exhibited significantly higher velocities than the uninvolved knees (46.5+/-16.8 mm/s vs. 37.8+/-8.3 mm/s, $p<0.05$). Discussion: The higher maximum slip velocity magnitude in ACL-deficient knees may increase the shear-related effects on cartilage degradation which precedes the development of osteoarthritis. Future work will seek to more fully describe local changes in velocity magnitude and direction at the contact regions.

46 Predicting Optimal Stimulation Patterns For A Range Of Knee Joint Motions During Functional Electrical Stimulation.

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Functional Electrical Stimulation (FES) is the coordinated electrical excitation of paralyzed or weak muscles in patients with upper motor neuron lesions to produce functional movements such as sit-to-stand or walking. Because responses to electrical stimulation are highly nonlinear and time varying, accurate control of muscles to produce functional movements is very difficult. Accurate and predictive mathematical models can facilitate the design of stimulation patterns and control strategies that produce desired forces and motions. Previously we developed a Hill-based nonisometric mathematical model that could predict accurately knee motions in response to a wide range of clinically relevant stimulation frequencies and patterns. In the current study we use our nonisometric model to predict stimulation pattern that can produce a given knee motion trajectory. As the model cannot be directly inverted to predict stimulation patterns from the knee motion, we fitted the model's knee motion trajectory to the desired trajectory to obtain the optimal stimulation patterns. The fitting was done using an optimization algorithm called DIRECT (DIviding RECTangles), which is a modification of the Lipschitz optimization. After obtaining the optimal stimulation pattern for each desired trajectory, we tested these optimal patterns on healthy subjects to determine if they produce the desired trajectories. Our results to date showed that the patterns predicted by our model could produce the desired trajectories accurately. Hence our model in conjuction with the DIRECT optimization algorithm can be used to design optimal patterns for generating FES-elicited movements.

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