7th Annual

Biomechanics Research Symposium

May 7, 2010

UNIVERSITY OF DELAWARE

Center for Biomedical Engineering Research | 201 Spencer Lab | Newark, Delaware 19716

Welcome

The Center for Biomedical Engineering Research at the University of Delaware is pleased to host the 7th annual biomechanics research symposium. The motivation for this symposium is to highlight the outstanding and varied biomechanics related research taking place at the University of Delaware. Throughout the day, poster and podium presentations will be led by UD student researchers with awards given to the best presentations.

Please join me in welcoming Dr. Mark Latash, Distinguished Professor of Kinesiology at Penn State University, who will give a keynote lecture entitled "Multi-digit synergies: effects of age and fatigue." Dr. Latash's research is focused on the control and coordination of human voluntary movements and has implications for our studies on stroke, arthritis, running, motor control and modeling featured in today's program.

I would like to recognize each of you for contributing to the scientific content of this year's research symposium, and specifically acknowledge the student committee and faculty judges who devote time and effort to enhancing today's event. Enjoy!

Jill Higginson

Acknowledgements

ORGANIZING COMMITTEE

Jill Higginson

Elaine Nelson

STUDENT COMMITTEE

Emily Gardinier

Geetanjali Gera

Ananth Gopalakrishnan

Chris Henderson

Laura Miller

David Olchowski

Kota Takahashi

Joshua Winters

JUDGES

David Burris

Slobodan Jaric

Anja Nohe

Mark Latash

Chris Price

Steven Stanhope

Liyun Wang

Keynote Lecture

MULTI-DIGIT SYNERGIES: EFFECTS OF AGE AND FATIGUE

Mark L. Latash

Pennsylvania State University, University Park, PA, USA

Recent developments of the notion of motor synergy and the computational apparatus of the uncontrolled manifold (UCM) hypothesis have allowed researchers to address a series of applied issues such as changes in multi-element coordination with healthy aging and under muscle fatigue. In particular, older persons show an impaired ability to organize co-variation of involvement of individual digits to stabilize such characteristics of performance as total force, total moment of force, and direction of the total force vector. These results, together with the documented higher indices of finger individuation (lower force production by non-instructed fingers) in the elderly suggest a shift from synergic to more somatotopic, element-based control. Aging is also associated with an impaired ability to adjust multi-digit synergies prior to action, that is, smaller anticipatory synergy adjustments. These observations may have the same origin as the reported lower anticipatory postural adjustments in older persons. A fatiguing exercise performed by one finger leads to an increase in the variance of forces produced by individual fingers of the hand, even by fingers that show minimal changes in their maximal voluntary force after the exercise. This is accompanied by stronger negative co-variation of commands to fingers during multi-finger accurate force production tasks. As a result, accuracy of single-finger tasks is significantly affected by fatigue, while multi-finger tasks show minimal changes in accuracy with fatigue. These findings suggest that an adaptive increase in motor variability of non-fatigued elements may be used to counterbalance the typical increase in motor variability in fatigued elements. Overall, translation of the recent studies of motor synergies to issues of impaired motor control is a promising direction of research.

DR. MARK LATASH is a Distinguished Professor of Kinesiology at Penn State University. He received equivalents of B.S. in Physics and M.S. in Physics of Living Systems from the Moscow Physico-Technical Institute and a Ph.D. in Physiology from Rush University in Chicago. His research interests are focused on the control and coordination of human voluntary movements. Three leading textbooks in this area have been authored by Dr. Latash, plus he has edited seven books and published over 250 papers in refereed journals. Mark Latash served as the Founding Editor of the journal "Motor Control" (1996-2007) and as President of the International Society of Motor Control (2001-2005). He is the 2007 recipient of the Bernstein Award which is the highest award presented by the ISMC for an individual who has made an exceptional contribution to the development of the area of motor control in the spirit of Nikolai Bernstein. When he is not studying posture or finger coordination, Mark enjoys mushroom hunting and playing guitar.

Schedule of the Day

WHEN	WHAT	WHERE
8:30	BREAKFAST & POSTER SET-UP	CLAYTON HALL LOBBY
9:00	WELCOME	CLAYTON HALL AUDITORIUM 125
9:15	KEYNOTE: DR. MARK LATASH	CLAYTON HALL AUDITORIUM 125
10:15	BREAK	
10:30	PODIUM SESSION 1	CLAYTON HALL AUDITORIUM 125
12:00	LUNCH	CLAYTON HALL LOBBY
1:00	POSTER SESSION 1 (ODDS)	CLAYTON HALL LOBBY
2:00	POSTER SESSION 2 (EVENS)	CLAYTON HALL LOBBY
3:00	PODIUM SESSION 2	CLAYTON HALL AUDITORIUM 125
4:30	AWARDS	CLAYTON HALL AUDITORIUM 125

Poster Presentations

Lower Extremity

(Continued)

Stroke

Bone, Cell and Cartilage

Motor Control

Methods and Modeling

(Continued)

# Denotes Podium #

Podium Presentations

Session 1

P.39 **1** A PROSPECTIVE STUDY OF LOADING VARIABLES IN FEMALE RUNNERS WHO DEVELOP PLANTAR FASCIITIS

Bradley Bowser, Joseph Hamill, Irene Davis

P.39 **2** PERTURBATION TRAINING IMPROVES GAIT PATTERNS IN ACL DEFICIENT FEMALES

Stephanie Di Stasi, Lynn Snyder-Mackler

P.40 **3** SPECIFICITY OF THE MUSCLES ABOUT THE KNEE DURING A STATIC STANDING TASK: THE UNIQUE SYNERGY BETWEEN THE VASTI AND THE HAMSTRINGS

Toran MacLeod, Lynn Snyder-Mackler, Thomas Buchanan

P.40 **4** GAIT AFTER UNILATERAL TOTAL KNEE ARTHROPLASTY: FRONTAL PLANE ANALYSIS

Ali Alnahdi, Joseph Zeni, Kevin McGinnis, Lynn Synder-Mackler

P.41 **5** A METHOD FOR CHARACTERIZING COMBINED ANKLE-FOOT DYNAMICS DURING STANCE PHASE OF GAIT

Kota Takahashi, Alexander Razzook, Lakisha Guinn, Elisa Schrank, Steven Stanhope

Session 2

P.43 **1** STRAIN-SOFTENING INTERFACIAL ELASTIC MODELS FOR THE CHARACTERIZATION OF ULTRASOUND CONTRAST AGENTS

Shirshendu Paul, Kausik Sarkar

P.43 **2** ATROPHY OF POST-STROKE PLANTAR FLEXORS

John Ramsay, Thomas Buchanan, Jill Higginson

P.44 **3** ARTICULAR LOADING IN PEOPLE WITH KNEE OSTEOARTHRITIS

Deepak Kumar, Katherine Rudolph, Kurt Manal

P.44 **4** PERLECAN-HA BASED BIOMATRICIES PROLONG THE ANABOLIC EFFECT OF BMP2 IN MICE ARTICULAR CARTILAGE

Padma Srinivasan, Sarah Yerkes, Weidong Yang, Amit Jha, Xinqiao Jia, Mary Farach-Carson, Catherine Kirn-Safran

P.45 **5** PERLECAN/HSPG2 DEFICIENCY ALTERS THE PERICELLULAR SPACE OF THE LACUNO-CANALICULAR NETWORK SURROUNDING OSTEOCYTIC PROCESSES IN CORTICAL BONE

William Thompson, Shannon Modla, Brian Grindel, Kirk Czymmek, Catherine Kirn-Safran, Liyun Wang, Randall Duncan, Mary Farach-Carson

POSTER PRESENTATIONS

Lower Extremity

1

DEVELOPMENTAL CHANGES OF VARIABLES INFLUENCING BODY COMPOSITION IN CHILDHOOD

S. Kaiser, I. Masci†, N. Getchell

† University of Rome "Foro Italico", Rome, Italy

Currently, there is a lack of a model detailing developmental changes of variables that have an impact on body composition. Stodden et al created a conceptual model that identifies specific variables that influence body composition and identifies the developmental changes of each variable and their relationship to body composition. The purpose of this study was to investigate the relationships among body composition, motor competence, physical fitness and physical activity. 19 participants from New Zealand (ages 4-6 and 10-12 years) had their height and weight taken for BMI as well as skinfold measurements. Participants completed the Test of Gross Motor Development-2 wearing an inertial sensor device (WISD) to assess their motor competence and they also completed the Fitnessgram for physical fitness evaluation. Children wore a lightweight accelerometer for 48 hours. As expected, the ongoing data analysis shows that younger age group averaged a lower score on the TGMD-2 and lower energy expenditure when compared to older group. Fitnessgram scores are able to distinguish the two age groups. BMI scoring reveals a range of 14.3 to 18.5 BMI for the younger group and 16.1 to 24.7 for the older group. Future analysis will describe detailed relationships among the four variables in terms of developmental changes according to the Stodden's et al model.

2

QUANTITATIVE ASSESSMENT OF LOCOMOTOR SKILLS DEVELOPMENT IN CHILDHOOD: THE RUNNING PARADIGM

I. Masci†, E. Bergamini†, G. Vannozzi†, N. Getchell, A. Cappozzo†

† University of Rome "Foro Italico", Rome, Italy

Running is one of the motor skills humans adopt to accomplish locomotion. Early appearing forms of running coordination are qualitatively different from later/advanced forms of coordination. Intra-skill developmental sequences are useful to provide running qualitative assessment and are fast and easy to practice but suffer from a low sensitivity and they are dependent on subjective evaluation. Quantitative human movement analysis using Wearable Inertial Sensor Devices (WISDs) may be considered as an alternative approach. Aim of the study was to examine the use of WISD data to evaluate developmental differences in running skill.

25 children (age: 7±2.7; m: 23.5±12.1kg; leg length: 0.63±0.07m) performed running trials at their own maximum speed on 18m. A WISD was positioned around the child pelvis. Video data was collected to determine subject's Developmental Level of the Leg Action (DLLA). Flight and stance durations (tf and ts), steps number (Ns), running frequency (fr) and mean velocity (vm) were calculated.

Video analysis allowed to identify 20 subjects into DLLA2 and 5 into DLLA3. Subjects with DLLA2 and DLLA3 exhibited slightly different tf (0.09±0.02s vs 0.08±0.02s), ts (0.16±0.02s vs 0.18±0.02s) and fr (4.04±0.30Hz vs 3.84±0.30Hz). Ns and vm presented more marked differences between DLLA2 and DLLA3: 21.3±1.3 vs 15.6±2.2 and 2.9±0.2ms-1 vs 4±0.4ms-1, respectively.

Time durations slightly varied with DLLA and age, but not significantly. fr presented a mean value of 4Hz confirming to be inappropriate to detect developmental differences. Conversely, vm and Ns were significantly different among DLLAs. Differences were emphasized when normalized data were taken into account.

3

COMPARISON OF MECHANICS IN MALE AND FEMALE RUNNERS WITH PATELLOFEMORAL PAIN SYNDROME

Richard Willy, Irene Davis

Females move in greater hip adduction (HADD) and internal rotation (HIR) compared to males. Females also move in genu valgus, where males move in genu varus. Female runners with patellofemoral pain syndrome (PFPS) exhibit even greater HADD and HIR, and less knee adduction (KADD) than healthy females. As healthy males move differently than healthy females, males with PFPS may have differing mechanics than females with PFPS.

Purpose: To compare the lower extremity mechanics of PFPS males to PFPS females. PFPS males were expected to demonstrate reduced peak HADD, HIR, and greater KADD than PFPS females and healthy male controls.

Methods: 19 runners tested to date: 4 males with PFPS (M-PFPS) (23.2 yrs± 1.4, 18.2 mi/wk±3.4), 5 male controls (M-CON) (21.4 yrs±1.8, 21.1 mi/wk±4.1), and 10 females with PFPS (F-PFPS) (22.2yrs±0.8, 19.4 mi/wk±3.2). Subjects traversed a 25-m runway at 3.35 m/s as 5 trials of kinematic data were collected at 200 Hz. HADD, HIR and KADD were calculated and averaged for each group.

Results: Peak HADD: M-PFPS: mean= 13.8° (sd=2.5), M-CON: 11.6° (4.1), F-PFPS: 21.2° (1.0). Peak HIR: M-PFPS: 1.1° (3.1), M-CON: 5.8° (4.1), F-PFPS: 7.8° (6.0). Peak KADD: M-PFPS: 4.2° (4.8), M-CON: 3.5° (3.6), F-PFPS: 0.9° (3.8).

Discussion: There was a clear delineation between genders for HIR. PFPS males actually ran with HER, while females ran with HIR. Femoral internal rotation has been shown to increase loading to the lateral patella, while external rotation has been shown to increase loading to the medial patella. It is interesting to note that all the PFPS males described medial patellar pain, while all the PFPS females described lateral pain. These preliminary data suggest a gender specific mechanism for PFPS.

4

IMPACT LOADING CAN BE REDUCED WITH A MIDFOOT STRIKE PATTERN

Allison Altman, Irene Davis

Most runners strike the ground with a rearfoot strike (RFS) pattern, 25% of runners land with a midfoot strike (MFS) pattern, and less than 1% land with a forefoot strike (FFS) pattern. RFS patterns are characterized by a transient vertical impact peak (IP), which is associated with high average and instantaneous vertical loading rates (AVLR, IVLR). When excessive, these have been shown to be associated with a number of running related injuries. It has been well-documented that impact loading is significantly reduced in a FFS pattern. This reduction has been attributed, in part, to a shorter stride length (SL). Our previous research suggests that loading during a MFS pattern is not reduced from a RFS pattern. However, the study only included runners who naturally run with a RFS pattern. PURPOSE: To investigate impact loading variables in runners with a natural MFS pattern. It was hypothesized that these runners would have reduced impact loading, as well as a shorter SL, compared to runners with a natural RFS pattern. METHODS: This is an ongoing study of which 15 runners, 10 with a natural RFS and 5 with a natural MFS have been recruited to date. Subjects ran with their natural pattern on an instrumented force treadmill at a self-selected speed (RFS=2.96±0.4, MFS=3.0±0.4 m/s) for 5 min. IP, AVLR, IVLR and SL, were extracted from the analog data. RESULTS: IP, AVLR and IVLR were reduced between 12-16% in the natural MFS condition. Surprisingly, the SLs were fairly similar between MFS and RFS. CONCLUSION: These preliminary results suggest that habitual MFS running is associated with reduced impact loading. This may provide justification to recommend a MFS pattern for injured runners with high impact loading. NIH 1-S10-RR022396, DOD W911NF-05-1-0097

5

A SEX COMPARISON IN REACTIVE KNEE STIFFNESS UNDER COGNITIVE LOADS

A. Kim, C.Swanik, C. Higginson‡,
S. Thomas

‡ Loyola University, Baltimore, MD, USA

Sex differences may exist in cognitive faculties and neuromuscular strategies for joint stiffness regulation which are critical in maximizing dynamic restraint and maintaining knee stability in response to joint loading. The purpose of this study was to assess reactive knee stiffening in males and females exposed to sex-biased cognitive loads. Forty (20 males, 20 females) healthy participants performed cognitive loading conditions (Judgment of Line Orientation (JOLO), Symbol Digit Modalities Test (SDMT), and Serial 7's) and a control condition while resisting a randomly timed knee perturbation. Participants were seated in the Stiffness and Proprioception Assessment Device (SPAD) and instructed to resist a knee flexion perturbation (excursion = 40°, velocity = 100°/sec, acceleration = 1000°/sec2). Reactive stiffness was measured from the starting position of 30° knee flexion to the end of the 40° perturbation. Total knee stiffness measurements were calculated, normalized to body weight, and recorded as Δtorque (Nm) / Δposition (degrees)/ kg. Reactive knee stiffness values were significantly less (2-way ANOVA with repeated measures, $p<0.05$) during the cognitive tasks compared to the control condition (JOLO = 0.034 ± 0.014 Nm/deg/kg, SDMT = 0.037 ± 0.013 Nm/deg/kg, Serial 7's = 0.037 ± 0.012 Nm/deg/kg, control = 0.048 ± 0.011 Nm/deg/kg). No significant sex differences were found among the 3 cognitive tests. Different kinds of cognitive tasks may all decrease the ability of healthy individuals to reactively stiffen their knee joint. Cognitive loading appears to interfere with the normal force attenuating properties of eccentric muscle contractions, which impairs the dynamic restraint mechanism and may expose individuals to joint injury.

6

NATURAL ANKLE PSEUDO-STIFFNESS DURING GAIT INITIATION

LaKisha Guinn, Kota Takahashi, Alexander Razzoo, Steven Stanhope

Introduction: Understanding the mechanism of gait initiation is important for the design of lower limb prosthetics and orthotics and for improving gait in persons with neurological disorders that inhibit or delay gait initiation. The results of previous studies suggest natural ankle pseudo-stiffness (NAS), the ratio of ankle moment relative to ankle angle, has a direct relationship to walking velocity. Therefore, we hypothesized that amplitude of NAS would be lowest during gait initiation. Thus, the aim of this pilot study was to quantify NAS in healthy individuals during gait initiation. Methods: Six healthy volunteers were instructed to begin walking at a comfortable speed when given the "go" command from an initial position of each foot on a separate force plate. Four trials were collected when initiating gait with each foot. In addition, three walking trials were collected at each of three targeted walking velocities: 0.4, 0.6, and 0.8 statures/s. Ankle angle, sagittal plane ankle moments, and mean NAS at gait initiation and each walking speed were calculated. NAS at gait initiation was compared to NAS during walking. Results and Discussion: The mean NAS at gait initiation was 0.137 ± 0.018 Nm/deg BW [BW is body weight (kg)], during the phase of eccentric contraction. The mean NAS during gait initiation was significantly different from mean NAS during walking at the slowest walking velocity (0.4 statures/s) ($p<0.001$). Conclusion: NAS was unexpectedly high during gait initiation. It was expected that the value at gait initiation would fit along the curve of NAS as a function of walking speed that was developed from the targeted velocity walking trials. This may indicate a separate mechanism is utilized to initiate gait.

7

RESTING MUSCLE SPINDLE ACTIVITY CORRELATES WITH ANKLE STIFFNESS

Alan Needle, C. Buz Swanik, William Farquhar

Investigations on the neuromechanical contributors to joint stability and functional performance both emphasize the importance of optimal joint stiffness regulation. Muscle tone

(mediated by muscle spindles (MS)) is often cited for its role in regulating joint stiffness, but no studies have simultaneously investigated resting MS afferent activity and stiffness values. The purpose of this study was to determine if resting MS afferent activity correlates with joint stiffness during passive ankle loading. 29 subjects (20.9yrs±2.2; 173.1cm±8.9; 74.5kg±12.7) underwent microneurographic recordings at the common peroneal nerve to obtain traffic from MS's. A modified ankle arthrometer was coupled with a nerve traffic analyzer and affixed to the subjects' ankles. Three anterior translation movements up to 125N of force were performed. The MS signal was normalized to peak values and stiffness (N/mm) was calculated at 30, 60, 90, and 125N. Pearson-product moment correlation coefficients were used to identify significant ($p<.01$), negative relationships between resting afferent traffic and joint stiffness from 0-30 N ($r=-0.612$), 30-60 N ($r=-0.867$), 60-90 N ($r=-0.765$), and 90-125 N ($r=-0.473$). We hypothesize that the inverse relationship between MS afferent traffic and ankle stiffness may reflect a neurologic optimization strategy whereby fundamental adaptations exist within the adult sensorimotor system that is based on the passive mechanical properties of a joint. Ankles with greater stiffness are able to passively resist loads and thus maintain lower muscle spindle activity at rest. However, relatively compliant joints may exhibit greater resting afferent activity, in an effort to detect relatively small changes in joint biomechanics earlier. This strategy may be biased to preserve joint equilibrium through heightened muscle tone and the reflexive recruitment of muscles to assist with joint stability.

8

DO THOSE WITH PERCEIVED ANKLE INSTABILITY HAVE ASSOCIATED MECHANICAL INSTABILITY?

K. Liu, G. Gustavsen, T. Kaminski

Introduction: The ankle is the most commonly injured joint in the body. The most common risk factor for an ankle sprain is a previous sprain. With recurrent sprains, residual symptoms of ankle instability increases dramatically. Ankle instability has been categorized into mechanical (MI) and functional instability (FI). There lacks evidence as to whether both are present in ankle instability or if they are independent from one another. Therefore, the purpose of the current study is to determine if there are differences in measured MI between ankles that have been categorized as stable or unstable by the Cumberland Ankle Instability Test (CAIT).

Methods: 46 Division I athletes participated in this study (21 females and 25 males, age= 18±1, height= 178.8±9.5 cm, mass= 77.2±13.2 kg). Measurements for inversion and eversion rotation, along with anterior displacement of the ankle were obtained using an ankle arthrometer. Subjects filled out the CAIT, a questionnaire used to determine ankle instability by self-reported symptoms. Data were analyzed using an independent t-test and statistical significance was set at $p \le 0.05$.

Results and Discussion: There were significant differences in inversion rotation between the stable and unstable groups as categorized by the CAIT. Subjects with unstable ankles demonstrated more inversion laxity than those with stable ankles. There were no significant differences in eversion rotation and anterior displacement. Ankle instability often affects those who have had previous ankle sprains. The CAIT has been found to be a reliable questionnaire to measure FI. The CAIT is a short 9-question survey that can be easily administered to assist the clinician with categorizing ankle instability.

9

FEASIBILITY OF DRIVING HEEL ROCKER DYNAMICS WITH SHANK KINEMATICS

Elisa Schrank, Kota Takahashi, Alexander Razzook, Lakisha Guinn, Steven Stanhope

During the first stance phase "rocker" mechanism in gait, the heel becomes a deformable pivot about which the foot rolls to achieve full ground contact. Ankle plantar flexion is thought to primarily control foot motion. However, we hypothesize that with restricted ankle motion, natural heel rocker dynamics can be achieved via shank rotation and heel surface curvature. The purpose of this study was to computationally explore the feasibility of driving heel rocker dynamics with shank kinematics.

Movement analysis data were collected on five healthy subjects walking barefoot at a scaled normal walking velocity of 0.8 statures/sec. Lower extremity kinematic and kinetic data during the right leg stance phase were examined.

The data revealed two distinct heel rocker intervals: a kinematic interval from heel strike (HS) to foot flat (FF) and a kinetic interval from HS to the termination of the ankle dorsiflexion moment (M0). FF occurred at 14% of stance. During the kinematic interval, the foot and shank rotated 15±2.5° and 12±2.2°, respectively. However, the ankle reached peak plantarflexion (PF) of 13±2.9° prior to the end of the kinematic interval. The dorsiflexion (DF) ankle moment peaked at 0.15±0.03Nm/kg half way through the interval and reached 0.06±0.04Nm/kg at FF. M0 occurred at 16±2.4% of stance. The shank continued to rotate after FF, for a total of 15±2.4° during the kinetic interval. From FF to M0, the ankle dorsiflexed and the ankle moment went to zero.

The results indicate ankle motion contributed minimally to obtaining the kinematic and kinetic limits of the heel rocker mechanism. Alternatively, shank motion appears ideal for driving the mechanism.

10

EFFECT OF A GAIT RETRAINING PROGRAM TO REDUCE VERTICAL LOADING ON THE CONTRALATERAL, UNTRAINED LIMB

Rebecca Fellin, Irene Davis

Excessive vertical loading, such as average and instantaneous vertical loadrates (AVLR and IVLR) and tibial shock (PPA) have been linked to tibial stress fractures (TSF) in runners. Many runners exhibit high vertical loading bilaterally. We have demonstrated that a gait retraining program using real-time visual feedback can reduce excessive load rates on the trained limb. However, it is unknown if loading on the contralateral, untrained limb is reduced as well.

PURPOSE: To determine whether subjects decrease vertical loading on their untrained contralateral limb following a gait retraining program.

METHODS: In this ongoing study, 8 runners (28.0 ± 8.5 yr) have participated. For inclusion, subjects ran at least 10 mi/wk. They also exhibited PPA > 8g at baseline, which placed them at risk for TSF. Each subject completed 8 sessions of real-time, visual feedback, aimed to decrease vertical loading on the trained limb. On the untrained, contralateral limb, we measured impact peak (VIP), AVLR and IVLR pre and post gait retraining during treadmill running. Although not an entry criteria, 6/8 subjects had high vertical loading on their contralateral limb. The data are presented descriptively due to the small sample size.

RESULTS: Overall, subjects decreased all variables, 12.3 to 22.5%. 5/8 subjects decreased vertical loading >15%. Despite not receiving feedback on their contralateral limb, some subjects appeared to adopt a running strategy that decreased loading bilaterally.

CONCLUSION: Contralateral limb loading is reduced in most subjects as a result of a gait retraining protocol aimed at reducing vertical loads in the opposite limb.

Support: DOD W911NF-05-1-0097 & W81XWH-07-1-0395 & NIH 1 S10 RR022396.

Abstract accepted for presentation at ACSM 2010 Annual Meeting.

11

QUADRICEPS ACTIVATION DEFICITS IN THE ACL DEFICIENT KNEE

Andrew Lynch, David Logerstedt,
Lynn Snyder-Mackler

Background: After a knee injury involving the ACL, the involved quadriceps has the potential to experience profound strength losses quickly, which have deleterious effects on knee stability and future function. Some of these strength losses can be attributed to the decreased ability of the patient to fully activate the quadriceps with a volitional contraction. Another frequent impairment in the ACL injured population is an effusion of the knee joint. A large experimental knee joint effusion has been shown to produce quadriceps inhibition in otherwise healthy knees, although this relationship has not been explored in a clinical population. The purpose of this investigation is to outline the patterns of activation of the quadriceps and the relationships between effusion and activation in patients post-ACL injury. Methods: This is a retrospective analysis of 197 patients presenting within 100 days of their index ACL injury. Quadriceps strength and activation was measured with a maximum volitional isometric contraction and electrical burst superimpositioning. Central activation ratio (CAR) is expressed as a ratio of the volitional contraction compared to the electrically elicited contraction, with values less than 95% being considered deficient. Results: Bilateral deficits in CAR were seen in 24% of patients, with an additional 17% demonstrating only involved limb deficits. There was no significant effect of effusion on the level of activation ($p=0.233$) or quadriceps strength ($p=0.358$). No meaningful relationship was found between quadriceps strength and activation ($r2=0.123$). Conclusion: While an experimental effusion appears to cause decreased quadriceps activation, this relationship is not seen in the clinical population. There is no reliable way to predict those with decreased activation without a comprehensive electrophysiological assessment.

12

EFFECTS OF PERTURBATION TRAINING ON JOINT LOADING AFTER ACL INJURY

Emily Gardinier, Kurt Manal, Thomas Buchanan,
Lynn Snyder-Mackler

INTRO: The onset of osteoarthritis after anterior cruciate ligament (ACL) rupture is related to altered knee loading patterns which may be due to neuromuscular compensation for injury. Perturbation training has been shown to promote better muscle coordination and improve function in individuals with ACL-deficiency, however its effect on joint loading is not known. The purpose of this study was to investigate the effect of standard quadriceps strength training (STR) versus quadriceps strengthening with perturbation training (PERT) on joint contact forces during gait. METHODS: Seven acute ACL-deficient non-copers (time from injury=11.4 ± 7.6 wk) were randomly selected to undergo PERT (2M, 2W) or STR(2M, 1W) training. Each training protocol consisted of 10 physical therapy sessions which were administered 2-5 times per week. Joint contact forces were estimated pre- and post-training using an EMG-driven model. EMGs and joint kinematics were input to a modified Hill-type model to estimate muscle forces. Muscle forces were applied to a frontal plane moment-balancing algorithm to compute contact forces, which were normalized to bodyweight (BW) and 100 points of stance. RESULTS: No group differences between limbs were found for medial or lateral compartment loading at pre-training (peak involved med=2.1BW, lat=1.3BW, uninvolved med=2.5BW, lat=1.4BW). Medial and lateral compartment loading increased in the STR group (med=2.8BW, lat=1.9) but remained similar in the PERT group (med=2.4, lat=1.5) post-training. CONCLUSIONS: Aggressive quadriceps strengthening is our current clinical practice because pre-operative strength is clearly predictive of knee function after surgery. Our results suggest that the addition of perturbation training to standard strength training (PERT) may be protective against harmful increases in joint loading.

13

QUADRICEPS STRENGTH RECOVERS FASTER THAN HOP PERFORMANCE FOLLOWING ACL RECONSTRUCTION

David Logerstedt, Andrew Lynch,
Lynn Snyder-Mackler

Background: Quadriceps weakness can persist for months following ACL reconstruction (ACL-R). Function has been shown to improve over time following ACL-R. Longitudinal clinical trials have not assessed the changes in quadriceps strength and functional performance in the involved and uninvolved limbs and the relationship between these two measures pre- and post ACL-R. Methods: Fifty-one highly active subjects with an acute, unilateral ACL tear who participated regularly in level I or II activities were screened following an injury to the index limb, underwent pre-operative perturbation training, and completed follow-up visits at 6, 12, and 24 months post ACL-R. Quadriceps strength and hop performance was assessed at each time period. Repeated measures ANOVA were used to study differences and changes in quadriceps strength, and two hops in the involved and uninvolved limb over time. Results: A time-by-limb interaction of quadriceps strength ($p=.001$) showed the involved quadriceps was weaker than the uninvolved quadriceps at initial screening and post-perturbation training. A time-by-limb effect for single hop test ($p=.001$) demonstrated that subjects did not hop as far as on the involved limb vs. the uninvolved limb at first four time periods. A time-by-limb interaction was observed in 6-m timed hop ($p=.001$) showing subjects hopped slower on their involved limb vs. their uninvolved limb at first three time periods. Conclusion: Limb asymmetry is present early after ACL injury, however, following ACL-R, the involved limb recovers to the level of the uninvolved limb recovers more quickly in quadriceps strength than in hop performance. Quadriceps strength appears to influence hop performance early in the rehabilitation process, whereas, quadriceps strength may have less impact than other factors in functional performance over time.

POSTER PRESENTATIONS

Stroke

14

EVALUATION OF MUSCLE CONTROL STRATEGY CHANGES IN POST-STROKE GAIT AFTER A FUNCTIONAL ELECTRICAL STIMULATION INTERVENTION USING MUSCULOSKELETAL SIMULATIONS

Brian Knarr, Trisha Kesar, Erin Helm, Darcy Reisman, Stuart Binder-Macleod

Computer simulation studies can demonstrate the function of individual muscles in healthy and post-stroke gait. The objective of this study was to use subject-specific simulations to determine the changes in activation of the ankle plantarflexor (PF) and dorsiflexor (DF) muscles in stroke patients after an FES gait retraining program. Eight subjects (age 63±8.6, 3 men, >6 months post-stroke) were recruited to participate in a 12-week FES gait retraining intervention, involving both plantar and dorsiflexor stimulation. Self-selected speed walking data were collected on an instrumented split belt treadmill (Bertec Corp./AMTI) using an 8-camera Motion Analysis system pre- and post-intervention. Three-dimensional, forward dynamic simulations were created from walking trials using OpenSim. The muscle activations were computed using the Computed Muscle Control algorithm. Differences in activation between pre- and post-intervention for the medial gastrocnemious, soleus, tibialis posterior and tibalis anterior muscles were evaluated using paired t-tests. Following intervention, a new muscle activation pattern consistent with the timing of PF FES used during the intervention was observed in the plantarflexor muscles. The average activation of PF tended to increase during pre-swing, as well as for the DF during swing. Subjects with greater peak knee flexion during swing also showed the greatest increases in PF activation in the pre- to post- intervention simulations. For the first time, muscle-actuated simulations were used to detect the effect of a gait retraining intervention on post-stroke muscle activation patterns.

15

EFFECTS OF TIMING OF FUNCTIONAL ELECTRICAL SIMULATION ON POST-STOKE GAIT

Dylan Thorne-Fitzgerald, Trisha Kesar, Ramu Perumal, Stuart Binder-Macleod

Individuals who experience a stroke have paresis on one side of their body, which results in asymmetrical walking patterns. The FastFES gait training program combines fast walking on a treadmill with functional electrical stimulation (FES) of the paretic ankle muscles to improve the quality, speed, and efficiency of stroke patients' gait. FES is delivered based on events of the gait cycle, relayed by footswitch sensors attached to the patients' shoe. The current footswitch setup for FES uses two footswitches, one under the heel and one under the toe. However, we recently observed that with the current two footswitch setup, dorsiflexion stimulation was initiated while the foot was still on the ground, before true toe-off occured. Due to this premature onset of dorsiflexion stimulation with the two-footswitch setup, the ankle plantarflexion angles at toe-off were adversely affected. Thus, in the current study, to improve the accuracy of delivery of dorsiflexor stimulation, we are testing a novel footswitch setup consisting of four footswitches one under the heel and three footswitches under the forefoot. Walking patterns of 6 post-stroke individuals will be compared during walking with FES using the four- versus two-footswitch setups. The findings of this study will help determine the best method to accurately time the delivery of FES during the FastFES gait training program.

16

THE RELATIONSHIP BETWEEN BALANCE AND FASTER WALKING SPEED AND SPEED MODULATION IN INDIVIDUALS POST STROKE FOLLOWING A TREADMILL TRAINING INTERVENTION WITH ELECTRICAL STIMULATION

Margie Roos, Darcy Reisman, Katherine Rudolph, Stuart Binder-Macleod

Slow self-selected walking speed is one of the most consistent gait impairments reported following a stroke. The relationship between balance and faster walking speed or balance and ability to modulate walking speed from a slower to faster pace has not been well studied. Twelve individuals with chronic stroke participated in a treadmill training program while walking at a faster speed with the use of electrical stimulation to the dorsiflexors and plantarflexors (FastFES). Subjects participated in a 30 minute walking session for up to 3 times per week for up to 12 weeks. Each subject under went clinical testing of self-selected walking speed (SS), fastest walking speed (Fast), Timed Up and Go (TUG), and the Functional Gait Assessment (FGA) prior to and at the conclusion of the treadmill training sessions. Speed Modulation (SpMo) was calculated as the speed difference between Fast and SS. Significant correlations were found pre-training and post-training between FGA and Fast, TUG and Fast and TUG and SpMo. There was no significant correlation at pre-training between FGA and SpMo, but there was a significant correlation post-training (Δ=.629, p=.028). The change score from pre-training to post-training for SpMo was -0.16 (SD:0.9); FGA was 0.21 (SD:0.18); TUG was -0.23 (SD:0.14); SS was 0.23 (SD:0.11); and Fast was .07 (SD:0.29). These results demonstrate that there is an improvement in balance and speed modulation following the FastFFES intervention and that these improvements appear to be related.

17

GAIT ASYMMETRY FOLLOWING STROKE: RELATIONSHIP TO CLINICAL MEASURES OF DYNAMIC FUNCTION

Erin Helm, Trisha Kesar, Stuart Binder-Macleod, Darcy Reisman

It has been argued that gait symmetry may be a valid outcome measure of improvements following rehabilitation interventions. The importance of symmetry has been explored in relation to improvements in gait speed but not in relation to other important clinical outcome measures. Here we examined the relationship between spatial and temporal gait asymmetry during treadmill walking and performance on dynamic functional clinical measures. We hypothesized that greater spatial and temporal asymmetry during walking would be related to poorer scores on clinical measures.

Nineteen stroke survivors with hemiparesis walked on an instrumented treadmill at their self-selected speed. Spatial (step length) and temporal symmetry (stance, double limb support (DLS), and single limb support (SLS) times) were assessed in relation to clinical scores on the Functional Gait Assessment test (FGA), Four Square Step Test, Activity-Specific Balance Confidence (ABC) scale, and short distance speed modulation.

Moderate correlations were found between the Four Square Step Test and double support time and SLS asymmetry (r=0.688, r=0.604, respectively); subjects with less asymmetry took less time to complete the test. A moderate correlation was found between step length asymmetry and speed modulation (r=-0.598); those with less asymmetry were better able to modulate their walking speed. Weak relationships were found between the FGA and DLS and SLS asymmetry (r=-0.345 for both). No relationship was found between the ABC and spatiotemporal gait measures. These results suggest that there is a relationship between clinically measured dynamic functional tasks and gait asymmetry, but not between balance confidence (as measured by the ABC) and gait asymmetry. However, none of the correlations exceeded 0.70, suggesting that additional factors also influence dynamic function after stroke.

18

MINIMAL DETECTABLE CHANGE OF POST-STROKE GAIT VARIABLES COLLECTED DURING TREADMILL WALKING

Trisha Kesar, Stuart Binder-Macleod, Gregory Hicks, Darcy Reisman

Introduction: To rigorously evaluate the efficacy of gait rehabilitation interventions, it is critical to accurately measure post-stroke gait impairments both at baseline and after rehabilitation. In conjunction with measures of walking speed and endurance, kinematic, ground reaction force, and spatio-temporal gait data derived from instrumented gait analysis provide a comprehensive assessment of post-stroke gait performance. Without information regarding the minimal detectable change (MDC) for these variables, however, interpretation of repeated measures is difficult.

Methods: The objective of this study was, therefore, to compute MDCs for post-stroke gait kinematics, ground reaction force (GRF) indices, temporal, and spatial measures during treadmill walking. Nineteen individuals with hemiparesis following stroke (12 males; Age = 47-75 years; Time since stroke = 72.6±63.4 months) participated in 2 testing sessions separated by 20.7±26.8 days.

Results: Our results showed that test-retest reliability was excellent for all gait variables tested (ICCs=0.799-0.986). MDCs were reported for hip, knee, and ankle joint angles (range 3.8° for trailing limb angles to 11.5° for hip extension), antero-posterior and vertical GRF-based indices (≥5% body weight), all temporal variables (≥4.2% gait cycle), and step lengths (≥6.7 cm).

Conclusions: The MDC values presented in this study can be used to interpret the magnitudes of change in multiple gait variables across repeated testing session in persons post-stroke.

19

POST-STROKE GAIT: STRIDE-TO-STRIDE AND DAY-TO-DAY VARIABILITY

Louis Awad, Trisha Kesar, Stuart Binder-Macleod

The walking patterns of individuals who have sustained a stroke show marked stride-to-stride and day-to-day variability. In able-bodied individuals, it has been well documented that even without intervention or training, improvements in task performance are often seen with repeated testing. This variability in post-stroke gait, and the potential interaction between the testing of gait and gait performance, may require clinicians to perform multiple testing sessions before an accurate assessment of the post-stroke gait can be obtained. However, the number of testing sessions necessary to obtain a stable baseline for post-stroke gait has not been previously reported. Thus, the primary purpose of this study is to determine the number of testing sessions necessary before a consistent response in task performance is achieved.

Peak swing phase knee flexion angle, ankle dorsiflexion angle, and peak anterior ground reaction forces (AGRF) were measured before treadmill walking in 5 post-stroke individuals on 5 separate days, using a testing protocol approved by the University of Delaware's Human Subjects Review Board. Across the 5 testing sessions, there were no overall consistent changes in means or variances for the three measured gait variables either within or across subjects. These findings suggest that there appears to be little advantage to using more than 1 testing session for collecting baseline gait data in individuals who have sustained a stroke.

20

THE NEURAL CORRELATES OF SLOWNESS IN STROKE SURVIVORS

J. Palmer, Stuart Binder-Macleod, C. Knight

Recent work from our laboratory indicates that motor unit firing rates in the paretic limb of stroke survivors are atypically low during sustained high-force muscular contractions. In addition to these findings on strength, we are also interested in the neural correlates of quickness. In healthy adults, motor unit firing rates are known to be very high during the onset of rapid muscular contractions. Thus far, pilot data indicate that these high initial firing rates are not produced in the paretic limb of stroke survivors when they are asked to produce most-rapid isometric force pulses. This likely explains the corresponding findings of a prolonged time to reach peak force. While the analysis of motor unit recordings is ongoing, the purpose of this project was to determine the corresponding changes in the electromyograms (EMGs) that were recorded simultaneously. Subjects were asked to produce several small, medium and large force isometric contractions of the ankle dorsiflexors or knee extensors, as quickly as possible. We evaluated the rate of farce development and the duration, RMS amplitude, and are within each EMG burst. As anticipated, compared to the unaffected extremity, the EMGs of the paretic limb showed longer duration and lower amplitude bursts to achieve each targeted force level.

POSTER PRESENTATIONS

Bone, Cell and Cartilage

21

DYNAMIC KNEE JOINT STIFFNESS AND KNEE JOINT MOMENTS AFTER UNILATERAL TKA

Kevin McGinnis, Joseph Zeni, Ali Alnahdi, Lynn Snyder-Mackler

Introduction: Total knee arthroplasty (TKA) is a widely used procedure in the management of knee osteoarthritis (OA). Over 500,000 TKA operations are performed each year, comprising nearly half of all total joint arthroplasties. Abnormal movement patterns that persist after TKA could result in excessive loads on the operated and non-operated limb. This could expedite the progression of OA in the non-operated limb or contribute to the failure of the components of the knee prosthesis. The purpose of this study was to compare sagittal plane kinetics and kinematics of the operated knee in patients 6 months and 1 year after surgery. Knee excursion, knee moment at peak knee flexion, and dynamic knee stiffness were compared during early stance phase.

Methods: 27 subjects were evaluated 6 months after surgery and 38 were evaluated 1 year after surgery. Gait analysis was performed and sagittal plane angles, joint moments and knee stiffness were calculated. Dynamic knee stiffness was calculated as the change in joint moment divided by the change in joint angle.

Results: Knee stiffness was significantly higher in the 6 month group compared to the 1 year group (P=0.004). No differences were found between the 1 year and control groups for knee stiffness, but differences between 6 months and control approached significant levels (p=0.085). Knee flexion moment significantly decreased between 6 months and 1 year post-surgery and the peak knee flexion moment at 1 year was also significantly lower than the control group.

22

STRATEGIES DURING WEIGHTED WALKING BETWEEN HEALTHY, OLDER ADULTS AND ADULTS WITH KNEE OSTEOARTHRITIS

Andrew Kubinski, Jill Higginson

Knee osteoarthritis (OA) is one of the most devastating rheumatic conditions and is associated with pain and disability in the United States. Though those with knee OA exhibit different gait patterns during normal walking, it is unclear whether unique kinetic and kinematic strategies are adopted during a challenging weighted walking task. We used an instrumented treadmill and 8 camera Motion Analysis system to collect gait data at 1.0 m/s for 40 subjects (20 healthy; 20 knee OA). The healthy group showed a smaller hip angle at initial contact and an increased load rate compared to the knee OA group during their unweighted walking trials. However, when challenged by walking with 1/6th of their body weight in a weighted vest, the healthy group had significantly increased hip flexion at initial contact and decreased load rate from the unweighted to weighted condition while the knee OA group did not. This strategy could be a way that healthy, older adults respond to the challenging task of walking under a load which saves them from the effects of degenerative knee OA. The implications of this strategy are still unknown and more research needs to be done since the knee OA group had a larger hip flexion angle at initial contact and smaller load rate than the healthy group in both conditions.

23

CENTRAL ACTIVATION RATIO AND ITS RELATIONSHIP WITH FUNCTIONAL MEASURES AND KNEE OSTEOARTHRITIS

J. Winters, K. Rudolph

Quadriceps weakness has been attributed to the inability to fully activate the quadriceps however people rarely use full muscle activation during daily activities. Better understanding the relationship between the ability to activate the quadriceps and physical function is necessary to better understand the role of muscle activation on knee instability in people with knee OA. Eighteen subjects with knee osteoarthritis were divided into 2 groups; those with CAR values similar to age matched controls (>0.95) (Normal) and those with CAR values < 0.90 (Inhibited). No group differences were found in strength, stair climbing time or any measures of physical function, however, in those with inhibition, CAR correlated with stair climbing time and walking speed. The amount of variance in hamstring activation during the preparation phase (p=.005) for landing were different between the groups as well as vastus medialis activation variance during the loading response (p=.026). The only correlations found between CAR and muscle activation parameters were with the lateral hamstring's variance during preparation (p=.038) and the vastus medialis variance during midstance (p=.030). The inhibited group's CAR showed significant correlation in the joint repositioning sense during flexion at 45 degrees (p=.012 and p=.020 respectively) and time to detect passive motion during extension starting at 15 degrees (p=.014). The fully activated group's CAR values had a significant relationship with only the active peak torque (p=.017) during stiffness testing but there were no significant differences for any of the proprioceptive or joint stiffness measurements. These data suggest similar functional outcomes between groups and that a poor association exists between the CAR results and both functional and kinematic gait measures during normal walking in subjects with knee osteoarthritis.

24

ESTIMATED MECHANICAL STRESS IN SUBJECTS WITH MODERATE KNEE OSTEOARTHRITIS AND HEALTHY CONTROLS

Chris Henderson, Andrew Kubinski, Jill Higginson

The high incidence of knee osteoarthritis (OA) in older adults and the increasing age of 'baby boomers' makes understanding OA a high priority. OA has previously been hypothesized to correlate with increasing mechanical stresses in the joint. We hypothesize that mechanical stress will be increased in the medial compartment of moderate OA subjects when compared to healthy, age and gender matched controls across peak loading conditions. Gait data were obtained through use of an instrumented treadmill. Peak vertical ground reaction force (GRF) and knee adduction moment were determined along with the knee flexion angle at that instant. Medial compartment articular cartilage contact area was estimated through use of magnetic resonance imaging at three knee flexion angles and linearly interpolated to determine the contact area at the exact knee flexion angle of interest. A third estimate of stress was calculated using the subject's weight and medial compartment articular cartilage contact area at 0° knee flexion. No signficant differences existed between the groups with respect to the 'axial' load selected, while the moderate OA subjects exhibited signficantly greater medial compartment articular cartilage contact area in all three cases (p = 0.03). Significant differences in stress were only found in the case of peak vertical GRF (p = 0.01) with the moderate OA subjects having a lower estimate of mechanical stress. The results suggest that articular cartilage contact area is the primary factor in knee joint stress. However, these results are limited through consideration of only the external loads crossing the joint, our inability to identify the component of these loads specifically spanning the medial knee joint, and neglecting the meniscal contact area.

25

ESTABLISHMENT OF MOUSE MODELS OF OSTEOARTHRITIS FOR DISCOVERY OF EARLY BIOMARKERS OF DISEASE PROGRESSION.

Sarah Yerkes, Padma Pradeepa Srinicasan, Catherine Kirn-Safran

Osteoarthritis (OA) is a prevalent joint disorder characterized by severe pain and disability. The disease process is marked by loss of cartilage, chondrocyte hypertrophy, ligament laxity, and osteophyte formation in affected joints. At the molecular level, OA is characterized by an imbalance between synthesis and degradation of both cartilage and bone extracellular matrix (ECM). Diagnosis of OA is often made at a late stage of disease by non-invasive radiographic imaging (x-ray, MRI) due to the inability to effectively monitor early disease progression. By this time, there are very few effective non-surgery treatment options available because of severe joint destruction. The objective of our research is to identify a profile of specific biomarkers for early detection and diagnosis of the OA disease process. In this study, we aim to validate mouse models of OA by correlating structural joint damage as measured by histology with serum levels of known OA biomarkers, and to identify novel biomarkers that may reflect the disease process. We will use partial medial meniscectomy as our experimental model, which will be evaluated in both wild type (WT) and a genetic mouse model with increased susceptibility to develop OA. The progression of joint damage will be assessed histologically by scoring knee sections for proteoglycan loss and articular cartilage degradation. In addition, serum collected at specific intervals will be used to assay for markers of collagen breakdown and synthesis and for novel markers of cartilage turnover. The discovery of reliable biomarkers will allow investigation of treatments that can be applied early in the disease process when they would be most effective.

26

DUAL-MODALITY IMAGING OF BOVINE ARTICULAR CARTILAGE USING OPTICAL COHERENCE TOMOGRAPHY AND PHOTOACOUSTIC MICROSCOPY

Mengyang Liu, Christopher Price, Bin Wang, Vincent Baro, Liyun Wang, Takashi Buma

Histology is the standard technique for analyzing spontaneous and collagenase induced osteoarthritis (OA) damage in articular cartilage. In experimental animal models of OA, histology requires sacrificing the animal and destroying the joint. Longitudinal studies would benefit from a non-destructive imaging technique with sufficient resolution and contrast to assess OA damage. Spectral Domain optical coherence tomography (SDOCT) is an emerging technique for high resolution biomedical imaging. SDOCT can produce thinly sliced cross-sectional images without physically slicing tissue for sample preparation. However, articular cartilage lesions are difficult to be determined solely with SDOCT due to the lack of image contrast. Photoacoustic microscopy (PAM) is a promising new technique that relies on optical excitation and ultrasonic detection. PAM produces high contrast images based on optical absorption. We hypothesize that combining SDOCT and PAM can provide three-dimensional visualization of OA damage in animal models. This dual-modality approach is minimally invasive and would enable longitudinal studies of animal models of OA. In this study, bovine osteochondral cores are treated with collagenase to induce OA-like changes. After various degrees of treatment, the cartilage surface is stained with India ink before imaging with SDOCT and PAM. The acquired SDOCT images reveal fine details of the cartilage topography, but do not visualize the ink-stained regions of collagenase-induced damage. The acquired PAM images readily show the distribution of India ink, but intact regions are invisible. Both intact and damaged regions are visualized by superimposing the SDOCT and PAM images. This study shows that the combining of SDOCT and PAM has the potential to non-destructively detect and monitor OA in animal models.

27

IN-SITU MEASUREMENTS OF CARTILAGE CONTACT AREA AND ITS IMPACT ON FRICTION

E. Bonnevie, V. Baro, L. Wang, D. Burris

Articular cartilage is the body's bearing material; it supports the loads of daily activity while enabling low friction sliding over decades of use. It comprises a soft porous matrix and an infiltrating fluid; during deformation, fluid pressure supports a significant fraction of the associated force and provides lubrication. The progressive degradation of this material seen in osteoarthritic (OA) joints ultimately results in joint failure. This study targets the contact and friction mechanics of cartilage to build a foundation for in-situ studies of OA initiation and progression. A custom instrument was designed to track contact area during microscale contact experiments with varying probe size and deformation rates. This work has demonstrated the following notable findings: 1) low friction and fluid pressurization was sustained for a sub-mm radius probe, 2) The contact area is a strong function of the probe radius and sliding speed; 3) the friction coefficient was proportional to contact area for both probes from 50μm/s-5,000μm/s. Contrary to typical engineering applications where increased sliding increases wear, the results suggest that joint motion is actually beneficial for maintaining low contact areas and effective lubrication.

28

BIOMECHANICAL RESPONSES OF MENISCUS TO CONTACT LOADING

Vincent Baro, Liyun Wang, David Burris

The meniscus of the knee is a complex fibrocartilagenous tissue that plays important roles in load-bearing. Meniscus tear is implicated in the early development of osteoarthritis. Although meniscus contains a biphasic structure (i.e., porous solid matrix saturated with interstitial fluid) similar to that of cartilage, its in vivo behaviors under various loading conditions is not well characterized. Using a custom micro-indenter, the mechanical behaviors of bovine menisci were determined. First, the hydrated meniscus explants (25 mm X 25 mm) were indented up to 50 micrometers at various speeds to determine the effective elastic modulus as a function of speed and the equilibrium aggregate modulus of the tissue. The spherical indenter (diameter 6.35 mm) was then moved reciprocally over 1.5 mm across the tissue at varying speeds to characterize the generated interstitial fluid support. As a comparison, articular cartilage explants from the same joints were also tested in the same fashion. Our preliminary results indicate that the biomechanical responses of meniscus to contact loadings differed from those of articular cartilage. The meniscus appeared to be less stiff than articular cartilage, as shown in previous studies. In both indentation and lift generation experiments, we found that meniscus was less sensitive to loading/movement speed than articular cartilage. The underlying mechanisms are currently being investigated. Together, these tests indicate that meniscus exhibits unique mechanical behaviors during joint loading and may account for its susceptibility to mechanical failures.

29

MONTE-CARLO SIMULATION OF SOLUTE TRANSPORT IN BONE CANALICULI

Xiaozhou Zhou, Liyun Wang

Osteocytes, which are embedded in mineralized matrix, rely on solute transport through lacunar-canalicular system for their survival and proper functioning. The space between canalicular wall and the osteocytic process is not completely void but filled with proteoglycan-like fibers. Experimental study in our lab suggested that this pericellular fiber matrix consists of heterogeneous porosities: the a small-scaled porosity associated with the spacing (2-7nm) of the glycosaminoglycans (GAG) side chains of proteoblycans and a larger-scaled porosity associated with the spacing of proteoglycan core proteins (order of 10 nm). To investigate the hindering effect of the pericellular matrix on solute transport inside canaliculi, we performed Monte-Carlo simulations of diffusion in a single canaliculus with varied patterns of two porosities and fiber distributions. Effective diffusion coefficients of solutes of different sizes in the canaliculus were calculated. Our preliminary results showed that the hindering effect of the fibers on the solute diffusion increased for larger solute molecules. However, the effect became less dependent on the solute size when solute molecules are too large to pass the small pores between GAG. This theoretical study, in combination of our experimental measures of in vivo transport studies, will help better understand the ultrastructure of the pericellular matrices surrounding the osteocytes, which is critical to quantify the cellular responses to their mechanical and fluid environments in both physiological and pathological conditions.

30

DOES BLOOD PRESSURE INFLUENCE SOLUTE TRANSPORT IN VIVO?

Wen Li, Joe Gardinier, Chris Price, Liyun Wang

Solute transport through bone plays an important role in tissue metabolism and cellular mechanotransduction. Both mechanical loading and vascular pressure have been proposed to drive interstitial fluid flow within the lacunar-canalicular system (LCS). Vascular pressure was shown to drive centrifugal tracer fronts away from the capillaries inside the bone in early tracer perfusion studies. However, later studies found that they were likely artifacts resulting from histological processing. To test our hypothesis that in vivo blood pressure enhances solute transport in the bone LCS, we performed paired fluorescence recovery after photobleaching (FRAP) experiements to directly measure and compare solute transport in live animals and after sacrifice within the same lacunae. Fluorescent tracers (sodium fluorescein) were injected in skeletly mature mice (n=5) via tail vein. After the tracers circulated for 20min to reach equilibrium in bone, the mouse left tibiae were exposed and stablized at the knee and ankle joints with the entire body immersed in a 37°C water bath. Six FRAPs per animal were performed on osteocyte lacunae to measure solute diffusivities. The animals were then sacrificed by CO_2 inhalation and FRAP experiments were repeated at the same lacunae. The diffusion coefficients were calculated using a custom MatLab program and a two-compartment model. Our results did not show any significant transport enhancement in the presence of blood pressure, and accepted the null hypothesis that blood pressure cannot enhances solute tranport in bone LCS. Our data help clarify a long-standing controverial issue on bone fluid flow and help provide a better understanding of the complex bone adaptation processes in both normal and diseases conditions.

31

IN SITU PERMEABILITY MEASUREMENT OF THE BONE LACUNAR-CANALICULAR SYSTEM (LCS)

Joseph Gardinier, Kei-Peng Jen*, Chris Townend*, Randall Duncan, Liyun Wang

** University of Villanova, Villanova, PA, USA*

At the tissue-level, stress/strain has been well documented in situ and in vivo, while quantification of the fluid pore pressure and fluid flow at the cellular level is often derived using poroelasticity models. We developed an in situ method to determine the LCS permeability of intact mammalian bone (a key parameter used in such models) based on the intramedullary pressure (IMP) response under axial loading. The IMP was measured during step loads of 50, 100, and 200 lbs compression via a pressure transducer inserted in the medullary cavity of the metacarpal bone of beagle dogs. The IMP response was fit to an exponential function and assumed to equilibrate throughout the vasular porosity to determine the pressure diffusion time constant. The permeability was derived from the time constant and average osteon radius. The radius of a single osteon was determined from transverse sections of each sample imaged under the microscope. At the onset of loading, IMP rapidly increased linearly with increasing magnitudes of induced strain. The time constant of pressurization and relaxation were on the order of 7 and 9 seconds respectively. The average osteon radius was 65 µm. As a result the pressure diffusion coefficient and permeability constant were on the order of 5 x 10-10 m2/s and 3 x 10-23 m2. Previous studies have reported the LCS permeability of dog bones to range between 1 x 10-19 to 1 x 10-22 m2. Experimental measurement of the LCS permeability provides more accurate characterization of in vivo pressure and flow environment surrounding the bone cells. This information is important to study bone adaptation and the pathological bone loss.

32

EFFECTS OF ENCAPSULATION ELASTICITY ON THE STABILITY OF AN ENCAPSULATED MICROBUBBLE

Amit Katiyar, Kausik Sarkar

Contrast microbubbles are intravenously injected for improved contrast of ultrasound images. They are also being explored for drug and gene delivery. To stabilize them against dissolution in the bloodstream, these bubbles are encapsulated with a nanometer-thick layer of proteins, lipids and other surface active materials.

The encapsulation decreases destabilizing surface tension and hinders gas permeation. We have modeled bubble dissolution that shows that these two mechnaisms can lengthen the bubble lifetime to just half an hour, and that too only in the case of extremely low surface tension (<1 mN/m). On the other hand, commercial encapsulated microbubbles at times show a shelf-life of months. With our model, we show that inetrfacial elasticity of the encapsulation is a new stabilizing mechanism that can provide long-term bubble stability. With our new model, we study bubble dynamics as a function of air saturation level, surface tension, interfacial elasticity, gas composition, gas solubility and encapsulation permeability. All encapsulated bubbles dissolve in undersaturated medium. In a saturated medium, an encapsulated bubble is found to achieve a long-time stable radius, when the interfacial elasticity is larger than the equilibrium surface tension. For bubbles with interfacial elasticity smaller than the equilibrium surface tension, stable bubbles of non-zero radius can be achieved only when the saturation level is greater than a critical value. Even if contrast microbubbles initially contain a gas other than air, bubbles that reach a stable radius finally become air bubbles. The model is applied to an octafluoropropane filled lipid-coated bubble of diameter 2.5 micrometer.

33

PGE2 MODULATES OSTEOBLASTIC CYTOSKELETON REORGANIZATION AFTER FLUID SHEAR STRESS EXPOSURE

W. Yang, X. Gong*‡, J. Pan*‡, L. Wang, R. Duncan

‡ University of Delaware, Newark, DE, USA

** Chongqing University, China*

Introduction: In responding to mechanical stimulation, osteoblastes change the structure of the cytoskeleton, and cytoskeleton plays a central role in regulation of mechanotransduction at the cellular level. PTH treatment was shown to increase the mechanosensitivity of osteoblasts by disrupting the actin filaments. We hypothesize that PGE2 increases the mechanosensitivity by accelerating the recovery of cytoskeleton to basal level after fluid shear stress exposure, which can potentially increase the sensitivity of osteoblasts to subsequent mechanical loading.

Method: To test the effect of PGE2 post-FSS cytoskeleton remodeling, 3 groups were designed: (1) static (2) FSS + DPBS (3) FSS + PGE2. PGE2 (1μM, Sigma) diluted in DPBS was added into petri dishes 15min FSS. After incubation without disturbance for 15min, cytoskeleton was visualized using fluorescent immunostaining. DPBS was used as a control treatment.

Results: MC3T3-E1 osteoblasts responded to 15min FSS with an increase in F-actin formation and the F-actin staining remained strong after 15min resting in PBS. Treatment of PGE2 (1μM) for 15min significantly decreased the F-actin intensity compared with the PBS treated group and the decreased F-actin staining was comparable to that of the static control group.

Discussion: Previous studies demonstrated that osteoblasts adapt their responses to mechanical stimuli by modulating cytoskeleton organization and increasing cellular stiffness, leading to the presence of refractory periods during continuous fluid shear stimulation.
Our results showed that PGE2 is capable to accelerate the cytoskeletal recovery to the static state after FSS exposure. We speculate that PGE2 may decrease the load-induced cell stiffness, and serves as a potential factor to increase the mechanosensitivity of osteoblasts.

34

STEPWISE INCREASING AND DECREASING FLUID SHEAR STRESSES DIFFERENTIALLY REGULATE THE FUNCITONS OF OSTEOBLASTS

Bin Wang*‡, Jun Pan*‡, Tingxiu Zhang*, Li Mi*‡, Liyun Wang

‡ University of Delaware, Newark, DE, USA

** Chongqing University, China*

It is well accepted that osteoblasts respond to fluid shear stress (FSS) depending on the loading magnitude, rate, and temporal profiles. Although in vivo observations demonstrated that bone mineral density changes as the training intensity gradually increases/decreases, whether osteoblasts perceive such slow temporal changes in the strength of stimulation remains unclear. In this study, we hypothesized that osteoblasts can detect and respond differentially to the temporal gradients of FSS. To test the hypotheses, stepwise varying FSS was applied on primary osteoblasts and osteogenic and resorption markers were analyzed. The cells were subjected to FSS increasing from 5, 10, to 15 at a step of 5 dyn/cm2 or decreasing from 15, 10, to 5 dyn/cm2 for either 6 or 12 hours. In a subset experiment, the cells were stimulated with stepwise increasing or decreasing FSS at a higher step (10 dyn/cm2) for 12 hours. Our results showed that, with the step of 5 dyn/cm2, stepwise increasing FSS inhibited the osteoclastogenesis with a 2- to 3-fold decrease in RANKL/OPG gene expression versus static controls, while the stepwise decreasing FSS increased RNKL/OPG ratio by 2- to 2.5-fold versus static controls. Both increasing and decreasing FSS enhanced alkaline phosphatase expression and calcium deposition by 1.1- to 1.8 fold versus static controls. For a higher FSS temporal gradient (10 dyn/cm2 , 12 h), the increasing FSS enhanced expression of alkaline phosphatase expression and calcium deposition by 1.2 fold, while the decreasing FSS slightly inhibited them by -10%. Our results suggested that osteoblasts can detect the slow temporal gradients of FSS and respond differentially in a dose-dependent manner.

35

BLOCKING DOWNSTREAM MOLECULES OF BONE MORPHOGENETIC PROTEIN SIGNALING INDUCED IN VIVO BONE FORMATION

B. Bragdon*‡, S. Thinakaran, L. Gurski, O. Moseychuk, W. Beamer†, A. Nohe

‡ University of Delaware, Newark, DE, USA
** University of Maine, Orono, ME, USA*
† The Jackson Laboratory, Bar Harbor ME, USA

Bone Morphogenetic Proteins (BMPs) are potent growth factors with osteoinductive properties. Due to these properties rhBMP2 is used in treatment for spinal fusions and long bone fractures. However, there are multiple drawbacks with the use of rhBMP2, high cost, the need for high doses to induce adequate bone formation, and large variations in response among patients. Therefore, an alternative to the rhBMP2 is desirable to exploit downstream molecules of the mechanism at which BMP2 is osteogenic.

BMPs signal through a hetero-oligomeric complex of BMP type I and type II receptors that activate the Smad pathway. We identified a novel interaction between Casein Kinase II and BMP type Ia receptor at the membrane of C2C12 cells. A peptide was designed to block this interaction which led to the initiation of BMP-induced Smad signal and increased mineralization in the absence of BMP2. The objective of this study was to test the osteoblastic differentiation properties of the peptide for induction of bone in vivo. The peptide was injected subcutaneously once per day for 5 days over calvaria of 4 week old C57BL/6J mice (n= 21 per group). Mice were necropsied at 8 weeks of age and calvaria were measured by PIXImus dual energy X-ray densitometry for areal BMD. Results showed a significant increase in areal BMD compared to control groups. Further, histologically examined calvaria showed an increase in bone width. These data suggest the peptide is osteogenic and could provide a cost effective alternative to rhBMP2.

36

BMP2 DEPENDENT SMAD SIGNALING INITIATION IN CAVEOLAE

O. Moseychuk, J. Bonor, B. Bragdon*, A. Nohe

** University of Maine, Orono, ME, USA and University of Delaware, Newark, DE, USA*

Bone Morphologic Proteins (BMPs) are growth factors that play a role in cell differentiation, proliferation, apoptosis, and morphogenesis. BMP2 is FDA approved for spinal fusion and long bone fractures due to its role in skeletal development and maintenance, but little is known about the initiation of signaling on the receptor level. Current literature suggests that initiation of BMP2 mediated Smad 1, 5, and 8 signaling occurs on the plasma membrane followed by receptor endocytosis via clathrin coated pits. However, our studies demonstrate ligand binding to BMP receptors (BMPRs) followed by receptor activation and initiation of Smad 1, 5, and 8 signaling is localized to caveolae, a membrane domain known to co-localize with BMP receptors.

Fluorescent Guided Force Microscopy, a combination of Atomic Force Microscopy (AFM) and advanced confocal imaging, was developed to quantify binding affinity of the ligand with free receptor on the surface of live cells. BMP2 was covalently linked to an AFM tip, and fluorescently tagged Caveolin-1 was used as a marker to visualize caveolae. Binding events on the plasma membrane of C2C12 cells showed binding of BMP2 predominantly in caveolae. We then performed fractionation of the membrane based on the lipid composition and showed that initial phosphorylation of BMPRIa and Smad 1, 5, and 8 occurs in caveolae as early as 10 min post stimulation with BMP2. Initiation of signaling is followed by endocytosis and degradation in lysosomes after 45 min post stimulation. From these data we concluded that ligand binding and initial phosphorylation of BMPRIa and BMP2 signal transduction via Smad 1, 5, and 8 takes place in caveolae.

37

CAVEOLAE ARE KEY SIGNALING CENTERS FOR BMP DEPENDENT STEM CELL DIFFERENTIATION AS DEMONSTRATED BY NOVEL IMAGING AND SYSTEMS BIOLOGY APPROACHES

Sven Saldanha, Prasad Dhurjati, Anja Nohe

Systems biology is a relatively young field, changing traditional experimentation approaches by minimizing experimentation time and costs, as well as providing a smaller domain in which to focus experimentation efforts. Bone Morphogenetic Proteins (BMPs) are vital in embryonic development and normal cell growth, and shown to induce bone formation. Elucidation of the mechanism by which BMP signaling occurs could potentially help to mitigate osteoporosis, through selective stem cell differentiation into osteoblasts, cells responsible for bone formation. The understanding of BMP signaling is currently very poor and systems biology approaches have not successfully been developed to aid in the understanding of the signaling process. A multidisciplinary effort has been employed to expedite the experimentation process and determine which cellular domains are most important in BMP signaling. The current dogma of BMP signaling states that clathrin coated pits (CCPs) are the signaling centers. It has been shown that the presence of BMP induces nucleocytoplasmic shuffling of BMP receptors between domains on the cell membrane, including CCPs and caveolae, producing a Smad signal. A mathematical model was constructed, primarily considering the activation of the Smad signaling pathway, one of the main BMP pathways, upon stimulation of BMP-2. The results of the model indicate that caveolae provide a considerably larger contribution to signaling than CCPs, directly conflicting with recent publications. Novel Atomic Force Microscopy techniques have experimentally validated these claims of the model. The discovery of the importance of caveolae instigates the exploration of factors in caveolae involved in BMP signaling.

POSTER PRESENTATIONS

Motor Control

38

GAIT KINETICS ARE AFFECTED BY THE USE OF HANDRAILS

Nicole Zahradka, Jill Higginson

Upper extremity movements and forces have important implications for rehabilitation of pathological gait. Patients with impaired gait due to stroke often rely on an outside source to assist them. The amount of force used on the handrail may influence loads on the lower extremity. The objective of this study was to evaluate the effect of handrail use on the kinetics during treadmill walking in healthy subjects. We compared (1) magnitudes of handrail and ground reaction forces and (2) left and right handrail forces when only one handrail is used. Three healthy subjects walked at their self selected speed under four conditions (no handrail (NHR), right handrail only (RHR), left handrail only (LHR), and both handrails (BHR)). An 8 camera Motion Analysis system (60Hz, Santa Rosa, CA), two force plates and two force transducers (1080 Hz, Bertec Corp., Columbus, OH) were used. The data showed the four conditions had varying peak forces during the first 30 percent of the gait, with NHR having the greatest GRF, and then had approximately the same peak force before right toe off. This suggests that force was applied to the handrail for balance after heel strike and no longer needed once stabilized. The handrail forces for the BHR condition were approximately twice as great as the handrail forces when only one of the handrails were held. The right handrail was out of phase with the right ground reaction force, similar to arm swing. The left handrail force had similar forces and timing patterns to the right. It is likely that subjects with a pathological gait pattern who use handrails have altered joint loads which should be considered during rehabilitation and other treadmill studies.

39

EFFECTS OF THE LOAD FORCE RANGE AND FREQUENCY ON GRIP FORCE COORDINATION IN STATIC MANIPULATION

Mehmet Uygura, Paulo de Freitas‡, Slobodan Jaric*

‡ University of Delaware, Newark, DE, United States
** Cruzeiro do Sul University, São Paulo, Brazil*

A frequency associated deterioration of the hand grip (GF; normal component of force acting at the digits-object contact area) and load force (LF; the tangential component) coordination has been shown in a variety of repetitive manipulation tasks. However, it remains unknown whether the effect originates from the task frequency per se, or from the rate of LF change (a prediction that could be derived from the minimum jerk hypothesis) which increases with both LF frequency and range. The aim of the study was to distinguish between the effects of LF frequency and LF range in static manipulation tasks. Subjects (N=15) exerted a sinusoidal LF pattern against an externally fixed instrumented handle at 5 different LF frequencies (0.67-3.33 Hz) and ranges (6-30 N). The results revealed weak and mainly non-significant effects of both LF range and frequency on GF scaling (GF/LF ratio). However, both GF-LF coupling (assessed by correlation coefficients) and GF modulation (change in GF relative to LF variation) demonstrated a prominent decrease associated with LF frequency, but not LF range. The observed findings were interpreted by switching between hypothetical synergies of GF and LF producing muscles separately employed in the phases of the increasing and decreasing forces. From the practical aspect, however, the results suggest that the frequency, but not the LF range should be taken into account when designing rhythmic manipulation tasks, developing standard tests of hand function based on GF-LF coordination, or comparing the data from different studies.

40

HAND FORCE COORDINATION: EFFECTS OF HAND POSITION AND ORIENTATION IN EGOCENTRIC SPACE

Xin Jin, Mehmet Uygur, Slobodan Jaric

Performance of a number of motor actions, such as the accuracy of pointing or kinematic patterns of grasping movements, depends on their location within the egocentric space. Although an elaborate coordination of the hand grip force (GF) and load force (LF) has been demonstrated in a variety of manipulation tasks, the possible effects of the task location within the egocentric space have not been studied yet. The aim of the study was to compare the patterns of GF control between the central and peripheral locations of the egocentric space, as well as to assess the preferred manipulation directions. Subjects (N=12) exerted a 1.33 Hz sinusoidal LF in each of two opposite directions against an externally fixed instrumented handle. The handle was oriented along either the vertical, or medio-lateral, or frontal axis, and placed either at the central or peripheral positions of the subject's egocentric space. The results generally revealed an overall high level of GF-LF coordination as seen through a relatively low GF/LF ratio and high GF-LF correlations with the time lags between them close to zero. However, neither the differences among the handle orientation nor between the task directions were observed, while the advantage of the central over the peripheral positions was relatively small and partly inconsistent. Therefore, we conclude that properties of GF control in static manipulation tasks may not be dependent on the position and direction of the manipulative actions. These findings provide additional evidence that the control of GF and the control of pointing and grasping movements could be based on partly different neural mechanisms.

41

CORTICAL MOTOR MAPPING IN CEREBRAL PALSY

T. Kesar, L. Sawaki‡, N. Cabrera‡, K. Kolaski‡, B. Smith‡, M. O'Shea‡, A. Koman‡, G. Wittenberg‡*

‡ Wake Forest University, Winston-Salem, NC, USA
** University of Maryland, College Park, MD, USA*

Cerebral palsy (CP) presents with diverse symptoms. However, diagnostic classifications and interventions in CP are currently largely empirical and based on clinical symptoms. Better understanding of the neural correlates of CP, using tools such as transcranial magnetic stimulation (TMS), can help develop improved classification schemes and maximize the effectiveness of neuro-rehabilitation.

We used TMS to identify hand (flexor digitorum indicis) and ankle (tibialis anterior) cortical maps in13 children with CP. Dependant variables were map volume (size) and center of gravity (location). We hypothesized that smaller map volume, greater overlap between maps, and lateralization of maps would correlate with worse function (i.e., lower GMFM and Melbourne upper extremity scores).

Among 7 individuals with right Hemiplegia, we found that the affected hand could be mapped on the ipsilateral (N=4), contralateral (N=2), or both (N=1) motor cortices. The 6 diplegic individuals showed either both contra- and ipsi-lateral (N=2) or contralateral (N=4) cortical hand maps. Six individuals showed maps for both the contra- and ipsi-lateral hands on the same motor cortex. Another finding was lateralization of ankle maps, with overlap between the hand and ankle maps (N=4). There was a positive relationship between map volume of the affected hand and age. Also, greater lateralization of hand maps correlated with decreased hand function. In individuals with ipsilateral maps, better hand function was associated with lesser distance between the right and left hand maps.

Our findings suggest a discrepancy between TMS-mapping data and the clinical classification for CP individuals, and provide information about cortical reorganization following CP. The current study is a step towards defining relationships between pathophysiology and functional impairments in CP.

POSTER PRESENTATIONS

Methods & Modeling

42

MOTION ANALYSIS DATA MANAGEMENT USING A RELATIONAL DATABASE

Ben Roewer, Lynn Snyder-Mackler

Background: Motion analysis is a widely-adopted tool in biomechanics research that can generate large amounts of data from a single testing session. Currently, there are no standards in place for managing these data; they are commonly stored on a combination of local computers, external hard drives, or server hard drive space. While these may be safe, redundant storage methods for small amounts of data, they do not scale well to larger studies. Retrieving subsets of these data can be time-consuming and error-prone. Storing motion capture data in a relational database can maintain data security and redundancy, but also make data retreival more accurate and efficient. Methods: A relational database schema was created in PostgresSQL. A primary table was developed to store subject-specific information and provide a foundation for joining clinical, kinematic, kinetic, and EMG data. Custom Matlab code was written to identify motion analysis data collected during an on-going clinical trial and insert them into the database. Sample SQL queries were written and executed in order to examine subsets of the data. Outputs from those queries were compared to data manually retrieved from individual source spreadsheets. Results: Our Matlab code located over 1 million rows of data and inserted them into the database. Retrieving data by hand from the source spreadsheets took anywhere from 4 to 8 hours depending on the number of subjects being examined and the complexity of the information in question. In comparison, SQL queries were written and executed in 5 to 30 minutes regardless of the number of subjects being examined. Conclusion: Using a database to store motion analysis data profoundly reduces the time needed to retrieve data and improves the accuracy of the results.

43

PREDICTING THE MAXIMUM FORCE GENERATING ABILITY OF ANKLE PLANTARFLEXOR MUSCLES USING SUBMAXIMAL CONTRACTIONS

Sarah Flynn, Brian Knarr, Ramu Perumal, Trisha Kesar, Stuart Binder-Macleod

Muscle weakness caused by muscle atrophy versus decreased neural drive from the nervous system (e.g. following a stroke) can be differentiated by comparing the maximum force generating ability (MFGA) of a muscle to the maximum volitional contraction an individual can produce. Unfortunately, there are presently no reported practical methods for calculating the MFGA for individuals with motor impairments due to CNS pathology. The purpose of the present study was to compare 5 methods of predicting the MFGA in muscles of able-bodied individuals that could potentially be applied to neurologically impaired populations. The Burst Superimposition, Twitch Interpolation, Doublet Interpolation, Twitch-to-Tetanus Ratio, and Adjusted Burst Superimposition methods were performed on ankle plantarflexor muscles of 13 healthy subjects contracting at submaximal volitional efforts (25%, 50%, and 75% of their measured MFGA). Percent errors were calculated between the predicted MFGAs from these tests at submaximal volitional efforts versus the measured MFGA. Kruskal Wallis and post-hoc tests showed that the % errors between predicted and measured MFGAs were lowest for the Adjusted Burst Superimposition test ($p>.05$) at each volitional level except for the Twitch-to-Tetanus Ratio method at the 25% and 50% levels and the Doublet Interpolation method at the 75% level. Compared to all other tests, the Adjusted Burst Superimposition test resulted in the most consistent predictions of MFGA at submaximal volitional efforts (Interquartile Range of % Error=12.20). Thus, the Adjusted Burst Superimposition test was concluded to be the most accurate predictor of MFGA among the methods compared. Future studies are needed to test the feasibility of using the Adjusted Burst Superimposition method with individuals post-stroke.

44

EMG-DRIVEN AND OPENSIM SUBJECT SPECIFIC MODELS: A COMPARISON OF MUSCLE FORCES

David Olchowski, Thomas Buchanan, Jill Higginson

Many different optimization approaches exist to solve the problem of muscle redundancy and estimate individual muslce forces. EMGs have been used in previous studies to derive subject-specific muscle parameters that match inverse dynamics, and generic models that redistribute loads between muscles crossing the joint have also been used. Our study incorporated optimized subject-specific parameters from an EMG-driven model to be used in place of OpenSim's generic values. Muscle foces were compared to determine how well OpenSim matched the EMG-driven output.

Three healthy young subjects were examined while walking on a split-belt, motorized treadmill at self selected speeds. Kinematic and kinetic data as well as EMGs were collected from 4 lower leg muscles (TA, MG, LG, Sol). The EMG-driven model incorporates a simulated annealing algorithm that optimizes the maximum isometric force (MF), tendon slack length (TSL), and optimial fiber length (OFL) within physiologically relevant ranges. For all three subjects the optimized values of TSL and OFL resulted in differences within 9% of generically scaled values. Muscle force magnitude and timing were comparable across all muscles. We perturbed a total of 12 parameters across 4 muscles while previous studies have looked at the sensitivity of perturbing one parameter and determining the differences in muscle forces. We believe the EMG-driven model may better represent actual physiological values for these subjects because the parameters were optimized. The EMG-driven model and OpenSim use fundamentally different cost functions and it is encouraging that our results show that the two models can still produce similar muscle forces in both magnitude and timing.

45

IS MUSCLE TIMING RELATED TO MUSCLE FORCE-LENGTH AND FORCE-VELOCITY RELATIONSHIPS IN RECUMBENT PEDALING?

Nils Hakansson, Jill Higginson

The contribution of individual muscle forces to a movement can elucidate the neuromuscular coordination in healthy and pathologic conditions. A biomechanical model can estimate individual muscle forces by solving the redundancy problem, i.e. distributing joint loads to the multiple muscles that cross the joint. The traditional approach has been to distribute forces based on the muscles' physiological cross-sectional area. This distribution approach has not been experimentally verified. Moreover, studies have demonstrated that the underlying assumptions are not valid under many conditions. As an alternative approach, this study sought to determine whether the muscle force-length and force-velocity relationships influence muscle activity timing and can thereby serve to address the redundancy problem. To test this hypothesis, muscle on-off timing were determined from EMG data recorded from 8 muscles of the right leg of 15 subjects as they pedaled a recumbent ergometer at 90 rpm and 250 W. The normalized muscle fiber lengths and velocities corresponding to the muscle timing were determined from generic musculoskeletal model of recumbent pedaling. The results indicated no discernable relationship between muscle activity and normalized fiber length. The soleus, vastii, and semimembranousus muscles were active when in the plateau region, the medial gastronemius and rectus femoris were active in the ascending region, and the gluteus maximus and biceps femoris short-head were active in the descending region of the force-length curve. The tibialis anterior and rectus femoris were the only muscles that contracted solely concentrically. The absence of a discernable pattern between the muscle force-length and force-velocity relationships and the activity of related muscles, e.g. flexors vs. extensors, mono vs. bi-articular, implies that these relationships would not be useful to solving the redundancy problem in recumbent pedaling.

PODIUM PRESENTATIONS

Session 1

1

A PROSPECTIVE STUDY OF LOADING VARIABLES IN FEMALE RUNNERS WHO DEVELOP PLANTAR FASCIITIS

Bradley Bowser, Joseph Hamill*, Irene Davis

** University of Massachusetts, Amherst, MA, USA*

Plantar fasciitis is reported to be one of the top 3 overuse injuries sustained by runners. The primary cause of this injury is often attributed to a repetitive stress or overloading of the plantar fascia. However, few studies have examined the potential role that loading variables may play in this injury. The purpose of this study was to compare vertical loading rates (instantaneous(VILR) & average(VALR)), vertical impact peak (VIP), and peak positive acceleration (PPA) between female runners who go on to develop plantar fasciitis (PF) and runners with no reported running injury (CON). Methods: Tibial accelerometry and ground reaction forces were collected on female runners (ages 18-45) who were running a minimum of 20 miles/week. Runner's mileage and injuries were tracked monthly for 2 years. During the follow-up period, 10 participants (age=28±8yrs) running 23±8 miles/week, were diagnosed by a clinician with plantar fasciitis. The CON group consisted of 10 runners (age=24±8yrs), running 23±9 miles/week who never reported a running injury during the 2 year follow-up. Percent difference and effect size (ES), were used to quantify group differences for VILR, VALR, VIP, and PPA of the tibia. Results: Loading rates were 40% higher in the PF group for both VILR and VALR. The external loads were also higher in the PF group with VIP and PPA being 15% and 76% higher, respectively, than the CON group. ES was considered large for all variables (VILR, d=1.20; VALR, d=1.29; VIP, d=0.89; PPA, d=0.98). Conclusions: The results of this prospective data suggest that runners who have high VILR, VILR, VIP, and PPA while running may be predisposed to developing plantar fasciitis. Supported by DAMD17-00-1-5.

2

PERTURBATION TRAINING IMPROVES GAIT PATTERNS IN ACL DEFICIENT FEMALES

Stephanie Di Stasi, Lynn Snyder-Mackler

Research has established that women are at higher risk for ACL injury than men. Women are also more likely to be classified as non-copers, ACL deficient athletes who have knee instability with daily activities. Non-copers present with the poorest functional performance after injury but have shown their adaptability by resolving aberrant knee motion following a neuromuscular treatment called perturbation training. Sagittal plane kinematics and kinetics of healthy men and women are similar. Therefore, observed differences in gait between genders after ACL injury or perturbation training can be attributed to a gender-specific response. The walking gait of 21 non-copers (9 females, 12 males) was evaluated acutely after injury, following perturbation training, and 6 months after ACL reconstruction using standard motion analysis techniques. Sagittal plane hip and knee angles and moments at peak knee flexion (PKF), and weight-acceptance knee excursions were calculated. Before training, only the women demonstrated kinematic differences between limbs both at the knee (Inv: 20.4° ± 6.1; Uninv: 26.4° ± 5.4; p=0.008) and the hip (Inv: 20.4° ± 7.6; Uninv: 24.4° ± 6.1; p=0.018). After perturbation, knee and hip angles were similar. Pre-training limb asymmetries in knee (Inv: 14.3° ± 5.8; Uninv: 18.2° ± 5.7) and hip flexion excursion (Inv: 11.5° ± 4.7; Uninv: 6.9° ± 4.2) also resolved after perturbation (Knee - Inv: 14.8° ± 5.8, Uninv: 16.8° ± 5.9; Hip – Inv: 9.7° ± 3.8, Uninv: 7.9° ± 4.3). Men demonstrated symmetrical knee and hip kinematics after injury and perturbation did not alter their movement behaviors. Asymmetrical hip and knee moments between genders were not found. Our findings support that non-copers are a variable group, and specifically, that gender is a meaningful subgroup in this cohort.

3

SPECIFICITY OF THE MUSCLES ABOUT THE KNEE DURING A STATIC STANDING TASK: THE UNIQUE SYNERGY BETWEEN THE VASTI AND HAMSTRINGS

Toran MacLeod, Lynn Snyder-Mackler, Kurt Manal, Thomas Buchanan

Muscle synergies have been examined during a variety of tasks and many theories about muscle coordination have been proposed. We examined neural control of muscle synergies about the knee during a standing posture. Electromyographic activity of eleven muscles was examined while subjects stood with their bare feet on two force plates. Subjects were instructed to equally divide their body weight between the force plates and simultaneously produce forces tangential to the plane of the force plate (20 degree increments in the forward-backward-medial-lateral plane) with their lead foot. Subjects were given visual feedback of their lead foot forces on the force plate and were asked to use this information to produce specific static postures. The gastrocnemii were very active when subjects pushed their foot forward. The adductors were active when subjects tried to move their foot medially and gluteus medius was active when the foot was pushed laterally. These results were not surprising as they correspond to the natural activity of the muscles. However, both vasti did not follow this expected pattern and were most active when subjects tried to push their legs backwards and were relatively inactive when subjects pushed their legs forward. The same was not true for the rectus femoris, which was active primarily in the forward direction. These results are very surprising. The vasti are not often observed to act synergistically with the hamstrings except during co-contraction. The lack of vasti and hamstrings activity during forward pushes indicates that this was not a typical co-contraction pattern. Further investigation is warranted on the use of the vasti muscles during these postural control tasks.

4

GAIT AFTER UNILATERAL TOTAL KNEE ARTHROPLASTY: FRONTAL PLANE ANALYSIS

Ali Alnahdi*‡, Joseph Zeni, Kevin McGinnis, Lynn Snyder-Mackler

** University of Delaware, Newark, DE, USA*
‡ King Saud University, Saudi Arabia

Introduction: After unilateral Total Knee Arthroplasty (TKA), osteoarthritis (OA) progresses in the contralateral knee. Patients after TKA present with altered walking mechanics that might change the loading in the contralateral side and predispose it to disease progression. This study aimed to examine knee mechanics of in individuals 6 months and 1 year after unilateral TKA, then to compare the mechanics of the TKA group to a healthy control group.

Methods: 31 and 44 subjects who are 6 months and 1 year after unilateral TKA and 20 control subjects were recruited. Gait analysis was performed. Knee joint angles, moments, angular impulse, and spatio-temporal parameters were calculated. Differences between sides over time were examined in the TKA subjects. The operated and non-operated knees of TKA group were compared independently with the control group.

Results: In TKA subjects, No changes were observed from 6 months to 1 year in peak knee adduction angle, peak knee adduction moment and walking speed, while the stance time and knee adduction impulse decreased. The non-operated knee in both TKA groups had higher adduction angle and adduction moment. Comparing TKA group to the control group revealed no difference between both the operated and non- operated knees and controls in peak adduction angle, peak adduction moment , adduction impulse, and stance time (P>0.05). The control group walked faster and with longer step length compared to the TKA group. The TKA group needs to take more steps to travel the same distance compared to controls thereby their repetitive exposure to loading would increase and that might explain the predictable progression of OA in the non-operated knee.

5

A METHOD FOR CHARACTERIZING COMBINED ANKLE-FOOT DYNAMICS DURING STANCE PHASE OF GAIT

Kota Takahashi, Alexander Razzook, LaKisha Guinn, Elisa Schrank, Steven Stanhope

The ankle-foot complex (AFC) plays a critical role during walking for generating forward propulsion and maintaining upright support. In individuals with a prosthetic AFC, the ability to achieve optimal gait patterns may be dependent on the prosthesis' ability to effectively mimic the biomechanical characteristics of a natural AFC. However, dynamic prosthetic feet often do not have well defined ankle joints and may inhibit the capability for direct comparisons with a natural ankle. Therefore, the purpose of this study was to present a universal method for quantifying the dynamics of the combined AFC during stance phase of gait. Our proposed method involved the analyses of the AFC roll-over shapes (ROS) and the ROS-dynamics. The ROS quantified the net deformations of an AFC by expressing the center-of-pressure (COP) into a shank-based coordinate system (SCS), while the ROS-dynamics quantified the external forces responsible for the net deformations by reporting the ground reaction force (GRF) into the SCS. Six able-bodied subjects underwent instrumented gait analysis while walking at a scaled velocity of 0.8 statures/second. The mean total displacement of COP SCSy, which described the total anterior progression relative to the shank, was 0.12 (+/- .01) statures. The mean total displacement of COP SCSz, which described the longitudinal pseudo deformation of the AFC, was 0.026 (+/- .005) statures. The GRF SCSy was negative for majority of stance (91.9 +/- 5.2 %), suggesting that the external forces were acting posteriorly on the AFC. The mean maximum GRF SCSz was 1.2 (+/- .04) body weights. The major advantage of this method was that the AFC can be analyzed as one unified segment, facilitating objective comparisons between natural and prosthetic AFCs.

PODIUM PRESENTATIONS

Session 2

1

STRAIN-SOFTENING INTERFACIAL ELASTIC MODELS FOR THE CHARACTERIZATION OF ULTRASOUND CONTRAST AGENTS

Shirshendu Paul, Kausik Sarkar

Intravenously injected micron-sized gas bubbles (typical diameter < 10μm) have been approved as contrast agents for cardiovascular imaging using ultrasound in USA, Europe and elsewhere. These bubbles have a thin encapsulation of proteins/lipids/surfactants that prevents premature dissolution. However, the encapsulation also critically affects the scattered response of these bubbles. Hence, the design of new contrast agents requires a proper characterization of the encapsulation and the establishing its role in determining the scattered response of these bubbles. An interfacial elastic model which characterizes the encapsulation using surface rheological parameters has previously been proposed by our group. To better characterize the encapsulation by incorporating strain-softening behavior of the encapsulation for large deformations, two non-linear extensions of the previous elasticity model have been employed. One assumes linear variation of elasticity with the area fraction and the other assumes exponential variation. The model parameters are estimated by matching linearized model dynamics with measured attenuation data for contrast agent Sonazoid [GE Healthcare]. Validity of the models is then investigated by comparing their predictions of scattered non-linear response at higher excitations against experimental measurements. The predicted fundamental and subharmonic responses from the nonlinear models match very well with the experimental data. Imposing condition of non-negativity on the effective surface tension term shows a “compression-only” behavior for the bubbles as has been observed experimentally for some contrast agents.

2

ATROPHY OF POST-STROKE PLANTAR FLEXORS

John Ramsay, Thomas Buchanan, Jill Higginson

Reduced strength and joint moments have been observed following stroke. However, it is unclear whether this weakness is primarily due to muscle atrophy or impaired activation. Plantar flexor weakness has been related to various gait impairments in post-stroke populations, which makes them of particular interest during rehabilitation. Since muscle strength is proportional to its size, the amount of muscle atrophy a muscle experiences is important in determining its force generating capability. Accounting for intramuscular fat content must be considered when determining the extent of muscle atrophy in order to prevent overestimation of the muscle’s true strength capability. The purpose of this study was to quantify the size and fat content in post-stroke hemiparetic plantar flexor muscles.

Fat-adjusted plantar flexor (e.g.soleus, medial and lateral gastrocnemius) muscle volumes were determined for eight post-stroke subjects using MR images and digital reconstruction software.Overall, the plantar flexors were significantly smaller on the weak side (482 cm3) compared to the strong side (642 cm3) ($p<0.001$), and had a significantly higher fat content ($p<0.05$). Individually, however, only the medial and lateral heads of the gastrocnemius were significantly smaller on the weak side, which suggests that the gastrocnemius atrophies preferentially over the soleus. This may occur because the soleus includes more type I fibers and may atrophy at a slower rate. It may also be possible that uniarticular muscles like the soleus serve as prime movers and may be spared while biarticular muscles like the gastrocnemius is recruited less post-stroke.

 Denotes Podium #

3

ARTICULAR LOADING IN PEOPLE WITH KNEE OSTEOARTHRITIS

Deepak Kumar, Katherine Rudolph, Kurt Manal

INTRODUCTION: Magnitude and distribution of articular loading is implicated in the development and progression of knee osteoarthritis. In this paper we present results of an EMG-driven modeling approach to predict articular loading for people with knee osteoarthritis and matched controls.

METHODS :An EMG-driven musculoskeletal model was used to compute joint loading at the knee during the stance phase of gait for 16 people with medial knee OA and 12 controls. Optimized parameters from one trial were used to predict medial and lateral compartment loading for three other trials for each subject. Mean of the three trials was used in analysis.

RESULTS: Loading values for our healthy subjects match with the data from the instrumented knee. Compared to controls, OA subjects were more malaligned, walked slower and had smaller angular excursions. After accounting for walking speed, OA subjects had higher absolute (in N) medial loading in early and late stance. The differences were not seen after normalizing to BW. OA subjects bore greater percentage of total load on medial compartment throughout stance with lateral compartmental lift-off seen for some. Mass and frontal plane angle (measure of dynamic malalignment) explained 46% of variance in 1st peak medial loading in OA subjects.

CONCLUSIONS: The EMG-driven musculoskeletal model predicted differential loading between the subjects with and without OA. Higher absolute loading would indicate a greater risk for cartilage damage assuming a critical threshold for cartilage breakdown. Higher and persistent medial loading, with lower excursions could lead to smaller areas of cartilage being exposed to detrimental loads and progression of medial knee OA. The results also support the fact that body weight (obesity) and alignment are risk factors for progression of OA.

4

PERLECAN-HA BASED BIOMATRICES PROLONG THE ANABOLIC EFFECT OF BMP2 IN MICE ARTICULAR CARTILAGE

Padma Pradeepa Srinivasan, Sarah Yerkes, Weidong Yang, Amit Jha, Xinqiao Jia, Mary Farach-Carson, Catherine Kirn-Safran

Bone Morphogenetic Protein 2 (BMP 2), a heparan binding growth factor has emerged as an alternate strategy for cartilage regeneration. However, its small size and rapid lymphatic clearance demands an effective delivery system for prolonged periods. For this reason, our goal is to use Perlecan Domain1 covalently bound to Hyaluronic acid (HA-PlnD1) as a novel delivery system for time dependant release of BMP2 and stimulate matrix expression by articular cartilage cells in a mouse model of osteoarthritis (OA). OA-like damages are induced by intraarticular injections of papain (1%). Seven days post papain injections, knees were injected with either HA PlnD1 preincubated with BMP2, HA-PlnD1 alone or saline. The knees were dissected at day 7 and day 14 following these treatments and analyzed by histological and immunohistochemical procedures. Knees treated with HA-PlnD1/BMP2 had lesser damage and showed increased proteoglycan expression when compared to control knees. In addition, the HA-PlnD1/BMP2 treated knees showed enhanced detection of aggrecan by immunohistochemistry. HA-PlnD1 biomatrices acts as an efficient in vivo delivery system for BMP2 and prolong the action of BMP2 in mice articular cartilage. This is evident from the attenuated damage and the presence of more matrix components in the treated knees versus control conditions. Ongoing work using RTPCR will ascertain whether this is due to decreased degradation or increased synthesis of matrix components. Ultimately HA-PlnD1/BMP2 may serve as a therapeutic agent for partial thickness cartilage lesions, preventing the onset of irreversible OA.

5

PERLECAN/HSPG2 DEFICIENCY ALTERS THE PERICELLULAR SPACE OF THE LACUNO-CANALICULAR NETWORK SURROUNDING OSTEOCYTIC PROCESSES IN CORTICAL BONE

William R. Thompson*, Shannon Modla*, Brian J. Grindel‡, Kirk J. Czymmek*‡, Catherine Kirn-Safran‡, Liyun Wang*‡, Randall L. Duncan*‡, Mary C. Farach-Carson‡†

‡ University of Delaware, Newark, DE, USA
** Delaware Biotechnology Institute, Newark, DE, USA*
† Rice University, Houston, TX, USA

Osteocytes project long, slender processes throughout the mineralized matrix of bone where they connect and communicate with effector cells. The interconnected cellular projections form the functional lacuno-canalicular network allowing fluid to pass for cell to cell communication and nutrient and waste exchange. Prevention of mineralization in the pericellular space of the lacuno-canalicular pericellular space is crucial for uninhibited interstitial fluid movement. Factors contributing to the ability of the pericellular space of the lacuno-canalicular network to remain unmineralized are unclear. In this study we examined osteocyte lacuno-canalicular morphology in mice deficient in the large heparan sulfate proteoglycan perlecan/HSPG2. Immunohistochemical imaging demonstrates perlecan/HSPG2 expression localized to the osteocyte lacuno-canalicular network of cortical bone and electron micrograph immunogold data reveal the presence of this proteoglycan in the pericellular space of the lacuno-canalicular network. Ultrastructural measurements using electron micrograph images of perlecan/HSPG2 deficient mice demonstrate diminished osteocyte canalicular pericellular area, resulting from a reduction in the total canalicular area. Additionally, perlecan/HSPG2 deficient mice show decreased canalicular density and a reduced number of transverse tethering elements per canaliculus. These data indicate that perlecan/HSPG2 contributes to the integrity of the osteocyte lacuno-canalicular network by maintaining the size of the pericellular space, an essential task to promote uninhibited interstitial fluid movement in this mechanosensitive environment.

Notes

Schedule of the Day

WHEN	WHAT	WHERE
8:30	BREAKFAST & POSTER SET-UP	CLAYTON HALL LOBBY
9:00	WELCOME	CLAYTON HALL AUDITORIUM 125
9:15	KEYNOTE: DR. MARK LATASH	CLAYTON HALL AUDITORIUM 125
10:15	BREAK	
10:30	PODIUM SESSION 1	CLAYTON HALL AUDITORIUM 125
12:00	LUNCH	CLAYTON HALL LOBBY
1:00	POSTER SESSION 1 (ODDS)	CLAYTON HALL LOBBY
2:00	POSTER SESSION 2 (EVENS)	CLAYTON HALL LOBBY
3:00	PODIUM SESSION 2	CLAYTON HALL AUDITORIUM 125
4:30	AWARDS	CLAYTON HALL AUDITORIUM 125

UNIVERSITY OF DELAWARE