University of Delaware | College of Engineering

8th Annual

Biomechanics Research Symposium

May 13, 2011

Center for Biomedical Engineering Research

201 Spencer Lab | Newark, Delaware 19716 | www.cber.udel.edu

Welcome from the Center for Biomedical Engineering Research

Thank you for your participation in the 8th annual biomechanics research symposium hosted by the Center for Biomedical Engineering Research at the University of Delaware. The motivation for this symposium is to highlight the outstanding and varied biomechanics research taking place at the University of Delaware. Students from across campus will lead all poster and podium sessions. We appreciate the support of the Delaware Rehabilitation Institute which has provided judges and awards for the best student presentations.

Please extend a warm welcome to Dr. Van Mow who is the Stanley Dicker Professor and Chair of the Department of Biomedical Engineering at Columbia University. Dr. Mow will share his perspective on the interdisciplinary field of biomedical engineering in his keynote lecture entitled "A Smorgasbord of Delectable Morsels: A Personal Odyssey to Biomedical Engineering".

I would like to recognize each of you for contributing to the scientific content of this year's research symposium, and 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
Liyun Wang

STUDENT COMMITTEE

Allison Altman
Amber Collins
Emily Gardinier
Ananth Gopalakrishnan
Amy Lenz
Laura Miller
Alan Needle
Jacqueline Palmer
Alex Razzook
Tyler Richardson
Shazlin Shaharudin
Ya Shu
Kyle Winfree

All student awards are sponsored by the Delaware Rehabilitation Institute.

Keynote Lecture

A SMORGASBORD OF DELECTABLE MORSELS: A PERSONAL ODYSSEY TO BIOMEDICAL ENGINEERING

Van C. Mow

Stanley Dicker Professor and Chair | Department of Biomedical Engineering | Columbia University | New York, New York 10027

From early studies in aeronautical engineering to graduate studies in applied mechanics and applied mathematics at RPI, I eventually evolved into a full-fledged biomedical engineer. My lecture will provide some background into those early days of my growing up during World War II in China, and during some very difficult circumstances as a displaced refugee from China in America following the Communist revolution in 1949, to my postdoctoral studies in applied mathematics at the Courant Institute of Mathematical Sciences (NYU) in 1967, and as a developer of anti-submarine sonar codes at Bell Laboratories, to my studies in biochemistry and musculoskeletal sciences in 1976 at Harvard Medical School, and eventually to evolving into a biomedical engineer, and as founder of Columbia's Biomedical Engineering Department. I have completed my 25th year at Columbia, first at the Orthopaedic Surgery Department as the Anne Stein Professor of Orthopaedic Research and Director of the New York Orthopaedic Hospital Research Laboratory at the College of Physicians and Surgeons, then at the Fu Foundation School of Engineering and Applied Science as the founder of Columbia University's Department of Biomedical Engineering on Jan. 1, 2000. Along the way, I have been fortunate to be where things were happening, as Malcolm Gladwell observed in his book, The Outliers: The Story of Success, and fortunate to have the courage to adapt and adopt new ideas. Within the same spirit of quest for new ideas, I developed the well known biphasic and triphasic theories to describe hydrated-charged-soft biological tissues which today are some of the most highly cited references in the bioengineering literature. Indeed, it is recognized that my studies have caused a change of paradigm on soft tissue and diarthrodial joint biomechanics research over the decades. I will attempt to summarize the state-of-art knowledge in some selected areas in the field. Thus, my story is a story of adversity and courage to overcome challenges, both personally and professionally, and this story has also had important impact on the development of biomedical engineering, particularly in biomechanics, in America today.

Dr. Mow is an elected fellow of the U.S. National Academy of Engineering and Institute of Medicine of the National Academy of Science, Academician of the Academica Sinica (Republic of China), and Associate Fellow of the Academy of Sciences of the Developing World (UNESCO).

Schedule of the Day

TIME	WHAT	WHERE
8:30 AM	BREAKFAST & POSTER SET-UP	CLAYTON HALL LOBBY
9:00 AM	WELCOME	CLAYTON HALL AUDITORIUM 125
9:15 AM	KEYNOTE: DR. VAN C. MOW	CLAYTON HALL AUDITORIUM 125
10:15 AM	BREAK	
10:30 AM	PODIUM SESSION 1	CLAYTON HALL AUDITORIUM 125
12:00 PM	LUNCH	CLAYTON HALL ROOM 120
1:00 PM	POSTER SESSION 1 (ODD #S)	CLAYTON HALL LOBBY
2:00 PM	POSTER SESSION 2 (EVEN #S)	CLAYTON HALL LOBBY
3:00 PM	PODIUM SESSION 2	CLAYTON HALL AUDITORIUM 125
4:30 PM	AWARDS SESSION	CLAYTON HALL AUDITORIUM 125

Podium Presentations

Denotes Podium #

Poster Presentations

Bone, Cell & Cartilage

Gait

Imaging

Denotes Poster #

Osteoarthritis

Robotic Training

Stroke

Denotes Poster #

PODIUM PRESENTATIONS

Session 1

1 MODELING SUBHARMONIC RESPONSE FROM CONTRAST MICROBUBBLES FOR NONINVASIVE BLOOD PRESSURE MEASUREMENT

Flemming Forsberg[1], Amit Katiyar, Kausik Sarkar

1 Department of Radiology, Thomas Jefferson University

We numerically investigate the variation of subharmonic response from contrast microbubbles with ambient pressure for noninvasive monitoring of local organ-level blood pressure. Several contrast microbubbles both in vitro and in vivo registered an approximately linear (5-15 dB) decrease of subharmonic response with the variation of 25kPa (188 mmHg) in ambient pressure. We show here that simulated subharmonic response from a single microbubble can either increase or decrease with increasing ambient pressure depending on bubble radius and acoustic excitation parameters. We first report results using the code BUBBLESIM for encapsulated contrast microbubbles, and then investigate the underlying dynamics with the well established model of a free bubble. We show that the primary determining parameter is the ratio of the excitation frequency to the natural frequency of the bubble increasing ambient static pressure increases resonance frequency. For the frequency ratio below a lower critical value, increasing ambient pressure monotonically decreases subharmonic response. On the other hand, above an upper critical value of the same ratio, increasing ambient pressure increases subharmonic response. In between, effect of ambient pressure on subharmonic response is nonmonotonic. The precise values of frequency ratio delineating these three different trends depend on the bubble radius and excitation amplitude. The excitation threshold for subharmonic generation also depends on ambient pressure affecting the dynamics. The underlying physics is investigated with simulations systematically varying radius, excitation frequency and the excitation amplitude. Furthermore, it is shown that the modeled increase or decrease of subharmonic with ambient pressure increase, when one happens, is linear only for certain range of excitation levels. Possible reasons for discrepancies between model and experiments are discussed.

2 GROWTH OF NECROTIC CORES IN ATHEROSCLEROTIC PLAQUE

Pak-Wing Fok

Plaques are fatty deposits that grow mainly in arteries and develop as a result of a chronic inflammatory response. Plaques are characterized as vulnerable when they have large internal regions of necrosis

and are heavily infiltrated by macrophages. The particular composition of a vulnerable plaque renders it susceptible to rupture, which releases thrombogenic agents into the bloodstream, and can result in myocardial infarction.

We propose a mathematical model to predict the development of a plaque's necrotic core. By solving coupled reaction-diffusion equations for macrophages and dead cells, we focus on the joint effects of hypoxic cell death and chemoattraction to Ox-LDL, a molecule that is strongly linked to atherosclerosis.

We do not model the mechanical properties of the plaque, its growth or rupture. Our model predicts cores that have approximately the right size and shape when compared to ultrasound images. Because our model is linear and autonomous, normal mode analysis and subsequent calculation of the smallest eigenvalue allow us to compute the times taken for the necrotic core to form. We find that the spatial distribution of Ox-LDL within the plaque determines not only the placement and size of cores, but their time of formation. Although plaques are biochemically complex, our study shows that certain aspects of their composition can be predicted and are, in fact, governed by simple physical models.

3 WITH AGING, REDUCTION IN WRIST COORDINATION WITH OTHER JOINTS IS MANIFESTED AS DECREASED HAND PATH STABILITY

Geetanjali Gera, Sandra Freitas, John P. Scholz

We investigated the extent of wrist joint motions coordination with other joints to stabilize the hand's path. The effect of artificial removal of covariation of wrist joint motion with other joints was investigated for a reaching task performed under two target conditions in healthy young adults, stroke survivors and age-matched control subjects. We hypothesized that the more strongly coordinated the wrist joint is with other joints, the greater effect removal of its covariance should have on indices of hand position stability. Uncontrolled Manifold Analysis was used to partition joint variance into 'good' variance, reflecting flexible joint configurations that achieve the same hand position, and 'bad' variance that leads to deviation in the hand path. The extent to which 'bad' variance increased when removing wrist covariation was used to indicate the strength of its coordination with other joints to stabilize the hand position. Analysis focused on the period from the time of the peak velocity to movement termination, where the wrist is expected to play a greater role in controlling the end-effector's position. Irrespective of the certainty of the target location after reach initiation, young subjects exhibited a reduction in 'good' variance and an increase in 'bad' variance with removal of wrist covariation. This effect also held for healthy older adults and the non-paretic limb of both RCVA and LCVA only when the final target location was predictable. The results indicate age-related changes in the coordination of wrist joint motions with those of other joints that affect hand position stability during reaching. Removal of wrist covariance did not affect the amount of 'bad' variance for the paretic limb, confirming poor coordination of wrist motion in the impaired limb.

4 MIS-LOCALIZATION OF BONE MORPHOGENETIC PROTEIN RECEPTOR TYPE IA IN BONE MARROW STROMAL CELLS FROM MICE EXHIBITING INCREASED PEAK BONE MASS

Beth Bragdon, Jeremy Bonor, Kathryn L. Schultz[1], Wesley G. Beamer[1], Clifford J. Rosen[2] and Anja Nohe

1 Jackson Laboratory, Bar Harbor Maine, 2 Maine Medical Center Research Institute, Scarborough, Maine

Bone development and maintenance is kept in balance by osteoblasts and osteoclasts. An imbalance of activity or number of osteoblasts or osteoclasts can lead to decreased or increased bone mineral density (BMD) which contributes to the overall bone health and stability. Bone morphogenetic protein 2 (BMP2) is a potent growth factor driving bone marrow stromal cell proliferation and differentiation toward osteoblasts. At the cell surface the initiation of BMP2 signaling is regulated by the membrane domain, caveolae. Yet the BMP2 receptor dynamics with caveolae associated with the BMP2 canonical Smad pathway for osteoblast differentiation is unknown.

The congenic mouse model B6.C3H-1-12 (1-12) has increased BMD with increased osteoblast activity and possible progenitors. Since BMP2 has a direct effect on osteoblast differentiation and the 1-12 demonstrates increased BMD, it is possible there is an increase BMP2 response and this is regulated at the cell surface. We determined with the use of Image Cross-Correlation Spectroscopy that both BMP receptor type Ia and caveolae dynamics in response to BMP2 is altered in the 1-12 compared to the control mouse, C57BL/6J (B6). Reporter gene assays were used to measure the genetic response for Smad. It showed Smad signaling was increased in the 1-12 with BMP2 stimulation. Further disrupting caveolae inhibited the BMP2-induced Smad signaling in both B6 and 1-12. These data indicate BMP2-induced membrane dynamics are crucial for Smad signaling. Membrane regulation by caveolae is a possible target of therapeutics for the treatment of altered BMD diseases.

5 XYLOSYLTRANSFERASE1 AS A POTENTIAL BIOMARKER FOR OSTEOARTHRITIS PROGRESSION

Sarah Yerkes McCoy, William Thompson, Padma Pradeepa Srinivasan and Catherine B. Kirn-Safran

Osteoarthritis (OA) is a degenerative joint disorder that is prevalent in aging populations and characterized by pain and disability. The disease process is marked by loss of cartilage, chondrocyte hypertrophy, ligament laxity, and osteophyte formation. At the molecular level, an imbalance exists between synthesis and degradation of cartilage extracellular matrix(ECM). Due to the inability to effectively monitor early disease progression, diagnosis is often made at a late stage of disease by non-invasive radiographic imaging (x-ray, MRI), at a point when there are very few effective non-surgery treatment options available. Biomarkers may serve as a tool to monitor disease progression before radiographic detection. Logical targets for biomarkers are proteins involved in the synthesis and degradation of articular cartilage ECM. Xylosyltransferase is a glycosyltransferase that catalyzes the addition of the linkage region during glycosaminoglycan synthesis in proteoglycans, a major component of articular cartilage. The objective of this study is to analyze Xylosyltransferase1(XT-1) as a potential biomarker of osteoarthritis progression in a surgery model of OA. Through histological analysis, osteoarthritis progression in our model is evident by one month and very severe by five months. Western blot analysis of xylosyltransferase1 protein expression reveals that, XT-1 levels decrease over a time period of 5 months after surgery. This decrease correlates with disease severity at 5 months post-surgery. To be useful as a biomarker, it is important to be able to detect changes in serum early in the disease process. Our future work will consist of looking at these early time points and up to 3.5 months post-surgery in our surgical model as well as comparing these time points to two genetic models of OA.

PODIUM PRESENTATIONS

Session 2

1 A PROPOSED METHOD FOR PD-AFO STIFFNESS PRESCRIPTION PROCEDURE

LaKisha D. Guinn, Kota Z. Takahashi, Alexander R. Razzook, Elisa S. Schrank, Steven J. Stanhope

Introduction. Passive dynamic ankle-foot orthoses (PD-AFOs) are frequently prescribed to correct impaired gait function. A PD-AFO functions like a torsional spring to supplement muscle function at the ankle joint. Our research group has developed a novel design and manufacturing procedure for the customization of the mechanical properties of PD-AFOs. Currently, a method to select the optimal PD-AFO stiffness for each patient has not yet been proposed.

Purpose. To propose the use of a systematic sequential-approximation approach to converge on a method for the prescription of PD-AFO stiffness.

Method. Children (7-18 years old) with plantar-flexor weakness and who wear an AFO(s) prior to study participation will be recruited. A model of natural ankle pseudo-stiffness (NAS) as a function of walking velocity will be used to select a prescribed stiffness. The model was developed from a database of 11 unimpaired subjects (22 limbs) walking at four targeted, scaled (by height) walking velocities. The mean self-selected velocity for typically developing children (1.15 m/s), scaled by height, will be input into the NAS model. Initially, the PD-AFO stiffness will be set to 50% of the NAS output from the model. The efficacy of the stiffness prescription will be evaluated using instrumented gait analysis techniques. The primary outcome variables are scaled walking velocity; timing of heel off; ankle, knee, and hip range of motion, peak moment and peak power during stance. Based on these variables, if the stiffness is too high or low for the subject, it will be sequentially adjusted by 10% and reevaluated until an optimal level of performance is achieved.

Conclusion. We hypothesize that a method to prescribe the optimal mechanical properties of a PD-AFO will produce optimal gait performance.

2 ANKLE COPERS DEMONSTRATE INCREASED ANTERIOR STIFFNESS COMPARED TO HEALTHY AND UNSTABLE ANKLES

Alan R. Needle, C. Buz Swanik

Ankle sprains are the most common athletic injury with ankle instability (AI) forming in approximately 50% of patients. While studies have investigated mechanical factors behind AI, those “potential copers” who do not develop instability are lost to follow-up. Understanding these “potential copers” can provide insight into relevant interventions to prevent AI. Objective: To determine changes in passive ankle stiffness that exists in “potential copers” when compared to healthy and unstable ankles. Participants: 39 subjects (23.0±2.9yrs, 171.5±10.3cm, 69.7±13.2kg) provided 78 ankles for this study, stratified into three groups using the Cumberland Ankle Instability Tool: healthy (HA, n=37), unstable (AI, n=22), and potential copers (PC, n=19). Interventions: Ankle laxity and stiffness were assessed using an ankle arthrometer. Three anterior translations to 125N and three inversion rotations to 4200Nmm were applied to the ankle. Main Outcome Measures: Univariate ANOVA’s were used to determine changes in peak laxity between groups. Passive ankle stiffness was calculated at 25N intervals to 125N of anterior force, and 1Nm intervals to 4Nm of inversion torque. Repeated-measures ANOVA’s were used to detect differences. Results: The PC group exhibited greater anterior stiffness than HA at 0-25N (p=.005), and greater stiffness than AI ankles up to 100N (p<.05). The AI group demonstrated increased anterior displacement compared to HA and PC groups (p=.005). No group differences were observed for inversion rotation (p=.29) or for inversion stiffness (p=.37). Conclusions: The PC group demonstrated increased resistance to anterior displacement, despite observing no changes in peak laxity. This data suggests a potential mechanical adaptation that may assist to prevent episodes of giving way in the ankle joint, particularly in short-range stiffness where previous research suggests is most important for the sensation of an impending roll-over event.

 All researchers are from the University of Delaware, Newark, DE, USA unless otherwise noted.

3 AN UNTETHERED SHOE WITH VIBRATORY FEEDBACK FOR IMPROVING GAIT OF PARKINSON'S PATIENTS: THE PDSHOE

Kyle N. Winfree, Shazlin Shaharudin, Vineet Vashista, Dave Hilgart, Ingrid Aboff, Sunil K. Agrawal

Those who suffer from Parkinson's disease often have trouble with ambulation. This simple task of walking, that most of us take for granted, is impeded by a condition similar to peripheral neuropathy. Some research has shown that vibratory biofeedback can improve the gait of such persons. We have developed a new vibratory feedback shoe, known as the PDShoe, which builds on existing research. This device can modulate both frequency and amplitude of feedback independently, targeting the combination which best stimulates the pacinian corpuscles of the wearer. It is untethered, and thus can be worn during daily activities. Pressure and tactor status data are transmitted wirelessly over a personal area network to a notebook computer. This computer can also control the tactor actuation and stimulation frequency. This paper describes the details of design and construction of the PDShoe. A preliminary evaluation with two

Parkinson's disease subjects is included to show usability of the device. This paper concludes with discussion of continued design changes and future studies with Parkinson's disease subjects.

4 TRAINING TODDLERS SEATED ON MOBILE ROBOTS TO DRIVE INDOORS AMIDST OBSTACLES

Xi Chen, Christina Ragonesi, James C. Galloway, Sunil K. Agrawal

Mobility is a causal factor in development. Children with mobility impairments may rely upon power mobility for independence, and thus require advanced driving skills to function independently. Our previous studies show that while infants can learn to drive directly to a goal using conventional joysticks in several months of training, they are unable in this timeframe to acquire the advanced skill to avoid obstacles while driving. Without adequate driving training, children are unable to explore the environment safely, the consequences of which may in turn increase their risk for developmental delay. The goal of this research therefore is to train children seated on mobile robots to purposefully and safely drive indoors.

In this talk, we present results where ten typically-developing toddlers are trained to drive a robot within an obstacle course. We also report a case study with a toddler with spina-bifida who cannot independently walk. Using algorithms based on artificial potential fields to avoid obstacles, we create force field on the joystick that trains the children to navigate while avoiding obstacles. In this `assist-as-needed' approach, if the child steers the joystick outside a force tunnel centered on the desired direction, the driver experiences a bias force on the hand. Our results suggest that the use of a force-feedback joystick may yield faster learning than the use of a conventional joystick.

5 EFFECT OF ROBOTIC PERFORMANCE-BASED ERROR-ENHANCEMENT VERSUS ASSIST-AS-NEEDED TRAINING ON THE GAIT PATTERN OF HEALTHY INDIVIDUALS

Pei-Chun Kao, Shraddha Srivastava, Sunil K. Agrawal, John P. Scholz

To ensure the success of locomotion training with robotic lower limb exoskeletons, it is important to identify control algorithms that can better facilitate motor learning. Training protocols emphasizing error feedback enhancement may be more effective in shaping motor outputs than those tending to reduce error feedback. The purpose of this study was to examine if a performance-based error-enhancement strategy can better promote learning of a new gait pattern compared to an assist-as-needed strategy. Ten neurologically intact subjects were assigned to each of the two groups: performance-based error-enhancement and assist-as-needed. All subjects completed a 45-min session walking in a robotic exoskeleton on the treadmill at their preferred speed. Target gait templates prescribed for training corresponded to an increased height of subjects' ankle spatial locations (i.e., ankle path). When subjects' instantaneous ankle positions fell below the inferior wall of target ankle path, robotic forces were applied, either away from or toward the target ankle path, respectively. While the force field was on during training, both groups walked with ankle paths toward their target template, evidenced by a significant reduction in the deviated area between the two paths ($p<0.05$). When the force field was removed unexpectedly, the error-enhancement group maintained an ankle path close to the target ankle path ($p<0.05$). In contrast, the assist-as-needed group returned to their baseline performance. These findings suggest that robotic training strategy emphasizing error feedback enhancement may be more effective for promoting changes in gait patterns of individuals with neurological dysfunction than an assist-as-needed paradigm, at least when online visual feedback about performance is unavailable. However, further testing on neurologically impaired populations is warranted.

POSTER PRESENTATIONS

Bone, Cell & Cartilage

1 RATE DEPENDENT DEFORMATION RESPONSE OF ARTICULAR CARTILAGE

Edward D. Bonnevie, Vincent J. Baro, Liyun Wang, David L. Burris

The progressive breakdown and failure of articular cartilage as seen in Osteoarthritis is currently one of the leading causes of severe disability in the United States. Consequently, previous research has been aimed at describing the mechanisms of cartilage lubrication that lead to a sustained low friction interface. Historically, tribological studies of cartilage displayed a time dependent friction coefficient, starting low (μ~0.01) and increasing to a steady state value (μ~0.2). One recent study has shown that sustained low friction is possible experimentally through pressurization of interstitial fluid using curved probes. Sliding curved probes on the cartilage surface can constantly deform the cartilage matrix which leads to flow and pressurization of interstitial fluid. Since there is not a strong background on the mechanics of cartilage using non-planar probes, this study experimentally analyzes the spherical contact problem to determine: 1) If Hertzian mechanics can be used to describe the response of cartilage to indentation, 2) If there is a depth dependence or substrate effect on aggregate modulus measurements, 3) How the deformation rate affects the force response, 4) What role the interstitial fluid plays in the response.

2 CYCLIC HYDRAULIC PRESSURE CONTRIBUTES TO THE ANABOLIC RESPONSE AND MECHANICAL BEHAVIOR OF MC3T3 OSTEOBLASTS

Joseph D. Gardinier, Liyun Wang, Randall L. Duncan

Mechanical loading of bone during physiological activities, osteoblasts experience several forms of mechanical forces that stimulate an anabolic response associated with bone formation. Since the anabolic response of osteoblasts has only been investigated in response to single forms of mechanical stimuli, the purpose of this study was to evaluate the anabolic response to multiple forms stimuli, controlled independent of each other. MC3T3 osteoblasts-like cells were subjected to fluid flow induced shear stress (FSS) with various gradients of static hydraulic pressure (SHP) or cyclic hydraulic pressure (CHP) to determine if pressure enhances the anabolic response of osteoblasts during FSS. The optimal magnitude for ATP release during FSS was found to be 15 mmHg of either SHP or CHP. Increasing the magnitude of pressure to 50 mmHg or 100 mmHg during FSS attenuated the ATP release during FSS. The virtual absence of pressure during FSS reduced ATP release to basal levels, and inhibited actin stress fiber formation (ASFF) and reorganization that normally occurs during FSS with 15 mmHg of pressure. The nuclear translocation of NFκB during FSS was unaltered by varying magnitudes of pressure, which would suggests that COX-2 production and resulting anabolic response is independent of purinergic signaling. Overall, hydraulic pressure during FSS regulates changes in the mechanical behavior of osteoblasts through cytoskeleton reorganization, while FSS alone stimulates an anabolic response independent of changes in purinergic signaling.

 All researchers are from the University of Delaware, Newark, DE, USA unless otherwise noted.

3 BIOMECHANICAL RESPONSES OF MENISCUS TO CONTACT LOADING

Vincent Baro, Edward Bonnevie, David Burris, Liyun Wang

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 200 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. Papain degraded tissue was also tested. We explored the differences between normal and papain degraded tissue. Our results indicate significantly reduced effective elastic modulus and aggregate modulus, and increased coefficient of friction of the papain degraded tissue.

4 TRANSMISSION OF A FLOOR-BASED, HIGH-FREQUENCY, LOW-MAGNITUDE VIBRATION STIMULUS ACROSS THE TIBIA AND FEMUR OF CHILDREN WITH OSTEOGENESIS IMPERFECTA: A PILOT STUDY

Marcus Spera, Kurt Manal, Erica Hartman, Brianne Mulrooney, Michael Bober[1], Lauren Davey[1], Christopher Modlesky[1]

1 Department of Genetics, AI duPont Hospital for Children

There is evidence that a high-frequency, low-magnitude vibration (HLV) treatment administered daily increases bone mass and improves bone structure. It is plausible that the effect of the treatment is dictated by the degree to which the HLV stimulus reaches a bone site. The aim of this pilot study was to determine the degree to which an HLV signal emitted by a floor-based platform transmits across the tibia and femur of children with osteogenesis imperfecta (OI), a group that is very susceptible to fracture. Seven children with mild OI (5–10 y) were randomly assigned to stand on a platform that emits an HLV (0.3 g, 30 Hz; n = 4) or a platform that makes a similar sound but does not emit an HLV (n = 3). Tri-axial accelerometers (CXL10GP3; Crossbow, Technology, Inc, San Jose, CA) were placed on the medial aspect of the distal tibia, the lateral condyle of the distal femur, the greater trochanter of the proximal femur and on the platform. Accelerations were assessed for 30 seconds while the platform was off and for 30 seconds while the platform was on. Relative to the platform, acceleration transmissions were 95 ± 10% at the distal tibia, 74 ± 10% at distal femur and 34 ± 7% at the proximal femur. On the other hand, no notable differences were observed at any site in the placebo group. The findings suggest that of the bone sites evaluated in the tibia and femur, the maximum effect of a floor-based HLV treatment should be at the distal tibia.

5 INJECTABLE PERLECAN DOMAIN1-HA BASED-MICROGELS PROMOTE BMP2 EFFECT AND ARTICULAR CARTILAGE HEALING IN MICE

Padma P. Srinivasan, Sarah Y. McCoy, Amit K. Jha, Weidong Yang, Xinqiao Jia, Mary C. Farach-Carson[1], Catherine B. Kirn-Safran

1 Rice University, Dept. of Biochemistry and Cell Biology, Houston, TX.

Bone Morphogenetic Protein2 (BMP2), a growth factor with heparan sulfate (HS) binding capability has emerged as an alternate strategy for cartilage regeneration. However, its short half-life and rapid clearance by the lymphatic demands an effective delivery system for their prolonged retention in joint cavity. Therefore, we developed a novel bio-mimetic delivery system by coupling perlecan domain1 (PlnD1) with hyaluronic acid (HA) for the time-dependant release of BMP2 and tested its efficiency in the mice model of early-osteoarthritis (OA). OA-like damages were induced by intra-articular knee injections of 1% papain. Seven days post-papain injection, knees were injected with either PlnD1-HA preincubated with BMP2 (PlnD1-HA/BMP2), PlnD1-HA alone or saline. The knees were dissected at day 7 and day 14 post-treatment and analyzed by histological scoring, immunohistochemical and gene expression approaches. Results of the histological scoring following Safranin O and Fast-green showed that the knees treated with PlnD1-HA/BMP2 had significantly lesser OA damages than the control knees injected with PlnD1-HA alone or saline both at day 7 and day 14 post-treatment. Also, the articular cartilage of PlnD1-HA/BMP2 treated knees had higher mRNA levels of proteoglycan core-proteins and collagen II and lower mRNA levels of cartilage matrix-degrading enzymes. Immunohistochemistry showed that PlnD1-HA/BMP2 treated knees displayed higher signal for aggrecan than the control knees. All findings taken together ascertain that PlnD1-HA functions as a potent in vivo reservoir of BMP2 which stimulates the synthesis of the proteoglycans and hinders the levels of catabolic enzymes in murine cartilage. Ultimately, HA-PlnD1/BMP2 may serve as an injectable therapeutic agent for stimulating repair in osteoarthritic joints.

6 DEFICIENCY IN PERLECAN/HSPG2 SECRETION PROMOTES OSTEOBLAST TERMINAL DIFFERENTIATION IN A MOUSE MODEL OF OSTEOARTHRITIS

Nadia Lepori-Bui, Dylan A. Lowe, Peter V. Fomin, William R. Thompson, Catherine B. Kirn-Safran

Osteoarthritis (OA) is a degenerative joint disease characterized by the degradation of articular cartilage, leading to pain and severe disability. Symptoms include inflammation of the synovial membrane and growth of abnormal bone at the joint margins. Perlecan (Pln) is a heparan sulfate proteoglycan abundant in cartilage which is essential for normal skeletogenesis. We used a genetic mouse model secreting reduced levels (hypomorphic mutation) of Pln to study events involved in OA progression. Pln mutant mice exhibit a short stature phenotype, bone deformities, and early OA relative to wild-type controls. In addition, Pln mutant bones displayed increased brittleness associated with elevated bone mineral density vs wild-type. This data is consistent with clinical findings in patients with mutations in the PLN gene. The goal of this project is to elucidate the molecular basis of accelerated OA in this mouse model using osteochondro-progenitors derived from mutant and wild-type embryos. We used primary mouse embryonic fibroblasts (MEFs) isolated from 13.5 day-old fetuses to assess the differentiation potential of cells expressing either normal or reduced levels of Pln. MEFs grown in osteogenic medium were treated with bone morphogenetic protein 2 to stimulate terminal differentiation. Under these conditions, Pln mutant MEFs differentiated into osteoblasts and mineralized at significantly higher rates when compared to WT control cells. This result is consistent with previous work that demonstrated that Pln is a modulator of the lacuno-canalicular space in mature bone. Altogether, our data indicates that Pln is an inhibitor of extracellular matrix mineralization and suggests that, during OA development, degradation of cartilage components such as Pln triggers an imbalance in mineralized tissue homeostasis leading to hypermineralization of the cartilage matrix.

POSTER PRESENTATIONS

Gait

7 COMPARING BAREFOOT RUNNING TO ALTERED STRIKE PATTERNS IN SHOES

Allison Altman, Irene Davis[1]

1 Harvard Medical School – Spaulding Outpatient

Barefoot (BF) running has become increasingly popular. BF runners adopt a midfoot strike (MFS) or forefoot strike (FFS) pattern to avoid the discomfort of landing on their heels. This strike pattern usually results in a shorter stride length (SL). Compared with rearfoot strike (RFS) patterns, both barefoot and shod MFS and FFS landings have been shown to significantly reduce the vertical impact transients. These impact transients have been linked to a variety of running injuries. However, it is not clear whether there is any difference in impact transients between BF running and shod MFS or FFS running.

PURPOSE: To compare vertical instantaneous (VILR) and average (VALR) loadrates, along with SL of BF running to shod MFS and FFS conditions.

METHODS: 13 runners have been collected to date in this ongoing study. To be included, subjects had to have run more than 10 miles/week BF or in Vibram FiveFingers for at least a month. On an instrumented treadmill, subjects ran BF, and shod with a MFS and FFS pattern. A shod RFS pattern was also collected as a reference. VILR, VALR, and SL were extracted from the GRF data. Due to low subject numbers, effect sizes were used for comparison.

RESULTS: In the shod conditions, loadrates were highest in the RFS pattern and lowest in the FFS pattern. Loadrates during BF running, which was typically a FFS pattern, were variable. In 8/13 subjects, loadrates were lowest during the BF condition. SL was longest in the RFS condition, and similar across the shod MFS and FFS, and BF conditions.

CONCLUSION: In terms of loading rates, BF running is associated most closely with a shod FFS pattern. Support: DOD W911NF-05-1-0097

8 EMG AND KINEMATIC RELIABILITY CHANGES WITH GAIT VELOCITIES

Stephen Suydam, Emily Gardinier, Kurt Manal, Thomas S. Buchanan

EMG and joint angles are common parameters used to assess abnormal gait. However, little is known about how the variability of these parameters changes with modulations in gait speeds. EMG of the lower limb muscles and 3-D motion capture data were recorded from 6 subjects during walking, running at a fixed speed (4 m/s) and running at their maximal speed (sprinting). Maximum EMG variability decreased with running and sprinting versus walking. Conversely peak joint angle variability increased with velocity. Increased variability in joint angles with increased velocity has been theorized to be a beneficial mechanism to prevent overuse injuries due to the larger loads carried by running versus walking. Greater EMG deviations at slower speeds may be due to sub-maximal muscle function allowing for altered activation patterns to improve motion efficiency and decrease metabolic cost. Variability should be taken into account when diagnosing biomechanics that may lead to or have caused injury and be included in rehabilitation programs.

9 TRANSFER OF GAIT RETRAINING EFFECTS FROM TREADMILL TO OVERGROUND RUNNING

Rebecca E. Fellin, Irene S. Davis

Tibial stress fractures (TSF) in runners have been linked to elevated tibial shock (TS) and vertical instantaneous and average load rates (VILR and VALR). We previously found that gait retraining with real-time visual feedback (FB) reduced high load rates on the trained leg during treadmill running. In most subjects, these variables were also reduced on the untrained, contralateral leg. However, it is unknown if these results transfer to overground running, where most runners log their mileage. PURPOSE: To determine if subjects decrease vertical loading on both legs following a gait retraining intervention. METHODS: 6 subjects (30.0 ± 5.2 yr), running > 10 miles per week have participated in this ongoing study. They exhibited high vertical loading at baseline, TS > 8g. Each subject completed 8 running sessions with no feedback (CTRL) followed by 8 sessions with FB aimed to decrease vertical loading on the trained limb. We measured VILR, VALR and vertical impact peak (VIP) at baseline, post CTRL and post FB during overground running on both legs. Due to the small sample size, the data were analyzed descriptively. RESULTS: At baseline, 5/6 subjects had elevated vertical loading on their untrained, contralateral leg, but it was not as excessive as their trained leg. On average, loads changed < 4% following CTRL. Following FB, loading decreased to within normal limits on both limbs. Load rates decreased 37% on each leg, and VIP decreased 30% on each leg. CONCLUSION: Loading appeared to reduce on both legs following gait retraining but not following a control period. Based upon these results, training effects gained from treadmill gait retraining transfer to overground running. Support: DOD W911NF-05-1-0097 & W81XWH-07-1-0395 & NIH 1 S10 RR022396.

10 KINEMATIC STRATEGIES USED BY RUNNERS TO REDUCE TIBIAL SHOCK FOLLOWING GAIT RETRAINING

Bradley Bowser, Rebecca Fellin, Irene Davis

High tibial shock (TS), during running has been linked to an increased risk for developing tibial stress fractures. However, gait retraining using real time feedback has been shown to reduce TS during running up to 25%. Although it is unclear what kinematic strategies are used, midfoot strike (MFS) and forefoot strike (FFS) patterns have been reported to reduce load rates in running. Therefore, we predict that runners will adopt more of an anterior strike pattern, subsequently reducing dorsiflexion (DF) and increasing knee flexion (KF) at foot strike (FS). PURPOSE: To determine the kinematic strategies runners use to reduce TS following gait retraining. METHODS: To date, 15 rearfoot strike (RFS) runners (age: 28±8 yr, 16.7±10.8 mpw, TS: 11.4±2.9 g) have participated in this ongoing study. The gait retraining protocol consisted of 8 retraining sessions with real time visual feedback aimed at reducing TS. Motion, ground reaction force, and accelerometry data were collected during running pre- and post gait retraining. Changes are reported descriptively. RESULTS: Of the 15 runners, 13 were able to decrease their TS. 7 of these adopted more of MFS or FFS pattern. These runners increased their strike index (Pre=7.8±1.1%, Post=40.2±11.2%), and increased their KF (Pre=11.8±0.8°, Post=17.6±2.3°) while decreasing their DF at FS (Pre=6.5±1.2°, Post=-0.3±2.5°), as hypothesized. The remaining 6 runners used an ankle strategy landing with greater dorsiflexion (Pre=9.4±0.8°,Post=14.1±1.0°) and decreased KF at FS (Pre=12.3±3.2°,Post11.0±3.0°). Interestingly, this group also exhibited lower approach accelerations. CONCLUSION: Two distinct kinematic strategies were exhibited by runners who reduced TS after participating in gait retraining; a MFS or FFS strategy or an ankle strategy.

Support: DOD W911NF-05-1-0097 & W81XWH-07-1-0395 & NIH 1 S10 RR022396 & 5R01HD50679-2.

POSTER PRESENTATIONS

Imaging

11 CRITERION VALIDITY OF ULTRASOUND IMAGING AS COMPARED TO MAGNETIC RESONANCE IMAGING IN OLDER ADULTS

Jaclyn M. Sions, Gregory E. Hicks

Background: When compared to magnetic resonance imaging (MRI), which is considered the "gold standard" for muscle evaluation, ultrasound imaging has been shown to be a valid tool for assessing lumbar multifidi cross-sectional area in the asymptomatic spine. To date, there are no studies comparing ultrasound imaging to MRI in individuals with low back pain (LBP). The purpose of this study is to evaluate the criterion validity of ultrasound imaging as compared to MRI in older adults with and without LBP. Methods: 5 older adults with chronic LBP and 5 older adults without LBP, ages 60-85 years will be included in this preliminary analysis. Participants will be excluded if he/she has 1) a history of low back surgery, 2) experienced a recent traumatic event, 3) received services for LBP in the last 6 months, 4) severely impaired mobility, or 5) non-mechanical LBP. Cross-sectional MRI and ultrasound imaging data of the posterior trunk, including the lumbar multifidi, adjacent to the L4 spinous process will be collected, de-identified, and analyzed by a single examiner, using ImageJ software. Statistical Analysis: We will estimate intraclass correlation coefficients (ICCs) using model 3,1 with 95% confidence intervals (CIs) to assess absolute agreement of the imaging techniques. Results: Regardless of pain presence, ultrasound imaging when compared to MRI, may demonstrate excellent agreement for measurements of paraspinal muscle cross-sectional area (ICC: .964; 95% CI: .707, .996). Discussion: Preliminary results suggest that ultrasound imaging may be a valid alternative to MRI in future skeletal muscle research. Trunk muscle assessments may improve our understanding of LBP on muscle morphology in older adults. Expansion of the sample size may increase our confidence in these criterion validity results.

12 IMAGE CROSS CORRELATION SPECTROSCOPY (ICCS) AND THE INVESTIGATION OF MEMBRANE DYNAMICS

Alex D'Angelo, Beth Bragdon, Jeremy Bonor, Igor Prudovsky[1], Anja Nohe

Maine Medical Center Research Institute

Image cross correlation spectroscopy is a technique employed to image membrane dynamics. Many proteins are found in clusters on the outer cell membrane and can be visibly detected with adequate magnification on the confocal microscope. After imaging fluorescently tagged cells, one need only analyze the images with specialized software. ICCS functions by overlaying the clusters of each individual protein of interest and ultimately gives a semi-quantitative value for the spatial overlap of the clusters. These values obtained from the cluster overlay are called colocalization values.

The interactions of fibroblast growth factor 1 (FGF1) and glycophosphatidylinositol (GPI) were studied to develop ICCS skills. FGF1 is believed to be involved in non-classical cellular transport, a transport process which bypasses the golgi apparatus and endoplasmic reticulum. Its interactions with GH were studied to explore how exactly FGF1 functions in the non-classical transport system.

13 HIP FLEXORS DO NOT EXHIBIT ATROPHY BETWEEN LIMBS IN POST-STROKE SUBJECTS

John W. Ramsay, Thomas S. Buchanan, Jill S. Higginson

In normal gait, forward propulsion is achieved primarily through the push-off force provided by the plantar flexors. However, during gait following stroke, muscle weakness in the hemiparetic plantar flexors may prevent the subject from utilizing these muscles, thus limiting forward progression and reducing their walking speeds. To compensate for plantar flexor weakness, some stroke subjects may use their hip flexors to pull the lower limb forward. In a previous study we showed that weakness in the plantar flexors is due in part to muscle atrophy, but noticed that the gracilis, a hip flexor, is actually larger on the paretic side. Therefore, we hypothesized that the hip flexors would not exhibit atrophy on the paretic side in chronic post-stroke subjects. Fat-adjusted muscle volumes for individual hip flexors were determined for two post-stroke subjects using MR images and digital reconstruction software. Individual muscles were then summed to represent the entire hip flexor group size as a whole. One-tailed paired t-tests were used to test for significant differences between the paretic and non-paretic sides. Our preliminary results indicate that there are no significant differences between individual paretic and non-paretic muscles except for the pectineus, which is larger on the non-paretic side ($p<0.05$). As a group, there was no significant difference between paretic and non-paretic hip flexors. Using hip flexors as a compensatory mechanism during gait may prevent atrophy of these muscles in post-stroke populations. Future work is needed to address the subject-specific relationship between individual compensatory mechanisms and muscle atrophy.

14 DEVELOPMENT OF BIOLOGICALLY STABLE FLUORESCENTLY TAGGED BMP-2 ANALOG

Hemanth Akkiraju, Jeremy Bonor, Racheal Schaefer, Anja Nohe

Quantum dots are semi-conducting nanocrystals superior to the conventional organic dyes. Their high extinction coefficient and their stability (minimizing photobleaching), makes the, 20 times brighter and 100 times more stable than traditional fluorescent probes. Quantum dots research, in biological applications has evolved greatly. BMP2, a disulfide bonding homodimer protein belonging to Transforming growth factor (TGF-β) super family, is recognized by the FDA to be used for therapeutic treatments in skeletal repair and regeneration. There is limited information on the interaction between BMP2 and cell surface interfaces in regulation of cell differentiation. BMP2 binding to BMP Receptor type I and type II receptors induces phosphorylation and activation of Smad1, 5 and 8 leading to the activation of the signaling pathway for differentiation. Using BMP2 fluorescently tagged to quantum dots is the first step in prospect to study the signaling pathway in real time imaging to redefine the dynamics of binding ligands to its receptors during differentiation. We have developed a biologically stable covalently linked quantum dots to Bone Morphogenetic Protein-2 (BMP2), to elucidate the cell signaling pathway of Bone morphogenetic proteins. We used this technique to better elucidate the signaling pathway of BMP2. Conjugating quantum dots with BMP2 we ran stability tests to identify the time scale for the protein degradation and cell signaling. These approaches should permit to be used in live cell imaging through microscopic techniques to elucidate the signaling pathway for future testing methods in vitro and in vivo.

15 CALCITRIOL BOUND QUANTUM DOTS ARE A NOVEL TECHNIQUE THAT CAN BE USED TO FLUORESCENTLY VISUALIZE 1,25-DIHYDROXYVITAMIN D3

Rachel J. Schaefer, Jeremy C. Bonor, Anja G. Nohe

Calcitriol or 1,25-dihydroxyvitamin D3 regulates the transcription of many genes in the nucleus and is involved in rapid non-genomic signaling at the membrane. In nuclear signaling, Calcitriol then binds to a VDR, or vitamin D receptor. The VDR binds to a RXR, or Retinoid X Receptor to form a heterodimer, which interacts with a VDRE, or vitamin D response element with co-activators or repressors to up-regulate or down-regulate a VDRE gene. It has been observed that Calcitriol mediated signaling has therapeutic effects against certain cancer types, such as inflammatory breast cancer. Since calcitriol could potentially be used as a cancer treatment, it is essential to understand the full signaling pathways involved. As a hormone, the inability of calcitriol to be labeled with an antibody or GFP has limited further discovery. Our lab has developed a technique to bind calcitriol to quantum dots. Quantum dots are nanoparticles that give off a fluorescent glow under UV light. The viability of calcitriol bound quantum dots in signaling and in live cell imaging has been demonstrated. This technique can be applied to perform research with direct imaging of calcitriol in live cells and animals, which had previously been impossible. Directly viewing calcitriol could reveal more than could ever be seen with previous methods. Calcitriol bound quantum dots can be extended to use in cancer research, as a tool to look further into calcitriol's abilities as a possible treatment and to further understand the pathways behind it.

16 ACOUSTIC CHARACTERIZATION OF "DUAL-PURPOSE" ECHOGENIC LIPOSOMES

Shirshendu Paul, Tapas Nandy[1], Sanku Mallik[1], Kausik Sarkar

1 Dept of Pharmaceutical Sciences,
North Dakota State University

Ultrasound based diagnostic imaging uses micron sized encapsulated microbubbles as contrast enhancing agents. Liposomes have been widely used as drug delivery vehicles due to their biocompatibility and ability to encapsulate both hydrophilic and hydrophobic drug molecules. Recently echogenic liposomes (ELIP) have been shown to be good scatterers of ultrasound. To better understand the acoustic responses, we report herein the characterization ELIP using acoustic experimentation. Both frequency dependent attenuation coefficient and pressure dependent scattered linear and non-linear responses were investigated using an in vitro setup. The attenuation did not show any peak for the range of frequencies investigated. The attenuation coefficients show a linear increase with increasing concentration. Around 15-20 dB enhancement was observed for both the scattered fundamental and second harmonic responses at 3.5 MHz excitation frequency with acoustic pressure amplitudes ranging from 50-800 kPa. The scattered response however did not show any distinct subharmonic peaks for acoustic excitation parameters studied. The effects of the cryoprotectant mannitol on scatterring response were also studied by measuring response from ELIP prepared with different mannitol concentrations. Results indicate slight improvement in echogenicity for mannitol concentration more than 250 mM. Overall this set of exploratory investigations reveals suitability of using ELIP for diagnostic imaging.

POSTER PRESENTATIONS

Methods & Modeling

17 COMPENSATORY ANKLE CONTROL STRATEGIES WHEN WALKING WITH A CUSTOMIZED PD-AFO

Elisa S. Schrank, Jill S. Higginson, Steven J. Stanhope

Passive-dynamic ankle-foot orthoses (PD-AFOs) use rotational stiffness to provide plantarflexor assistance during stance. We have developed a novel customization and manufacturing framework for PD-AFOs. While the rotational stiffness of these PD-AFOs can be precisely selected, a process for prescribing optimal stiffness levels has not been established as the compensatory strategies induced by PD-AFO walking are not well understood. The purpose of this study was to develop and implement a predictive model of movement control strategies for PD-AFO gait to better understand the cause and effect relationship between PD-AFO stiffness and compensatory strategies.

Movement data were collected as a healthy subject (age: 24 yrs, height: 1.62m, mass: 63.6 kg) walked overground under two conditions: without and with a customized PD-AFO. In OpenSim, healthy and PD-AFO-integrated musculoskeletal models were scaled to anthropometric measurements. The PD-AFO was modeled using two bodies connected at the ankle joint by a six DOF bushing force, mimicking a spring with user-prescribed passive stiffness values. A simulation tracked the experimental gait data, and predicted muscle activity was calculated through a computed muscle control optimization scheme.

The subject walked with decreased ankle range of motion during the AFO condition. The simulation predicted PD-AFO stiffness substituted for all soleus activity during stance. However, gastrocnemius compensated by increasing its activity. The combined effect resulted in a compensatory strategy characterized by a premature increase in the plantarflexion moment during the AFO condition, a change that could not be accounted for entirely by the PD-AFO stiffness. The bushing force only accounted for 11% of the peak plantarflexion moment. These results indicated that, for this subject, a PD-AFO with a stiffness of 3.0 Nm/deg induced a complex compensatory movement control strategy involving changes in kinematics and muscle function.

18 A UNIFIED DEFORMABLE (UD) SEGMENT MODEL FOR MEASURING COMBINED SHANK-FOOT POWER

Kota Z. Takahashi, Alexander R. Razzook, Lakisha D. Guinn, Elisa S. Schrank, Thomas M. Kepple, Steven J. Stanhope

The natural shank-foot (NSF) system and the prosthetic shank-foot (PSF) system are two dramatically different structures that perform mechanical actions primarily through different mechanisms (i.e. muscular contractions versus spring deformation). Despite their differences, previous studies have often used an anatomically-relevant (AR) biomechanical model to compare the mechanics of the shank-foot systems during gait. However, traditional AR models are not valid for analyzing PSF components that have no defined ankle joints. Therefore, the goals of this study are to develop and validate a universal method for measuring the total segmental power (TSP) of a unified deformable (UD) shank-foot segment in normal gait.

Eleven healthy subjects participated in instrumented gait analysis, while walking at a targeted scaled walking velocity of 0.8 statures/second. The TSP derived via the AR model was calculated as the sum of the net ankle joint and the distal foot power. The TSP derived via the UD model was the sum of the total power of the distal end of the UD segment. Validity of the UD model for the NSF system was assessed by comparing peak powers, and the net positive and net negative work, between the AR and UD models.

The percent differene between the average total peak powers between the AR and UD model was 0.37%. The net positive work, and net negative work differed by 0.33% and 5.04%, respectively. These results indicated that the estimates of TSP between the AR and UD model showed a very close agreement. Conclusion::The UD model is a valid univesal method for measuring net powers of a combined shank-foot segment, and may facilitate direct comparisons between NSF and PSF systems.

19 A PREDICTIVE MODEL FOR NATURAL ANKLE STIFFNESS DURING WALKING: IMPLICATIONS FOR ANKLE FOOT ORTHOSIS PRESCRIPTION

Alexander R. Razzook, Kota Z. Takahashi, Lakisha D. Guinn, Elisa S. Schrank, Steven J. Stanhope

Introduction: A Passive-dynamic ankle foot orthosis (PD-AFO) is a type of ankle brace that functions like a rotational spring and can store and return mechanical energy. An emerging trend in the development of personalized assistive devices is customizing PD-AFOs to best replicate ankle joint dynamics such as natural ankle stiffness (NAS). Therefore we propose to measure healthy NAS, develop a predictive model of NAS and test the validity of the model for predicting NAS.

Methods: Eleven healthy subjects underwent instrumented gait analysis walking at four targeted scaled walking velocities of 0.4, 0.6, 0.8 and 1.0 body heights/second. NAS was calculated during the second rocker of gait and scaled by body weight (BW) (N) and body height (BH) (m). A one-way repeated measures ANOVA was used to identify the velocity effects of NAS and guide in model selection.

Results/Discussion: NAS varied significantly across the four walking velocities ($p<.05$) from .00377 (BH*BW)-1 (±.00067) at 0.4 BH/s to .00640 (BH*BW)-1 (±.00194) at 1.0 BH/s. A 2nd order polynomial was used to fit the scaled NAS means at each walking velocity (R2=.993) and used to determine the generalized model y=[.00323x2+ .000002x+.00323]*(BH*BW). This model was then used to predict the peak ankle moment for a population of 15 7y/o's with an average BH=1.21m, BW=243.29N and walking velocity =1.3m/s that was reported in Ganley and Powers (2005). The predicted peak ankle moment was within 0.13Nm or 0.45% of the experimentally obtained peak moment during stance demonstrating remarkable predictability.

Conclusion: We have developed a robust predictive model that can be used to estimate NAS for subjects based on BH and BW for a given walking velocity for the purpose of prescribing optimally tuned PD-AFOs.

20 IDENTIFICATION OF SCAPULAR KINEMATICS USING SURFACE MAPPING

Jeffrey M. Mattson, Stephanie A. Russo, James G. Richards

The immediate goal of this project is to develop and validate a computational approach to measuring scapular kinematics by using available motion capture technology in an innovative manner. The long-term goal of this research is to determine the role of the scapula in children with brachial plexus birth palsy (BPBP) in order to facilitate the development of individualized medical and surgical treatment plans. For convenience, validation of the method used healthy participants with minimal soft tissue covering their scapulae. Equivalent or better results are expected for participants with BPBP, due to more prominent surface deformation from minimal tissue covering their scapulae. A "neutral trial", i.e. arm relaxed at side, was collected to create a subject-specific template from palpated scapular landmarks. Following the neutral trial, participants performed the positions of the modified Mallet classification. The scapular landmarks were re-palpated and re-marked in each of the six Mallet positions. The palpated scapular markers were then replaced by a grid of approximately 300 markers covering the scapula to create a surface map for each position. Participants repeated the series of six Mallet positions three times and the trial with the arm position that was closest to each corresponding palpated trial was analyzed. The subject-specific template created in the neutral trial was fit to the surface map from each grid trial to estimate the orientation of the scapula in each Mallet position. For all positions, estimations of scapular orientation derived from the surface maps were compared with direct measures from the palpated landmarks. When all data are collected, a two-way ANOVA and Pearson's r will be used to test the agreement between the two approaches at the different positions.

21 DESIGN OF A NOVEL MOBILITY DEVICE CONTROLLED BY THE MOVEMENT OF A CHILD'S FEET

Zachary R. Schoepflin, Xi Chen, Christina B. Ragonesi, James C. Galloway, Sunil K. Agrawal

Self-generated mobility is a major contributor to the physical, emotional, cognitive, and social development of infants and toddlers. When young children have disorders that hinder self locomotion, their development is at risk for delay. Independent mobility via traditional power mobility devices may prevent this delay, but do little to encourage the child's development of gross motor skills. This research aims to develop a bio-driven mobile-assistive device that is controlled and driven by moving the feet, which may encourage the development of gross motor skills.

In this study, system feasibility is shown by experiments on five typically developing toddlers and one special needs toddler with spastic cerebral palsy. Children were placed in the bio-driven device and instructed to navigate through a maze. All subjects were able to successfully complete the maze in multiple trials. Additionally, two toddlers showed evidence of improved driving skill by completing the maze in shorter times in successive trials on a given testing day. The results suggest that such a device is feasible for purposeful driving. Recommendations are given for the device and protocol redesign for related future testing.

POSTER PRESENTATIONS

Motor Control

22 LOWER EXTREMITY NEUROMUSCULAR COORDINATION DURING STATIC STANCE: THE EFFECT OF VISUAL FEEDBACK

Toran D. MacLeod, Lynn Snyder-Mackler, Kurt Manal, Thomas S. Buchanan

Bipedal standing postural control strategies have been studied in response to a variety of unidirectional support perturbations. Our understanding of how the limbs coordinate bidirectional forces is limited, as is commonly performed in daily life. To study this, we had participants stand on two 6 degree of freedom force platforms. A randomly selected limb was chosen as the "mobilizing limb," making the other the "stabilizing limb." Simultaneous visual feedback was given of the forces and moments of the mobilizing limb on the force platform. The task required that subjects guide a cursor with their mobilizing limbs into a randomly selected target in one of 18 directions (every 20° around the circumference of a circle) in a forward-backward-medial-lateral plane while keeping the foot on the platform. Knee muscle EMGs were recorded during the time subjects matched the static isometric postures. Our hypotheses were that the mobilizing limb would have different neuromuscular coordination when compared to the stabilizing limb and that both play important and independent roles (under nearly identical external forces). We found that the lateral hamstrings were more specifically recruited and with a greater percentage of maximum contraction as a mobilizer; that the medial hamstrings were recruited with more specificity and in a different principal direction as a stabilizer; and that the lateral gastrocnemius had a principal direction of action as a mobilizer in nearly the opposite direction as when stabilizing, and with a greater relative percentage of maximum as a stabilizer. Our results suggest that the CNS coordinates the lower extremity differently when acting as a mobilizer in comparison to a stabilizer while coordinating the same posture, which has implications for dynamic knee stability rehabilitation interventions.

23 IMPROVEMENTS IN THE RATE OF FORCE DEVELOPMENT-SCALING FACTOR FOLLOWING A HIGH SPEED-LOW RESISTANCE CYCLING EXERCISE PROGRAM

Maria Bellumori, Christopher A. Knight

When an individual performs a set of isometric muscular contractions to varied amplitudes under the instructions to generate force most rapidly, there is a linear relationship between the peak forces (PF) achieved and corresponding peak rates of force development (RFD). The slope of this relationship, termed the rate of force development–scaling factor (RFD-SF), quantifies the extent to which RFD scales with the amplitude of contractions. The aims of this study were to determine: 1) whether a six week exercise program using high speed-low resistance stationary cycling can improve the quickness of muscular force production and functional measures in older adults and 2) if training for the lower extremities would transfer to increases in quickness in the upper extremities. Participants (n=6, mean (SD) age=73(6.8)) completed a pre- and post-exercise test as well as 4 week follow-up to determine retention of changes. It was hypothesized that there would be improvements in the following measures: 1) Greater RFD-SF is known to correspond with higher quality function of the nervous system. 2) The Timed Up & Go (TUG), 6 meter walk, and nine-hole peg tests are standardized measures of function. 3) The Activities-specific Balance Confidence (ABC) Scale was used to assess whether any improvements in quickness or function induced changes in perceived status. After 6 weeks of exercise there were significant improvements in RFD-SF in both the legs and arms as well as the TUG, 6 meter walk, and 9-hole peg tests ($p<.05$). Although non-significant, there were slight improvements in ABC scores. Four weeks post exercise, RFD-SF decreased toward baseline while improvements in functional measures were retained ($p<.05$). That improvements were observed in the arms suggests a central nervous system adaptation to exercise. However, because RFD-SF trended toward baseline four weeks post exercise represents the importance of continued exercise to optimize neural function.

24 ALTERED WALKING PERFORMANCE DURING SIMULTANEOUS COGNITIVE TASKS

Amy L. Lenz, Christopher I. Higginson[1], Jill S. Higginson

1 Loyola University Maryland, Baltimore, MD, USA

Postural control during motor tasks may be influenced by simultaneous performance of cognitive tasks such as numerical verbal tasks and obstacle crossing. Dual task walking is of particular concern in older adults due to the increased risk of falling with age. The objective of this study was to explore kinematics and kinetics of walking during simultaneous performance of cognitive tasks. We tested the hypothesis that cognitive tasks would alter hip, knee, and ankle joint angles, anterior/posterior ground reaction forces and vertical force at heel contact. Five healthy young adults participated in this IRB approved study. Subjects performed eight 120s walking trials on a split-belt instrumented treadmill at preferred speed and a fast speed (120% of preferred speed). During each test, three different congitive tests were performed of varying difficulty. Whole body kinematics were recorded using a passive motion capture system. All components of analysis were evaluated for the last five gait cycles of each trial. Stastical analysis was performed using paired t-tests comparing walking during each dual task with baseline walking at both speeds. Self-selected speed trials including the most demanding cognitive task illistrutated significant ($p<0.05$) increase in peak hip extension, decrease in peak hip flexion, decrease in peak knee flexion during stance and decrease in peak plantar flexion. Walking kinematics in healthy young adults appears to mainly be disturbed when challenged by only the most demanding of cognitive tasks. Although the t-test is robust to violations of the assumption of normality, more subjects are necessary to draw firm conclusions about this population. Further investigation of the influence of cognition on walking kinematics and kinetics in an older adult group may prove to have greater changes relevant to risk of falling.

25 EFFECTS OF INSTRUCTIONS AND HAND DOMINANCE ON GRIP FORCE COORDINATION IN MANIPULATION TASKS

Xin Jin, Mehmet Uygur, Slobodan Jaric

The ability to grasp and hold an object is the most frequent action performed in our daily motor activities and also essential for living an independent life. According to a simple prehension model, the force applied upon a vertically oriented hand-held object could be decomposed into two distinctive but highly coordinated components: the grip force (GF; the component perpendicular to the hand-object contact area that provides friction) and the load force (LF; the component parallel to the hand-object contact area that can either move the object or provide external support of the body). The GF-LF coordination could be affected by a number of factors that still remain underexplored. The aim of this study is to investigate the effect of instructions and hand dominance. Sixteen right-handed subjects were tested on a custom designed instrumented device. They performed bimanual manipulation tasks under different instructions and mechanical conditions. The exerted GF and LF were recorded and analyzed. Indices of GF scaling, GF-LG coupling and GF modulation were calculated separately for the dominant and non-dominant hand. The result showed that the instruction "to pull" leads to higher indices of GF-LF coordination than the instruction "to hold", as seen by a lower GF-LF ratio, higher GF-LF coupling, and higher GF modulation. The only effect of hand dominance was a more prominent time lag of GF of the non-dominant hand. Overall, the observed findings suggest that the instructions could play an important role in GF-LF coordination and, therefore, they should be taken into account either when studying hand manipulation activities or when routinly testing hand function in various patient pupolations.

26 FES CAN IMPROVE EXERCISE IN CHILDREN WITH CEREBRAL PALSY

Nicole Zahradka, Samuel C.K. Lee

Physical activity is important to preserving health and preventing disease amongst the general population, however, physical activity is often difficult to achieve for individuals with physical disabilities such as cerebral palsy (CP). Stationary recumbent cycling is suggested as a viable method for exercise in individuals with CP because it does not require the dynamic balance demanded by standing positions while providing a potential means of improving strength, cardiovascular function and range of motion. Unfortunately, many individuals with CP may not have the strength or motor control to cycle at therapeutic levels. FES-assisted cycling for CP is a translational approach from treatment of individuals with SCI. The goal of this study is to determine if 8-weeks of FES-assisted cycling provides greater changes to cycling ability (power output and duration) than 8-weeks of volitional cycling training in adolescents with spastic CP. Eight individuals (7 Males), 13.9 ± 1.9 years old, were randomly assigned to participate in one of two training programs: (1) volitional cycling (n=3) and (2) FES-assisted cycling (n=5). Subjects received video game feedback to assist training at their prescribed target power. The FES-assisted group also received stimulation to the quadriceps muscles during the appropriate times of pedal crank rotation to assist cycling. If needed, FES intensity ramped up to assist cycling if target powers were not achieved and vice versa when target powers were sustained. Most subjects showed improvements in average power output and duration of time spent at target at the end of 8-weeks. The FES-assisted group demonstrated increased target powers during week 4, suggesting that FES may be a useful tool to elevate a subject's maximum cycling power. As this study continues, the evidence suggesting FES-assisted cycling is a beneficial tool should become more prominent.

POSTER PRESENTATIONS

Osteoarthritis

27 KNEE OSTEOARTHRITIS RESULTS IN ASYMMETRIC JOINT MOMENT DISTRIBUTION DURING GAIT

Tyler Richardson, Jill Higginson

Individuals with knee osteoarthritis (OA) exhibit abnormal kinetic and kinematic gait patterns. The total support moment is the summation of the hip, knee, and ankle internal extensor moments and has been shown to be a reliable method of measuring intersegmental coordination and distribution of joint moments. While many studies have analyzed the affected limb of knee OA subjects, very few have examined the contralateral unaffected limb and degree of symmetry. Using an instrumented treadmill and an 8 camera Motion Analysis system, we collected gait data for 23 healthy subjects and 23 OA subjects at their self-selected walking speed. We compared the peak total support moment magnitude and relative joint contributions at the corresponding time step of the affected and unaffected limbs. The healthy group showed no significant differences between limbs. There also was no significant difference in peak total support moment or hip contribution for the OA group. The OA group significantly decreased knee contributions and increased ankle contributions in the affected limb. This suggests that when the loading of the affected knee joint is reduced, the displaced loading is not shifted to the unaffected limb, but rather to the ipsilateral ankle joint. This is evidence of interlimb asymmetry with respect to joint moment distribution. While our results demonstrate that redistribution of joint contributions to the peak total support moment is a quality of OA gait, it is not clear as to whether this is a governing control strategy or a consequence of one of many other known compensatory strategies. In future research we plan to analyze the kinematics and spatiotemporal parameters in order to better understand the mechanisms of this compensatory joint moment redistribution.

28 DYNAMIC LOADING DURING A STEP TASK AND ITS RELATIONSHIP WITH FUNCTIONAL MEASURES AND KNEE OSTEOARTHRITIS

Joshua D. Winters, Deepak Kumar[1], Katherine S. Rudolph

1University of California at San Francisco

Dynamic loading patterns during walking influence the initiation and progression of osteoarthritis (OA) of the knee. Loading rates play an important role in the deformation and degradation of cartilage and may help in understanding the types of loading experienced by the knee during common activities of daily living (ADLs). 13 OA and 13 healthy controls completed a step up and over task. Loading rates and loading impulses were calculated from the ground reaction forces. Knee Outcome Surveys (KOS) and Knee and Osteoarthritis Outcome Score (KOOS) self-reports were completed prior to testing. Independent-samples t-tests were used to calculate loading differences between the OA and healthy control groups and Person product correlations were used to determine significant relationships between the loading variables and clinical measures that may influence loading. The OA group experienced significantly lower average loading rates ($t=-3.013$, $p=.008$), lower peak impact loading ($t=-2.396$, $p=.029$), and lower peak GRF ($t=-3.187$, $p=.004$) when landing or descending with their involved limb than that of the healthy controls. Significant correlations were found in the OA group between both the average loading rates and the peak impact loading with KOS Global($r=-.699$, $p=.008$, and $r=-.805$, $p=.001$), the KOOS ADLs ($r=-.629$, $p=.021$, and $r=-.804$, $p=.001$), and the KOOS pain ($r=-.574$, $p=.040$, and $r=-.658$, $p=.014$) respectively. Assessing the different types of loading patterns encountered by the knee during common activities of daily living, examining the strategies used to minimize these loading patterns, and determining the relationships between these loading patterns and functional assessments may allow for more effective individualized intervention strategies for knee OA.

29 GAIT RETRAINING TO REDUCE KNEE JOINT CONTACT FORCES

Amelia S. Lanier, Kurt Manal, Thomas Buchanan

Gait retraining is a useful, noninvasive rehabilitation tool for many patient populations. Altering gait mechanics could be an effective means to reduce pain and prevent disease progression. Gait retraining has been used to reduce medial compartment knee loading, a risk factor for osteoarthritis. Knee contact force, the sum of inter-segmental forces and muscular compressive forces at the knee, peaks during early and late stance of gait. The initial peak contains the highest amount of medial loading; intervention during this phase could be beneficial in preventing osteoarthritis progression.

This study aims to use gait retraining to reduce knee joint contact force by increasing knee flexion during early stance using audio/visual feedback. Kinematic, kinetic, and EMG data will be collected while subjects walk on a split-belt instrumented treadmill. For initial assessment, over-ground data will be collected as baseline data. For training, subjects will receive real-time feedback of knee flexion angle following a fading paradigm, where feedback is incrementally reduced from 100% to 0%, over the training phase. Over-ground data will be used for evaluation immediately following training, one week post training, and one month post training. Knee joint contact force will be monitored during all phases. Changes between initial assessment and post-training evaluation will be used to evaluate knee joint contact force reduction and learning. In coming weeks preliminary data will be collected to design a feedback method and assess our calculations of knee joint contact force.

Future efforts will work to develop powerful feedback methods that enable this gait retraining to have long-term motor learning effects, a limitation of current retraining methods. An effective method to reduce knee joint loading by increasing knee flexion during early stance could be used to further develop gait retraining rehabilitation.

30 NOVEL INTERVENTION IMPROVES CONTRALATERAL KNEE FUNCTION POST-TOTAL KNEE ARTHROPLASTY

Portia Flowers, Joseph Zeni, Jodie McClelland, Lynn Snyder-Mackler

Introduction – After total knee arthroplasty (TKA), patients walk with residual asymmetrical movement patterns and increased loads in the contralateral limb, which may lead to osteoarthritis (OA) progression in the non-operated limb. Rehabilitation that restores symmetrical strength and movement patterns may provide optimal outcomes after TKA. Objective – Evaluate a rehabilitation protocol that restores symmetrical movement patterns after primary TKA. Methods – Six individuals with knee OA scheduled for unilateral TKA were analyzed. Subjects participated in 4-6 weeks of post-operative physical therapy, 2-3 sessions per week. Two of the subjects participated in outpatient physical therapy that focused on symmetrical loading during functional activities and progressive strengthening, while the remaining subjects received usual care. Interlimb symmetry feedback was provided by a custom computer program that used a Wii Balance Board as input. Feedback during leg press exercises was provided by a monitor on the SymSlide, a leg press device with dual integrated force plates under each foot. Functional and motion analysis testing was performed prior to surgery and at discharge from outpatient physical therapy. Qualitative comparisons were made between subjects in the symmetry and usual care groups. Results – After rehabilitation, symmetry subjects had improved sagittal knee moments in the operated limb compared to pre-operative values and these values were larger than those from the usual care group. Post-operatively, symmetry subjects had reduced knee adduction moments in the contralateral knee compare to the usual care group. One symmetry subject demonstrated a dramatic restoration of knee flexion excursion during walking. Discussion – The symmetry protocol is promising as it reduced post-operative joint loading in the contralateral limb and may be a clinically useful method to improve movement symmetry after TKA.

POSTER PRESENTATIONS

Robotic Training

31 DESIGN OF A MINIMALLY CONSTRAINING, PASSIVELY SUPPORTED GAIT TRAINING EXOSKELETON: ALEX II

Kyle N. Winfree, Paul Stegall, Sunil K. Agrawal

This paper discusses the design of a new, minimally constraining, passively supported gait training exoskeleton know as ALEX~II. This device builds on the success and extends the features of the ALEX~I device developed at the University of Delaware. Both ALEX (Active Leg EXoskeleton) devices have been designed to supply a controllable torque to a subject's hip and knee joint. The current control strategy makes use of an assist-as-needed algorithm. Following a brief review of previous work motivating this redesign, we discuss the key mechanical features of the new ALEX device. A short investigation was conducted to evaluate the effectiveness of the control strategy and impact of the exoskeleton on the gait of six healthy subjects. This paper concludes with a comparison between the subjects' gait both in and out of the exoskeleton.

32 QUANTIFYING GRAVITATIONAL TORQUE REQUIREMENTS FOR A POWERED EXOSKELETON

Daniel Ragonesi, Sunil Agrawal, Whitney Sample[1], Tariq Rahman[1]

1 AI duPont Hospital for Children

Designing an upper extremity exoskeleton for people with arm weakness requires a knowledge of the passive and active residual force capabilities of users. This paper experimentally measures the passive gravitational torques of 3 groups of subjects: able-bodied adults, able-bodied children, and children with neurological disabilities. The experiment involves moving the arm to various positions in the sagittal plane and measuring the gravitational force at the wrist. This is then converted to static gravitational torques at the elbow and shoulder. Data are compared between look-up table data based on anthropometry and empirical data. This experiment informs designers of upper arm orthoses on the contribution of passive human joint elements.

 All researchers are from the University of Delaware, Newark, DE, USA unless otherwise noted.

33 EXPERIMENTAL STUDIES ON THE HUMAN GAIT USING A TETHERED PELVIC ASSIST DEVICE (T-PAD)

Vineet Vashista, Shabbir K. Mustafa[1], Sunil K. Agrawal

1 Singapore Institute of Manufacturing Technology, A*STAR

This paper presents the prototype of a novel tethered pelvic assist device (T-PAD). This is a purely passive device, consisting of a set of elastic tethers with one end attached to a hip brace worn by a subject walking on a treadmill, and the other end attached to a fixed frame surrounding the subject. T-PAD offers the flexibility of varying the assistance required on the pelvis by changing the configuration of the tether attachment locations, number of tethers and tether elasticity.

Experimental studies were conducted using a full and a partial pelvic constraint configuration of T-PAD, with varying tether elasticity. The studies were aimed at observing the effect of T-PAD on the human gait. Results show that T-PAD reduced the range-of-motion for the pelvic angles with increase of tether elasticity. However, it had mixed effects on the range-of-motion of the hip angles, but negligible effect on the knee and ankle joint angles. Overall, T-PAD shows potential as a low-cost pelvic support device with pelvic motion control capabilities, and can work in tandem with existing gait trainers.

34 ADULT-HUMAN LEARNING ON A ROBOTIC WHEELCHAIR USING A FORCE FEEDBACK JOYSTICK

Vineet Vashista, Xi Chen, Shazlin Shaharudin, S.K. Mustafa[1], Sunil K. Agrawal

1 Singapore Institute of Manufacturing Technology, A*STAR

Individuals with mobility impairments often find it challenging to use powered wheelchairs, even after being given training. Hence the motivation of this research is to study the effect of a robotic wheelchair with force feedback joystick on adult-human learning behavior.

In this paper, results are presented when healthy adult subjects drive a robotic wheelchair in a real environment. 'Assist as needed' paradigm was used to calculate the feedback force in order to train the user necessary driving skills for a particular trajectory. Two commonly used trajectory tracking control algorithms, i.e., line following and point following, were implemented. The training protocol, consisting of pre-training, training, and post-training on two different trajectories, showed improvement in driving skills using only the line following based controller (t-test, p = 0.0026 for pre-training day 1 and day 2).

35 A CABLE DRIVEN UPPER ARM EXOSKELETON FOR UPPER EXTREMITY REHABILITATION

Ying Mao, Sunil K. Agrawal

Conventional robotic rehabilitation devices for upper extremity are bulky, heavy or lack the ability to provide joint level rehabilitation. Some designs address these issues by replacing rigid links of the exoskeletons with light weight cables. However these designs are controlled in position mode instead of force control which is desirable for rehabilitation. In this paper, a 5 degree-of-freedom cable-driven upper arm exoskeleton, with control of force, is proposed. In this design, attachment points of cables on the arm are adjustable. The attachment points are optimized to achieve large workspace to perform activities of daily living. Simulation results of force field control for training and rehabilitation of the arm are presented. Experiments have been performed on a dummy robotic arm in the upper arm exoskeleton.

POSTER PRESENTATIONS

Stroke

36 DOES THE TIMING ACCURACY OF ANKLE DORSIFLEXOR FUNCTIONAL ELECTRICAL STIMULATION INFLUENCE GAIT PERFORMANCE POST-STROKE?

Dylan Thorne-FitzGerald, Trisha Kesar, Sarah Flynn, Erin Helm, Stuart Binder-Macleod

Foot drop is a common impairment after stroke, and often leads to slowed walking speeds, and decreased community ambulation. Functional electrical stimulation (FES) delivered to the dorsiflexor muscles during the swing phase results in improved walking speed and efficiency in post-stroke individuals. The goal of this study was to determine the optimal timing for delivering functional electrical stimulation (FES) for correction of foot drop to the ankle dorsiflexor muscles during gait. In a previous study, ankle dorsiflexor FES was shown to decrease peak swing phase knee flexion during treadmill walking. This could occur because the FES was triggered using footswitches, causing the FES onset to be earlier than true toe-off, as measured using ground reaction forces. Eight post-stroke subjects participated in this study. Our primary outcome measures were peak knee flexion and ankle dorsiflexion. For each subject, we computed the difference (delay) between the vertical ground reaction force toe-off and the footswitch toe-off. Different FES timing delays for onset of dorsiflexor FES were tested, ranging from 0% delay to 200% delay. Results from this study suggest that additional delays to dorsiflexor FES do not substantially improve peak swing phase knee or peak swing phase dorsiflexion. However, promising results were seen with the addition of delays for the secondary outcome variable, ankle plantar flexion angle at toe-off.

37 QUANTIFICATION OF ATROPHY AND ACTIVATION FAILURE IN THE PLANTARFLEXORS POST-STROKE

Brian A. Knarr, John Ramsay, Thomas Buchanan, Stuart Binder-Macleod, Jill Higginson

Muscle weakness is a common impairment for chronic stroke survivors, and is characterized by lower forces during maximal volitional contraction on the affected side. Post-stroke muscle weakness is commonly thought to be a result of a combination of central nervous system impairments and muscular atrophy due to disuse. Changes in muscle properties such as specific tension and architecture, may also contribute to muscle weakness. The goal of this study is to assess the loss in force generating ability of the plantarflexor muscle group related to activation failure. We hypothesize that activation failure will account for a large portion, but not all, of muscle weakness. Thirteen subjects post-stroke (Age 60±8 yrs., 2 Female, 4.2±3.2 yrs. post-stroke) were recruited to participate in this study. All subjects were at least 6 months post-stroke and signed informed consent forms approved by the Human Subjects Review Board at the University of Delaware. Muscle strength was tested using the burst superimposition test with their knee in extension and ankle at neutral. The volume of the soleus, medial gastrocnemius, and lateral gastrocnemius muscles were measured from axial MRI images. Predicted max torque of the paretic plantarflexors (82.4±20.2 Nm) was 66.5±9.6% of the non-paretic limb (124.9±30.4 Nm). The average paretic plantarflexor volume was 79.8±9.1% of the non-paretic limb. With full activation, the paretic limb had a 34% lower maximum torque than in the non-paretic limb. Some of this difference can be accounted for by muscle atrophy, however our results suggest that additional changes in muscle properties such as specific tension, muscle architecture and overall muscle quality are likely the cause of significant (~13%,p=.002) loss in maximum torque of the paretic limb in relation to the non-paretic limb.

38 ROBOTIC ERROR-ENHANCEMENT GAIT TRAINING FOLLOWING STROKE

Shraddha Srivastava , Pei-Chun Kao, Sunil Agrawal, John Scholz

Robotic gait training has been developed recently as a potential method of gait rehabilitation. Application of robotic error-enhancing force-field may facilitate motor learning because error based learning may encourage more effort and participation. The purpose of this study is to determine whether error-enhancement gait training with a robotic exoskeleton can lead to improvements in walking ability of chronic stroke survivors. To date, two male stroke subjects with right hemiparesis have participated in this study to receive five 40-min training sessions walking in a robotic exoskeleton (ALEX) on the treadmill. Virtual ankle path prescribed for training were based on that of healthy controls. When subjects' instantaneous ankle positions were below the virtual path, the error-enhancing force-field controller applied forces that take subjects' leg further away from the virtual path. Subjects received intermittent visual feedback on their instantaneous ankle positions and the virtual ankle path. Both the stroke survivors walked with an ankle path closer to healthy subjects' ankle path by the end of training, evidenced by a smaller computed area between the two paths compared to the pre-training (S1: 105 cm2 57 cm2, S2: 71 cm2 52 cm2). Increased total joint range of motion at hip and knee during swing phase was also demonstrated after training. Moreover, preferred over ground walking speeds increased slightly for both subjects (S1: 0.81 0.86 m/s, S2: 0.7 0.76 m/s). These preliminary results suggest that robotic gait training emphasizing error-enhancement may have potential to improve walking capacity in the long-term for chronic stroke survivors. Future work is to conduct a relatively long-term training protocol with this paradigm and to compare the changes in walking ability for stroke survivors receiving error-enhancement to those receiving assist-as-needed robotic training.

39 THE NEURAL CORRELATES OF MUSCLE WEAKNESS AND SLOWNESS POST STROKE

Li-Wei Chou[1], Jacqueline A Palmer, Darcy Reisman, Stuart A. Binder-Macleod, Christopher A. Knight

1 Department of Physical Therapy and Assistive Technology, National Yang-Ming University, Taipei, Taiwan

Individuals with stroke suffer from symptoms such as muscle weakness and movement slowness, which limits the ability to function independently. The central nervous system (CNS) uses two mechanisms, motor unit (MU) rate-coding and recruitment, to control forces generated by skeletal muscles. However, information regarding how MUs are controlled to produce forces in individuals with stroke and the mechanisms behind muscle weakness and movement slowness is scant, yet quite valuable. The purpose of this study is to determine how stroke impairs MU rate-coding during voluntary muscle contractions and how the rate-coding deficiencies in post-stroke individuals contribute to motor deficits.

Isometric knee extension or dorsiflexion force and single motor unit discharge patterns and EMG signals were recorded from the affected and unaffected lower extremities of nine stroke survivors. Experimental conditions included ramp contractions, constant force contractions, and quick pulse contractions.

Slow initial discharge rates as compared with the unaffected limb is an obvious motor unit correlate of slowness in the stroke survivors in this study. A severely limited range of discharge rates during contractions involving gradual increases in force was observed. EMG data shows a reduction in the magnitude of neural excitation and the scaling factor used by the CNS in the rate of force development, which were significantly greater than the reductions in strength.

Understanding the specific impairments in the neural mechanism of muscle force production and their relationships with motor deficits could lead to the development of advanced and physiology-based rehabilitation strategies in the future that target the muscular strength and quickness that are critical for performing daily functions.

40 CAN IMPROVEMENTS AT 4 WEEKS PREDICT WHO WILL RESPOND TO 12 WEEKS OF FASTFES TRAINING AFTER STROKE?

Erin E. Helm, Stuart A. Binder-Macleod, Trisha M. Kesar, Darcy S. Reisman

Gait deficits persist even after rehabilitation in many persons post-stroke. To provide optimal intervention it would be useful to predict who will respond to a particular treatment. We hypothesized that responses to four weeks of FastFES training would predict outcomes observed after 12 weeks of the intervention.

Methods: 12 individuals with chronic post-stroke hemiparesis (5 males, Age 63+8 years, time post-stroke 56+44 months) participated in 12-weeks (3x/week) of FastFES gait training. Each training session comprised ~30-minutes of fast walking with electrical stimulation of the dorsi- and plantar-flexor muscles. Gait kinematics & kinetics, walking speed, endurance, and the Functional Gait Assessment (FGA) were assessed pre training, and after 4, 8 and 12 weeks of training.

Results: As hypothesized, there were significant correlations between the improvement in ankle plantar flexion at toe off, peak knee flexion during swing , and forward propulsion after 4 versus12-weeks of training ($p<0.05$). Changes in walking speed, endurance and the FGA at four weeks were not significantly correlated with changes at 12 weeks.

Conclusions: Our findings suggest that individuals post-stroke who do not improve gait kinematic and kinetics within four-weeks will not improve these variables with an additional 8 weeks of FastFES training. In contrast, lack of improvement in walking speed, endurance and function at 4 weeks does not appear to dictate outcomes at 12 weeks. This suggests that there is a different time course for change in specific gait impairments versus overall gait function. This may be due to the myriad of mechanisms that underlie changes in gait function versus the relatively specific mechanisms that underlie changes in gait kinematics and kinetics.

41 HOW MANY TESTING SESSIONS ARE NECESSARY TO DETERMINE THE EFFECTIVENESS OF POST-STROKE GAIT INTERVENTIONS?

Louis Awad, Trisha Kesar, Stuart Binder-Macleod

In able-bodied individuals, improvements in task performance are often seen with repeated testing. The presence of a similar interaction between the testing of post-stroke gait and gait performance may require multiple testing sessions before an accurate reflection of baseline walking ability can be obtained. However, because the interaction between gait testing and performance has not been previously explored in the post-stroke population, it is unknown whether multiple testing sessions are necessary to evaluate the effectiveness of post-stroke gait interventions.

Nine individuals with chronic, post-stroke hemiparesis participated in two testing sessions. Five of these individuals participated in an additional three testing sessions. An 8-camera motion analysis system was used to measure sagittal plane knee and ankle joint kinematics during walking on an instrumented treadmill with and without Functional Electrical Stimulation (FES) applied to the ankle dorsiflexors.

Whether measured across two or five sessions, no consistent changes in knee or ankle kinematics were observed, suggesting that there is little advantage to collecting more than one testing session when assessing baseline walking ability. Thus, clinicians do not need to waste valuable time and resources collecting multiple testing sessions when evaluating the effectiveness of post-stroke gait interventions. As expected, FES consistently increased peak ankle angle across sessions. Interestingly, FES also reduced ankle and knee kinematic variability within each session, suggesting that gait intervention protocols should not depend solely on FES; periods of no FES should be included to maximize the motor learning benefits of variable task practice.

Notes

8th Annual Biomechanics Research Symposium

Schedule of the Day

TIME	WHAT	WHERE
8:30 AM	BREAKFAST & POSTER SET-UP	CLAYTON HALL LOBBY
9:00 AM	WELCOME	CLAYTON HALL AUDITORIUM 125
9:15 AM	KEYNOTE: DR. VAN C. MOW	CLAYTON HALL AUDITORIUM 125
10:15 AM	BREAK	
10:30 AM	PODIUM SESSION 1	CLAYTON HALL AUDITORIUM 125
12:00 PM	LUNCH	CLAYTON HALL ROOM 120
1:00 PM	POSTER SESSION 1 (ODD #S)	CLAYTON HALL LOBBY
2:00 PM	POSTER SESSION 2 (EVEN #S)	CLAYTON HALL LOBBY
3:00 PM	PODIUM SESSION 2	CLAYTON HALL AUDITORIUM 125
4:30 PM	AWARDS SESSION	CLAYTON HALL AUDITORIUM 125