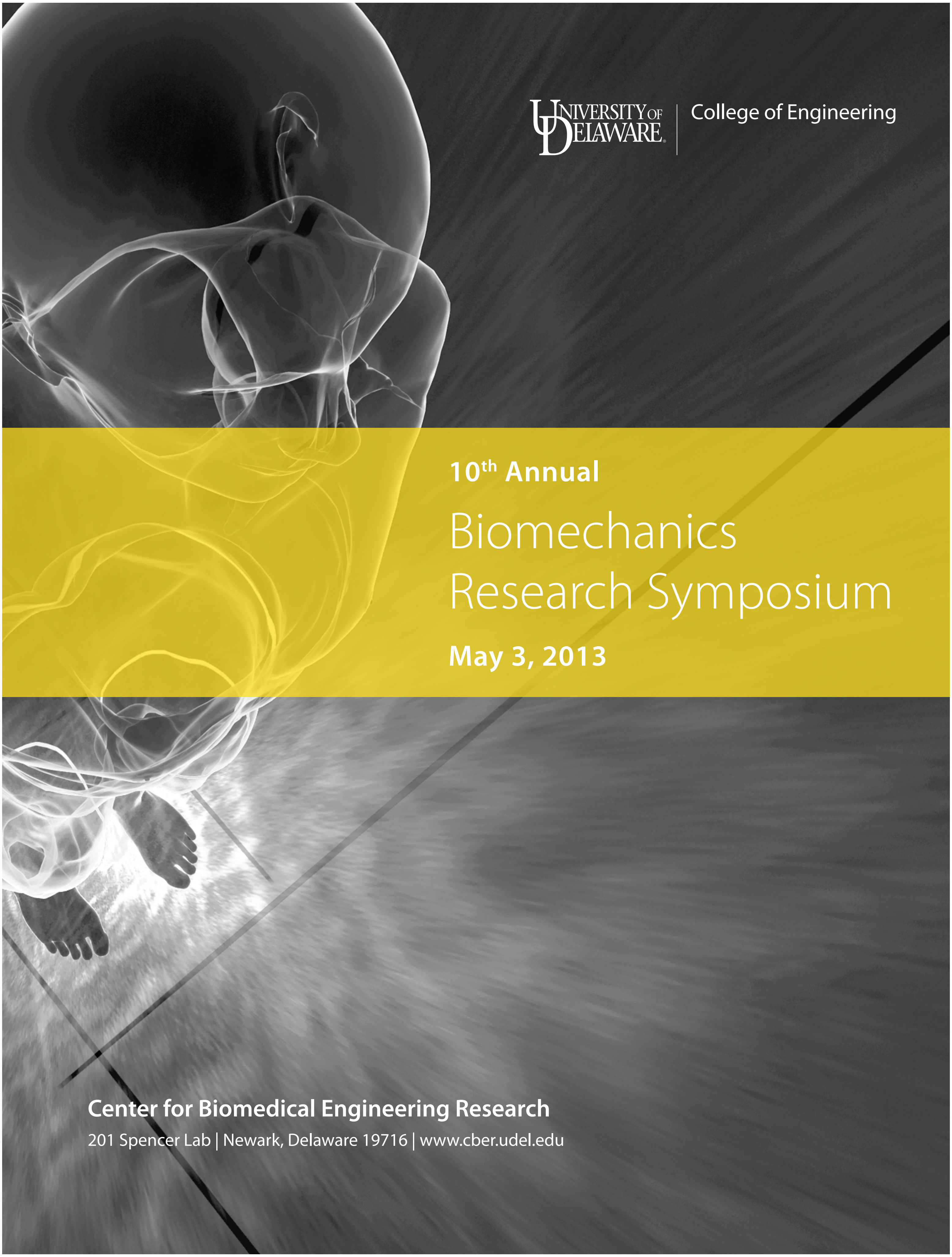

University of Delaware | College of Engineering

10th Annual

Biomechanics Research Symposium

May 3, 2013

Center for Biomedical Engineering Research

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

Welcome students, faculty and friends!

Thank you for participating in the **10th 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 with students presenting their findings in all poster and podium sessions. We would like to acknowledge the support of the Delaware Rehabilitation Institute for the student awards presented at the conclusion of today's events.

The CBER mission is to provide engineering science and clinical technology to reduce the impact of disease on the everyday life of individuals. To that end, we are delighted to welcome this year's keynote speaker, **Dr. Carolee Winstein**. Dr. Winstein is professor of Biokinesiology and Physical Therapy at the University of Southern California where she also directs the Motor Behavior and Neurorehabilitation Laboratory. She has conducted extensive research on functional neural and behavioral basis of motor control and learning and its relationship to neurorehabilitation, particularly following stroke.

In this 10th year anniversary, we celebrate the interdisciplinary and collaborative spirit exhibited by CBER members and embodied by the keynote speakers who have shared their insights with us over the years (see pages 24-25 for an overview). Since its inception, "CBER day" has grown to more than 100 participants and showcases the high quality research conducted at the University of Delaware. I would like to recognize each of you for contributing to the scientific content of this year's research symposium, and look forward to another outstanding event this year!

Enjoy!

Jill Higginson

p.s. Please celebrate with us at the cocktail reception at the Courtyard Marriott this evening!

ACKNOWLEDGEMENTS

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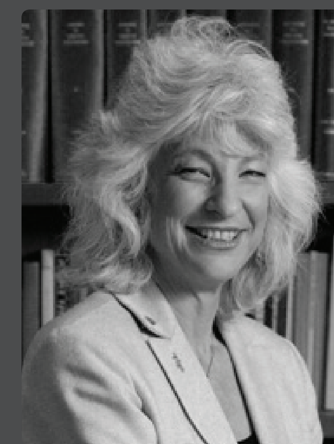
Keynote Lecture



Learning and Memory Processes: Mechanisms and Application to Task-Oriented Practice for Stroke Recovery

Carolee Winstein, PhD, PT, FAPTA

In a 2006 paper, John Krakauer made the following observation: "There have been surprisingly few studies of motor learning after stroke and almost none looking at deficits in motor memory formation despite the likely relevance of these processes to rehabilitation" (Krakauer, 2006, p.85). This lecture describes three projects from my laboratory motivated by Krakauer's 2006 observation. First, we describe the mechanisms of the contextual interference effect in individuals post stroke using a computational model of motor memory. We then describe the neural substrates of motor memory consolidation in non-disabled adults using an rTMS paradigm. We follow this with an fMRI study demonstrating how action observation modulates the motor system after stroke. Finally, we conclude with a description of the principle-based application, the Accelerated Skill Acquisition Program (ASAP) delivered early between 1 and 3 months post stroke in the out-patient setting. This intervention is currently under investigation for its effectiveness in the phase III ICARE multi-site RCT.

Dr. Winstein runs an interdisciplinary research program focused on understanding control, rehabilitation and recovery of goal-directed movements that emerge from a dynamic brain-behavior system in brain-damaged conditions. With NIH funding, she and her team are leading a multi-site phase III randomized controlled trial—ICARE (Interdisciplinary Comprehensive Arm Recovery Evaluation) stroke initiative--to improve outpatient therapy for arm paresis after stroke. With funding from the Foundation for Physical Therapy, she led the first Physical Therapy Clinical Research Network, PTClinResNet that supported clinical research on the effectiveness of task-specific/muscle-specific training to enhance muscle performance and functional activities across four disability groups including adult spinal cord injury, children with cerebral palsy, adult stroke, and low back pain. In 2008, with NIDRR/DoE funding, she and her colleagues at USC and Rancho Los Amigos National Rehabilitation Hospital established a Rehabilitation Engineering Research Center (RERC) to study the challenges of growing older with and into disabilities and the positive effects that new technologies can have on independence, health and quality of life. Recently with funding from NICHD and in collaboration with colleagues at USC, Winstein launched a new development-of-concept trial, Optimizing Dosage of Rehabilitation after Stroke (DOSE) to ultimately determine prospectively the dose of therapy that maximizes the efficacy of treatment—determine the smallest effective dose for individual patients.

Schedule of the Day

TIME	WHAT	WHERE
8:30	BREAKFAST & POSTER SET-UP	CLAYTON HALL LOBBY
9:00	WELCOME & INTRODUCTORY REMARKS	CLAYTON HALL AUDITORIUM 125
9:15	KEYNOTE: DR. CAROLEE WINSTEIN	CLAYTON HALL AUDITORIUM 125
10:15	BREAK	
10:30	PODIUM SESSION 1	CLAYTON HALL AUDITORIUM 125
12:00	LUNCH	CLAYTON HALL ROOM 101A
1:00	POSTER SESSION 1 (ODD #S)	CLAYTON HALL LOBBY
2:00	POSTER SESSION 2 (EVEN #S)	CLAYTON HALL LOBBY
3:00	PODIUM SESSION 2	CLAYTON HALL AUDITORIUM 125
4:30	AWARDS SESSION	CLAYTON HALL AUDITORIUM 125

5:00-7:00 COCKTAIL RECEPTION
NEWARK COURTYARD MARRIOTT | OUTSIDE PATIO

Podium Presentations

Session 1

Session 2

Denotes Podium #

POSTER PRESENTATIONS

Bone, Cell and Cartilage

Gait

Methods and Modeling

Denotes Poster #

Motor Control

P.38 28 THE DEFAULT MODE NETWORK (DMN) IN THE PREFRONTAL CORTEX (PFC) IN HEALTHY ADULTS USING FUNCTIONAL NEAR-INFRARED SPECTROSCOPY (FNIRS)—A PILOT STUDY

Ling-Yin Liang, Jia-Jin Jason Chen, Nancy Getchell

P.38 29 LIGAMENTOUS LOADING OF THE ANKLE INCREASES CONTRALATERAL SOMATOSENSORY CORTEX ACTIVITY IN HEALTHY SUBJECTS

A.R. Needle, M. Schubert, K. Reinecke, J. Baumeister, J.S. Higginson, C.B. Swanik

P.39 30 EFFECTS OF MUSCLE FATIGUE ON FORCE COORDINATION AND PERFORMANCE OF MANIPULATION TASKS

Nicholas Emge, Mehmet Uygur, Slobodan Jaric

P.39 31 THE ROLE OF MUSCLE TORQUE IN STABILIZING UPRIGHT POSTURE DURING VISUAL PERTURBATIONS

Eunse Park, John P. Scholz

P.40 32 FORCE SENSE DOES NOT DIFFER BETWEEN POWER AND ENDURANCE TRAINED COLLEGIATE ATHLETES

An Y.W., Oates C., Needle A.R., Kaminski T.W., Swanik C.B.

P.40 33 REAL-TIME WEIGHT BEARING FEEDBACK IMPROVES MOVEMENT SYMMETRY DURING SIT TO STAND TASK

Sumayeh Abujaber, Adam R. Marmon Joseph Zeni Jr.

Pediatrics

P.42 34 MODIFIED RIDE-ON CAR USE FOR MOBILITY AND SOCIALIZATION: A CASE REPORT OF AN INFANT WITH DOWN SYNDROME

Lisa George, Samuel W. Logan, Hsiang-Han Huang, Kylee Stahlin, James Cole Galloway

P.42 35 "SPECTRUM TECHNOLOGY" I: THE DEVELOPMENT OF A "STANDING CAR" TO ENCOURAGE MOVEMENT, MOBILITY AND SOCIALIZATION

Samuel W. Logan, Vinayak Rajendran, Kevin Chang, Daniel Charytonowicz, Stacy Hand, Heather Feldner, Christina Ragonesi, James Cole Galloway

P.43 36 "SPECTRUM TECHNOLOGY" II: A NEW GENERATION OF PEDIATRIC ASSISTIVE TECHNOLOGY.

Samuel W. Logan, Allyson Zeitschel, Kyle Ingram, Timothy Veltre, Lisa George, Scott Adkins, Desiree Pinto, James Cole Galloway

Stroke

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Devina Kumar, Erin Helm, Christine Malecka, Darcy S. Reisman

P.45 38 MUSCLE ARCHITECTURAL CHANGES OF THE POST-STROKE TIBIALIS ANTERIOR

Molly A. Wessel, John W. Ramsay, Stephen M. Suydam, Thomas S. Buchanan, Jill S. Higginson

P.46 39 THE RELATIONSHIP BETWEEN THE ENERGY COST OF TRANSPORT AND WALKING ACTIVITY IN INDIVIDUALS POST STROKE

Kelly Danks, Tamara Wright, Margie Roos, Evan Matthews, William Farquhar, Darcy Reisman

P.46 40 INVESTIGATION OF FACTORS ASSOCIATED WITH SELF-SELECTED WALKING SPEED IN INDIVIDUALS POST-STROKE

Victoria Stanhope, Brian Knarr, Jill Higginson

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Geetanjali Gera, Kelsey McGlade, John P. Scholz

Denotes Poster #

PODIUM PRESENTATIONS

Session 1

1 EFFECT OF LOCATION ON THE LOCAL INTERSTITIAL LUBRICATION RESPONSE OF CARTILAGE IN THE BOVINE STIFLE JOINT

Axel Moore, David L. Burris

Osteoarthritis (OA), a major economic and public health issue in the United States, is a disease characterized by the progressive degradation of cartilage. Although the causes remain unclear, altered loading due to ligament or meniscus tear is a known risk factor. Andriacchi et al. propose that altered kinematics initiates localized damage by increasing the tribological intensity in functionally unprepared regions. This hypothesis is supported by Bendele who showed that meniscectomy results in almost immediate localized damage on the tibial plateau at a location previously shielded by the meniscus. Based on these studies, we hypothesize that tissue functionality varies spatially across the joint according to the healthy mechanical environment.

In this study the model was the bovine stifle joint; from each we extracted 20 half-inch diameter cartilage plugs. 5 samples were obtained from each femoral condyle and tibial plateau to test the effect of location on material properties and the functional response of the tissue. In situ sliding was used to measure friction coefficient and fluid load fraction while rate-controlled indentation was used to characterize the material properties using the model described in Bonnevie et al.

The medial femoral condyle had the lowest permeability and greatest modulus ratio, both of which are consistent with the observation of high interstitial functionality. The medial tibial plateau demonstrated the largest spatial variability in material properties. The results support the hypothesis that functionality varies across the joint to satisfy a specific spatial distribution of expected mechanical conditions. Naturally, regions with poor interstitial lubrication are most likely to be damaged. The results support the hypothesis that altered joint loading leads to local tissue failure through biological and mechanical means.

2 MECHANO-RESPONSIVE HYDROGELS WITH ANTI-INFLAMMATORY FUNCTIONS

Longxi Xiao, Xinqiao Jia

Mechano-responsive structural motifs are abundant in nature. Through the coordinated conformational changes over a range of mechanical forces, these motifs can ultimately produce changes at the biochemical level to effectively direct cellular behaviors. These design principles, combined with the mechano-sensitivity of many cells, point to the potential of incorporating mechano-responsive modules in synthetic matrices to enhance tissue repair and regeneration. Herein, radically crosslinkable block copolymer micelles (xBCMs) assembled from amphiphilic block copolymers with a rubbery hydrophobic core were employed as the constituent building blocks and the microscopic crosslinkers for the preparation of mechano-responsive hydrogels. TEM imaging revealed force-induced reversible micelle deformation when the hydrogels were mechanically stretched. Hyaluronic acid (HA)-based hydrogels with dexamethasone (DEX) being sequestered in the core of the immobilized BCMs were prepared by radical polymerization of acrylated HA in the presence of xBCMs. The resultant hydrogels were found to release DEX in a controlled fashion with only 30% DEX being released in a week while the traditional HA hydrogels showed a burst release of 80% DEX within the first 24 h. Most interestingly, DEX release from HA-xBCM gels were accelerated by intermittently-applied external compression and the release kinetics was compressive strain-dependent. Culturing macrophages in the presence of DEX-releasing HA-xBCM gles significantly reduced cellular production of inflammatory cytokines (TNF-α). Incorporating mechano-responsive modules in synthetic matrices offers a novel strategy to harvest mechanical present in the healing wounds to initiate tissue repair.

3 FEMALES DEMONSTRATE INCREASED KNEE ADDUCTION MOMENTS 5 YEARS AFTER ACLR

Kathleen White, Lynn Snyder-Mackler

Introduction: Long term knee joint health is a growing concern as the incidence of osteoarthritis (OA) rises after anterior cruciate ligament (ACL) injury. More than half of females demonstrate radiographic knee OA 10 years after ACL injury. The knee adduction moment has been used to describe the potential mechanism of the progression of knee OA. The purpose of this study is to evaluate the external knee adduction moment during gait for males and females 5 years after ACLR.

Methods: Twenty-six subjects were included in this study (6 females, 20 males) that had undergone a unilateral ACLR 4.8 (±0.8) years prior. All subjects participated in jumping, cutting and pivoting activities > 50 hrs/year prior to their injury. Biomechanical variables include the external knee adduction moment at peak knee flexion during gait. Repeated measures ANOVA was used to determine differences between limbs and sex.

Results: There was an effect of sex ($p=0.003$) for the knee adduction moment at peak knee flexion. There was no limb x sex interaction ($p=0.58$), but a trend towards a main effect of limb ($p=0.071$) for the knee adduction moment. Females demonstrated greater external knee adduction moments bilaterally (Involved= 0.28 Nm/kg*m; (95% CI: 0.22, 0.34); Uninvolved= 0.32 Nm/kg*m; (95% CI: 0.26, 0.38)) compared to males (Involved= 0.196 Nm/kg*m; (95% CI: 0.16, 0.23); Uninvolved= 0.22 Nm/kg*m; (95% CI: 0.19, 0.25)).

Discussion: These preliminary data suggest that increased frontal plane moments are present in females 5 years after surgery. Increased knee adduction moments may be the mechanism associated with the progression of knee OA. The limited statistical significance is likely due to unequal groups and a limited number of female subjects. Further examination of clinical measures as well as radiographs may better explain these variances.

4 T-TYPE VOLTAGE SENSITIVE CALCIUM CHANNEL (T-VSCC): A NOVEL TARGET FOR TREATMENT OF OSTEOARTHRITIS

Padma Pradeepa Srinivasan, Andris Kronbergs, Randall L Duncan, Catherine Kirn-Safran

Involvement of subchondral bone in osteoarthritis (OA) is well established, as indicated by the presence of osteophytes and subchondral bone sclerosis in late OA patients. It is believed that soluble metabolites released from mechanically stimulated osteoblasts enhance catabolic changes in the adjacent cartilage tissue. Here we propose that reduced mechanosensitivity of subchondral bone is chondroprotective using a genetically-engineered mouse model carrying a null mutation for the pore forming subunit of the T-type voltage sensitive calcium channel (T-VSCC). We demonstrated that T-VSCC is essential for the anabolic response of subchondral bone to load. Also, selective inhibition of T-VSCC in murine osteoblastic cells (MC3T3) prior to fluid shear stress (FSS ~3.5 dynes/cm^2 for 2 hours) significantly reduced the expression of genes such as cyclooxygenase II (COX 2) and osteopontin that are known to be initiators of pro-inflammatory and bone formation responses, respectively. Additionally, treatment of chondrocytes with conditioned media (CM) obtained from sheared MC3T3 induced expression of markers of hypertrophy. This early osteoarthritic response was nearly abolished when primary chondrocytes were treated with CM obtained from MC3T3 sheared in the presence of a specific inhibitor of T-VSCC. These results indicate that T-VSCC is upstream to the release of catabolic factors from osteoblasts and therefore can serve as a target for blocking subchondral bone-induced cartilage degeneration in OA. To understand the link between T-VSCC and OA, we are currently comparing OA progression between the T-VSCC knockout and the control mice using a load-induced OA model. The overall translational aim is to determine whether pharmaceutical blocking of T-VSCC is a novel therapeutic approach for OA in high-risk patients such as athletes who suffered from a joint injury.

5 HEMISPHERIC LATERALIZATION IS RELATED TO GAIT IMPAIRMENTS POST STROKE

Jacqueline A. Palmer, Alan R. Needle,
Stuart A. Binder-Macleod

Previous research using Transcranial Magnetic Stimulation (TMS) has demonstrated that abnormal cortical mapping and increased laterality of upper extremity muscles is correlated with poor motor recovery following stroke. However, no reports could be found that have investigated the hemispheric laterality of the lower extremity and its relation to function among chronic stroke patients. The purpose of this study is therefore to investigate how lower extremity laterality measures in chronic stroke subjects are related to functional impairments.

Twelve chronic stroke subjects underwent TMS over the "hotspots" of the paretic (P) and nonparetic (NP) tibialis anterior (TA) muscle. Data was also collected for 40 able-bodied control subjects. Approximately 60 pulses of varying intensities were delivered as motor evoked potentials (MEPs) were collected bilaterally from TA muscles. Motor thresholds (MTs) were obtained using parameters from the stimulus-response curve. The laterality index (LI) was calculated as the difference between P and NP MT's divided by the sum of P and NP MT's, at the NP hotspot. Walking speed was determined using a 10-meter walk test.

Among fast walkers, all LIs were positive (mean LI=0.174+0.081, range=0.086-0.281). These LIs were similar to those observed in able-bodied control subjects (mean LI=0.212+0.18, range=0.016-0.664). All slow walking subjects had negative LIs (mean LI=-0.262+0.184, range= -0.053- -0.501).

Results of this study suggest that increased lateralization of the P lower extremity is related to gait impairments and walking speed in individuals with chronic stroke. This unbalanced excitability between the affected and unaffected hemispheres of the lower extremity is similar to previous studies investigating the upper extremity. Future research should investigate whether modulation of lower extremity cortical excitability in the unaffected hemisphere can influence these impairments and other functional outcome measures.

6 PREDICTING POST-STROKE LOCOMOTOR RECOVERY: BASELINE VERSUS CHANGE SCORE RELATIONSHIPS

Louis Awad, Darcy Reisman, Tamara Wright,
Stuart Binder-Macleod

The purpose of this study was to develop a predictive mathematical model of post-stroke functional walking capacity recovery based on changes following rehabilitation in commonly targeted clinical variables. Thirty-six individuals with chronic stroke completed 12 weeks of gait retraining. 6 Minute Walk Test (6MWT) performance measured functional walking capacity. The Berg Balance Score (BERG), Functional Gait Assessment (FGA), Activities-Specific Balance Confidence Scale (ABC), gait economy, and self-selected (SSWS) and fastest walking speed (FSWS) were our selected measures of commonly targeted clinical variables during post-stroke rehabilitation. Clinical evaluations occurred prior to and following intervention. Change scores (Change) were calculated as the difference between pre (Baseline) and post treatment. Correlation and regression analyses quantified Baseline and Change relationships. Each measure correlated with 6MWT performance (pearson r for all variables > .61; $p < .01$) at Baseline. A significant difference was observed following intervention for each measure ($p < .05$). All Baseline measures except the ABC correlated with 6MWT Change (pearson r ranging from .35 to .56; $p < .05$); however, when controlling for baseline SSWS or FSWS, no significant relationships were observed. Only changes in SSWS ($r = .56$) and FSWS ($r = .71$) correlated ($p < .05$) with changes in 6MWT performance. Multivariate step-wise regression revealed that a model containing FSWS Baseline, Change, and interaction (Baseline*Change) terms best predicted 6MWT change (adjusted R2 = .643; $p < .01$). The model generated suggests that measures related to an individual's fast walking speed are the best predictors of post-stroke functional walking capacity recovery following gait rehabilitation. Clinical use of this model may facilitate efficient post-stroke rehabilitation.

PODIUM PRESENTATIONS

Session 2

Denotes Podium #

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

1 EVIDENCE FOR INTERFIBRILLAR SHEAR LOAD TRANSFER BETWEEN SLIDING FIBRILS IN TENDON

Spencer E. Szczesny[1], Dawn M. Elliott[2]

[1]University of Pennsylvania
[2]University of Delaware

While collagen fibrils are the primary tensile load bearing components in tendon, it is unknown whether fibrils bear load independently or if the applied load is transferred across the fibrils through interfibrillar shear forces. Resolving this fundamental question will help identify the primary structural causes of tissue degeneration and aid design of tissue engineered replacements. Therefore, the objective of this work is to quantify the contribution of interfibrillar sliding on tendon macroscale mechanics by simultaneously measuring the tissue behavior at both length-scales and interpreting the results with a micro-structural shear lag model directly incorporating interfibrillar shear stresses. Uniaxial tension testing of rat tail tendon fascicles (n=4) was conducted on the stage of a confocal microscope. Macroscale mechanics (equilibirum modulus, percent stress relaxation) and microscale deformations (fibril strain, interfibrillar sliding) were simultaneously measured at 2, 4, 6, 9, and 12% applied tissue strain. A microstructural shear lag model was used to fit the macroscale stress strain curve and predict the fibril-to-tissue strain ratio. With greater applied strains, the macroscale equilibrium modulus decreased while the stress relaxation increased. The microscale deformations matched these findings, with fibril strains decreasing and interfibrillar sliding increasing. The shear lag model was successful in fitting the macroscale tissue behavior and was validated by accurately predicting the drop in the fibril-to-tissue strain ratio. These results provide strong support for the hypothesis of interfibrillar shear load transfer as a mechanism underlying the macroscale mechanics of tendon.

2 MODULATING STEM CELL BEHAVIORS VIA THE SYNERGY OF MECHANICAL AND BIOCHEMICAL SIGNALING

Zhixiang Tong, Xinqiao Jia

The human vocal fold is a stratified structure composed of epithelium, lamina propria and the vocalis muscle. Numerous deleterious factors can cause vocal fold dysfunction. Tissue engineering strategy offers an alternative treatment option for functional vocal fold regeneration and mesenchymal stem cells (MSCs) are an attractive cell source for this purpose. Here, we demonstrate that physiologically relevant vibratory stimulations, in combination with connective tissue growth factors (CTGF), synergistically modulate the ability of MSCs cultured in a three dimensional (3D) fibrous scaffold to produce vocal fold-like ECM. The picogreen DNA assay revealed that dynamic culture did not compromise the proliferative potential of MSCs. F-actin and integrin α5β1 staining results demonstrated that after a 3-day dynamic preconditioning, the actin filament was reinforced and integrin expression was enhanced, implicating that the mechanotransduction process is mediated by the actin-integrin coupling. Real time PCR results demonstrated that the mRNA levels of decorin (DCN), collagen III, HA synthase 1 (HAS1) and elastin (ELN) were markedly up-regulated by the initial 3 days of vibration, and this trend was further enhanced with an additional 3 days of CTGF-conditioned culture. Moreover, compared to the controls without dynamic preconditioning or CTGF treatment, constructs exposed to the 3-day dynamic preconditioning and subsequent 3-day CTGF treatment showed a significantly higher mRNA levels of Collagen I and III, fibroblast specific protein-1 (FSP-1) and tenascin-C. These results indicate that dynamic vibrations combined with soluble growth factors synergistically fostered MSCs to adopt the behaviors of vocal fold fibroblasts. Finally, our western blotting results suggest that the classical mitogen-activated protein kinase (MAPK) pathway, ERK1/2, was significantly activated in the aforementioned synergism.

3 GRAFT DIFFERENCES AND KNEE BIOMECHANICS SIX MONTHS AFTER ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION

Zakariya Nawasreh, David Logerstedt, Kathleen White, Lynn Snyder-Mackler

Background: Patients with Anterior Cruciate Ligament Reconstruction (ACLR) exhibit asymmetries in knee biomechanics six months after ACLR and differences exist between autograft types. However little is known about how potential donor site morbidity in autografts (Auto) after ACLR compared to allografts impacts knee biomechanics. The purpose of this study was to investigate knee biomechanics between semitendinosus-gracilis (STG) Auto and soft tissue allograft (Allo) in patients six months after ACLR.

Methods: Forty-two patients underwent ACLR with either an Allo (n=26) or STG Auto (n=16). 3-D joint biomechanics were collected for the operated (OP) and nonoperated (NONOP) limbs during the stance phase of gait six months after ACLR. Joint excursions and external joint moments were calculated for comparisons between the OP and NONOP limbs. Two-way ANOVA (mean + standard error) was used to determine if limb differences existed between graft types.

Results: There was no graft type x limb interaction for all measures (p>.12). There was no main effect of graft types for all measures (p>.12); Knee Flexion Excursion (KFE) (Allo: 16.49°+1.09°; Auto: 17.00° + 1.34°, p=0.78), external knee flexion moment at Peak Knee Extension (PKE) (Allo: 0.12+0.19 Nm/kg*m, Auto: 0.11 + 0.03 Nm/kg*m, p=0.962). There was a main effect of limb for KFE (OP: 14.7° + 0.95°, NONOP: 18.79° + 0.91°, p<.001) and external knee flexion moment at PKE (OP: 0.09 + 0.02 Nm/kg*m; NONOP: 0.14 + 0.02 Nm/kg*m, p<.001).

Conclusion: Sagittal plane knee joint asymmetries exist six months after ACLR irrespective of graft type. Potential donor site morbidity from AUTO does not influence sagittal plane biomechanics compared to Allo.

4 MODELING DUAL-COLORED FLUORESCENCE RECOVERY AFTER PHOTOBLEACHING IN LOADED BONE: POTENTIAL APPLICATIONS IN QUANTIFYING THE OSTEOCYTIC PERICELLULAR MATRIX IN SITU

Xiaohan Lai, Christopher Price, Liyun Wang

Osteocytes are believed to sense the mechanical loads through the pericellular matrix (PCM), which can be deformed under load-induced fluid flow, like trees bent under winds. PCM also modulates the transport of signaling molecules and nutrients in bone. Despite its physiological importance, quantitative study of the PCM in situ and in vivo is challenging, since the PCM is encased in the mineralized matrix, and also extremely thin and easy to collapse. Our lab has recently developed an approach combining fluorescence recovery after photobleaching (FRAP) approach as well as mathematical modeling to quantify the osteocyte PCM. However, in the current one-tracer FRAP approach, velocities of fluid and solute were measured in different sets of bone, which introduced variability from anatomical and loading parameters. To address these limitations, we propose a novel dual-colored FRAP approach allowing simultaneous measurements of both fluid and solute velocities. In this study, the feasibility of dual-colored FRAP in detecting the change of PCM's ultrastructure was tested through mathematical simulations. The model developed in this study aimed to quantify the ratio of the transport rates of the two tracers under dynamic loading with varying PCM fiber density and anatomical parameters. A three-compartment model created previously was adopted for the quantification of the solute transport of the two tracers. A biphasic behavior was found between the PCM fiber density and solute transport: a linear relationship was found when PCM fiber volume fraction (kvf) was larger than 0.1 while nonlinear when kvf smaller than 0.1. The results suggest that dual-colored FRAP could be successful in detecting the change of PCM's ultrastructure and will provide guidelines for future dual-colored FRAP experiments.

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

Denotes Podium #

5 EFFECTS OF BISPHOSPHONATE ON LONG-TERM CULTURE OF CARTILAGE ALLOGRAFTS

Yilu Zhou, Lauren Resutek, Liyun Wang, X. Lucas Lu

Zoledronic acid (ZA), an FDA approved bisphosphonate (BP) medicine, is widely used for the treatment of osteoclast-related bone loss diseases. Our previous study has found that systemic administration of ZA could dramatically suppress the development of post-traumatic osteoarthritis (PTOA) in the DMM (destabilization of the medial meniscus) mouse model, a model recapitulating the altered joint loading associated with PTOA. This finding is consistent with a few similar studies using different animal models. However, little is known about the cellular and biochemical mechanisms of BP mediated chondro-protection in PTOA pathogenesis. As one of the earliest responses of chondrocytes to mechanical stimulation, intracellular calcium ([Ca2+]i) signaling is the upstream of numerous mechanotransduction pathways. In this study, we hypothesized that the chondro-protective mechanisms of ZA could be reflected by the characteristics of [Ca2+]i signaling of in situ chondrocytes. We investigated the direct effects of ZA on the in situ spontaneous [Ca2+]i responses of chondrocytes and biomechanical moduli of cartilage allografts. We found that ZA increased the spontaneous [Ca2+]i signaling activities of chondrocytes during long-term in situ culture. The responsive rate of cells, responding intensity, and frequencies were all improved in the ZA treated group. The biomechanical moduli of cartilage allografts in the ZA treated culture are significantly larger than that in the non-ZA culture. The beneficial effect of ZA on chondrocyte calcium signaling may be related to its chondro-protective function. A thorough proof of this hypothesis could lead to a localized administration of ZA for PTOA treatment. In future studies, we will investigate the effects of ZA on trauma damaged cartilage allografts.

6 MUSCLE SYNERGIES DURING WALKING POST-STROKE

Shraddha Srivastava, Pei-Chun Kao, John P. Scholz

Individuals post-stroke demonstrate a lack of adequate foot clearance, increasing their risk of falls. Lack of adequate foot clearance can result from weakness and/or atypical synergies compared to healthy individuals. Functional muscle synergies involve sharing patterns among several muscles, called muscle modes (M-modes), and their flexible combination to achieve consistent task performance. This preliminary study investigated the role of muscle synergies in stabilizing the footpath during the swing phase of walking in seven stroke survivors while walking over ground at their comfortable speed. M-modes were estimated from EMG data obtained from muscles of the impaired leg using non-negative matrix factorization. Uncontrolled manifold analysis was applied to determine how much of the M-mode variance across cycles reflected flexibility in their combinations that produced a consistent footpath (VUCM or "good" variance), or led to footpath variability (VORT or "bad" variance). Preliminary results indicate that 'good' variance was significantly higher than 'bad' variance, suggesting that more of the M-mode variance across cycles represents flexible combinations of the M-modes to stabilize the footpath. Thus, muscle synergies were organized to stabilize the footpath even for the impaired limb of stroke survivors. However, the footpath still was too shallow to achieve normal foot clearance. Comparison to non-neurologically impaired control subjects will be needed to determine the extent to which their muscle synergies differ from stroke survivors. Future study also will be needed to determine if the changes in the structure of these synergies is associated with improved foot clearance during swing as a result of natural recovery or due to specific interventions.

POSTER PRESENTATIONS

Bone, Cell & Cartilage

1 STRAIN GAUGING OF MURINE ULNA

Ashutosh Parajuli, Christopher Price, Liyun Wang

Living bone experiences mechanical strains in vivo and adapts to its mechanical environment. To study how different bones respond to mechanical loading, it is important to apply well-controlled strain level and account for the varied size and bone tissue properties. Strain gauges are widely used in measuring deformations in loaded bone samples. Measurement Setup: In this study, we integrated a strain measurement circuit into a Bose Testbench loading system, where bone samples were axially loaded. The strain measurement ciruit consisted of a single element strain gauge (EA-06-015DJ-120, Vishay,Micro-Measurements), a bridge completion module (MR1-350-127, Vishay, Micro-Measurements), and a signal conditioner/amplifier. The voltage signals and the applied mechanical load were recorded simultaneously by the Bose system. Strain Calibration: Five random picked strain gages were placed on a cantilever beam under varied weights with local 0-2500 microstrains. For each strain level, 10 repeated voltage readings were recorded per gauge. The inter- and intra-gauge readings showed excellent repeatibility, with the coeffient of variation < 3% and 1%, respectively. The voltage (V) to strain (microstrain) conversion factor of the current setup was 91.6±4. Strain Gauging of Murine Ulna: The strain gauge was placed on the lateral surface 1-2mm promixal to the ulnar midshaft. Intact ulnae in adult (5-6 months old) male Akita (C57BL/6-Ins2/J) and B6 controls were axially loaded, ramping from the tare load (0.2N) to 4N, followed by unloading. The compliance of the ulna during the loading phase was found to be 1599.16±220 and 1147.55±151 microstrain per Newton for Akita (n=10 ulnae) and the B6 controls (n=5 ulnae), respectively, suggesting weaker bone in Akita than controls (p-value=0.006). We are currently applying 2N and 2.8N (3200 microstrain) to live Akita and B6 mice to study their adaptation responses.

2 NOVEL PEPTIDE CK2.3 DECREASES OSTEOCLASTOGENESIS AND OSTEOCLAST ACTIVITY

Kristine Olli, J Bonor, H. Akkiraju, Chris Bowen, Randall Duncan, Anja Nohe

Osteoporosis is a disease that results in a drastic loss of bone mass and affects approximately 4.5 million women and 800,000 men in America. The current treatment options are either antiresorptive or anabolic. However these options come with a myriad of negative side effects. Bone Morphogenetic Protein 2 (BMP2) is a potent inducer of bone formation. Unfortunately, it also is known to induce osteoclast activity, therefore leading to increased bone turnover. We recently developed a novel peptide, CK2.3, that acts downstream of BMP2 signaling. BMP2 signals via BMP receptors type I and type II, with Bone Morphogenetic Protein Receptor Type Ia (BMPRIa) being the most frequently expressed type I receptor. Recent data shows that Casein Kinase II (CK2) is released from BMPRIa upon BMP2 stimulation leading to the activation of the pathway. Our in vitro studies showed that CK2.3 can induce osteogenesis and inhibit osteoclastogenesis in vitro and in vivo. This finding is in sharp contrast to BMP2, since BMP2 enhances osteoclastogenesis. We hypothesize that CK2.3 signals through a BMP2 independent pathway in osteoclasts. To test this we downregulated BMPRIa by using siRNA, which led to a significant reduction in osteoclast number and activity. Surprisingly, the addition of CK2.3 did not cause a further reduction. This suggests that BMPRIa is necessary for osteoclastogenesis and osteoclast activity, and that CK2.3 signals through BMPRIa. Therefore, the results suggest that BMP2 may have signaling pathways that inhibit osteoclastogenesis, but are overruled by activating pathways, and CK2.3 acts more specifically than BMP2 making it a potential treatment for osteoporosis.

3 THE NOVEL PEPTIDE CK2.3 AS A POTENTIAL TREATMENT FOR OSTEOPOROSIS

Christopher M. Bowens, Oleksandra Moseychuk, Jeremy C. Bonor, Anja G. Nohe

Osteoporosis is a disease of the bone, defined as a decrease in bone mineral density by over 2.5 standard deviations from the norm, which results from an imbalance between bone resorption and bone formation. It leads to a loss of bone strength, thereby increasing the likelihood of fractures and breaks, and is estimated to affect over 10 million Americans. The US Department of Health and Human services projects that by the year 2025, the annual cost of osteoporosis will exceed 25 billion dollars annually. Currently, treatment options for osteoporosis are limited, both in efficacy and in safety, and so an alternative treatment is highly desirable. One of the primary signaling pathways concerned with osteogenesis is BMP2 signaling through BMPRIa and II. Our lab has developed a novel mimetic peptide, CK2.3, which mimics one of the phosphorylation target site of CK2 on BMPRIa. Treatment with this peptide has been shown to enhance mineralization and inhibit lipid droplet formation in in vitro C2C12 cells. We have since moved on to testing on human primary cells. Osteoblasts have been isolated and grown from human femur heads, and treated with CK2.3, which resulted in an increase in mineralization by 70%, as well as a reduction in adipogenesis by 10%. We are now looking into the possibility of there being a correlation between the efficacy of CK2.3 and the bone mineral density of the samples.

4 BIOCHEMICAL CUES FOR DIRECTING MESENCHYMAL STEM CELL FUNCTION FOR LIGAMENT REPAIR

Matthew S. Rehmann[1], April M. Kloxin[1,2]

Mesenchymal stem cells (MSCs) are multipotent cells present in the bone marrow that show promise for ligament repair. MSCs are attractive for improved ligament repair as they proliferate rapidly, produce large amounts of extracellular matrix proteins, and can differentiate into ligament cells. However, controlled conditions promoting ligamentogenic differentiation of MSCs are not yet well-established. In this study, we aim to elucidate the effects of ligament development-related biochemical signals on directing MSC function for ligament repair. MSCs are grown in the presence of growth factors and ascorbic acid, and the synergistic effects of these soluble factors are assessed by measuring collagen production and the expression of ligament-related markers, including scleraxis and tenascin-C, by immunocytochemical staining and RT-PCR.

5 CK2.1 A MIMETIC PEPTIDE ACTIVATES BMP2 SIGNALING; INDUCES CHONDROGENESIS AND COLLAGEN PRODUCTION WITHOUT HYPERTROPHY

Hemanth Akkiraju, Jeremy Bonor, Padma P. Srinivasan, Catherine B. Kirn-Safran, Randal L. Duncan, Anja Nohe

Many properties are shared by growth plate and articular cartilage, however, their differences in collagen expression are consistent with their functions. In particular, collagen X is expressed predominantly in growth plate cartilage and in chondrocytes undergoing hypertrophy, while collagen IX is found only in the chondrocytes of the articular region. Growth factors like Bone Morphogenetic Protein 2 (BMP2), activates collagen synthesis during chondrogenesis. BMP2 induced anabolic effects on cartilage formation are however short-lived and over time result in chondrocyte hypertrophy and cartilage matrix calcification. During this switch collagen IX synthesis decreases with an increase in collagen X synthesis. Recently we identified a new BMP2 receptor interacting protein, Casein Kinase 2 (CK2). We designed peptides CK2.1, CK2.2, CK2.3 that release CK2 from the BMP receptor type Ia (BMPRIa) isoform activating the downstream BMP signaling pathways in the absence of BMP2. Here, we show that treatment of mesenchymal progenitor cells and articular chondrocytes with CK2.1 but not CK2.2 or CK2.3 stimulated chondrogenic collagens II and IX but not collagen X expression. This effect was in contrast to BMP2 stimulation which is known to induce collagen X synthesis. Additionally, CK2.1 led to an increase in COMP, CREB and SOX9 levels in mature articular chondrocytes cultured for seven days. Based on these findings we propose the following peptide CK2.1 induced mechanism increases chondrogenic differentiation and ECM secretion in vitro without induction of chondrocyte hypertrophy, as opposed to BMP2 induced collagen X secretion marker of chondrocyte hypertrophy.

6 AN IN VITRO CARTILAGE BONE CO-CULTURE MODEL TO SIMULATE THE MICROFRACTURE SURGERY FOR CARTILAGE LESION REPAIR

Miri Park, Anna Sung, Brandon Zimmerman, Enoch Cheung, Yilu Zhou, X. Lucas Lu

Microfracture is an arthroscopic surgery to promote the repair of a cartilage lesion with subchondral bone marrow. However, quality of the repaired tissue in microfracture is often inferior to the surrounding cartilage. Improvement of surgical procedure or rehabilitation protocols requires animal or clinical studies, which could be expensive with ethical limitations. In this study, we propose to investigate the feasibility of an in vitro cartilage-bone co-culture model to simulate microfracture surgery.

Cartilage-bone cores were harvested from tibia plateau in knee joints of 3-month-old calves. An artificial cartilage lesion was made in the center of an explant by removing cartilage tissue. Subchondral bone marrow was harvested from the same joint and filled in the lesion. Using this model, we have shown that bone marrow cultured in the lesion of cartilage-bone explants can generate cartilaginous tissue with the supplement of proper medium and growth factors. Mechanical properties and GAG content of repaired tissue were significantly improved with culture time and higher than those in a control group. In the top zone of new tissue, a dense layer of type II collagen was generated and connected with natural cartilage, which may be attributable to the sufficient exposure of bone marrow cells to culture medium. Dynamic loadings were applied on the explant model to see the effect of the mechanical loading and it was found out that the dynamic loading provides better mechanical properties on the marrow filled in the lesion.

In summary, the co-culture system developed in this study showed great potential to fill in the knowledge gap regarding the cartilage repair after microfracture.

7 LOCAL STRESS CONCENTRATION AROUND A DEFECT IN FIBER-REINFORCED TISSUE

John M. Peloquin[1], Dawn M. Elliott[1,2]

[1]University of Pennsylvania
[2]University of Delaware

Fiber-reinforced soft tissues such as ligaments and tendons have exceptional strength and stiffness, yet can fail at unexpectedly low stress if a local defect exists. The presence of a defect produces local stress concentrations that may lead to crack initiation and propagation. The stress distribution around a crack is largely uncharacterized in fiber-reinforced soft tissue. Consequently, this study was designed to examine the effect of fiber orientation, relative to the crack, on the stress concentration, and determine which orientation results in the maximum stress concentration. Finite element analysis of a transversely isotropic tissue with a through-thickness center crack was conducted using FEBio. The fiber angle was varied from 0° to 90° in 15° increments with respect to the crack. The maximum stress concentration was observed for samples with fibers at 45° with respect to the crack. The standard fracture test configuration has the crack oriented 90° to the fibers; this configuration exhibited the least stress concentration. This result is likely caused by a large crack opening displacement in the 90° orientated sample, which blunts the crack and reduces its stress concentration. In contrast, the 45° sample exhibits rotations that close (sharpen) the crack and realign the notch roots perpendicular to the fibers, resulting in it having the highest stress concentration and therefore the highest risk of failure. The smaller stress concentration in the standard 90° oriented fracture test configuration means that tests using this configuration may overestimate the tissue's resistance to fracture.

8 THE EFFECTS OF BONE CELL SUPERNATANT ON NON-INFLAMMATORY BREAST CANCER MIGRATION WITHIN THE BONE (IN-VITRO)

Regina A. Adeleye, Jeremy C. Bonor, Anja G. Nohe, Jill S. Higginson[1]

According to the National Cancer Institute, breast cancer is the second leading cause of death in women in the United States following heart disease. Statistics show 232,340 new cases of breast cancer will occur in 2013. Metastatic cancer cells are cells that spread from their origin to other parts of the body and approximately 70% of breast cancer patients have metastasis. Roughly two out of three breast cancer metastasizes to the bone. The objective of this study is to understand the mechanism of breast cancer metastasis to the bone. Due to its ability to metastasis to different sites such as bones, liver, lungs, MDA-MB-231, a non-inflammatory metastatic breast cancer cell-line, was used to perform a scratch assay, which monitors cancer cell migration every 12 hours for 48 hours. The MDA-MB-231s were subjected to three different concentrations of bone cell supernatant to determine whether amount of supernatant influences cancer cell migration. These supernatants were extracted from myoblasts (C2C12), pre-osteoblasts (MC3T3), primary mouse calvarial, bone marrow stromal cells (BMSC) from 8-week and 6-months old mice and osteoclast that were cultured for two days. Compared to the control, result analysis of the obtained data show a significant reduction in the migration rate of the breast cancer cells under the influence of most bone cell supernatant except for the supernatant extracted from osteoclast and the 8-weeks old BMSCs. Overall, the method used in this study is useful in understanding the mechanism of breast cancer metastasis to the bone.

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

9 IN SITU CALCIUM SIGNALING OF CHONDROCYTES UNDER NON-SERUM AND SERUM CULTURE

Yilu Zhou, Lauren Resutek, Liyun Wang, Anna Sung, X. Lucas Lu

Chemically defined serum-free medium could maintain the mechanical properties of cartilage allografts better than serum supplemented medium during long-term in vitro culture. However, little is known about this beneficial mechanism at a cellular level. Intracellular calcium ([Ca2+]i) signaling is one of the earliest responses in chondrocytes under mechanical stimulation. In this study we hypothesized that the beneficial mechanisms of serum-free culture could be reflected by the spatiotemporal features of [Ca2+] i signaling of chondrocytes in situ. We compared the in situ spontaneous [Ca2+]i responses of chondrocytes cultured in medium with and without serum, and investigated the correlation between the [Ca2+] i responses of chondrocytes and the biomechanical properties of cartilage explants. From the results, we found that exposure to serum after harvest increased this spontaneous [Ca2+]i signaling in short-term compared with serum-free culture. However, serum-free medium improved and maintained the calcium signaling activity of chondrocytes at a constant high level during long-term culture. This trend matches perfectly with the biomechanical properties of allografts cultured in two conditions. Both the biomechanical moduli of cartilage and the concentration of GAG (per wet weight) increased over time during serum-free culture, but decreased in culture with serum. Linear regression analysis showed a positive correlation between the biomechanical moduli of cartilage explants and the [Ca2+]i responses of chondrocytes in tissue. The results imply that the benefit of serum-free culture in biomechanical properties of cartilage allografts is correlated with the modified [Ca2+] i signaling activities of chondrocytes residing in the cartilage solid matrix.

10 PROTEOGLYCAN-RICH DEPOSITS ATTENUATE STRAIN TRANSFER FROM TISSUE TO CELLS IN THE MENISCUS

Woojin Han, Lachlan Smith, Robert Mauck, Dawn Elliott

Mechanical deformation applied at the joint or tissue level is transmitted through the local extracellular matrix, where it is transduced to cells within the tissues and modulates tissue growth, maintenance, and repair. Yet, how tissue level strain is transferred to cells is confounded by highly variable strain fields within local matrix of fiber-reinforced tissues such as the meniscus. In addition, studies also suggested that micro-structures of these tissues are inhomogeneous, particularly with proteoglycan-rich deposits (PG-rich μ–domains) dispersed within ordered collagen fibers (fibrous μ–domains). However, the relationship between tissue micro-mechanics and structural inhomogeneities remains unknown. Therefore, the objective was to test a hypothesis that tissue strain transfer to local matrix, cell, and nuclei is more attenuated in PG-rich μ–domains compared to fibrous μ–domains. To carry out the study, we developed a custom confocal microscope-mounted tensile testing device and simultaneously monitored strain across multiple length scales. During testing, previously determined relationship between μ–domain and nuclear shape via histology was used to identify PG-rich or fibrous μ–domains. The result showed that the strain transfer from tissue to local matrix in PG-rich μ–domain was significantly attenuated (27% strain transfer) compared to fibrous μ–domain (70% strain transfer). At the cellular level, 83% of fibrous local matrix strain was transferred to the cells while only 49% of PG-rich local matrix strain transferred to the cells. Similar trend was observed at the nuclear level, where strain transfer from tissue to nuclei in PG-rich μ–domain was significantly more attenuated compared to fibrous μ–domain.

Notes

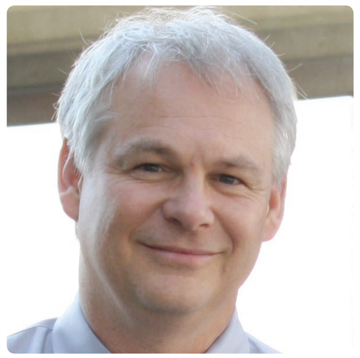
TIMELINE OF

Past Keynote Speakers

Dr. David Lloyd 2004

University of Western Australia
"ACL Deficient Gait"

Dr. Steve Kautz 2005

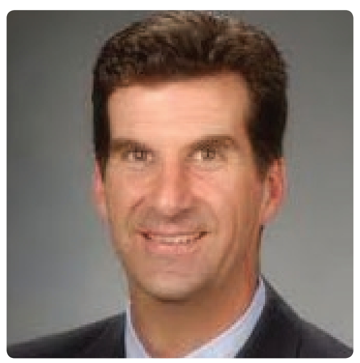


VA Rehabilitation Research Center,
University of Florida
"Coordination of hemiparetic locomotion"

Dr. Milos Popovic 2006

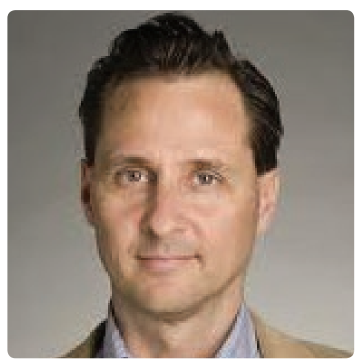
Director, Rehabilitation & Engineering Laboratory, Institute of Biomaterials & Biomedical Engineering, University of Toronto
"Surface Functional Electrical Stimulation Technology for Restoration of Function in Severe Stroke Patients"

Dr. Steven J. Stanhope 2007



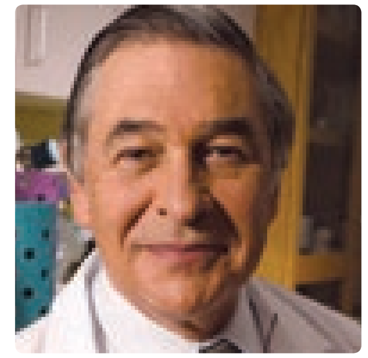
Director, Physical Disabilities Branch, National Institutes of Health
"A Passive Dynamic Ankle-Foot Orthosis Approach To Enhanced Gait Function"

Dr. Hugh Herr 2008



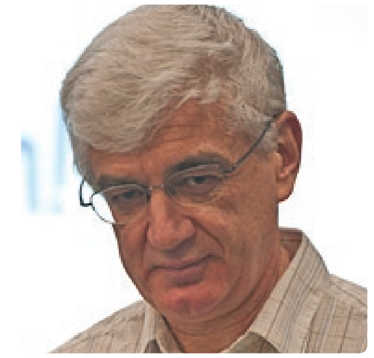
Associate Professor, Massachusetts Institute of Technology Program of Media Arts & Sciences Harvard-MIT Division of Health Sciences & Technology
"The Importance of Neuromechanical Limb Models in the Design of Leg Prostheses and Orthoses"

Dr. Irving M. Shapiro 2009



Professor of Orthopedic Surgery, Biochemistry & Molecular Biology, Thomas Jefferson University
"Molecular Engineering Of Orthopaedic Implants: From Bench To Bedside"

Dr. Mark L. Latash 2010

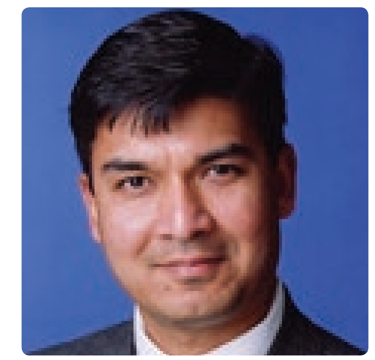


Distinguished Professor of Kinesiology, Penn State
"Multi-digit synergies: effects of age and fatigue"

Dr. Van C. Mow 2011

Stanley Dicker Professor & Chair of the Department of Biomedical Engineering, Columbia University
"A Smorgasbord of Delectable Morsels: A Personal Odyssey to Biomedical Engineering"

Dr. Darryl D'Lima 2012



Director, Orthopaedic Research Laboratories, Shiley Center for Orthopaedic Research & Education (SCORE) at Scripps Clinic in San Diego; Assistant Professor, Division of Arthritis Research, The Scripps Research Institute; Associate Professor, Scripps Translational Science Institute
"Knee forces during activities of daily living, rehabilitation, exercise and sports after total knee arthroplasty"

2013

Dr. Carolee Winstein

Professor of Biokinesiology and Physical Therapy, University of Southern California where she also directs the Motor Behavior and Neurorehabilitation Laboratory

"Learning and Memory Processes: Mechanisms and Application to Task-Oriented Practice for Stroke Recovery"

POSTER PRESENTATIONS

Gait

11 LOWER LIMB STRENGTH AND GAIT BIOMECHANICS OF INDIVIDUALS WITH END-STAGE HIP OSTEOARTHRITIS

Federico Pozzi , Sumayeh Abujaber, Portia Flowers, Joseph Zeni

Total Hip Arthroplasties (THAs) successfully reduce pain, but patients continue to exhibit movement asymmetries after surgery. These assymetries may be related to excessive trunk lean toward the surgical (SX) side and weak hip abductors. The aim of this study is to analyze the functional status and gait biomechanics of subjects with end-stage hip osteoarthritis (OA) during over-ground walking. Six subjects scheduled for unilateral THA were recruited for this study. Pain in both hips was assessed using a visual analog scale (0, no pain; 10, worst pain). Isometric hip abductor strength was measured using a hand held dynamometer. Isometric quadriceps strength was measured using an electromechanical dynamometer. Kinematic and kinetic data were collected during over-ground gait at self-selected speed. Pain, strength, peak lateral trunk lean, peak hip adduction, peak hip flexion and peak external adduction moment during the stance phase were compared between the SX and non-surgical (NSX) limbs using a paired-sample t-test. The SX hip was significantly more painful than the NSX limb (mean differences [MD]: 4.66 ± 3.32, p=.019) and weaker (abductor strength MD: -35.11 ± 16.28 N, p=.003). Differences between limbs in quadriceps strength approached significant levels with the SX limb being -150.33 ± 166.45 N weaker (p=.078). On the SX limb, subjects had greater lateral trunk lean (MD: -5.47 ± 3.53 degree, p=.013) and greater peak hip adduction (MD: 4.41 ± 2.19 degree, p=.004). Subjects ambulate with lateral trunk lean toward the affected limb, but continue to demonstrate greater hip adduction angles on the SX limb during single limb stance. These movement abnormalities may be related to the unilateral hip abductor weakness observed in this sample.

12 EFFECT OF HANDRAIL USE ON GAIT PATTERNS IN YOUNG HEALTHY SUBJECTS

Kelly Seymour, Jill Higginson, Brian Knarr

Analyzing the gait patterns of young healthy individuals walking with and without a handrail could have many implications for a population requiring assistive devices. The objective of this study was to determine the impact of walking speed on handrail forces and to observe whether modifying handrail conditions altered kinematics. This study tested five healthy subjects (21.4 ± 1.52 years) walking at a controlled (1.0 m/s), self-selected (1.24 ± 0.073 m/s), and fast speed (1.79 ± 0.12 m/s), with and without a handrail.

There is not a significant difference between knee and hip flexion angles with and without handrails for the three different speeds. This displays that varying the walking conditions by adding a handrail does not alter the gait patterns for young healthy subjects.

Recorded handrail forces show statistically significant differences with subjects pushing the handrail more in the posterior direction as walking speed increased from controlled to self-selected (p = 0.005), from self-selected to fast (p = 0.007), and from controlled to fast (p = 0.008). This indicates that increasing speed also increases upper extremity support on handrails posteriorly during gait. Marginal significance was shown for ground reaction forces between all speeds with and without the handrail (p = 0.04), suggesting there was tradeoff between handrail forces and ground reaction forces.

Handrail use has implications for loading on the upper and lower extremities even in healthy adults, as shown by the increase in posterior handrail force with speed, and should be monitored in patients undergoing gait rehabilitation.

Denotes Poster #

13 HEEL RISE OCCURS EARLIER IN STANCE WITH INCREASED WALKING VELOCITY

Lakisha D. Guinn, Elisa S. Schrank, Steven J. Stanhope

Introduction: Understanding the mechanism of heel rise (HR) and its changes with walking velocity may be helpful in the prescription of prosthetics and orthotics to improve walking velocity in impaired populations. Therefore, the purpose of this study was to investigate the changes in timing of HR with walking velocity, and the concurrent changes in longitudinal foot center of pressure position (COP), ankle angle, and ankle moment.

Methods: Eleven unimpaired subjects participated in an instrumented gait analysis. Each walked at four scaled velocities (0.4, 0.6, 0.8, and 1.0 body height/s) in a randomized order. One-way repeated measures ANOVAs were used to determine significance ($p<0.05$), with Bonferroni corrections for pairwise comparisons.

Results: HR occurred earlier (% stance) with increased walking velocity for all comparisons between 0.4, 0.6, and 0.8 BH/s ($p<0.005$), but was not significantly different between the two fastest velocities. The small change in COP at HR with velocity (greatest mean difference of 8.5mm) was not meaningful. There were no significant differences between COP (% foot length) at HR across all velocities except between 0.4 BH/s and 1.0 BH/s ($p<0.002$). The ankle angle and ankle moment at HR decreased with increasing walking velocity, but not significantly between the two slowest velocities for the angle and between the two fastest velocities for the moment.

Conclusion: While HR occurs earlier as a percent of stance with increased walking velocity, there appears to be a positional COP threshold along the longitudinal axis of the foot at which HR occurs that is invariant for the walking velocities examined. Future studies are needed to determine if these changes are beneficial to increasing walking speed or are a result of gait being more dynamic with increased velocity.

14 LIMB ASYMMETRIES DURING GAIT IN PATIENTS AFTER TKA

Portia Flowers, Joeseph Zeni, Lynn Snyder-Mackler

Total knee arthroplasty (TKA) reduces pain and improves function in patients with knee osteoarthritis (OA). Persistent movement asymmetries and muscle weakness after surgery may explain the high rate of contralateral knee OA following initial TKA surgery. The purpose of this study was to quantify short and long-term movement asymmetries after unilateral TKA. We hypothesized that 2 years after TKA, patients will have more symmetrical frontal plane knee angles and moments and more asymmetrical frontal plane knee moments.

Thirty age- & sex-matched subjects who underwent unilateral TKA for OA were evaluated 6 months and 2 years. Motion analysis testing during gait was performed on all subjects. Differences between limbs over time were assessed using 2x2 (limb by time) 2-way repeated measures ANOVA.

There were no significant limb by time interactions for any of the kinetic and kinematic variables. There was a main effect of limb for flexion at initial contact, 1st & 2nd peak knee adduction moment (PKAM 1, PKAM2), and average knee adduction moment (KAMave). The non-operated limb had 3.4° less flexion at initial contact, 40% greater PKAM1, 32% greater PKAM2, and 42% greater KAMave than the operated limb. There was a main effect of time for peak knee extension moment (PKEM), PKAM2, and KAMave. Two years after TKA, PKEM was 137% larger, PKAM2 was 20% larger, and KAMave was 19% larger than at 6 months after surgery.

Kinematic and kinetic movement asymmetries existed 6 months and 2 years after TKA. Larger contralateral loading (greater adduction moment in the non-operated limb) 2 years after TKA is indicative of greater medial compartment loading. This is concerning given that higher adduction moments are related to increased risk of OA progression.

15 OLDER SUBJECTS DEMONSTRATE LARGER EXTERNAL KNEE ADDUCTION MOMENTS ONE YEAR AFTER ACLR

Elizabeth Wellsandt, Kathleen White, Lynn Snyder-Mackler

Purpose: Knee osteoarthritis (OA) is traditionally associated with an aging population; however, following anterior cruciate ligament reconstruction (ACLR) younger populations also demonstrate knee OA. Increased medial tibiofemoral compartment loading is a potential mechanism for the progression of knee OA, and has been quantified by the external knee adduction moment (KAM). Sagittal plane asymmetries are also suspected factors. The purpose of this study was to examine the relationship between age and KAM and external knee flexion moment (KFM) one year after ACLR.

Methods: Forty-two subjects ages 13-55 were included. KAM and KFM at peak knee flexion during gait were evaluated 1 year after ACLR. Paired t-tests analyzed inter-limb differences in KAM and KFM. Linear regression evaluated the relationship of age and walking speed with KAM and KFM.

Results: Significant inter-limb difference existed for KFM ($p<0.001$) but not for KAM ($p=0.549$). Age and walking speed explained 18.5% of the variance for involved KAM ($p=0.018$) with age being the best predictor ($p=0.005$), but were not significant predictors for the uninvolved limb ($p=0.500$). Age and walking speed explained 24.2% of the variance for involved KFM ($p=0.005$) and 33.3% for uninvolved KFM ($p<0.001$), but age did not contribute significantly (Inv: $p=0.237$; Uninv: $p=0.233$).

Discussion: Older individuals demonstrate a larger involved KAM representing higher relative medial tibiofemoral joint loading. Subjects also demonstrate lower involved KFM, possibly representing a compensatory strategy involving hamstring-quadriceps co-contraction and smaller knee flexion angles. These asymmetries may be a mechanism for the progression of OA and risk long-term knee joint health.

Conclusion: Larger KAM for the involved limb were present in older subjects 1 year after ACLR, warranting further work to evaluate the risk factor of age in the progression of OA following ACLR.

16 IS ECHOGENICITY A VIABLE CLINICAL EVALUATION METRIC

Stephen M. Suydam, Thomas S. Buchanan

Introduction: The reflectivity of sound waves, or echogenicity, of soft tissue has recently become a popular ultrasound metric for determining changes in mechanical properties of tendon which has been linked to pathologies; however, previous studies have not studied echogenicity of human tendon in vivo. It is the aim of this study to determine if echogenicity of a tendon can be correlated to increased tension based on the contraction intensity of a subject. It is our hypothesis that a stretched tendon will have increased ultrasound reflection intensity.

Methods: 25 healthy Achilles tendons were split into two groups: contraction intensity versus echogenicity (CvE) and strain versus echogenicity (SvE). The CvE was seated in a dynamometer with their legs fully extended and the SvE with their knees at 90o. Longitudinal images were taken of subjects' Achilles tendons as they increased from 0% to 80% of their MVIC by steps of ~20%. Similar images were taken of the SvE at rest and 1 body weight (bw), 1.5bw and 2bw. The echogenicity was measured by mean pixel brightness of the Achilles tendon. Regression lines showed correlations between tendon brightness and contraction intensity for the CvG and strain for the SvE.

Results: A fair and significant correlation exists ($r=0.36$, $p<0.01$) between the percent MVIC and brightness for the CvE but no correlation ($r<0.01$) exists between strain and brightness within the SvE.

Discussion: The intensity of the ultrasound image increased with contraction intensity, but not with the strain. While correlation of the %MVIC with brightness shows an increased echogenicity with tension, the lack of relation to strain, and therefore mechanical properties, poses a problem for using echogenicity as a clinical assessment or rehabilitation metric.

POSTER PRESENTATIONS

Methods & Modeling

17 INCREASED ROTATIONAL LOADING DURING STABLIZATION IN ACL DEFICIENT PATIENTS

Amelia S. Lanier, Kurt Manal, Thomas S. Buchanan

After ACL injury most will get reconstruction while a small group who are able to dynamically stabilize their knee may be eligible for non-operative care. Dynamic stability is a crucial factor in returning patients to pre-injury levels of activity. ACL tears typically occur when landing from a jump and/or changing directions during sports emphasizing the need to understand how the lower limbs interact to keep the body upright while completing specified tasks. Rotational loading about the long axis of the tibia has become a measure of interest in ACL injured and reconstructed populations as it relates to the ACL's function, injury, and osteoarthritis Our goal was to use standing target matching to evaluate rotational loading of the stabilizing limb in three patient populations: healthy uninjured controls, 1 year after injury (ACL-d 1yr), and after reconstruction (ACL-r). We hypothesized those which do not receive reconstruction would experience reduced rotational stability as measured by increased loading. A total of 21 subjects completed standing target matching: 8 healthy subjects, 5 1-yr ACL-d subjects, and 8 ACL-r subjects. We found that subjects that do not receive ACL reconstruction generate significantly greater transverse knee moment when compared to both healthy uninjured subjects and ACL reconstructed patients. Additionally, there is no difference in rotational loading of the stabilizing limb when comparing ACL-r and healthy uninjured controls. After initial ACL injury those that do not receive reconstruction are compensating differently for the missing ligament as seen by higher rotational loading. These results emphasize the need for rehabilitation that focuses on rotational stability and the importance of the stabilizing limb as they are crucial for completing sport related tasks.

18 PREDICTING SAGITTAL KINEMATICS OF DORSIFLEXOR FES USING FORWARD DYNAMIC SIMULATIONS

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

Regaining the functional ability to walk is a primary goal of post-stroke rehabilitation. Functional electrical stimulation (FES) provides active muscle contraction to muscles at specific times during gait. The objective of study was to investigate whether a forward dynamic simulation can replicate the experimental sagittal kinematics following FES. We hypothesized that the hip, knee, and ankle joint angles could be predicted during a simulated task within 5^o of the experimental data during swing. One male post-stroke subject walked on a split belt treadmill at his fastest speed. Motion analysis was performed during two 20-second trials (STIM and NO STIM). Electrical stimulation was delivered to the paretic ankle dorsiflexor using surface electrodes using a Grass S8800 stimulator in combination with an SIU8 stimulus isolation unit. Forward simulations were performed using OpenSim 3.0 on the paretic leg during swing. Simulations of the NO STIM condition were first used as a baseline. Then, electrical stimulation was applied "virtually" by adjusting the dorsiflexor muscle excitations during swing to simulate the experimental protocol. The predicted sagittal kinematics during "virtual" stimulation were compared to the kinematics observed experimentally. We found that the sagittal kinematics during NO STIM swing were within 5^o for all joint angles when compared between experimental and simulation. After STIM was applied to the simulation, up to 50% mid-swing, both the knee and ankle joint angles tracked within the desired range, but diverged toward the end of the simulation. While the simulations did not fully predict STIM conditions when electrical stimulation was applied virtually, this motivates the need to continue refining our model with more experimental data. By improving forward simulations with experimental data, novel therapeutic interventions may eventually be investigated.

19 CHANGE IN KNEE CONTACT FORCE DUE TO MODEL KINEMATICS PROCESSING

Brian A. Knarr, Jill S. Higginson

Background: Compressive forces experienced at the knee can have significant impact on cartilage degeneration and contribute to the initiation and progression of osteoarthritis. It has been shown previously that individuals can alter these compressive forces at the knee by adopting new gait kinematics. Purpose: The objective of this study is to evaluate the relationship between changes in kinematics due to model processing methods and changes in predicted knee joint contact force (KJCF) for an individual using musculoskeletal modeling. It is hypothesized that the methodology of fitting a model to experimental data by using weighting constants during optimization can have a meaningful impact on predicted values for KJCF. Methods: Musculoskeletal simulations were built using OpenSim 3.0 for one healthy subject without knee pathology while walking at self-selected speed on an instrumented split-belt treadmill. Multiple simulations were generated for the subject using the same experimental data. Model kinematics were altered through systematic selection of weighting factors when performing model scaling and inverse kinematics on the models. Static optimization was run for each simulation to calculate the muscle forces necessary to recreate the desired kinematics and kinetics. KJCF was calculated for each simulation and differences in peak KJCF were compared. Results: By altering the optimization weighting factors used during subject-specific scaling, peak differences of ~5-10° were seen in knee and ankle angles when using the same experimental data. This change in kinematics resulted in changes in peak KJCF approaching 0.5 times body weight. Discussion: Processing of model kinematics can yield meaningful differences in predicted KJCF and should be carefully considered. The use of additional measurements during static calibration trials may aid in the accurate modeling of subject kinematics.

20 EVALUATING THE ACROMION MARKER CLUSTER AS A METHOD FOR MEASURING SCAPULAR ORIENTATION IN CHILDREN WITH BRACHIAL PLEXUS BIRTH PALSY

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Several studies have described using an acromion marker cluster for measuring scapular orientation in healthy adults performing planar motions. It is unknown whether the acromion marker cluster method will provide the same level of accuracy in children with brachial plexus birth palsy. This study compared this method to palpation for calculating scapular orientation in children with brachial plexus birth palsy performing clinically relevant movements.

Scapular orientation in ten patients was determined by palpation and an acromion marker cluster in neutral and six Modified Mallet positions. RMSEs and mean relative errors were calculated.

Resultant RMSEs ranged from 5.2 degrees to 21.4 degrees. The averages of the mean relative errors across all positions for each axis were 177.4% for upward/downward rotation, 865.0% for internal/external rotation, and 166.2% for anterior/posterior tilt.

The acromion marker cluster method did not accurately measure scapular rotation relative to the total movement on an individual or group basis in the population. With most relative errors over 100%, the acromion marker cluster method often produced errors larger than the actual measured motion. The accuracy of the acromion marker cluster method limits its use as a clinical tool for measuring scapular kinematics on children with brachial plexus birth palsy.

21 GAIT LAB INSTRUMENTED TREADMILL CALIBRATION

Edward C. Skolnick, Zachary B. Sniffen, Alexander Razzook, Steven Stanhope

In order to measure and study the gait cycle, an instrumented treadmill can be utilized. Properly carrying out instrumented treadmill calibration is crucial to acquiring accurate and precise data for gait analysis. The presence of a camera coordinate system and a treadmill coordinate system working in unison presents inherent errors with respect to the six basic loading cases being outputted. Working through the calibration in a systematic manner allows for careful reduction of error. The manner in which Dr. Stanhope's lab was calibrated is as follows. The dual treadmill system was placed in the field of view of the cameras. An L-frame and wand were used to establish a general camera coordinate system and measure the precision of the equipment, respectively. Next, unique force plate jigs were placed on either treadmill. During this time, CalTester trials were carried out on each treadmill to establish an optimized rotation matrix and corner locations of both treadmills. At this stage in the process both coordinate systems are calibrated, but the accuracy of that calibration is unknown. To test the accuracy, static and dynamic rotational CalTester trials were carried out on nine known locations, multiple times, under the same calibration and analyzed using Visual3D. The results of these trials outputted orientation angle and center of pressure values. While the results were accurate, certain regions were not within sub-millimeter precision. In order to assess the optimization, the repeatability of placing the jigs was tested and validated using the camera and treadmill coordinate systems. Next, certain variables from the center of pressure equations were isolated using static CalTester trials. Utilizing this information, it was found that the variables Fy (force along the y-axis) and Mx (moment about the x-axis) present in the equation necessary to calculate the center of pressure for an instrumented treadmill were causing the errors.

22 A COMPARISON OF EXTERNAL ROTATION SHOULDER STRENGTH AT DIFFERENT RANGES OF MOTION IN COLLEGIATE LEVEL BASEBALL PITCHERS

Mathew Failla, John Delucchi, Airelle Hunter-Giordano, Lynn Snyder-Mackler

Introduction: Upper extremity injuries account for 75% of time lost in collegiate baseball players. Shoulder External Rotation weakness is a proposed factor for increased injury risk in baseball pitchers. The purpose of this study is to measure rotational shoulder strength in collegiate baseball pitchers in thrower's neutral compared to previously reported testing positions and determine if differing arcs of rotational motion from dominant to non-dominant arms alters external rotation strength.

Methods: 26 Collegiate Level Baseball Pitchers were included. Dominant and non-dominant arm total rotational motion was measured. 3 isometric strength Trials taken at 3 different positions were recorded bilaterally using a hand held dynamometer. Position 1 is supine 90 degrees abduction and neutral rotation; Position 2 is seated at 30 degrees scaption, 30 degrees abduction, and 30 degrees diagnal. Position 3 is the thrower's neutral position(mid-point of total arc of rotational motion). Data was Analyzed using a Two-Way repeated measures ANOVA, with post-hoc T-Tests.

Results: No differences were found between position and limb($p=0.362$). Differences were found between throwers neutral position and the other two positions($p<0.001$ and $p=0.034$).

Conclusion: External Rotation strength was lower at thrower's neutral position compared to supine 90 or 30/30/30 positions, which further supports the need for functional overhead exercises as part of off-season exercise programs. Collegiate pitchers were weakest at their most functional position.

23 CALCITRIOL CONJUGATED QUANTUM DOTS USED AS TARGETING VECTOR FOR INFLAMMATORY BREAST CANCER IN VIVO

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Novel treatments are desperately needed to diagnose and treat a large variety of aggressive cancers. Epidemiological data show that women with Vitamin D deficiency at the time of breast cancer diagnosis are 94% more likely to experience cancer spread and are 73% more likely to die over the next 10 years, compared to women with adequate Vitamin D levels. A limitation for the use of Calcitriol, the active form of Vitamin D3, as a treatment for cancer is that high concentrations of Calcitriol must be delivered to the tumor. This is even more complicated for Inflammatory Breast Cancer (IBC), because the tumor rapidly metastasizes and disseminates through the lymphatic system. We successfully designed Mucin-1 (MUC-1) antibody-Calcitriol conjugated Quantum Dots (MC-QDs) that infiltrate the lymphatic system and also accumulate at the original and distant tumor sites. Using this approach, we analyzed the distribution and accumulation of MC-QDs in vivo in an inflammatory breast cancer mouse model over 4 days using an IVES Lumina system. Organs were extracted and accumulation of nanoparticles was analyzed. Using image analysis, we showed that the MC-DS accumulate at the tumor site as well as at the metastasized organs and tissues. The data suggest that quantum dots can be used to image drug-tumor interactions in vivo and to deliver therapeutics to the tumor and metastasized sites as well. This data shows that the quantum dots complex is a useful tool that can be targeted for any type of cancer and bound with a large array of therapeutics.

24 MUSCLE DRIVEN FORWARD DYNAMIC SIMULATION OF MAXIMAL VERTICAL JUMPING IN THREE DIMENSIONS

Reza Khoeilar, Brian A. Knarr, Jill S. Higginson

The redundancy of the musculoskeletal system enables fine motor control and elaborate movement schemes, but complicates resolution of individual muscle forces and functions. Forces produce motion in forward dynamic musculoskeletal simulations. This makes forward dynamics a powerful tool that can shed light on the inner workings of individual muscles. Inputs are usually in the form of muscle excitations that can be derived using an optimization algorithm that minimizes some objective function. Dynamic optimization problem can be reduced to a parameter optimization problem by discretizing excitation patterns to control nodes and varying the magnitude of these nodes to produce the desired motion. With the launch of OpenSim 3.0, live scripting through MATLAB has become available using the Application Programming Interface. The objective of this study was to produce a closed loop simulation of maximal vertical jumping .The human body is modeled as a 10-segment, 23 degree-of-freedom mechanical linkage, actuated by 54 muscles. A genetic algorithm was implemented to solve the parameter optimization problem. The initial population of 125 solutions evolved for 100 generations until the solution converged. The simulation reproduced ground reaction forces, EMG data, peak acceleration, take off velocity and displacement of center of mass similar to previous studies and experimental data. While this study does not focus on improving the performance of previous maximal vertical jumping models, it introduces a simple platform to use the scripting features of OpenSim 3.0 to make MATLAB -OpenSim integration seamless.

25 SHOULDER DISSECTION: MEASUREMENT OF BROAD MUSCLE FIBER ANGLES FOR APPLICATION IN MUSCULOSKELETAL MODELING

R. Tyler Richardson, Joseph A. Zeni

Musculoskeletal modeling is capable of estimating the underlying muscle forces and excitation patterns of dynamic activities. However, a model must be significantly robust in order to provide accurate estimates of force and excitation. One challenge in developing a physiologically accurate model of the upper extremity is to represent the many broad muscles of the shoulder girdle with multiple linear force actuators. Using too few actuators may fail to capture a muscle's function, while implementing unessential actuators becomes computationally expensive resulting in excessively long simulation times. The objective of this study was to determine the number of linear actuators required to sufficiently express the actions of trapezius and latissimus dorsi muscles. Measurements were taken on the right shoulder of an embalmed elderly female cadaver. The lengths of the muscle origins were measured and fiber angles were calculated at discrete intervals along the length of each origin. Adjacent fibers with similar angles (within 5°) were grouped and these regions were assumed to have comparable lines of action and thus could be represented by a single linear actuator. The muscle fiber angles of the trapezius ranged from 23° at the inferior origin to 124° at the superior origin. Grouping adjacent fibers with similar angles revealed that the trapezius could be represented with seventeen linear actuators. The latissimus dorsi's fiber angles varied from 54° at the inferior origin to 85° at the superior origin resulting in five linear actuators. These results provide information to ensure that upper extremity models represent the trapezius and latissimus dorsi muscles realistically and effectively, which will provide more accurate and time-efficient estimates of the mechanics that occur in vivo.

26 ASSESSMENT OF MUSCULOSKELETAL MODELS OF THE UPPER EXTREMITY

R. Tyler Richardson, Kristen F. Thomas, Brian A. Knarr, Jill S. Higginson

Insight into pathological movement and muscular dysfunction of the shoulder joint has been limited due to difficulty in tracking scapular motion and the inability to directly measure the underlying muscle forces during dynamic motion. Musculoskeletal modeling possesses the capability to reproduce recorded kinematics and estimate the muscle forces and excitation patterns that characterize patient-specific muscular deficits. However, the validity of the results must first be assessed to ensure that the model is sufficiently robust to recreate the mechanics that occur in vivo. Three upper extremity models – the Stanford VA, the Arm500, and the Delft Shoulder and Elbow Model (DSEM) – were examined to determine the most accurate kinematic model. All models allowed for three rotational degrees of freedom at the glenohumeral joint, while each permitted different degrees of freedom for scapular motion. Motion data was recorded with an eight camera motion capture system during shoulder abduction for one healthy subject. Scapular orientation was tracked using an acromion marker cluster. Models were scaled based on subject mass and marker locations. Marker positions from motion capture were compared with those estimated by OpenSim and the average root mean squared error (RMSE) of each marker was calculated for each model over the trial. Estimated muscle forces during abduction were computed on the most accurate kinematic model. Muscles forces were estimated using the static optimization tool within OpenSim. The average RMSE values were consistently smallest for the DSEM. The muscle forces estimated by the DSEM for shoulder abduction were in qualitative agreement with the established anatomical actions of upper extremity muscles. These findings suggest that the DSEM is sufficiently robust to warrant further analysis in future studies.

27 ANALYSIS OF TRAPEZIOMETACARPAL JOINT MOTION USING MULTIPLE MEASUREMENT TECHNIQUES

Robert L. Hulbert, Kristen F. Thomas, William C. Rose, Todd Royer, James G. Richards

Thumb function accounts for up to 50 percent of total hand function with most of its function coming from the trapeziometacarpal (TMC) joint. Past studies have analyzed overall ROM of the TMC joint by simultaneously measuring maximal planar and composite motions, which together form a spherical surface area used to find the maximal workspace. However, none of these studies have compared their results with range of motion (ROM) or workspace measurements obtained during clinical tests such as the Modified Kapandji Index (MKI), which is designed to measure the thumb component of overall hand mobility. The purpose of this study was to determine the difference in ROM and workspace measurements at the TMC joint using clinical and maximal ROM measurement techniques. An 8 camera motion capture system was used to track the location of retroreflective markers placed on the wrist, hand, and thumb. TMC axis orientation and TMC workspace were calculated using custom software written in LabVIEW and Matlab. Comparisons were made between thumb measurement techniques for TMC ROM and TMC workspace. Results show that the MKI task displayed significantly less abduction/adduction ROM and overall workspace than the maximal ROM task. This indicates that the clinical MKI test is ineffective in measuring the entire ROM and workspace of the thumb and may need to be done in unison with other tests to ensure that the patient is exploring a greater amount of their available TMC abduction/adduction ROM and workspace. These results are important to both clinicians and patients as it may help to improve on the process of clinically measuring and evaluating thumb ROM and function in injured and pathological populations.

POSTER PRESENTATIONS

Motor Control

28 THE DEFAULT MODE NETWORK (DMN) IN THE PREFRONTAL CORTEX (PFC) IN HEALTHY ADULTS USING FUNCTIONAL NEAR-INFRARED SPECTROSCOPY (FNIRS)—A PILOT STUDY

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The DMN, a spontaneous activity during resting states, plays an important role in the intrinsic mental activities and accounts for the preparation of conscious activities. The disruption of the DMN could underlie mental disorders such as autism. The understanding of the DMN can be applied to the control mechanism of human behaviors. However, the database of the DMN lacks the information of children. The aims of our study were using fNIRS to measure brain activity during resting states in the PFC in children with and without autism. This pilot stduy was conducted to evaluate the feasibility of proposed research protocal.

Two healthy participants participated in the pilot study. Raw fNIRS signals were collected using NIRScout system. Two trials, one with their eyes closed and one with their eyes open, were collected for each participant. The concentration of oxygenated hemoglobin (oxy-Hb) of 24 channels covered the PFC were calculated. The differences of the concentration of oxy-Hb among different regions in the PFC and between two eyes conditions were compared.

Twenty-four channels were grouped in six regions. No significant differences were found among the regions in both eyes closed and eyes open conditions ($F(5,35) = 0.941$, $p = .467$; $F(5,35) = 0.223$, $p = .950$, respectively). The concentration of oxyHb was higher in eyes closed condition (0.688 µm ± 2.201 µm) than in eyes open condition (0.145 µm ± 3.146 µm). However, there was no significant difference between eyes open and eyes closed conditions ($t(47) = 1.467$, $p = .149$).

29 LIGAMENTOUS LOADING OF THE ANKLE INCREASES CONTRALATERAL SOMATOSENSORY CORTEX ACTIVITY IN HEALTHY SUBJECTS

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Ligamentous injury to the ankle has been associated with neurological phenomena including decreased muscle spindle activity and diminished reflexes. While preliminary studies have suggested changes in cortical function following ligament injury, no studies have quantified somatosensory cortex (S1) activity during ligamentous loading. We therefore aimed to investigate the effect of anterior joint loading on S1 activation using electroencephalography (EEG). Nine right leg-dominant subjects (21.0±2.6yrs, 165.0±9.0cm, 62.2±13.2kg) were fitted with an EEG cap following international standards. Subjects were positioned supine on a padded table and an ankle arthrometer was used to apply 50 anterior loads to the right ankle to 125N, with 5s between each load. Event-related desynchronization (ERD, %) in upper Alpha frequency (α-2, 10-12Hz) was used to detect changes in maximal ERD amplitude from a baseline period (BASE, 1-2s prior to load), and the first 2 seconds of the load (LOAD1=0-1s; LOAD2=1-2s) for the CP3 electrode (contralateral S1). Bonferroni-corrected t-tests revealed higher ERD in both load conditions compared to baseline (BASE=0.6±1.6%, LOAD1=36.8±16.0%, LOAD2=33.4±11.6%, $p \leq 0.001$), indicating higher S1 activity. No significant difference was observed between LOAD1 and LOAD2 conditions. This data is the first to detect alterations in cortical activity during in-vivo ligamentous loading, even at relatively low levels of force, and lends support to the hypothesis that ligamentous injury could potentially lead to cortical changes. This approach could improve our understanding of sensory integration that must occur between the perception of impending and potentially injurious loads and the formation of reflexive responses.

30 EFFECTS OF MUSCLE FATIGUE ON FORCE COORDINATION AND PERFORMANCE OF MANIPULATION TASKS

Nicholas Emge, Mehmet Uygur, Slobodan Jaric

Muscle fatigue is known to be associated with a deteriorated muscle coordination and impaired movement performance in variety of voluntary movements. The aim of this study is to investigate a generally underexplored effect of muscle fatigue on both the coordination between the grip force (GF; the force component perpendicular to the hand–object contact area that provides friction) and the load force (LF; the parallel force component that can move the object or support the body) and movement performance in manipulation tasks. Fifteen participants performed a variety of static and dynamic manipulations both with and without a preceding procedure aimed to fatigue the arm and hand muscles. The tasks involved exertion of ramp-and-hold and oscillation patterns of LF against an externally fixed instrumented device, and a simple lifting of a free moving device. The results revealed a fatigue associated decrease in GF scaling (i.e., the magnitude of GF relative to LF) and GF-LF coupling (correlation between GF and LF), while the task performance regarding the accuracy of exertion of the prescribed LF profiles remained unaffected. We conclude that muscle fatigue both partly decouples GF from LF and reduces the overall GF magnitude that could explain why the hand-held objects are more likely to drop when manipulated with fatigued muscles. However, the unaffected task performance could be explained either by a relatively low level of muscle forces required by the tested tasks, or by a moderate level of the fatigue imposed, or both.

31 THE ROLE OF MUSCLE TORQUE IN STABILIZING UPRIGHT POSTURE DURING VISUAL PERTURBATIONS

Eunse Park, John P. Scholz

The stability of quiet standing is considered to be dependent primarily on the action of muscles around the ankle, although hip muscle activity may play a role when perceptual incongruity leads to increased postural sway. Kinematic analysis using the Uncontrolled Manifold (UCM) approach suggests that stability in upright standing, even during such incongruities, results from multi-joint coordination. It could be argued that part of the observed multijoint coordination may result from passive mechanical effects. In this study, we used Lagrangian mechanics to estimate net torques at the ankle, knee, hip and L5-S1 joints and decomposed them into gravitational, motion dependent and generalized muscle (MUS) torques. MUS at the four joints were then treated as elemental variables in UCM analysis to determine whether MUS torque variance (VUCM) across 0.2-Hz visual perturbation cycles were consistent with the use of flexible coordination to stabilized the CM position. We further tested this hypothesis by removing covariation among the four joints' MUS and repeating the analysis, hypothesizing that evidence of flexible combinations of MUS related to CM stability would be reduced significantly following removal of covariance. The variance related to the motion of the body (VORT) was selectively increased at 0.2-Hz with the visual perturbation, but not at other frequencies or during quiet standing, as predicted. However, VUCM was greater than VORT in all cases. After removing covariation, the selective increase in VORT at 0.2-Hz was removed, and the relative difference between VUCM and VORT decreased significantly ($F_{1,13} = 129.7$, $p<0.001$) at all frequencies and conditions. The results suggest that a significant component of coordination of the ankle, knee, hip and trunk is due to active muscle torque and not strictly passive mechanics.

32 FORCE SENSE DOES NOT DIFFER BETWEEN POWER AND ENDURANCE TRAINED COLLEGIATE ATHLETES

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Force sense (FS) is a perception influenced by adaptations to Golgi Tendon Organs (GTO) and muscle spindles, which play an important role in regulating joint stiffness and responding to injurious loads. Recent studies have linked deficits in the early detection of joint loading to recurrent episodes of instability. Enhancing force sense through specific types of conditioning programs may be desirable during prevention and rehabilitation, but it is unclear whether power or endurance training would convey any advantages. Forty-two male athletes (15 endurance athletes (END), 12 power athletes (PWR), 15 recreational athletes (CON)) with no history of knee injury were tested for quadriceps and hamstrings FS at 30% of their maximum voluntary isometric contraction without visual feedback on a custom-built assessment device. Subjects were instructed to exert their target torque and depress a hand-held switch. A period of 500ms from depression of the switch was used to determine matched force. The independent variables were group (END, PWR, CON) and muscle (hamstrings and quadriceps). Dependent variables included relative error (RE, %), coefficient of variation over the 500ms match (CV, %), and time-to-matched torque (sec). Separate repeated-measures analysis of variance was used to determine differences between muscles (2 levels) and groups (3 levels). The main effect for both conditioning history (group) and muscle were not significant for RE, CV, or time-to-matched torque except the main effect for muscle for time-to-matched torque. Time-to-matched torque for the hamstrings was faster than quadriceps. FS does not appear sensitive to differences in physical conditioning among healthy subjects; therefore future studies may explore whether FS deficits existing in injured populations may benefit from conditioning programs.

33 REAL-TIME WEIGHT BEARING FEEDBACK IMPROVES MOVEMENT SYMMETRY DURING SIT TO STAND TASK

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Background: Asymmetrical movement patterns present during daily activities in patients with end stage of hip osteoarthritis (OA), with more load shifted to the non-affected limb. Total hip arthroplasty (THA) improves pain and function, yet aberrant biomechanics persist in different motor tasks. During a sit to stand (STS) task, patients after THA increase the load on the non-operated side, such altered pattern may predispose contra-lateral joints for more OA risk.

Purpose: To examine whether providing real-time visual feedback of force under each limb can improve symmetry of lower extremity biomechanics during STS, in patients before and after THA. We hypothesized that patients would exhibit improved symmetry in hip and knee biomechanics when provided only with force feedback.

Methods: Ten patients participated in this study; five patients with end-stage hip OA and five patients 3 months after THA. Patients performed STS task in two conditions (with and without visual feedback). All patients underwent 3D motion analysis of STS task. Feedback given through the use of a custom-written software program was displayed on a monitor in front of patient. The outcome measures were the symmetry ratio of vertical ground reaction force (VGRF), peak hip flexion moment (PHFM), hip sagittal angle (HSA), peak knee flexion moment (PKFM), and knee sagittal angle (KSA).

Results: Patients before and after THA demonstrated more symmetrical biomechanics when receiving feedback; inter-limb symmetry ratio for VGRF, PHSM and PKSM were improved whereas KSA and HSA were very symmetrical in both conditions.

Conclusion: Visual feedback may be effective for retraining biomechanics symmetry during STS, and may reduce the risk of contra-lateral joints OA if retention of symmetrical patterns occurs.

POSTER PRESENTATIONS

Pediatrics

34 MODIFIED RIDE-ON CAR USE FOR MOBILITY AND SOCIALIZATION: A CASE REPORT OF AN INFANT WITH DOWN SYNDROME

Lisa George (presenting author), Samuel W. Logan, Hsiang-Han Huang, Kylee Stahlin, James Cole Galloway

Medical professionals typically do not consider children working towards the goal of independent walking to be candidates for powered mobility (aka powered wheelchairs). The purpose of this case report is to determine whether it is feasible for a 13-month old child with Down syndrome who is concurrently working towards the goal of walking to use a modified ride-on car to advance mobility and socialization. The study included 2 phases: Baseline (12-weeks) and Intervention (12-weeks). During baseline, we videoed Natalie during bi-weekly driving sessions of 10-minutes. During the intervention, her family provided 20 minutes of driving five days/week. Once per week, we videoed a 10-minute driving session. Independent driving increased from 19% (baseline) to 98% (intervention) of total time, and the frequency of positive and negative facial expressions increased and decreased, respectively. Pediatric Evaluation of Disability Inventory scores indicated positive gains in self-care, mobility, and social function behaviors in each domain of functional skills and care-giver assisted skills. In conclusion, these results are the first indication of a potentially positive effect of using ride-on cars on the outcomes of self-care, mobility, and social function behaviors. Modified ride-on cars may be used as an intervention supplement that emphasizes activity/participation goals in comparison to traditional forms of interventions that are focused primarily on walking. Future research will implement a group design to formally examine the benefits of ride-on car use on children and their family.

35 "SPECTRUM TECHNOLOGY" I: THE DEVELOPMENT OF A "STANDING CAR" TO ENCOURAGE MOVEMENT, MOBILITY AND SOCIALIZATION

Samuel W. Logan, Vinayak Rajendran, Kevin Chang, Daniel Charytonowicz, Stacy Hand, Heather Feldner, Christina Ragonesi, James Cole Galloway

Pediatric rehabilitation technology typically is designed to promote progress in body/structure and function, activity, or participation but rarely to promote progress in all three simulataneously – which we term 'Spectrum Technology'. Spectrum Technology is difficult as the design must encorporate multiple factors ranging from child's likes and abilities, equipment materials and transportablility, areas of device use, caregiver requests and perceptions. The purpose of this technical report is to briefly outline the chronology and general features of the development of a "standing" version of our modified ride-on car. We will also outline how the standing version of a ride-on car can be encorportated into an early intervention plan to allow very young children to progress in multiple goals including bone and muscle strength, balance, and coordination, while increasing their daily mobility and social participation with peers and adults at home, in school, or in the community. We will also speculate about the future prototypes that further push design and fabrication principles for pediatric spectrum technology.

36 "SPECTRUM TECHNOLOGY" II: A NEW GENERATION OF PEDIATRIC ASSISTIVE TECHNOLOGY.

Samuel W. Logan, Allyson Zeitschel, Kyle Ingram, Timothy Veltre, Lisa George, Scott Adkins, Desiree Pinto, James Cole Galloway

In rehabilitative settings, Assistive Technology (AT) is frequently provided as a means to increase children with special needs' ability to move and interact with the world. The purpose of this abstract is to introduce two bench studies of different types of AT provided to children with mobility impairments. Device 1: An in-home, body-weight support harness system for a 6 year-old child (Andrew) diagnosed with Spina Bifida. Typically, Andrew uses arm crutches for mobility. Harness House is a mechanical device that provides dynamic vertical force to support vertical and horizontal movement. For two months, we videoed Andrew's behavior with and without the harness during general play and physical therapy sessions. Preliminary results will be provided. Device 2: A ride-on car was electrically and mechanically modified to simultaneously provide powered mobility and independent standing to a 4 year-old child (Xander) diagnosed with a tethered spinal cord. Typically, Xander uses arm crutches for mobility. We modified the activation switch of a 12-volt, all-terrain-vehicle style car such that Xander had to stand up in order to activate the device. We videoed Xander's behavior in the classroom (crutches only), gym (crutches, ride-on car), and playground (crutches, ride-on car). Preliminary results will be provided. Each device provided a new means for a child to be "socially mobile" in different contexts. Mobility itself is not an end goal, but rather using mobility to socially interact with peers and explore the world is ideal. Future research will determine the feasibility of offering both (and additional) devices as part of an "exploration" package of AT devices that are meant to compliment each other to maximize the potential benefits of their usage.

POSTER PRESENTATIONS

Stroke

37 SELECTING OPTIMAL WALKING PATTERNS AFTER STROKE

Devina Kumar, Erin Helm, Christine Malecka, Darcy S. Reisman

Introduction: Stroke survivors walking on a split-belt treadmill demonstrate adaptation similar to healthy individuals for a novel walking task. The goal of this study was to compare whether after longer-term learning of this novel walking pattern stroke survivors and control subjects were equally able to select the optimal walking pattern. We hypothesized that after days of practice,stroke survivors would demonstrate differences in the ability to adjust walking pattern, as assessed by after-effects, on the final day of split-belt walking compared to the control subjects.

Methods:16 individuals with stroke (>6 months) and their age matched controls participated. Kinematic and kinetic data was collected with subjects walking on an instrumented split-belt treadmill. Data was collected over 5 consecutive days followed by a two day break and then a retention test. On the first day, baseline data was collected while subjects walked with both belts at the same speed. Thereafter, subjects walked for 15 minutes with the belts split in a 2:1 speed ratio. During the retention test the 15 minutes of split-belt walking was followed by 5 minutes of walking with the belts tied to test for after-effects. Step length and limb phasing symmetry after-effects were compared between the groups using repeated measures ANOVA.

Results: There was no difference in the magnitude of the after-effect between groups, but a group X time interaction over the first 50 strides, indicated a slower rate of de-adaptation in the stroke subjects ($p<0.05$).

Discussion: This suggests that with 5 days of practice stroke survivors could learn and retain the new walking pattern on the split-belt treadmill, but were slow to switch to their normal walking pattern once the perturbation was removed.

38 MUSCLE ARCHITECTURAL CHANGES OF THE POST-STROKE TIBIALIS ANTERIOR

Molly A. Wessel, John W. Ramsay, Stephen M. Suydam, Thomas S. Buchanan, Jill S. Higginson

Introduction: Stroke survivors often suffer from hemiparesis. In the lower leg, foot-drop commonly occurs in the paretic leg and manifests itself as a decrease in dorsiflexion range-of-motion. The objective of this study was to investigate the correlation between ankle joint motion and muscle fascicle length and pennation angle of the tibialis anterior (TA). Methods: One stroke survivor (69 yrs old, 8 yrs post-stroke) and one healthy control (22 yrs old) were provided as preliminary data. At least two longitudinal ultrasound images of the muscle belly of the TA were taken, starting at 0º and incremented 10º in both plantar flexion and dorsiflexion until maximum range-of-motion was reached. Fascicle length and pennation angle were measured from each image using the point-to-point method and averaged for each joint angle. Results: Healthy TA fascicles were approximately 1 - 1.5 cm longer (y-intercept of 7.86 cm) than both non-paretic (y-intercept 6.94 cm) and paretic fascicles (y-intercept 6.27 cm). The fascicle lengths for all 3 groups trended towards larger lengths at larger plantar flexor angles. Paretic TA pennation angles were 2.5 - 4º greater (y-intercept 14.07º) than both healthy (y-intercept 11.49º) and non-paretic angles (y-intercept 9.80º). The pennation angles for all 3 groups trended towards smaller pennation angles at larger plantar flexion angles. Disscussion: We found that fascicle lengths were smaller and pennation angles were greater in the paretic TA when compared to healthy values. Additionally, non-paretic fascicle lengths were slightly longer and pennation angles were smaller compared to paretic muscle. Since we have observed architectural differences between these two sides, it is likely that paretic dorsiflexor strength is influenced by structural changes post-stroke.

39 THE RELATIONSHIP BETWEEN THE ENERGY COST OF TRANSPORT AND WALKING ACTIVITY IN INDIVIDUALS POST STROKE

Kelly Danks, Tamara Wright, Margie Roos, Evan Matthews, William Farquhar, Darcy Reisman

Introduction: Daily walking activity in individuals post stroke is very low, well below that of sendentary adults (<5,000 steps/day). The energy cost of transport (CT) or the oxygen consumption per unit distance walked (mL O_2/kg/m) is generally greater after stroke. The purpose of this study was to examine the relationhip between daily walking activity and CT after stroke. We hypothesized that individuals with the greatest energy cost of walking would show the greatest impairment in daily walking activity. Methods: To obtain activity levels, twenty-one persons with chronic stroke wore a step activity monitor for at least 4 days. Oxygen consumption was measured as they walked at their self-selected speed on a treadmill. VO_2 was normalized to body mass and speed, resulting in energy cost per meter walked (CT).The descriptors of step activity were averaged across the days monitored, and were used to analyze the relationship to CT. Descriptors of step activity included: steps per day (SPD), walking bouts per day (BPD) and total time walking per day (TTW). Results: There was a negative correlation between CT and SPD ($r=-0.512$, $p<0.05$), BPD ($r=-0.485$, $p<0.05$), and TTW ($r=-0.510$, $p<0.05$) . Conclusions:These results suggest that in persons poststroke, higher energy cost of transport is related to decreased levels of walking activity. To better understand this relastionship, future studies should examine whether there is a relationship between improvements in CT and walking activity with rehabilitaiton after stroke.

40 INVESTIGATION OF FACTORS ASSOCIATED WITH SELF-SELECTED WALKING SPEED IN INDIVIDUALS POST-STROKE

Victoria Stanhope, Brian Knarr, Jill Higginson

Approximately two out of three individuals post-stroke experience walking impairments and exhibit high concern to regain gait function. Individuals post-stroke have a wide range of SSWS and consequently have a wide range of community mobility. Frontal plane compensatory strategies, i.e. pelvic hiking and circumduction, are observed in post-stroke gait as mechanisms for improving foot clearance in response to reduced knee flexion and ankle dorsiflexion. Kinematic trends have been linked to walking speed but findings are primarily in the sagittal plane, considerably limiting our understanding of frontal plane compensatory patterns. In addition to kinematic joint abnormalities, spatiotemporal asymmetry characterizes hemiplegic gait and is related to mechanical inefficiency and higher risk of falls. Kinematic asymmetry trends have not been identified over SSWS in post-stroke gait. The objective of this study was to investigate kinematic factors that may enable post-stroke individuals to have a faster SSWS. Gait analysis was performed at SSWS for 21 individuals post-stroke. Four kinematic variables were calculated: peak pelvic tilt, peak hip abduction, peak knee flexion, and peak ankle dorsiflexion. Paretic joint angles were compared between functionally relevant ambulation categories (household <.4m/s, limited community .4-.8m/s, community >.8m/s), between the paretic and nonparetic limbs, and also with overall regressions.

Significant differences were found between speed categories for peak paretic pelvic tilt, knee flexion, and ankle dorsiflexion while peak paretic circumduction was not found to be significantly different across speed categories. All joint angles had significant relationships with SSWS and significant differences between paretic and nonparetic joint angles were found in pelvic tilt and knee flexion. Understanding the distinct kinematic patterns between low and fast SSWS may provide improved understanding upon a simple clinical evaluation of SSWS.

41 DIFFERENCES BETWEEN HEALTHY CONTROLS AND STROKE SURVIVORS IN TRUNK MUSCLE COORDINATION DURING REACHING

Geetanjali Gera, PT, MS, PhD, Kelsey McGlade, John P. Scholz

Studies targeting deficits in arm-trunk coordination for reaching primarily have investigated downwardly directed reaches initiated primarily from the upper trunk. However, stroke survivors have been found to struggle more when reaching upward, which is related to their atypical hemiparetic arm synergies, but also requires lower trunk movement initiation that most stroke survivors struggle to achieve.

The current study investigated differences between 10 stroke survivors and 9 healthy control subjects in how they use trunk muscle synergies to control the trunk when performing upward or downward, forward reaching. Principal component analysis was used to identify four combinations of ten trunk muscles, or muscle mode (M-mode) vectors. Flexibility in coordinating these muscle-modes to stabilize the trunk's motion was investigated using Uncontrolled Manifold analysis (UCM). It was hypothesized that there would be altered coordination among muscle modes in stroke-survivors compared to controls, resulting in a less consistent trunk movement path, especially when reaching upwards.

M-mode variance across repetitions of the task in controls primarily was associated with consistent trunk motion (VUCM), whereas M-mode variance resulting in variable trunk motion (VORT) was much smaller. For stroke survivors, VORT was larger and VUCM was smaller than for controls, especially when reaching upward. The results suggest that stroke survivors were unable to selectively coordinate the M-modes to achieve a consistent trunk path across repetitions. Moreover, poorer ability of stroke survivors to reach upward toward target appears to be related to even poorer M-mode coordination compared to reaching downward. An understanding of deficits in trunk coordination provides a framework for identifying the effects of training studies on trunk muscle coordination impairments related to specific functions.

10th Annual Biomechanics Research Symposium

Schedule of the Day

TIME	WHAT	WHERE
8:30	BREAKFAST & POSTER SET-UP	CLAYTON HALL LOBBY
9:00	WELCOME & INTRODUCTORY REMARKS	CLAYTON HALL AUDITORIUM 125
9:15	KEYNOTE: DR. CAROLEE WINSTEIN	CLAYTON HALL AUDITORIUM 125
10:15	BREAK	
10:30	PODIUM SESSION 1	CLAYTON HALL AUDITORIUM 125
12:00	LUNCH	CLAYTON HALL ROOM 101A
1:00	POSTER SESSION 1 (ODD #S)	CLAYTON HALL LOBBY
2:00	POSTER SESSION 2 (EVEN #S)	CLAYTON HALL LOBBY
3:00	PODIUM SESSION 2	CLAYTON HALL AUDITORIUM 125
4:30	AWARDS SESSION	CLAYTON HALL AUDITORIUM 125

COCKTAIL RECEPTION

5pm - 7pm

Newark Courtyard Marriott Patio

LIVE MUSIC BY: TYLER RICHARDSON & BILL HANDY

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