2009 Biomechanics Research Symposium

May 15, 2009

CBER is a Research Center of the University of Delaware
Department of Mechanical Engineering, 126 Spencer Lab, Newark, DE. 19716

The Center for Biomedical Engineering Research at the University of Delaware is pleased to host the 6th annual CBER research symposium. The motivation for this symposium is to highlight the outstanding and varied biomechanics related research taking place at the University of Delaware.

Our keynote lecture will be given by Dr. Irving Shapiro, Professor of Orthopedic Surgery, Biochemistry and Molecular Biology at Thomas Jefferson University. Dr. Shapiro's research interests include mechanisms of bone growth and repair, tissue engineering of the intervertebral disc, and creating bioactive surfaces for repair of fractured and infected bone.

Poster and podium presentations will be led by UD student researchers with awards given to the best presentations. Podium presentations will be held in the morning in CCM 106 and the posters will be on display in the afternoon (2nd floor Spencer Lab).

The keynote lecture will be delivered at 9:00 AM in CCM 106.

ACKNOWLEDGEMENTS

Organizing Committee Members

Jill Higginson
Elaine Nelson

Judges

Kurt Manal
Darcy Reisman
Irving Shapiro
Steven Stanhope

Student Committee Members

Rebecca Fellin
Geetanjali Gera
Trisha Kesar
Deepak Kumar
John Ramsey
Ben Roewer
Joe Zeni, Jr.

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Schedule of the Day

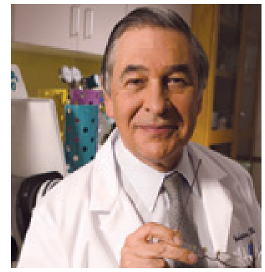
Time	What	Where
8:00	Poster set-up	2nd floor Spencer Lab
8:30	Breakfast	CCM 106
8:45 - 9:00	Introductory Remarks	CCM 106
9:00 - 10.00	Keynote: Dr. Irving Shapiro	CCM 106
10:00 - 10:15	Break	
10:15 - 11:15	Podium Session 1	CCM 106
11:15 - 11:30	Break	
11:30 - 12:30	Podium Session 2	CCM 106
12:30 - 2:00	Box Lunch	
2:00 - 3:00	Poster Session 1 (Even #s)	2nd floor Spencer Lab
3:00 - 4:00	Poster Session 1 (Odd #s)	2nd floor Spencer Lab
4:00 - 4:15	Awards	Spencer 209

Podium Presentations

	Presenter	Abstract #
Podium Session 1	Joe Gardinier	1
10:15 - 11:15	Chris Price	2
	Amit Jha	3
	Xi Chen	4
	Ann Tokay Harrington	5
	Break	
Podium Session 2	Ming Xiao	6
11:30 - 12:30	Qi Shao	7
	Mehmet Uygur	8
	Erin Hartigan	9

Keynote Lecture

MOLECULAR ENGINEERING OF ORTHOPAEDIC IMPLANTS: FROM BENCH TO BEDSIDE



Irving M. Shapiro, B.D.S., Ph.D.
Thomas Jefferson University, Jefferson Medical College
Department of Orthopaedic Surgery
Professor of Orthopaedic Surgery, Biochemistry and Molecular Biology

Patients who receive implant devices can experience biomaterial-associated infections which can lead to destruction of local tissues, patient disability and morbidity, and on occasion, death. Bacteria adhere to the implant surface and synthesize a complex glycocalyx that protects the organisms from immune surveillance and antibiotic treatment. To address this problem, we are developing a new, smart orthopaedic implant that besides providing secure fixation for fracture healing has a bactericidal surface that prevents potential infection or eradicates established infection. We use silane chemistry to covalent bond antibiotics to a metal surface via a membrane soluble linker. The efficacy of the attachment chemistry is evaluated in two ways. First, using microbiological assays, immunohistochemical techniques and cell biology techniques, we have assessed the distribution, stability and activity of the tethered antibiotic. Second, we have developed an animal model to determine the utility of the antibiotic-modified surface to prevent or mitigate bacterial infection of bone. Results of these ongoing studies indicate that the tethered antibiotic can inhibit bacterial adherence and biofilm formation. We predict that the this smart bactericidal surface may have the most profound long-term impact on general healthcare, and serve as a starting point for the development of the next generation of bioactive implants.

BIOSKETCH: Dr. Shapiro, received a degree in Dental Surgery (BDS) from the University of London, and the degree of Ph.D. in Biochemistry from the University of London in 1968. He joined the faculty of the University of Pennsylvania (Penn) in 1969 and rose to the rank of Full Professor in 1976. He served as Chairperson of the Department of Biochemistry in the School of Dental Medicine for 9 years; in 1997, with faculty from the Department of Bioengineering at the School of Engineering at Penn, he was instrumental in forming the Center for Bioactive Material Research. During this time period Dr. Shapiro had the honor of chairing two separate Gordon Conferences (Bones and Teeth and Biomineralization) and organizing the First International Conference on the Growth Plate. In 2001, Dr. Shapiro was recruited by the Department of Orthopaedic Surgery at Thomas Jefferson University to lead the Division of Orthopaedic Research. Currently, he is Professor of Orthopaedic Surgery, Biochemistry and Molecular Biology and Director of the Tissue Engineering and Regenerative Medicine Graduate Training Program at Thomas Jefferson University. When not working (a rare occurrence), he enjoys playing with wife, daughter and grandchildren, cooking very hot curries and tap dancing.

Current research activities now being pursued by Dr. Shapiro can be summarized as follows: (a) Fate of the hypertrophic chondrocyte in the endochondral growth plate. The current project is part of a long term interest in the mechanism of chondrocyte hypertrophy and mineralization. Having shown that cells in the epiphysis end their life history through the induction of apoptosis, he has recently shown that prior to apoptosis the chondrocytes assume a new state, autophagy. (b) Creating bioactive surfaces for repair of fractured and infected bone. The goal of this work is to develop a new generation of “smart” implants that promote osteogenesis and prevent bacterial infection. This study relies heavily on the development of new chemical techniques to generate linkages between metals and bioactive molecules and uses imaging techniques such as mass spec analysis, micro-tomography light, electron and X-ray imaging to evaluate efficacy of healing. (c) exploring the origin, form and function of cells of the intervertebral disc. Following a bout of lower back pain, Dr. Shapiro directed his research to determining if stem cells exist in the disc, and whether they can be used to repopulate the nucleus pulposus. His more recent work is aimed at learning how the notch signaling system regulates intervertebral disc proliferation and differentiation.

1 INTRAMEDULLARY PRESSURE RESPONSE DURING AXIAL CYCLIC LOADING

Joseph Gardinier[1], Kei-Peng Jen[3], Chris Townend[3], Randall Duncan[2], Liyun Wang[1]
[1]Department of Mechanical Engineering and [2]Department of Biological Sciences, University of Delaware [3]Department of Mechanical Engineering, University of Villanova

Skeletal strength and mass is dependent on the anabolic response of bone cells to the mechanical environment. Given the dependence of this response on magnitude and frequency of applied loads, the purpose of this study was to quantify the hydraulic pressure that osteoblasts may experience by directly measuring the intramedullary pressure (IMP) of intact bone under axial loads. We hypothesize that IMP will increase linearly with increasing load magnitude and exponentially with increasing load frequencies. The third metacarpals of two beagle dogs were isolated and capped at both ends with epoxy resin. A catheter pressure transducer was sealed within the medullary cavity. Each sample was axially compressed using an Instron machine under either cyclic loading or/and step-loading. Cyclic sinusoidal loading was applied with a peak load of 50, 100, or 200 lbs (induced surface micro-strain ~900, 1,800, and 3,600) and at frequencies of 0.5, 1, 3, and 5 Hz for 120 seconds. Step-loading was applied at 50, 100, or 200 lbs within 0.002 sec, which was held for 120 seconds before release. The peak IMP during cyclic loading increased linearly with applied load, with 200 lbs generating a peak IMP of 15-20 mmHg. An exponential relationship between the peak IMP and load frequency occuried for 200lbs loading, but was not observed for smaller loads. IMP reached magnitudes of ~5, 10, and 20 mmHg during step-loading of 50, 100, and 200 lbs compression, respectively. In conclusion, osteoblasts are subjected to varying magnitudes of hydraulic pressure during axial loading of long bone in addition to the load-induced fluid flows throughout bone's complex architecture.

2 DIRECT MEASUREMENT OF LOADING ENHANCED SOLUTE TRANSPORT WITHIN THE LACUNAR-CANNICULAR SYSTEM OF BONE

Christopher Price, Wen Li*, Liyun Wang**
**Center for Biomedical Engineering, Department of Mechanical Engineering, University of Delaware*

Since Piekarski and Munro published their Nature paper in 1977 and proposed that load-induced fluid flow is the primary transport mechanism operating between blood supply and osteocytes, load-induced fluid flow within the osteocyte lacunar-cannicular system (LCS) becomes accepted as the mechanism of bone metabolism and mechnosensation. Over these years analytical models have been developed in exploring the behavior of the bone fluid flow as a function of loading parameters and bone structures. Tracer-based studies provide indirect support to this hypothesis. However, direct, unequivocal observation of load-induced fluid flow and solute transport has been lacking. In this investigation, we utilized the advanced live imaging technique based on fluorescence recovery after photobleaching (FRAP), which allowed us to measure solute transport at the same osteocyte lacunae under loading and nonloading conditions. Five adult B6 mice were injected with 2 mg sodium fluorescein (376 Da). Tibae were harvested 30 min after injection and axially compressed in a custom-made system consisting of a micro-mechanical loading device and a laser scanning confocal microscope. An intermittent loading regimen with 3N peak load (~400me), 2 sec/cycle and 4 sec resting (imaging) window between two cycles were used for alternative loading and imaging of the bone. Individual lacunae were identified and subjected to FRAP, first under loading followed by non-loading conditions (no dynamic force applied). We found ~40% increase of the transport rate in the loading condition than the non-loading condition, which agrees with the predictions from our previous analytical model. To our knowledge the present investigation provides the first direct observation of load-induced transport and confirms the long-standing fluid-flow hypothesis, the very basis of current bone mechanosensation studies.

3 HYALURONIC ACID-BASED HYDROGEL PARTICLES AND DOUBLY CROSS-LINKED NETWORKS FOR SOFT TISSUE REGENERATION

Amit K. Jha,[1] Weidong Yang,[2] Randall L. Duncan, Mary C. Farach-Carson,[2] and Xinqiao Jia[1]
[1]Department of Materials Science and Engineering, [2]Department of Biological Sciences, University of Delaware

We have developed a new class of HA-based matrices that have HA hydrogel particles (HGPs) embedded in and covalently cross-lined to a secondary matrix. Two types of HA HGPs were synthesized using an inverse emulsion polymerization technique, and the resulting HGPs have varying overall sizes and surface functionalities. Hierarchically structured, doubly cross-linked networks (DXNs) were engineered using HA HGPs as the building blocks and water soluble polymer as the cross-linker. These hydrogels are soft and elastic, exhibiting unique frequency-dependent viscoelasticity. The DXNs are stable, elastic gels that become stiffer at higher frequencies. Their viscoelastic properties can be readily modulated by varying the particle size, surface functional group, inter-particle and intra-particle crosslinking. In vitro cell proliferation assays showed that HA HGPs did not adversely affect the proliferation of the cultured fibroblasts. To further enhance the biological activities of HA HGPs, perlecan Domain I (PlnDI) proteoglycan was conjugated to the particles via reductive amination through a poly(ethylene glycol) (PEG) linker. The immobilized PlnDI maintains its ability to bind bone morphogenetic protein (BMP-2) specifically. PlnDI conjugated HA HGP allows for sustained release of BMP-2 over 15 days. The released BMP-2 was shown to stimulate the chondrogenesis of mesenchymal stem cells (MSC). These novel HA-based HGPs are promising materials for soft tissue engineering.

4 TRAINING OF ROBOT DRIVING ON ADULTS AND INFANTS USING FORCE FIELD TUNNELS

Xi Chen, Sunil Agrawal, and James Galloway

Haptic devices are being used today frequently for training. Our research goal is to train babies with powered mobility to impact cognitive and social skills. An important milestone is to train babies to drive directionally. We are exploring the use of a force-feedback joystick for direction training. In this paper, we describe experiments of training humans to drive a robot using a force- feedback joystick with virtual tunnels. The force field algorithm calculates a desired control command and maps it to the joystick in the form of a virtual tunnel. If a driver moves the joystick outside this tunnel, certain force-feedback effects are triggered. This new force field tunnel is smooth and the results show that it can train the human to drive more accurately and quickly. Navigational results from 8 healthy adults and 8 infants with typical development will be presented

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FUNCTIONAL ELECTRICAL STIMULATION-ASSISTED CYCLING IN ADOLESCENTS WITH CEREBRAL PALSY

A.Tokay Harrington[1,2]; C.G.A. McRae[1]; T.E. Johnston[1,3], S.C.K. Lee[1,2]
1-Shriners Hospitals for Children, Philadelphia; 2- University of Delaware; 3- University of the Sciences in Philadelphia

Cerebral palsy (CP) is a non-progressive disorder of the brain that results in weakness, abnormal muscle tone and difficulty with gradation of movement. This leads to decreased independence with functional mobility and impaired ability to participate in traditional forms of exercise. Twelve adolescents with CP (7 male, 5 female; 10-19 years old) participated in pilot work to assess the feasibility and efficacy of FES-assisted cycling. All subjects required the use of an assistive device for ambulation (GMFCS III-IV) Subjects completed cycling trials with and without FES assistance using a recumbent tricycle mounted on a bicycle trainer to allow for stationary cycling. For trials with FES assistance, FES was applied to the bilateral quadriceps femoris muscles using surface electrodes. The stimulation settings for frequency (33-50 Hz) and pulse width (20-100 μsec) were individual-specific; the amplitude of the stimulation was 40 mA for all subjects. The timing of FES assistance was based on the crank angle and cadence which allowed for delivery of stimulation during the arc of rotation when the quadriceps should be active. The cycle was fitted with instrumentation to collect cadence, torque, and power output during cycling. Constant-load and incremental-load cycling tests were performed with and without FES assistance. All subjects tolerated the FES-assisted cycling trials without skin irritation or discomfort. FES assistance during cycling resulted in increased power output, heart rate and oxygen consumption and improved motor control as demonstrated by an increase in the percentage of the cycle spent producing positive torque. This project describes an FES technique that assists individuals to cycle at higher intensities than they can achieve on their own, which thus may assist in cardiovascular gains if used in a training program. Future work includes optimization of stimulation strategies, further development of a closed-loop control system for FES, and implementation of FES-assisted cycling training programs in individuals with CP.

6

COMPUTER SIMULATION OF POST-STROKE HEMIPARETIC WALKING

Ming Xiao and Jill Higginson, Mechanical Engineering

Stroke is the leading cause of long-term disability in the United States. Individuals with stroke usually suffer from abnormal walking patterns, such as slow walking speed, small stride length, excessive hip movement and insufficient knee flexion during swing. Stroke rehabilitation programs, such as body weight supported treadmill training and functional electrical stimulation, have had promising results to help stroke subject regain better walking patterns. These programs usually use kinematics and kinetics as their criteria, e.g. walking speed, knee flexion angle and ankle flexion angle. These gait deviations may reflect the impaired ability of certain muscles during walking. In this study, we generated three dimensional computer simulations of post-stroke hemiparetic walking and examined individual muscle contribution to joint and COM accelerations. We used muscle function to explain the gait deviation found in joint kinematics. Specifically, we found out how muscle function changes to compensate certain muscle weakness on the paretic side (compensatory strategy) and how muscle function changes to produce certain abnormal movement such as hip circumduction. The findings of this study could have important implications for stroke rehabilitation programs. Physical therapists could use muscle muscle function as guidelines to determine which muscle group should be treated and clinicians could use muscle function as rehabilitation goals when training stroke subjects to get better walking patterns.

7 AN EMG DRIVEN MODELTO ESTIMATE ACL FORCES DURING NORMAL WALKING

Qi Shao, Kurt Manal and Thomas S. Buchanan
Department of Mechanical Engineering, University of Delaware, Newark, DE, USA

The ACL is the most frequently injured knee ligaments, and it is of great importance to know internal knee-ligament loading. In this report we describe an EMG-driven model that incorporates a knee-ligament model, and we apply this approach to estimate ACL forces during normal gait. Five young healthy subjects who gave informed consent were included in this study. EMGs, joint positions and force plate data were collected from four walking trials. In this study we simulated the stance phase of the walking trials. We calculated ACL forces through a two-step procedure. First, a forward dynamics model of the whole body was developed to calculate muscle forces, joint torques and joint angles, and the model was verified by successfully replicating experimental joint angles. Second, the forward dynamics model was used to calculate the translations between femur and tibia, and then the result was incorporated with a knee-ligament model to calculate ACL force. The results showed that the forward dynamics model successfully tracked measured kinematics. The model could also be implemented to calculate the translations between femur and tibia. The calculated ACL force profile had two peaks near left toe off and right toe off, which was consistent with previous studies, and could be explained by the onset of two GRF peaks during stance phase. This model can be applied to patients with pathologies, which could provide insight of patients' knee ligament loading to clinicians. It also has great potential for the study of ligament biomechanics associated with different rehabilitation protocols.

8 KINEMATICS AND KINETICS OF MISSTEP CONDITIONS: IMPLICATIONS FOR FEMORAL FRACTURES IN THE ELDERLY

Mehmet Uygur, James G. Richards, Slobodan Jaric, Paulo B. de Freitas, David A. Barlow
Human Performance Lab, University of Delaware

Most hip fractures are thought to occur after falling during everyday activities. We speculated that hip fractures might also occur because of excessive loading of the hip joint during an unexpected misstep consequently leading to a fall. The aims of this study were to explore the kinematics and kinetics of the lower extremity joints during missteps as compared with regular stepping. We also compared the magnitude of forces acting upon the hip joint with the threshold forces expected to fracture the hip. Healthy adults (N=14) performed two forward steps on a 17.8 cm high platform under the following four conditions: forward with and without vision, as well as a misstep (the box for the final step unexpectedly removed without participant awareness), and regular stepping down with eyes open. The results revealed no differences between stepping forward with and without vision. When compared with both stepping forward and regular stepping down, the misstep revealed altered joint positions accompanied by increased forces and moments acting upon the hip joint. For example, the peak vertical proximal thigh segment force was 3.05±0.55 BW vs. 1.23±0.14 BW and 0.91±0.09 BW ($p<.001$; misstep vs. regular stepping down and stepping forward, respectively), while the proximal thigh segment moment in frontal plane was 1.39±0.70 Nm/kg vs. 0.18±0.32 Nm/kg of adduction and 0.16±0.19 Nm/kg of abduction ($p<.001$). The forces during misstep were within the range of those forces reported in the literature that resulted in hip fractures in the elderly. Therefore, it could be possible for the elderly to experience hip/proximal femur fractures during missteps prior to falling.

9

INCREASED KNEE MOMENTS DURING GAIT AFTER PERTURBATION TRAINING IN NON-COPERS

Erin Hartigan PT, DPT, ATC, Michael Axe, MD, Lynn Snyder-Mackler PT, ScD, SCS, Department of Physical Therapy, Graduate Program in Biomechanics and Movement Science, University of DE.

Non-copers reduce knee flexion moments at peak knee flexion during the stance phase of gait after acute ACL rupture. A neuromuscular intervention, called perturbation training, was created to break up aberrant knee stiffening strategy used after acute ACL rupture as it negatively impacts function and may predispose athletes to knee osteoarthritis. Perturbation training has effectively reduced aberrant gait patterns used by potential copers (Chmielewski 2005) who utilize a more successful dynamic knee strategy compared to non-copers. This study investigated whether the non-copers demonstrate increased knee moments during gait after a pre-operative intervention and if increases are maintained 6 months following ACL reconstruction. 38 non-copers were randomly assigned to receive perturbation training with strength training (PERT: n=18) or strength training only (STR: n=20). All subjects received 10 pre-operative sessions, underwent ACL reconstruction, and received similar post-operative physical therapy. Gait was analyzed prior to and following the pre-operative intervention and 6 months after ACL surgery. Paired t-tests were used to compare knee flexion moments at peak knee flexion during the stance phase of gait between limbs and in the involved limb over time over time within each group. The PERT group's knee flexion moments increased after the pre-operative intervention and this group maintained higher knee moments 6 months after surgery. The STR group's knee moments were not effected by the pre-operative intervention though did show a trend for improvement 6 months after surgery. Both groups demonstrated similar knee moments between limbs 6 months after surgery. The STR group did not demonstrate a significant reduction in knee moments in the involved limb compared to the uninvolved limb at baseline testing. Despite this, the magnitude of the uninvolved limbs in the STR group were below the mean values for the uninvolved limb of the non-copers and both limbs of the control group reported elsewhere (Rudolph 2001). Knee responsiveness after the pre-operative intervention in the PERT group suggests non-copers can be trained.

10

PREDICTING RETURN TO SPORT FAILURE IN NON-COPERS: A REASON FOR CHANGING POST-OPERATIVE CARE

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[1]University of Delaware, Biomechanics and Movement Science Program

Non copers are a group of anterior cruciate ligament (ACL) deficient athletes that demonstrate functional knee instability and have difficulty returning to high level sports activity in the absence of surgical reconstruction. Predicting the ability of non copers to safely return to sport (RTS) could aid in the identification of those athletes who may need additional rehabilitation in order to achieve their return to activity goals. The purpose of our study was to identify the characteristics of non-copers who failed RTS criteria at six months. Eight clinical variables from the initial screening examination were entered into a binary logistic regression model. Variables that yielded significant steps in the model were then included in a secondary binary logistic regression to determine the superior predictive model. Quadriceps index was a significant predictor of RTS outcome ($p = 0.018$). There was also a significant contribution of age ($p = 0.006$) when accounting for quadriceps index to the prediction model ($p = 0.002$, Nagelkerke R square = 0.365). The regression model correctly predicted 87.5% of those athletes who failed to RTS and 76.5% of those non copers who passed RTS. Both age and strength symmetry appear to play an important role in predicting the RTS outcome of non-copers at 6 months after ACL surgery. This model better predicts the non copers who will fail RTS criteria at 6 months after surgery than those who can be successful. The University of Delaware RTS criteria requires that athletes achieve nearly symmetrical strength and function prior to returning to sport. Predicting failure of RTS criteria in non-copers supports the need to further explore alternate post-operative treatment paradigms for this group.

11 TRABECULAR BONE MICROARCHITECTURE ASSESSED BY MAGNETIC RESONANCE IMAGING: RELATIONSHIP WITH AGE, GENDER, BODY SIZE AND BODY COMPOSITION IN CHILDREN

Deepti Bajaj[1], Joshua T. Kirby[1], Brianne M. Mulrooney[1], Freeman Miller[2], Christopher M. Modlesky[1]
[1] Health, Nutrition and Exercise Sciences, University of Delaware; [2] AI duPont Hospital for Children

Trabecular bone microarchitecture (TBM) is important for the assessment of bone growth and development; however, it is unclear if factors associated with more traditional measures of bone should be considered. The purpose of this study was to determine if age, gender, body size and body composition are related to TBM in the distal femur of children (20 boys and 20 girls; 6-12 y and pre or early pubertal). Magnetic resonance images were collected from the lateral side of the distal femur and measures of TBM [i.e., apparent trabecular bone volume to total volume (appBV/TV), trabecular number (appTb.N), trabecular thickness (appTb.Th) and trabecular separation (appTb.Sp)] were determined. Dual-energy X-ray absorptiometry was used to assess bone mineral content (BMC) in the distal femur and fat-free soft tissue mass (FFST) and fat mass in the total body. There were no gender differences in measures of TBM or BMC ($p > 0.05$). Age, height and FFST were positively related to appBV/TV, appTb.N and appTb.Th ($r = 0.35$ to 0.77, $p < 0.05$) and negatively related to appTb.Sp ($r = -0.48$ to -0.67, $p < 0.05$). Fat mass was positively related to appBV/TV and appTb.Th (0.38 and 0.37, respectively, $p < 0.05$) and inversely related to appTb.Sp ($r = -0.31$, $p = 0.05$). However, when all independent factors were included in a regression model, only the relationships between FFST and appBV/TV, appTb.Th and appTb.Sp remained significant ($p < 0.05$). Similarly, age, height, FFST and fat mass were all positively related to BMC ($r = 0.41$ to 0.87, $p < 0.05$), but when all independent factors were included in a regression model, only the relationship between FFST and BMC remained significant ($p < 0.05$). In conclusion, age, body size and body composition are related to TBM in the distal femur of pre and early pubertal children, but FFST is the strongest predictor. Future studies are

12 RELATIONSHIP BETWEEN CO-CONTRACTION AND DYNAMIC KNEE STIFFNESS IN ACL-DEFICIENT NON-COPERS

Emily S. Gardinier, Lynn Snyder-Mackler
Biomchanics and Motor Control, University of Delaware

Anterior cruciate ligament-deficient (ACL-D) individuals who fail to dynamically stabilize their knee (termed non-copers) are reported to adopt a neuromuscular strategy characterized by reduced knee flexion excursions, reduced external knee flexion moments and generalized co-contraction during gait. This unsuccessful neuromuscular strategy has been qualitatively described as the “knee-stiffening strategy,” although dynamic knee stiffness has not been measured in the non-coper population. While the generally ascribed function of muscular co-contraction is to increase joint stiffness and stability, it’s relationship to dynamic knee stiffness during gait has not been evaluated. Establishment of a reliable relationship between these two measures would render stiffness a simpler means by which to infer co-contraction among individuals with ACL-D knees.

PURPOSE: To determine (1) whether ACL-D non-copers walk with a quantifiably stiffer involved knee and (2) whether dynamic knee stiffness correlates with muscular co-contraction in this dynamically unstable population.

METHODS: Kinematic and kinetic data were collected from 42 ACL-D non-copers (male, N=31; female, N=11; age, 27.8±10.1 yrs) during the weight acceptance phase of gait for calculation of dynamic joint stiffness. Electromyography for 6 lower extremity muscles (M/L vastus, M/L hamstring, M/L gastrocnemius) were also collected for determination of co-contraction indices.

RESULTS: No significant differences in dynamic knee stiffness were found between the involved and uninvolved limbs in this sample. Furthermore, dynamic knee stiffness did not correlate with co-contraction during gait.

CONCLUSION: These results suggest that during gait, absence of the ACL does not result in a quantifiably discernible “knee-stiffening strategy” as measured by dynamic knee stiffness. Because stiffness values did not correlate with co-contraction, dynamic stiffness cannot be used as a surrogate for co-contraction during gait.

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ENGINEERING BONE STEM CELLS TO FACILITATE OSTEOBLAST DIFFERENTIATION

Beth Bragdon1, Jeremy Bonor1, Wesley G. Beamer2, Clifford Rosen3, Anja Nohe1
1 University of Delaware, Newark, Delaware; 2 Jackson Laboratory, Bar Harbor Maine; 3 Maine Medical Center Research Institute, Scarborough Maine

Osteoporosis is a disease affecting millions of Americans annually. In age related osteoporosis, there are high levels of adipocytes present within the bone. It is thought that bone stem cells differentiate into adipocytes, not into osteoblasts. Treatments associated with this bone disease include medications to slow bone resorption or injections of PTH analog to increase osteoblast activity. The only treatment to increase osteoblast is PTH, but the cost associated with this treatment is very high, therefore new treatments to increase osteoblasts and are cost effective are needed. Bone stem cells can differentiate into different lineages such as chondrocytes, adipocytes, osteoblasts, and other cell types. Thus engineering bone stem cells to differentiate into osteoblasts and not adipocytes could potentially lead to novel therapies. Membrane domains, such as caveolae, are involved with regulating signaling pathways that are crucial for osteoblast differentiation. We investigated membrane surface differences between bone stem cells from mice models exhibiting either normal or low peak bone mass. The low peak bone mass mouse can be used as an osteoporotic mouse model. The use of confocal imaging followed by quantifying techniques such as the Family of Image Correlation Spectroscopy showed membrane organization differs depending upon the bone phenotype. The addition of a ligand know to form bone, redistributed the membrane domain, caveolae. This change was not similar between the different mice, as well as the downstream signaling measured with reporter gene assays. Possibly altering the membrane surface of these cells will directly affect pathways needed for osteoblasts and therefore bone mass.

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KNEE FUNCTION FOLLOWING PERTURBATION TRAINING IN POTENTIAL COPERS AND NON-COPERS

David Logerstedt[1], Lynn Snyder-Mackler[1], Michael J. Axe[2]. [1]University of Delaware, Newark, DE. [2]First State Orthopaedics, Newark, DE.

Single leg hop tests have been used to assess knee function in athletes following an ACL injury. Most noncopers (NC) can be unwilling to hop and those that do hop demonstrate different movement strategies than copers. The use of perturbation training has only been previously used to train knee function in potential copers (PC). **PURPOSE:** To assess knee function utilizing a series of 4 hop tests in the involved (INV) and uninvolved (UNINV) limb following perturbation training in NC and PC. **METHODS:** 56 subjects with an acute ACL tear who participated regularly in level I or II activities were screened following an injury to the index limb and classified as a PC (15 women, 24 men; 25.2 $\pm$ 9.9 yrs) or NC (5 women, 13 men; 31.9 $\pm$ 11.6 yrs). Knee function was assessed using 4 single leg hop tests before and after perturbation training. Independent t-tests were used to study differences between PC and NC in the INV and UNINV limbs. Paired t-tests were used to study differences between limbs in PC and NC. **RESULTS:** NC hop index was significantly less than PC in the single hop for distance (SHP), triple hop (THP), and the 6-m timed hop (TimHP) pre-training (PrTr) and significantly less in the SHP and the THP post training (PoTr). In NC, THP index was significantly higher PoTr as compared to PrTr ($p<.05$). SHP and THP scores were significantly lower in the INV as compared to the UNINV PrTr ($p<.05$) and PoTr ($p<.05$). SHP scores significantly lower in the INV and UNINV limbs PrTr to PoTr ($p<.05$) and in the INV THP scores PrTr to PoTr ($p<.05$). In PC, SHP and THP index are significantly higher PoTr as compared to PrTr ($p<.05$). SHP and TimHP scores were significantly lower in the INV as compared to the UNINV PrTr ($p<.05$) and PoTr ($p<.05$). Cross-over hop (XHP) and THP scores were significantly lower in the INV as compared to the UNINV PrTr ($p<.05$). TimHP scores significantly lower in the INV and UNINV PrTr to PoTr ($p<.05$) and in the INV XHP and THP scores PrTr to PoTr ($p<.05$). **CONCLUSIONS:** Perturbation training can improve knee function in the INV in NC and PC. The differences between limbs and between groups may be due to the number of training sessions, training plateau effect, or neuromuscular differences within and between groups. Supported by NIH Grant R01HD037985-6.

15 IN-SITU FLUORESCENCE-BASED OPTICAL STRAIN MEASUREMENT FOR IMAGING MECHANICALLY LOADED BONE

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Mechanical loading is a crucial factor influencing the growth and adaptation of the tissues of the musculoskeletal system. In bone it has been hypothesized that load-induced fluid flow within the lacunar-cannicular system is sensed by osteocytes and initiates a cascade of biological events leading to bone adaptation. Thus, the application and quantification of well-controlled tissue strains is a important perquisite of investigations into load-induce fluid flow and adaptation in the skeleton. Although many commercial and custom extensometry systems exist for larger samples, integrated loading/strain measurement for small samples is lacking. There is also a need for a strain measurement system that is fully compatible with advanced imaging protocols such as confocal microscopy. In this investigation we describe the development and validation of a fluorescence-based, optical extensometry system that utilizied standard fluorescence and confocal microscopy equipment and allowed the in-situ measurement of surface strain in parallel with live imaging in small bone samples. This optical extensometry system was capable of accurately and reproducibly measuring physiologically relevant compressive and tensile surface strains, ranging from 200 to 4000-microstrain, in beams machined from various well-characterized materials, including bovine femoral cortex, and in intact murine tibia. This simple optical extensometry system provides a powerful tool for observing and quantifying the relationships between mechanical loading, fluid and solute transport, and mechanosensation within the musculoskeletal system.

16 ABBREVIATED TRAINING REGIMEN IS EFFECTIVE IN IMPROVING FUNCTIONAL TEST RESULTS IN ACL DEFICIENT SUBJECTS

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Purpose: To explore the results of an abbreviated course of non-operative neuromuscular retraining in ACL deficient subjects. Ten sessions of perturbation training have been shown to improve the likelihood of success in returning to sport in an ACL deficient state, but decreasing the number of sessions has not been noted. **Methods:** 57 patients were recruited for participation in a larger study. Group A consisted of 9 subjects receiving fewer than 10 sessions (average of 5.78), and group B consisted of 48 subjects receiving 10 sessions. Both groups underwent pre- and post-intervention functional tests. **Results:** The groups showed no significant difference in involved quadriceps strength, involved hop distances or self-report of function, either before or after perturbation training. Both groups experienced a statistically significant increase ($p < 0.05$) in their involved quadriceps strength, global rating of perceived function and time to complete a 6m hop test. A statistically significant increase was seen in the single hop distance of Group A only. Overall, both groups improved in all aspects of function. Both groups demonstrated abnormal symmetry values (<90% of uninjured side) before perturbation training in quadriceps index (89%), single hop (88%) and triple hop performance (88%), as well as low levels of perceived function measured by the KOS-ADLS (88%) and global rating (77%). After either the full ten or abbreviated training sessions, the groups demonstrated >90% on all measures of strength, function and ratings of perceived function. **Conclusion:** These results suggest that even an abbreviated course of neuromuscular retraining with perturbation training has the potential to improve functional test performance in ACL deficient individuals. Further investigation is needed to determine the effect of abbreviated training on the athlete's ability to return to high level activity. Continued data collection is in progress for these subjects.

17 QUASI-STEADY DIFFUSION BETWEEN TWO SPHERICAL CELLS IN CONNECTIVE TISSUES

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Introduction: Connective tissues consist of large amount of extracellular matrix (ECM) with embedded cells. Solute transport is critical for nutrition, inter-cellular signaling, and homeostasis in these tissues. To quantify solute transport, a mathematical model is developed to analyze the data from fluorescence loss induced by photobleaching (FLIP) experiments and derive solute diffusivity.
Method: Two spherical cells of higher permeability were embedded in an infinite ECM and subjected to a FLIP experiment, where the concentration in one cell (sink) was decreased suddenly by repeat photobleaching while the concentration in the other cell (source) is decreased due to tracer diffusion between sink and source. By solving Laplace equation in bispherical coordinate system, the steady-state solute distribution and outflux from the source were first obtained, from which the time-course of solute concentration in the source were predicted analytically in the case of quasi-steady diffusion. The solution was then corrected for unsteady diffusion using numerical simulations.
Results: This model, in combination with the FLIP technique, has been applied to measure the intrinsically slow diffusion process in calcified cartilage. The experimental data fit a logarithmic function [(ln $[(I(t) - I_{std})/(I_0 - I_{std})]$ vs. time with good agreement ($R^2 > 0.98$) and the apparent diffusion coefficient (D) of lysozyme in calcified cartilage was obtained as 0.253 ± 0.150 μm^2/s
Discussion: The mathematical model and FLIP approach can be used in live animal study and in other connective tissues where cells are relatively packed and the transport in the dense ECM is slow

18 GAIT PATTERNS FOR INDIVIDUALS AFTER SIMULTANEOUS BILATERAL TOTAL KNEE ARTHROPLASTY

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Altered gait patterns for individuals after total knee arthroplasty (TKA) have been reported. Individuals after unilateral TKA demonstrated asymmetrical knee flexion excursion during loading response related to asymmetrical quadriceps strength between limbs. The asymmetrical gait patterns seemed to improve when the quadriceps strength achieved near symmetry through compensations by the other joints. The contralateral hip and knee, the primary compensating joints, are often involved in secondary osteoarthritis (OA) following unilateral TKA. On the other hand, gait patterns for individuals after bilateral TKA have not been established well. A case report stated that individuals after bilateral TKA demonstrated different knee flexion and different muscle activation patterns between limbs. However, a case report is not enough strong to determine what typical gait patterns are among individuals after bilateral TKA. The purpose of this study is to determine whether hip compensation strategies are remarkable only unilateral TKA, or it could happen on simultaneous bilateral TKA to discuss a different possibility of secondary knee osteoarthritis on the joints.

A comprehensive gait analysis was performed to 18 patients 1 year after TKA for knee OA. Six of them are patients who underwent simultaneous bilateral TKA.

There were no significant asymmetry results in bilateral TKA. Hip flexion angle at peak knee flexion in both limbs showed a significant less flexion in bilateral TKA group compared to unilateral TKA (operated: p=0.01, nonoperated: p=0.03). Bilateral TKA showed a significant less hip extension moment at peak knee flexion compared to unilateral TKA (operated; p<0.01, nonoperated: p=0.01). Bilateral TKA also showed less flexor moment on the nonoperated limb at peak knee extension compare to unilateral TKA (p=0.01), and less ankle planter flexion moment at peak knee flexion compare to unilateral TKA (p=0.03).

Individuals after bilateral TKA demonstrated not only symmetrical gait patterns, but also completely different gait patterns compared to the unilateral TKA. Altered hip patterns during walking had been observed in both limb for individuals bilateral TKA. The risk of secondary OA may be different in individuals between unilateral TKA and bilateral TKA.

19 OSTEOCYTIC CELLS EXPRESS THE T-TYPE, CA$_V$3.2 VOLTAGE SENSITIVE CALCIUM CHANNEL THAT COMPLEXES WITH THE A$_2\Delta_1$ EXTRACELLULAR SUBUNIT: A POSSIBLE LINK TO THE EXTRACELLULAR ENVIRONMENT

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Regulation of skeletal remodeling is the focus of great attention in translational osteoporosis research. A recent linkage association study identified CACNA2D2, which encodes for a $\alpha_2\delta$ subunit within the voltage sensitive calcium channel (VSCC) complex, as a novel susceptibility marker for bone mineral density variation. VSCCs are a functional complex of polypeptide units consisting of a pore forming α_1 subunit, an intracellular β subunit, disulfide linked α_2 and δ subunits, which form an extracellular auxiliary complex and a γ subunit in some tissues. VSCCs play an important role in osteoblast mechanotransduction; yet, their role in osteocyte function remains elusive. Osteoblasts predominantly express L-type Ca$_v$1.2 VSCCs; however, osteocytes express the T-type Ca$_v$3.2 subunit. The purpose of this study was to measure expression of VSCC subunits in osteocytes and to determine which auxiliary subunits associate with T-type VSCCs in these cells. We assessed the expression of all known VSCC subunits in the MLO-Y4 cell line and showed that osteocytes express the T-type Ca$_v$3.2 subunit to a much higher extent than the L-type Ca$_v$1.2 subunit in well differentiated cells. We also demonstrated expression of $\alpha_2\delta_1$, $\beta_{1\text{-}3}$ and γ_7 subunit transcripts. Co-IP revealed the ability of the $\alpha_2\delta_1$ subunit to complex with the Ca$_v$3.2 subunit suggesting that these subunits associate in the MLO-Y4 cell line. Recent evidence indicates that the $\alpha_2\delta$ subunit interacts with the extracellular matrix, providing a mechanism through which the conductance of these channels may be modulated by mechanical stimuli. Association of $\alpha_2\delta_1$ with T-type channels in osteocytes can stabilize the channel, providing a mechanism for interaction with the extracellular environment.

20 EARLY POST-OPERATIVE MEASURES PREDICT ONE AND TWO YEAR OUTCOMES AFTER UNILATERAL TOTAL KNEE ARTHROPLASTY: THE IMPORTANCE OF CONTRALATERAL LIMB STRENGTH

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Background: Total knee arthroplasty (TKA) has been shown to be an effective surgical intervention for persons with end-stage knee osteoarthritis. Despite this, recovery of function is variable and not all individuals have successful outcomes. **Objective:** The aim of this study was to discern which short-term post-operative functional measures will predict one year and two year functional ability. **Design and Methods:** One hundred fifty-five persons who underwent unilateral TKA participated in the prospective longitudinal study. Functional evaluations were performed at initial outpatient physical therapy appointment after surgery. Subjects returned for one year and two years after surgery for follow-up evaluations. Evaluations consisted of measurements of height, weight, quadriceps strength, knee range of motion, Timed Up and Go test (TUG), stair climbing task (SCT) and Knee Outcome Score (KOS) questionnaire. The ability of early post-operative measures to predict one and two year outcomes was performed with a hierarchical regression. Differences in functional scores were evaluated with an analysis of variance with one repeated measure (time). **Results:** Significant improvements were found for TUG, SCT and KOS scores between initial evaluation and one and two years ($p<0.001$). Weaker quadriceps strength on the non-operative limb was related to worse one and two year outcomes even after accounting for the influence of the other early post-operative measures in the regression. Older subjects with higher body mass also had worse outcomes at one and two years. Post-operative measures were better predictors of the TUG and SCT than KOS. **Conclusions:** Treatment regimens after TKA should include exercises to improve the strength of the non-index limb in addition to the deficits imposed by the surgery. Emphasis on improving age-related impairments and reducing body mass may also improve long-term outcomes.

21 STIMULATION OF CARTILAGE REPAIR BY PERLECAN DOMAIN 1 CONJUGATED TO HYALURONAN PARTICLES: A PROMISING SYSTEM FOR PREVENTING OSTEOARTHRITIS PROGRESSION

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Osteoarthritis (OA) is a progressive disorder characterized by articular cartilage attrition and metabolic changes in the subchondral bone and the synovium. During the early stages of OA, growth factors with high affinity for both cartilage and bone extracellular matrix are released and become involved in the repair of lesions. Recently, bone morphogenetic protein 2 (BMP-2), a growth factor with heparan sulfate (HS) binding capability, demonstrated anabolic cartilage activity when locally administered in the joint space of OA animal models. Because clearance of small compounds from the synovial fluid into the lymphatic system is efficient, the residence time of highly diffusible unbound cartilage-stimulating factors such as BMP-2 is extremely limited, and the release of these factors often is unable to counteract the damaging effects of proteinases and inflammatory cytokines. For this reason, our goal is to develop a novel delivery system for slow release of chondrogenic factors to induce local repair of damaged articular cartilage surfaces and slow the progression of OA. We show that HS-bearing fragment of perlecan coupled to hyaluronan particles prolongs delivery of chondrogenic factors and supports chondrocyte differentiation *in vitro*. The repair potential of these bioactive complexes is currently being tested *in vivo* using an intra-articular injection approach in mouse osteoarthritic knees. Ultimately, we expect that this new therapeutic strategy will benefit patients by locally inducing self-regeneration of damaged articular surfaces and preventing development of irreversible OA symptoms.

22 SPATIOTEMPORAL PARAMETERS FOR INDIVIDUALS WITH KNEE OSTEOARTHRITIS DURING A WEIGHTED WALKING CHALLENGE

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Knee osteoarthritis (OA) plagues the adult population. Motion capture has been utiliized as a reliable method for quantifying gait performance. Weighted walking has been studied to understand gait biomechanics in children, adolescents, and young adults, and to identify metabolic and strength gains in older adults. The purpose of our study is to understand how healthy adults and those with knee OA respond to a weighted challenge. We used a modified Helen Hayes marker set with a 6 camera Motion Analysis system (60Hz, Santa Rosa, CA) and an instrumented, split-belt treadmill (1080Hz, Bertec Corp., Columbus, OH). Analysis includes 8 healthy and 7 knee OA subjects (K/L ≥ 2) who all walked at a controlled walking speed of 1.0 m/s. We analyzed the data using t-tests and set our level of significance at $p < 0.05$. The unweighted knee OA group had a significantly increased double support time while the affected limb was forward, an increased single support time on the unaffected limb, and a decrease in the swing time of the unaffected limb compared to the unweighted healthy group. The same significant results were found for the weighted healthy subjects in comparison to the unweighted. This result means that the healthy group compensated for the load by walking asymetrically. There was a significant increase in double limb support time with the unaffected limb forward in the weighted knee OA group compared to the unweighted. The same result was seen in the weighted knee OA group when compared to the weighted healthy group. We plan to analyze this data along with kinetics and kinematics to look for adverse compensations to the weighted challenge that could be risk factors for the progression of knee OA.

23 EFFECT OF GENDER ON BONE PROPERTIES IN A MOUSE MODEL OF SUB-EFFICIENT PROTEIN SYNTHESIS

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As an important protein for ribosome function, ribosomal protein 29 (RPL29) knockout results in global skeletal growth deficiencies that persist into adulthood. Specific structural differences in male and female null mice are also visible at the embryonic stage. Recent data obtained by micro-computed tomography (microCT), three-point-bending tests, and Fourier transform infrared analysis (FT-IR), indicated that depletion of RPL29 results in sex dependent changes. For example, microCT analysis of cortical bone demonstrated an increase in the bone mineral density (BMD) of six-month mutant male femurs, with respect to controls. This important change was not found in female samples. Additionally the surface area of cancellous bone versus bone volume ratio (BS/BV) in female RPL29 null mice increased (+37.33%, $p < 0.0001$) while the total volume of the region decreased (-44.91%, $p < 0.0001$. FT-IR analysis, conducted to explain these structural changes on a molecular level, showed an increase in the mineral-to-matrix ratio in three month-old male tibia growth plates. FT-IR analysis also showed that collagen in the trabecular bone of three-month female tibiae was not as mature as collagen found in the trabecular bone of age-matched controls. Additionally, neither male nor female null animals could tolerate the same maximum load as gender-matched controls in three-point bending tests, indicating an increase in bone fragility likely due to increased BMD in null males and poor collagen organization in null females, compared to their respective controls. These data are consistent with the notion that early defects in cartilage template and bone deposition have negative repercussions on adult bone quality. To understand what is at the origin of these gender dependent defects, future studies will analyze mineralization apposition rates in young adult bone samples of both genders.

24 ARTICULAR CARTILAGE CONTACT AREA CHANGES WITH INCREASING KNEE FLEXION IN SUBJECTS WITH MODERATE KNEE OSTEOARTHRITIS: APPEARANCE OF TWO SUBGROUPS

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Knee osteoarthritis (OA) is a potentially debilitating disease that is detrimental to the quality of life of millions of Americans. Magnetic resonance imaging (MRI) is a promising research tool for non-invasively assessing knee OA *in vivo*. The goal of this study was to evaluate differences in tibiofemoral articular cartilage contact area in varying degrees of OA severity. Partial weightbearing MRIs were taken of the knee on both healthy and OA subjects at full extension, as well as approximately 15° and 30° knee flexion. Three dimensional models of the knee joint were constructed from the MRIs using a novel method. Cartilage contact area was estimated using a contact threshold of 0.5mm and actual knee flexion angles were determined by using an established knee joint coordinate system. In the healthy control subjects, there was a significant correlation between knee flexion angle and medial compartment cartilage contact area estimate, with cartilage contact decreasing with increasing knee flexion. In the OA group, there was no significant correlation, but two subgroups seem to be present. Half of the OA group follows the trend of the healthy controls and have decreasing contact area with increasing knee flexion, while the other half increases contact area with increasing knee flexion. The differences in medial compartment contact area trends may be related to differences in co-contraction of muscles spanning the knee joint or altered gait mechanics. Identifying OA subgroups is very important for developing appropriate approaches to limit further disease progression as well as maintain or restore a subject's quality of life.

25 IN SITU MEASUREMENT OF TRANSPORT BETWEEN SUBCHONDRAL BONE AND CARTILAGE: A POTENTIAL FACTOR IN OA DEVELOPMENT

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Osteoarthritis (OA) is characterized with changes not only in articular cartilage but also in bone, ligament, synovium, and muscle. There is increasing evidence from OA patients and animal models that subchondral bone turnover is increased and may play a significant role in the initiation and/or progression. Specifically, it was proposed that the cytokines and growth factors released during subchondral bone turnover may reach the overlying articular cartilage. There they may initiate a vicious cycle of confounding signaling between attempted cartilage and bone repair processes that eventually leads to OA progression (Lajeunesse, 2004. Osteoarthr Cartil 12A: S34-8.1). To test the hypothesis, the first step is to define the transport for the bone-cartilage communication. Using the newly developed Fluorescence Loss in Photobleaching (FLIP) under confocal microscopy and a bi-spherical model that accounts for the dimension and distance of the chondrocytes and osteocytes, we qualified the diffusion coefficients of sodium fluorescein (376 Da) in calcified cartilage and between calcified cartilage and subchondral bone to be 0.26±0.22 and 0.07±0.03 μm^2/sec, respectively. Electron microscopy revealed that calcified cartilage matrix contained non-mineralized regions (~22% volume fraction) that are either large patches (53±18 nm) among the mineral deposits or numerous small regions (4.5±0.8 nm) within the mineral deposits, which may serve as transport pathways. These results suggest that there exists a possible direct signaling between subchondral bone and articular cartilage, and they form a functional unit with both mechanical and biochemical interactions, which may play a role in the maintenance and degeneration of the joint.

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26 THE EFFECT OF ISOLATED GASTROCNEMIUS CONTRACTURE AND SURGICAL RECESSION ON STRENGTH AND FUNCTION

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Isolated gastrocnemius contracture (IGC), characterized as reduced ankle dorsiflexion with full knee extension, has been linked to foot injuries limiting function and activities of daily living. Patients with IGC may be unable to produce normal plantarflexion force. Gastrocnemius recession surgery has been shown to increase function and dorsiflexion range of motion, but the impact on force production is unknown. **PURPOSE:** To determine the effect of gastrocnemius recession surgery on function and force production. **METHODS:** 7 legs with IGC matched for gender, age, weight, and height from a database of 35 control legs performed isometric plantarflexion at maximum ankle dorsiflexion with full knee extension. Subjects with IGC were tested pre- and 3 months post-surgery. The Foot and Ankle Ability Measures (FAAM) questionnaire was used to evaluate function. Passive ankle dorsiflexion range of motion (PROM) was measured with the knee in full extension using a bi-plane goniometer. **RESULTS:** Post-surgery, subjects with IGC had significantly increased self reported function and global rating scores. PROM significantly increased post-surgery, and was not different from control subjects. There was a 10% increase in isometric plantarflexion strength post-surgery; post-operative strength was not different from control subjects. **CONCLUSION:** Gastrocnemius recession surgery is a beneficial treatment option for patients with IGC. Increased function, range of motion, and plantarflexion strength were observed post-surgery. Although improvements were noted following gastrocnemius recession, subjects were still exhibited differences in functional rating compared to controls and therefore may benefit from organized post-surgical rehabilitation.

27 COMPARE SOLUTE TRANSPORT IN THE BONE LACUNAR-CANALICULAR SYSTEM IN LIVE VS. DEAD ANIMALS

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Osteocytes, the most abundant bone cells, play a significant role in bone adaptation and metabolism. In response to mechanical loading, osteocytes release signal molecules to modulate functions of other bone cells. Transport of these signaling molecules and metabolites occurs mainly in the pores around osteocyte bodies and cell processes, termed the lacunar-canalicular system (LCS). We have measured the diffusion coefficients of molecules of various size in the LCS of sacrificed animals using fluorescence recovery after photobleaching (FRAP) technology. To further understand solute transport in vivo, we redesigned a temperture controlled water bath and a more stablized testing setup for live aniaml experiments. Paired FRAP experiments were performed as follows: Fluorescent tracers were injected in mice via tail vein. After the tracers circulated for 20min~1.5hr to reach equilibrium in bone, the mouse left tibiae were exposed and stablized at the knee and ankle joints with the entire body immersed in a 37°C water bath. Three to five FRAP experiments were performed on osteocyte lacunae 30 micron below the the exposed tibial surface to measure solute diffusivities as the animals were under Avertin anesthesia. The animals were then sacrificed by an overdose of Avertin and FRAP experiments were repeated at the same lacunae. The diffusion coefficients were calculated using a custom MatLab program and a two-compartment model. Preliminary data suggest that solute diffusivity of sodium fluorescein (376 Da) did not differ between live and dead animals. However, parvalbumin (14kDa) was endocytosized into cytoplasm and did not show mobility in the LCS in live animals. Fourty min after sacrifice, parvalbumin was released and mobility was detectable in LCS. Studies are under way to address the differential behaviors of the tracers in live and dead animals.

28 DIFFERENCES IN MUSCLE ENERGETIC CONTRIBUTIONS BETWEEN WALKING AT SELF-SELECTED AND VERY SLOW SPEEDS

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A common feature of ambulating individuals with an injury or disability is a reduction in walking speed. Slow speed walking is associated with shorter stride lengths and increased proportions of stance time within the gait cycle that can provide greater stability. Associated with different walking speeds are different demands from the leg musculature. The goal of this study was to identify differences in muscle mechanical energetics when walking at self-selected and very slow speeds to gain a better understanding of coordination strategies employed in pathological conditions. To achieve this goal, subject specific simulations of walking at self-selected and 25% of self-selected walking speeds were developed for a healthy subject. Computed muscle control was used to determine the excitations to the 24 muscles per leg that in walking simulations that best reflected experimentally measured kinematic and kinetic walking data. The muscle forces and lengths were used to compute muscle powers generated throughout the gait cycle. The muscle powers were integrated to compute muscle mechanical energies. Preliminary data indicate the net muscle mechanical energy is reduced when walking at very slow speeds with the greatest differences observed in the biceps femoris long-head, quadriceps, gastrocnemius, and tibialis anterior muscles. There was little difference in the net muscle mechanical energy of the soleus for the two walking conditions. The increase in muscle mechanical energies observed with self-selected walking speed were not unexpected. The limited difference in soleus net energy may indicate a threshold of energetic contribution to walking at these two speeds.

29 VIBRATIONAL STIMULATION OF HUMAN FIBROBLASTS FOR VOCAL FOLD TISSUE ENGINEERING

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The human vocal folds (VF) are mechanically active. During normal phonation, they vibrate at frequencies of 75-1000 Hz, and can sustain up to 30% strain. VF biomechanical properties and biological functions can be easily damaged due to voice abuse or disease resulting in VF disorder. Although various techniques are available to treat those disorders, none produce satisfactory outcomes. We are interested in developing tissue engineering methods for the reconstruction of functional vocal fold lamina propria. To this end, we have manufactured and characterized a bioreactor capable of generating vibrational stimuli to cultured cells at human phonation frequencies with varying strain. In our initial studies, neonatal human dermal fibroblasts were seeded on a collagen I-coated silicone membrane and subsequently subjected to different vibrational stimulation patterns. The cell proliferation, cytoskeleton organization, gene expression and ECM production were systematically analyzed. Our current results show that cells are more sensitive to variation in strain that variation in frequency. Results obtained from this study will help establish the optimum dynamic culture conditions that will trigger the cells into producing vocal fold LP-specific ECM. Our ultimate goal is to engineer a functional VF LP in vitro by 3D dynamic culture of fibroblasts in a biomimetic hydrogel matrix.

30 SMART BRACE BALANCE: PARADIGM FOR PREDICTING FALLS

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Impairments in people can lead to falls, specially in older adults. *Fall* is one of the leading causes of injuries and the primary etiology for accidental deaths in persons over the age of 65 years. In this project, a Smart Knee Brace (SKB) is used to investigate balance. SKB enables to perturb the walking pattern of a subject during a gait cycle and the response to this perturbation can be observed and analyzed. The current study focuses on improvements of an existing SKB hardware and software. Using a biped walking dynamic model during swing, it was found that the human response to a perturbation in gait fits well the model of a PD control, involving a time delay. The results of this study provides insights into dynamic balance during walking and may help to potentially develop markers for training targeted at improving dynamic balance, thereby reducing falls.

31 MODELING OF ARTERIAL HEMODYNAMICS

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Accurate noninvasive measurement of the blood pressure waveforms throughout the body is clinically desirable, but difficult to accomplish. We use a computational model, based on a description of the architecture and mechanical properties of the arterial network and blood, to predict dynamic pressure throughout the arterial vasculature. Applanation tonometry is used to measure dynamic pressure noninvasively at the carotid, radial, and femoral arteries under different hemodynamic conditions (baseline, cold pressor test, Nitroglycerin). A pressure waveform from one recording site serves as input to the model. Model parameters are adjusted to obtain the best fit between the pressures predicted at other locations and the pressures directly measured at those locations. The site whose pressure was used as the input is altered, and the ability to accurately predict pressures at the other sites is compared.

The femoral and radial artery pressures have allowed most accurate prediction of pressures elsewhere. Vascular stiffness, resistance, and the dependence of stiffness on arterial diameter were estimated from the fitted model parameters. The model provides insight into the effects of physiological and pharmacological stimulation on arterial vascular properties in vivo. The model also provides a noninvasive estimate of central aortic pressure, which is valuable for understanding ventricular-vascular coupling in health and disease.

32 AGE INFLUENCES MUSCLE ACTIVATION STRATEGIES AT THE KNEE DURING DISTURBED WALKING

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Following an external perturbation the ability to restore balance without altering the base of support may be difficult for humans particularly with changes that occur with healthy aging. This study examined the effect of age on muscle responses to perturbations during walking. Movement and muscle activation patterns were collected during level walking and when the support surface translated laterally after heel strike. Knee joint position sense, threshold to detect passive motion, and muscle stiffness were also measured. Ten young (mean= 21.9 years) and ten older adults (mean= 63 years) participated. Despite no differences in the knee movement and muscle activation patterns between the groups, the Young subjects showed a trend to maintain or increase walking speed while more of the Middle Age subjects (MA) slowed their walking speed during the 1st perturbation (P1) compared to level walking (Young X^2=6.4, p=0.011, MA X^2=.400, p=0.527). Subjects within the Young group also tended to flex their knee slowler (X^2=3.600, p=0.058) during the 1st perturbation compared to level walking while subjects in the MA group showed no trend. These trends, walking speed and knee flexion during P1 indicate that the Young subjects try to advance their body forward in space more quickly while slowing the rate of knee flexion. Knee flexion angle during midstance (MSt) of P1 correlated with hamstring EMG values (LH p=.019, MH p=.044) and quadriceps EMG values (VL p=.034, VM p=.022) within the Young group. No correlations were found in the MA group during Mst. Trends were also found in the Young group during loading response while none were found for the MA group. These trends indicate that it may become more difficult to develop compensation strategies with healthy aging.

33 GRIP FORCE CONTROL IS ALTERED WHEN GRASPING OBJECTS USING DIFFERENT HAND AREAS

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To manipulate a hand-held object one needs to prevent slippage caused by the tangential force component (i.e., load force – LF) acting upon the skin-object contact area. This is accomplished by exerting sufficient normal force (i.e., grip force – GF) against the object. The neural controller sets GF to a magnitude that is sufficient to prevent slippage, but not excessive to cause muscle fatigue, disrupt task control, or crash fragile objects. The difference between the exerted GF and the minimum GF needed to prevent slippage (GF_{min}) is called *safety margin* (SM). It is still unknown whether SM differs when the object is grasped with hand areas specialized and non-specialized for object manipulation, which could also show different coefficients of friction. Also, the differences in GF control while manipulating a free moving and an externally fixed object still remains underexplored. Fourteen participants were asked to grasp an instrumented handle and perform the free holding (free moving handle) and the static holding (fixed handle) tasks that required a same pulling force of 5 N. Each task was performed using different grasps [precision, fingers, palm, wrist, and fist] and two object coatings [rubber and acetate], both providing different skin-object frictions. The absolute [($GF_{exerted} – GF_{min}$)] and the relative SM [($GF_{exerted} – GF_{min}$)/GF_{min}] were calculated. They were smaller when the tips of the digits (i.e. precision and fingers grasp) were used, as compared to the grasps performed with the non-specialized hand areas. Both absolute and relative SM were also higher in the free holding than in the static holding. The findings suggest that (1) GF adaptation to changes in friction is more efficient when tips of the digits are used and (2) GF control could be partly different when manipulating free and fixed objects.

34 KINEMATIC AND KINETIC COMPARISON OF RUNNING IN NEUTRAL CUSHIONED SHOE AND A MINIMALIST SHOE

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Purpose: It is unclear if barefoot running reduces vertical ground reaction forces over shod. However, it does appear that barefoot running results in kinematic changes, especially a more foot-flat position at heel strike. Minimalist shoes have been suggested by clinicians as a means to reduce injury risk by mimicking barefoot running. Therefore, the purpose of this study was to determine if a minimalist shoe results in a reduction in ground reaction forces and alters kinematics over shod in recreational runners.
Methods: This is an ongoing study with 5 subjects examined to date. Subjects were male recreational runners (24.4 y/o ± 2.7) running at least 7 miles per week (18.4, ±10.6). Subjects were tested while running 3.35 m/s on an instrumented treadmill (AMTI, Watertown, Mass). Nike (Beaverton, Ore) Pegasus served as the neutral cushioned shoe (NS). Nike Free 3.0 shoes were utilized for the minimalist shoe condition (MS). Tibial shock (PCB Piezotronics, Depew, NY), forceplate, and kinematic (Vicon, Oxford, UK) data were collected at 200Hz, 1000Hz, and 1000Hz, respectively. Twenty-one retroreflective markers were attached to the lower extremity. Separate calibration trials were collected for each shoe condition to create an accurate foot segment. Variables of interest were average vertical load rate (AVLR), tibial shock (TS), ankle dorsiflexion at heel strike, and horizontal angle of the foot in the lab coordinate system at heelstrike. Data were collected for 5 consecutive foot falls at onset and after 10 minutes of running.
Results: MS running resulted in a more dorsiflexed ankle (6.4°±3.3 vs. 2.2°±4.3) and greater inclination of the foot in the lab coordinate system (12.0°±3.8 vs. 9.6°±6.6) than the NS. TS was elevated in the MS (5.8g's ±1.5) vs. the NS (4.5g's ±0.63). AVLR was 85.5 BW/sec ±24.0 vs. 53.7 BW/sec ±14.9 in the MS and the NS, respectively.

35 EFFECTS OF TASK COMPLEXITY ON COORDINATION OF INTER-LIMB AND WITHIN-LIMB FORCES IN STATIC BIMANUAL MANIPULATION

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We studied the coordination of grip force (G; force acting normally to the grasping surface) and load force (L; acting in parallel) in bimanual static manipulation tasks. We hypothesized that (1) both switching from symmetric to asymmetric tasks and increasing the task frequency would be associated with a decrease in overall force coordination, as well as (2) that the decrease in force coordination would be more prominent in within-limb than in inter-limb force pairs. Healthy participants (N=14) performed symmetric and asymmetric bimanual tasks (regarding either the L magnitude or direction exerted in oscillatory fashion by each hand) at both the comfortable and high frequency. Most of the dependent variables revealed the hypothesized deterioration in force coordination (e.g., regarding the accuracy of the prescribed L exertion and correlations among the forces, but not regarding G/L ratio) associated with asymmetric and high frequency manipulation. Therefore, we conclude that both a high frequency and asymmetry of bimanual manipulation tasks could be considered as factors of the task complexity. However, contrary to the second hypothesis, the inter-limb force coordination deteriorated more than the within-limb force coordination. Specifically, while the coordination of inter-limb forces (i.e., of G and L of two hands) may be based on ad-hoc and task-specific muscle synergies, the within-limb coordination of G and L could be based on more stable and partly reflex mechanisms. Nevertheless, as seen through both a somewhat affected within-limb coordination and a moderate bimanual assimilation of L in asymmetric tasks, the G-L control mechanism could be also moderately affected by the task asymmetry, possibly through a 'neural crosstalk'.

36 FREE MOMENT CHANGES FOLLOWING GAIT RETRAINING PROTOCOL TO REDUCE TIBIAL SHOCK

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High vertical loading, such as peak positive tibial acceleration (PPA) and average vertical loadrate (ALR), have been associated with tibial stress fractures in runners. In addition, high free moments (torsional loading between the foot and the ground) have also been implicated. We have shown that runners are able to reduce their PPA and ALR through a gait retraining protocol using real-time feed-back. However, it is unknown whether torsional loading is reduced as well.
PURPOSE: To determine whether reductions in vertical loading following gait retraining are also associated with decreases in torsional loading.
METHODS: Data from 10 subjects (24.7±8.4 yrs) have been collected, to date. Subjects ran >10 mpw. All subjects exhibited baseline PPA >8g's, placing them at increased risk for stress fractures. They each completed 8 sessions of real-time visual feedback training aimed at teaching them to land softer and decrease their vertical loading. We measured PPA, ALR, the adduction free moment (resisting toe out) (FMADD), and the free moment at peak braking force (FMBR) pre and post retraining. The data are presented descriptively due to low subject numbers at this time.
RESULTS: All subjects reduced their PPA and ALR by 34 and 29%, respectively. On average, FMADD decreased 11% while FMBR did not change. However, some subjects did demonstrate a reduction in their torsional loading with an average decrease of 16.0% for FMADD (7/10) and 17% for FMBR (6/10). Subjects who did not have an associated reduction in their torsional loading may have adopted a different gait strategy than the others.
CONCLUSION: Torsional loading is reduced in most subjects as a result of a gait retraining program aimed at reducing vertical loads.

37 A UNIQUE KINEMATIC MODEL FOR DESCRIBING GLENOHUMERAL JOINT MOTION DURING THE WINDMILL SOFTBALL PITCH

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Clinical application of upper extremity joint angle calculations have proven challenging in biomechanics. Kinematic descriptions of joint angles provide the clinician the position of the joint during response to various stresses. It is therefore critical that joint angle calculations are both clinically applicable and accurate. Various models have been developed in biomechanics to explain glenohumeral joint angles, including Euler angles, helical (screw) axis angles, and spherical coordinate systems. Applications of these methods have been established in baseball literature, resulting in a consistent utilization of the internal rotation/horizontal flexion/internal rotation (YZY) Euler sequence. Accepted methods of kinematic analysis are not yet defined with regards to softball pitching. The circumduction motion of the glenohumeral joint during a softball pitch challenges current methods of calculations. The windmill motion of the softball pitch requires full circumduction of the humerus, with varying degrees of internal and external rotation depending on pitch type. The circumduction motion of the humerus lends itself to errors during calculations using standard Euler and Helical models. The aim of this communication is to describe a unique kinematic model to calculate glenohumeral joint angles during a ballistic motion: the softball pitch; while also providing clinically useful measures of joint angles not previously reported in the literature. The kinematic model for the shoulder used in this project was unique in describing shoulder motion without conventional Euler rotation sequences. This model employed a combination of plane devation angles and internal/external rotation angles derived from Helical methods. The use of planar deviations provides a clinically useful means of describing the orientation of the humerus relative to the trunk, is a consistent method throughout the entire motion, and offers no discontinuities or errors when compared to three-dimensional motion. While it is not customary to utilize separate methods to explain kinematic data, the windmill pitch presents complications that require this practice.

38 MUSCLE ONSET TIMING IN SUBJECTS TRAINED TO REDUCE TIBIAL SHOCK

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Stress fractures are one of the most serious overuse injuries in runners. High tibial shock, or peak positive tibial acceleration (PPA), is correlated to high loading rates and tibial stress fracture incidence. Runners are able to reduce their PPA by altering their footstrike pattern. This change may be associated with earlier onset times of the ankle musculature.
PURPOSE: To compare the onset times of the ankle dorsiflexors and plantarflexors, before and after a gait retraining protocol.
METHODS: 9 subjects with high PPA have been studied to date. Following a baseline instrumented gait analysis, all subjects underwent a gait retraining protocol aimed at reducing their PPA. Along with kinematics, electromyographic (EMG) data were collected from the medial and lateral gastrocnemius, soleus, and tibialis anterior muscles. Data were sampled at 1200 Hz. Onset was determined when the linear envelope exceeded 2.5 standard deviations above the resting mean. Onsets were extracted from the period from 125 ms before footstrike through the end of stance. These times were compared between baseline and post-gait retraining.
RESULTS: Subjects reduced their PPA by 39%. 6/10 increased, and 2/10 decreased their dorsiflexion at footstrike. Mean EMG onset times were similar before and after the retraining. However, the between-subject variability for these times was extremely high for all four muscles tested. The individual differences were largest in the soleus and tibialis anterior. For example, one subject activated the soleus as much as 22 ms later while another 27 ms prior to the pre-retraining onset time.
CONCLUSION: While all subjects reduced their tibial shock significantly, there were no consistent changes in ankle muscle onset times.

39 STUDY ON EFFECT OF SELECTIVE MUSCLE WEAKNESS ON RANGE OF MOTION OF UPPER EXTREMITY

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We have developed a computational tool for optimization-based forward dynamic simulation of upper extremity movements. Simulations replicate joint kinematics measured during shoulder abduction in four planes of elevation and estimate muscle excitations. The objective of this study was to quantify the effect of selective muscle weakness on range of motion, determine appropriate muscle excitation patterns, and identify which muscles can provide compensation. The simulated annealing–based optimization algorithm accurately tracked kinematic data for five degrees of freedom actuated by 26 muscle elements which crossed the shoulder complex and elbow joint. The output excitations were verified with recorded EMG. Using simulations, we studied the effect of selective muscle weakness on range of motion in four different planes of elevation (90°, 30°, 0°, -30°), while accounting for muscle compensation for 50% weakness in five muscles (anterior, middle and posterior deltoids, infraspinatus and subscapularis). For example, an increase in excitation of anterior deltoid, pectoralis major and both heads of biceps were observed for weakness in anterior deltoid for abduction in 0° plane of elevation, while weakness in middle deltoid was compesated by increase in excitation of anterior deltoid, supraspinatus, infraspinatus and subscapularis. The final states of the distal end of the humerus with weak muscles were within ±3.5cm of the normal condition. Clearly, a subset of healthy muscles can compensate for weakness in a single muscle. From this study, we gained insight about the role of muscles over a large range of motion, which may have clinical implications. By determining which upper extremity muscles play major roles in compensation, clinicians can choose which muscles to target for strength training and rehabilitation programs.

40 SPLIT-BELT TREADMILL LOCOMOTION: ADAPTATION OF FORCES AND WEIGHT-BEARING DURING WALKING AFTER STROKE

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Healthy adults and chronic stroke survivors can adapt spatial-temporal gait parameters when they walk on a split-belt treadmill (Reisman et al. 2004, Reisman et al, 2007, 2009). Recently, we have found that healthy adults also adapt kinetic gait parameters (Malecka, Reisman SfN Poster Presentation 2008). Here, we investigate whether the kinetic locomotor variables adapt in chronic stroke survivors during split-belt treadmill walking. To date, 3 chronic stroke survivors have been tested on a split-belt treadmill instrumented with two force platforms (AMTI). Subjects were tested under two conditions: paretic leg fast, and paretic leg slow, with the following paradigm: baseline (belts tied at slow and fast speeds), adaptation (belts split in a 2:1 speed ratio), post-adaptation (belts tied slow.) Peak AGRFs (push-off force), and mean vertical GRFs (weight-bearing) were calculated for both legs, then symmetry measures were calculated (fast/slow leg values). Averaging across subjects and conditions, both peak push-off symmetry (baseline 1.12+/-0.43, early adaptation 2.68+/-1.56, post-adapt 1.02+/-0.36) and weight-bearing symmetry (baseline 0.99+/- 0.08, adaptation 0.90+/-0.08, post-adapt 1.03+/-0.08) demonstrated adaptation and after-effects. However, when the conditions were evaluated separately, the push-off effects were more robust when the paretic leg was on the slow belt (baseline 1.35+/-0.47, adaptation 3.93+/-0.79, post-adapt 1.16+/-0.52), and the weight-bearing effects were more robust when the paretic leg was on the fast belt (baseline 0.93+/-0.04, adaptation 0.83+/-0.05, post-adapt 0.95+/-0.02.) These findings suggest that when the adaptation phase requires greater forces to be produced by the paretic leg, the overall magnitude of both adaptation and the after-effects are tempered. Thus, while chronic stroke survivors can adapt GRFs, the force magnitudes continue to be limited by their hemiparesis.

41 *IN VIVO* GLENOHUMERAL POSTERIOR CAPSULE THICKNESS MEASUREMENT WITH ULTRASONOGRAPHY

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Purpose: To determine if dynamic ultrasonography (US) could be a valid and reliable tool for measuring posterior capsule thickness of the glenohumeral joint.
Materials and Methods: The validation portion of the study was performed on a fresh frozen cadaver shoulder. A 13-MHz linear-array transducer was used to measure posterior capsule thickness with the shoulder in 0° of abduction and neutral rotation. A plicate suture was placed through the posterior capsule under US guidance. The posterior capsule was then identified again with US and the sutures were pulled to cause the posterior capsule to move. This allowed verification with US that the posterior capsule was accurately being identified. Next, two orthopedic surgeons entered the shoulder joint arthroscopically and verified that the sutures were passing through the posterior capsule. Another set of sutures were then passed through the posterior capsule under arthroscopic guidance and the posterior capsule was again identified by pulling on the sutures. For the final validation process the posterior shoulder was dissected down to the rotator cuff. The infraspinatus and teres minor were then split to visualize that the sutures were only plicated through the posterior capsule. For the reliability portion of the study, US was performed in 11 healthy subjects [males (age = 30.2± 6.38yrs, mass = 85± 4.42kg, height = 70.8± 0.84cm), females (age = 29± 5.39yrs, mass = 68.74± 23.53kg, height = 65± 4.0cm)]. A certified Athletic Trainer had undergone training by a radiologist prior to the testing session. Both testers were used to examine intertester reliability and both testers were blinded to the results of each subject. Images were obtained in both the dominant and non-dominant arms [continued]

41 [continued from previous page] with a 13-MHz linear-array transducer. Each of the reliability measures were calculated using an Intraclass Correlation Coefficient (ICC). Intratester reliability ICC (3,1) was calculated for the primary investigator by comparing three measurements of posterior capsule thickness during the same session. The average thickness of the posterior capsule was calculated for each of the two testers and compared for the intertester reliability ICC (2, K). Finally each subject returned 5-7 days after the first test session and posterior capsule thickness was measured again to calculate test re-test reliability ICC (2, K) for the primary investigator. Standard Error of Measures (SEM) were also calculated for each of the reliability measurements.

Results: The ICC and SEM for the lead authors' intratester reliability was 0.88 (0.02cm). The ICC and SEM for the intertester reliability was 0.77 (0.026cm) and the lead authors' test re-test reliability was 0.72 (0.022cm).

Conclusion: Dynamic US proved to be a valid and reliable tool for measuring posterior capsule thickness of the glenohumeral joint. The observed thickness did correspond with previous histological examinations of the posterior capsule. Future research may be performed on overhead athletes and pathologic population to determine if relationships exist between anatomical adaptations and function/dysfunction.

42 FRONTAL PLANE INTERNAL WORK DECREASES AND REMAINS SYMMETRICAL AFTER STROKE

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Intro: Post-stroke gait is characterized by asymmetric movement patterns and the use of compensation strategies in order to clear the affected leg during swing. Strategies such as hip hiking and circumduction can lead to greater excursions of the stroke-affected limb in the frontal plane. These altered movement patterns can increase the amount of work done by the muscles in order to walk. It is unknown how pathological gait affects frontal plane internal work (W_{int_ml}). **Methods:** An over ground walking trial was conducted in order to determine self-selected walking speed (SSWS) for seven healthy subjects and ten stroke subjects. Each healthy subject was tested on a treadmill at speeds ranging from 25% to 200% of their SSWS. Each stroke subject was tested on a treadmill at speeds ranging from 20% slower than their SSWS to the fastest speed at which they could safely walk. Kinematic data were collected on all subjects. Data were processed in Visual 3D and Matlab in order to calculate W_{int_ml}. Analyses of covariance were performed to compare W_{int_ml} between healthy and stroke subjects across walking speeds, and to compare W_{int_ml} between legs in stroke subjects and between legs in healthy subjects across walking speeds. **Results:** No significant difference was found in W_{int_ml} production between legs in healthy or stroke subjects. Healthy subjects produced significantly more W_{int_ml} than stroke subjects. **Discussion:** The symmetric work production between the healthy and affected legs in stroke subjects may be explained by reduced step length and stance time on the affected leg in stroke subjects. Even though the affected leg travels further laterally during swing, the healthy leg swings faster and thus has greater volitional changes in the frontal plane. The greater W_{int_ml} production by healthy subjects may be explained by the fact that stroke subjects required the use of a handrail when walking on the treadmill. The COM of stroke subjects appeared not to move over the stance leg during single support as much as the healthy subjects. This decreases the relative velocity of the stroke subjects' legs with respect to the COM resulting in decreased W_{int_ml}. Even though differences in W_{int_ml} were discovered, W_{int_ml} appears to be a negligible component of overall mechanical energy expenditure in healthy and post-stroke gait.

43 COMPARISON OF FUNCTIONAL AND ISOKINETIC FATIGUE PROTOCOLS: INJURY RESEARCH IMPLICATIONS

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The deleterious outcomes on performance elicited by fatigue are typically related to altered biomechanics or motor control strategies; however, studies predicting such effects may use inadequate techniques to fatigue subjects relative to author's conclusions. Perhaps, future studies could be refined by understanding differences in fatigue methodology. The purpose of this study was to compare the effects of intense exercise-induced fatigue on quadriceps/hamstring torque production and EMG using a functional fatigue protocol (FFP) and an isokinetic fatigue protocol (IFP). Twenty healthy subjects volunteered for this investigation. In both sessions, subjects completed isokinetic strength testing for knee flexion (KF) and extension (KE) while simultaneous surface EMG was recorded from vastus medialis, vatus lateralis, biceps femoris and semitendinosus. In the first session, subjects were fatigued using the FFP, which consisted of a series of timed sprinting, cutting, and jumping tasks. After a one month washout period, subjects reported for the second session incorporating the IFP, where subjects performed CON KF and CON KE at various velocities, starting at 240°/sec and decreasing by 30°/sec intervals. Peak torque (PT), average torque (AT), EMG Root Mean Square Amplitude (RMS) and Median Spectral Frequency (F_{med}) values were extracted and compared using a mixed-model repeated measures ANOVA where ($P<0.05$). There were statistically significant differences in both PT and AT for the KE muscle group pre- to post-fatigue for the FFP and IFP. Interestingly, for the KF muscle group, significant decreases in PT and AT were only evident pre- to post-fatigue for the FFP. Additionally, the deficits in quadriceps and hamstring activation evident (indicated by EMG data) with the FFP are suggestive of a more proximal (central) fatigue mechanism.

44 COMPENSATORY STRATEGIES WITH MODELED MUSCLE ACTIVATION DEFICIENCY DURING GAIT

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INTRODUCTION: Impaired activation has been cited as a mechanism to post-stroke muscle weakness(Landau and Sahrmann). The extent of activation deficits can have a direct effect on a person's ability to maintain a normal gait. Several studies have explored the effects of muscle atrophy on gait pattern, and the body's ability to compensate with other muscles to maintain a normal gait (Goldberg, Jonkers). These studies have not looked at muscle deficiencies associated with activation. The objective of this study is to identify compensatory strategies used to maintain a normal gait when activation defiecies are introduced to muscles. METHODS: The software OpenSim is used for analysis in the study. A 23 degree of freedom model with 54 muscle actuators is used to generate a 3D, forward dynamic simulation from motion capture walking trials. Using OpenSim's CMC algorithm, the muscle forces and activations required to reproduce normal gait kinematics are computed. Constraints were set on the activation capacity of the dorsiflexor and plantarflexor muscle groups separately to simulate activation impairments to these groups. The calculated set of muscle activations, forces, and resulting kinematics are analyzed to determine compensation strategies.
RESULTS: The plantarflexor muscle group shows decreases in force and activation to compensate for deficencies in the dorsiflexors. Compensation was more difficult with plantarflexion imparment, causing a 5 degree increase in dorsiflexion at 25% maximum activation. CONCLUSION: The simulations are able to maintain normal gait kinematics despite some activation impairment with compensatory strategies. These strategies are limited, and are no longer effective at high levels of impairment in certain muscle groups.

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TRICEPS SURAE STRENGTHENING DOES NOT REDUCE DORSIFLEXION PASSIVE RANGE OF MOTION IN CHILDREN WITH SPASTIC DIPLEGIC CEREBRAL PALSY

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Children with spastic cerebral palsy (CP) present with increased tightness and spasticity in the triceps surae (TS).muscle. Despite the increasing popularity of strength training programs in the treatment of weakness in CP, there is disagreement as to whether or not spastic muscle can be strengthened without increasing tightness in the muscle. Twenty-three children with CP were randomly assigned to an NMES strengthening program (n=7; 10.8±2 years), a volitional strength training program (n=8; 10.5±2 years), or a control group (n=8; 10.6±2.3 years). Subjects in the NMES group had percutaneous electrodes implanted to activate the TS muscles and performed 15 isometric NMES contractions, 3 times per week for 12 weeks. Subjects in the volitional group trained at the same frequency using maximum voluntary isometric contractions. A blinded physical therapist measured ankle dorsiflexion (DF) passive range of motion (PROM), in prone with the knee extended, before and after the 12-week training intervention. The pre- and post-training DF PROM was averaged within each group and the difference in pre- to post-training PROM for each subject was used to calculate change scores, which were also averaged within groups. There were no significant differences in pre- to post-training ankle DF PROM measurements in any of the groups ($p>0.05$). The change in pre- to post-training values were within the standard measurement error for goniometric measurement. This study provides evidence that strength training in spastic muscle can be performed without an increase in muscle tightness. There was not a decrease in DF PROM with strength training, regardless of whether NMES or voluntary effort was used.

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AN EMG DRIVEN MUSCULOSKELETAL MODELING APPROACH TO ESTIMATE ARTICULAR LOADING AT THE KNEE.

Kumar,Deepak [1]; Rudolph, Katherine.S [1,2,3]; Manal, Kurt [1,3] . 1. BIOMS 2. Physical Therapy 3. CBER

INTRODUCTION : The relationship between the knee adduction moment and joint loading is not straightforward, particularly when agonist/antagonist muscle groups are co-activated, in people with knee osteoarthritis (OA). Computational methods which account for subject specific neuromuscular activation patterns are important when studying articular loading. In this paper we present results of an EMG-driven modeling approach to predict articular loading for patients with different muscle activation patterns and frontal plane knee moments. METHODS :An EMG-driven musculoskeletal model was used to compute muscle forces at the knee during the stance phase of gait . Three adult male subjects participated in this study: one healthy, one with medial knee OA and one with lateral OA. Gait kinematics and ground reaction forces were sampled using traditional methods (ie., video cameras and force platform). In addition, muscle activity was recorded from 3 of the 4 quadriceps, all 4 hamstrings and both gastrocnemii. RESULTS AND DISCUSSION :The subject with medial OA had the largest adductor moment while the individual with lateral OA had the smallest. Both subjects with OA exhibited similar peak medial loading during early stance while loading of the lateral condyles was dramatically different during late stance. Negative loading for the subject with medial OA indicates lateral compartment unloading during late stance involving lateral soft tissue restraints (ie., ligament & capsule) to balance the external moment. Loading profiles for the healthy subject in our study were similar to patterns reported for an elderly subject fitted with an instrumented knee implant. Both subjects had a two-peak pattern of loading for the medial condyle with the first peak larger than the second. Lateral compartment loading for both subjects was less than noted on the medial side. The lateral compartment for our subject never became unloaded, consistent with findings reported by Fernandez et al. CONCLUSIONS: The EMG-driven musculoskeletal model predicted differential loading between the subjects with medial and lateral OA. Assuming joint moments of comparable magnitude, smaller loading implies a greater proportion of the frontal plane moment was supported by the muscles. The subject with medial OA appears to have used more of a muscle balancing strategy compared to the individual with lateral OA. Additional work is underway to evaluate the efficacy of this modeling approach for investigating healthy and pathological gait.

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THE EFFECT OF VARIOUS METHODS OF INFANT CARRYING ON THE HUMAN BODY AND LOCOMOTION

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One of the most distinguishing human characteristics is bipedalism, walking on two legs. While there are many hypotheses for why bipedalism evolved, one consequence is that the hands are free from use in locomotion, making it possible to use them to carry objects. Such objects include food, water, firewood, and dependent, helpless offspring. Carrying an infant allows frequent nursing, and also allows the mother to do work. For most of human evolutionary history, females almost certainly carried their infants for large parts of the day as they foraged for food. Cross-culturally, there are many different methods and tools to carry babies: front wrap, back wrap, side slings, and carrying in-arms. Indeed, many archaeologists think that a carrying device, like a sling, was among the first human tools. Because such devices are made from perishable materials like plants, they would not appear in the archaeological record.
For my senior thesis, I investigated four ways of carrying infants by using motion analysis on 19 women carrying 7 and 20 lb weights. In the biomechanical engineering lab, I monitored women carrying two different heavy loads while walking, to look at the change in their center of mass and variation in gait. The protocol was approved by the Institutional Review Board (Human Subjects) at the University of Delaware and does not involve harmful or invasive procedures. The two main objectives of this research were to understand the effects of baby weight and baby carrying position on trunk and hip angles. The front wrap significantly affects the hip flexion and extension angles. The back wrap and the in arms carrying influence the forward trunk angle. While the side sling shows no significant difference in the angles, there is a trend for the carrier to lean towards the preferred carrying side. All changes in the hip and trunk angles may be a result of the carrier trying to maintain balance and compensate for the displacement of the center of mass. This study will lead to a better understanding of a cultural practice that affects the biology of the human skeleton.

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COMPARISON OF KNEE CONTACT FORCE BETWEEN SUBJECTS WITH VARYING OA SEVERITIES

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INTRODUCTION: Osteoarthritis (OA) is the most common form of arthritis, with the knee being the most affected joint. OA is the progressive degeneration of articular cartilage resulting in pain, which in turn results in changes in gait. These changes in gait, and the underlying neuromuscular activity, can then further the progression of the disease. By using musculoskeletal models, researchers can calculate muscle forces, and subsequently joint contact forces, providing insight into the progression of the disease. METHODS: Walking data was obtained from 16 subjects with varying grades of OA (0-1 are healthy, 2-3 moderate OA, 4 severe OA). Subjects walked at a self-selected speed on our custom built, split-belt treadmill with dual integrated forceplates. 3-D kinematc data was collected using eight infrared cameras at 60 Hz while ground reaction forces (GRF) were simultaneously collected at 1080 Hz. OpenSim was then used to generate a three-dimensional, subject-specific, forward dynamic simulation of the walking trial using a 23 degree of freedom, 54 muscle actuated model. Through OpenSim's CMC algorithm, with experimental kinematic (marker position) and kinetic (GRF) data as inputs, muscle forces that reproduced the subject's gait were calculated. Knee contact forces (KCF) were calculated using the vector sum of the muscle forces and joint reaction forces along the longitudinal axis of the femur. KCF was normalized to body weight. RESULTS: Peak KCF occurred during early single-limb support for all OA groups. There are two notable patterns in the KCF curve. First, moderate OA subjects exhibited a similar pattern to healthy subjects, with lower KCF (peak KCF 4.79, healthy; 4.30 moderate). Second, although subjects with severe OA had similar initial peak KCF to healthy subjects (4.66, 4.79, respectively), the pattern of the KCF was very different between groups. After initial peak, subjects with severe OA constantly unloaded the joint, whereas healthy subjects and subjects with moderate OA reloaded the knee during late stance/pre-swing. CONCLUSION: In subjects with symmetric OA grades, there appears to be differences in loading between OA severities. Reduction of peak KCF may not be a compensatory strategy for OA patients.

49 DIMENSIONAL ACCURACY OF A RAPID FIT CUSTOMIZATION AND MANUFACTURING PROCESS FOR ORTHOSES

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Ankle-foot orthoses (AFOs) are commonly prescribed to individuals with muscular weakness about the ankle and serve to support the ankle during gait. Passive-dynamic AFOs (PD-AFOs) comprise a class of AFOs that provide plantar flexion assistance via a spring-like action. Traditionally, customized PD-AFOs are fabricated by an orthotist through a time-intensive, manual process.
Computer aided design (CAD) enables the virtual modeling and analysis of physical parts. Parameterization of CAD models can be used to automatically customize the size and shape (fit) and function characteristics of parts. Furthermore, rapid freeform manufacturing, such as selective laser sintering (SLS), can be used to rapidly manufacture unique CAD models. Although very powerful tools, currently these technologies are scarcely used for orthosis applications.
We have developed a method for rapidly fit-customizing and manufacturing PD-AFOs using a digitizer arm, CAD, CAD-integrated parameterization, and SLS. In our eight-step automated fit customization and manufacturing method, the locations of strategically-selected skeletal landmarks on the subject's shank and foot were digitally acquired, aligned, and then used as the parameters to drive the fit-customization of a PD-AFO CAD model. Four PD-AFOs were then fabricated via SLS, and their dimensions were verified by comparing the average of selected PD-AFO dimensions, measured on the fabricated PD-AFOs with a digtizer arm, to the CAD model dimensions.
The PD-AFOs, customized for a healthy male subject (height 1.77m; mass 71.8kg), were fabricated in less than 24 hours and had excellent dimensional accuracy (max difference = 0.975mm; mean difference = 0.284mm; SD = 0.280mm). This study demonstrates the ability to rapidly fit-customize and manufacture dimensionally-accurate orthoses.

50 MUSCLE PARAMETER PERTURBATION IN OPENSIM USING EMG-DRIVEN SIMULATIONS

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Subject-specific analyses of dynamic human movement tasks have become easier with the development of OpenSim software. Currently, OpenSim uses computed muscle control (CMC) to predict individual muscle excitations and subsequent muscle forces that will drive a forward dynamic simulation. While this method is computationally efficient, forces determined by the model do not take into account the subjects individual electromyographic (EMG) recordings. EMG-driven simulations have been used to estimate subject-specific muscle parameters and the forces produced as a result.
Previous studies have investigated muscle parameter sensitivity during gait simulation by varying the parameters by a fixed percentage (± 10%). However, muscle parameters based on an EMG-driven simulation have shown to be well outside these fixed ranges. Currently, the EMG-driven model optimizes three parameters that can be altered within OpenSim: maximum isometric force, tendon slack length, and optimal fiber length. This is beneficial to the results of the CMC because previous studies have shown these Hill-type muscle parameters to be more sensitive than any others. This study focuses on the sensitivity of EMG-driven muscle parameters on gait simulation using OpenSim.

51 A NOVEL METHOD FOR ESTIMATING STIFFNESS OF PASSIVE DYNAMIC ANKLE FOOT ORTHOSES

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Passive Dynamic Ankle Foot Orthoses (PD-AFO) are spring-like braces that are prescribed for patients with various gait impairments, including children with cerebral palsy, and patients recovering from stroke. The external assistance supplied by the PD-AFOs are influenced by the mechanical stiffness properties, and the stiffness may ultimately predict the effectiveness of the orthotic during gait. Therefore, developing an accurate and reliable method for determining stiffness experimentally is essential for appropriate PD-AFO prescription.
Traditional assessment of AFO stiffness involves a linear approximation of the ratio of externaly applied moment to the angular deformation. Numerous researchers have evaluated AFO mechanical properties under various experimental loading conditions. However, there are currently no definitive methods for the most accurate and reliable stiffness determination. In addition, recent work from our laboratory has shown that the stiffness estimations are influenced by the external loading conditions. Using the insights gained from our previous work, we have developed a new device for assessing PD-AFO stiffness properties. The device (used in conjucntion with motion capture technologies) is designed to replicate congruent loads and congruent deformations induced while a person walks with the AFO, such that the experimental stiffness values equate the stiffness supplied by the AFO during gait. Therefore, stiffness values estimated from our new method can be included in future gait analyses and simulations studies.

52 VOLITIONAL MVC EMG NORMALIZATION TASKS BETWEEN DAYS

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EMG should be normalized to compare between days. The ideal normalization task is quick and reliable between subjects and data collections first, and is similar in motion to the trial being normalized second. Possible between day variability in EMG normalization tasks could affect comparisons between studies, within intervention, or pre-post comparisons. Reliability of a single isometric or isokinetic MVC peak EMG used as a normalization task is unknown. Surface vastus lateralis and medialis EMG were collected during six different normalization tasks and five running trials on three separate days. We tested a range of isometric angles, and isokinetic speeds, commonly used for EMG normalization tasks. Processed stance phase EMG data collected during running trials were normalized to the peak EMG value of the six different normalization tasks. Peak normalized EMG values during stance phase were averaged across the five running trials. This was repeated for the six different normalization tasks. Subject data were then pooled to compute averages and standard deviations for each of the normalization tasks. These data were then used to compare peak EMG standard deviation values during running using different normalization tasks between days. Stance phase peak normalized EMG (%MVC) means and standard deviations tended to increase for both muscles as isokinetic speed increased, and continued to be larger and more variable as the isometric knee angle increased. We found that normalized stance phase EMG (%MVC) will vary because of the unreliability of commonly used normalization methods. However, isokinetic normalization tasks at slower speeds are less variable, and are a more reliable method of EMG normalization. We found that an isokinetic MVC at either 60 or 180 deg./s was a reliable EMG normalization task for two muscles of quadriceps EMG during running trials.

53 OVERWEIGHT AND OBESITY IN US CHILDREN CONTINUES TO RISE

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A recent report has indicated a halt to the rate of rise in incidence of overweight and obesity in young American girls and boys. The objective of this study was to use the human body shape index (HBSI) to examine changes in the distribution of the human body shape over a 35 year period and identify changes in the incidence of overweight (OW) and obesity (OB) using physiologic thresholds. The HBSI was evaluated from height and weight measurements for girls and boys age 6-18 years across six time period (TP) data sets collected from 1971-2006 (TP1=1971-1975,TP2=1976-1980,TP3=1988-1994,TP4=1999-2001,TP5=2003-2004,TP6=2005-2006).The power of the HBSI and the cutoffs for OW and OB were determined from a population of children that were not affected by OW or OB. Changes in the distribution of HBSI across TPs, the percentage of OW and OB children in each TP, and linear regression of the changes in percent OW and OB over time (years) were examined. The mean HBSI increased with time for girls and boys and the amplitude of the distribution decreased with each consecutive TP, widening the distribution. In each successive TP, the percentage of the distribution that occurred after the peak increased for boys. The percentage of OW (except for girls from TP1-TP2) and OB (except for boys from TP4-TP5) increased with each TP. Contrary to a recent report, the rate of increase in OW and OB continues to rise. Assuming a linear regression model (OW: r^2girls=0.83, r^2boys=0.83, OB: r^2girls=0.91, r^2boys=0.74), 50 percent of US girls will be OW by 2033.3

54 DIFFERENCES IN KNEE STIFFNESS AND GRF DURING DROP JUMPS FROM UNKNOWN HEIGHTS

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Functional knee stability can be described by stiffness measures, which quantify the resistance of a joint to changes in position. Muscle recruitment increases joint stiffness, protecting ligamentous structures from excessive loads. However, previous studies have demonstrated that muscle activation is attenuated when visual feedback is impaired and that visual-spatial skills are associated with the unanticipated errors in coordination leading to non-contact knee injuries. No direct evidence exists linking visual feedback with altered stiffness regulation strategies during functional activities. The independent variables were knowledge of the drop jump height (full vision, no vision) and 2 drop heights (50 cm control height, 35 cm early landing height). 20 healthy collegiate football players stood on a hydraulic lift platform, self initiated a drop on an AMTI force plate, landing on both legs with a toe heel sequence and then jumped vertically as quickly and high as possible. Subjects performed 12 jumps with height and vision condition randomized. Reflective markers defined the trunk, thigh, lower leg, and foot segments and were recorded (240Hz) with an 8 camera system. Kinematic and kinetic data was imported into Visual3d software using Euler angles and net joint moments (internal) for data reduction and calculation of knee stiffness. The dependent variable was knee stiffness (Nm/kg/degree) determined as the change in knee moment (normalized to body mass) divided by the flexion angle from ground contact to maximum knee flexion. A 2-way ANOVA was performed on knee stiffness. Two-way ANOVA's were performed on peak vertical ground reaction force, time to peak force, knee angle at ground contact, maximum knee flexion angle and knee excursion. Knee stiffness was significantly decreased during the no vision conditions (vision mean = 0.043±0.022 Nm/kg/deg, no vision mean = (0.030±0.017 Nm/kg/deg P=0.0001). No significant differences were observed between drop jump heights (50cm height mean = 0.035±0.019 Nm/kg/deg, 35cm height mean = 0.038±0.018 Nm/kg/deg, P = 0.14) and no interactions were observed. Time to peak force was significantly less (p=.003) in the no vision (time=45±12ms) versus vision conditions (time =.54±13ms) and peak force was significantly greater (p=.018) in the no vision (force=2409±874N) versus vision conditions (force=2016±656N). [A significant (p=.01) interaction was identified whereby peak force was even greater in the no vision-50cm condition. Knee angle was significantly less flexed when landing without vision and the least flexed during the no vision-35cm condition. Unanticipated early (35cm height) landings, that occur without reliance upon visual cues, leads to higher forces, in a shorter period of time and {continued]

54 [continued from previous page] with the knee in a more extended position. A decrease in knee joint stiffness during a drop jumps from unknown heights suggests this methodology may simulate the biomechanical aberrations describing non-contact knee injuries where sudden “buckling” or “giving way” into rapid knee flexion occurs shortly after ground contact.

55 MOTOR UNIT DISCHARGE BEHAVIOUR IN PATIENTS WITH STROKE

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Stroke is the number one cause of adult disability in the USA. Many stroke survivors display muscle weakness and movement slowness, which limit their ability to function independently. Information regarding how motor units (MU) are controlled to produce forces in individuals with stroke and the mechanisms behind muscle weakness and movement slowness is scant mainly due to technical challenges during single MU recording. Thus, the purpose of this study is to study MU discharge behavior during force control tasks at different force levels using a quadrifilar needle electrode, which enables us to identify the action potentials of multiple MUs simultaneously. Subjects performed isometric force tasks of their vastus lateralis (1 subject) or tibialis anterior (2 subjects), including ramp and steady hold contractions and quick force pulses with force levels ranging from 10 to 100% of MVC. The discharge timings of individual MUs were identified offline using a template matching algorithm. Results showed that the mean MU discharge rates were lower in the paretic tibialis anterior (7.0-15.6 Hz for 10-100% MVC) compared to the contralateral side (9.1-20.0 Hz) during across all force levels tested and that the differences in discharge rate increased with force. During quick force pulse contractions of the paretic vastus lateralis, MU discharge rates remained constant at 8 Hz, with force levels from 20% to 80% of MVC. Our work demonstrated that in the patients with stroke, there is a marked decrease in their abilities to use rate-coding for the modulation of force production, which is a potential factor limiting their ability to perform strong and quick contractions.
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