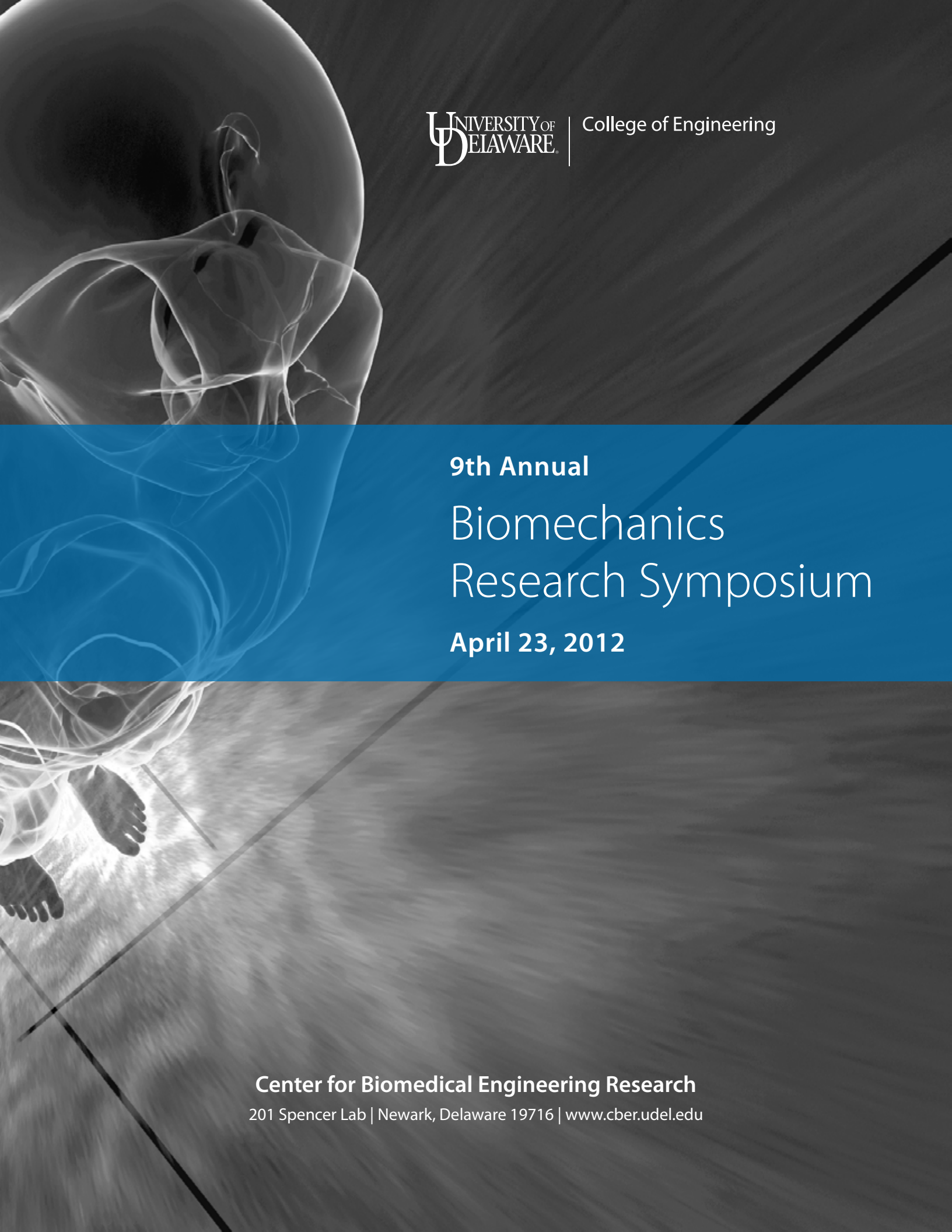

University of Delaware | College of Engineering

9th Annual

# Biomechanics Research Symposium

**April 23, 2012**

**Center for Biomedical Engineering Research**

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

# Welcome students, faculty and friends!

Thank you for participating in the 9th annual biomechanics research symposium hosted by the Center for Biomedical Engineering Research at the University of Delaware. The motivation for this symposium is to highlight the outstanding and varied biomechanics research taking place at the University of Delaware with students presenting their findings in all poster and podium sessions. We would especially like to thank the support of the Delaware Rehabilitation Institute which has provided judges and awards for the best student presentations.

We are extremely excited to welcome this year's keynote speaker, Dr. Darryl D'Lima. Dr. D'Lima is the director of the Orthopaedic Research Laboratories at Shiley Center for Orthopaedic Research and Education (SCORE) at Scripps Clinic in San Diego, as well as an assistant professor in the Division of Arthritis Research at The Scripps Research Institute and an associate professor at the Scripps Translational Science Institute. In his keynote lecture, titled "Knee forces during activities of daily living, rehabilitation, exercise and sports after total knee arthroplasty," Dr. D'Lima will share results from his groundbreaking work pertaining to the E-Knee, an instrumented prosthesis that he helped pioneer.

I have had the wonderful opportunity to see this research symposium grow in participant size and quality of research over my past 7 years at the University and I am looking forward to another outstanding event this year. I would like to recognize each of you for contributing to the scientific content of this year's research symposium, and specifically acknowledge the student committee and faculty judges who devote time and effort to enhancing today's event.

Enjoy today's event!


## ACKNOWLEDGEMENTS

**ORGANIZING COMMITTEE**

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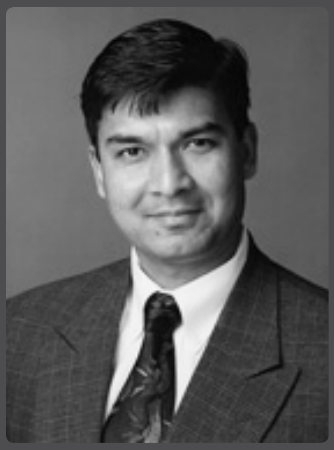
*All student awards are sponsored by the Delaware Rehabilitation Institute*

# Keynote Lecture



## Knee forces during activities of daily living, rehabilitation, exercise and sports after total knee arthroplasty

*Darryl D'Lima, MD, PhD*

Tibiofemoral forces are important in the design and clinical outcomes of TKA. Knee forces and kinematics have been estimated using computer models or traditionally have been measured under laboratory conditions. Although this approach is useful for quantitative measurements and experimental studies, the extrapolation of results to clinical conditions may not always be valid. We therefore developed a tibial tray combining force transducers and a telemetry system to directly measure tibiofemoral compressive forces in vivo.

Tibial forces were measured for activities of daily living, athletic and recreational activities, and with orthotics and braces, for 4 years postoperatively. Additional measurements included video motion analysis, EMG, fluoroscopic kinematic analysis, and ground reaction force measurement. A third-generation system was developed for continuous monitoring of knee forces and kinematics and for classifying and identifying unsupervised activities outside the laboratory using a wearable data acquisition hardware.

This presentation will review forces measured for a wide spectrum of common and relevant activities including walking, jogging, stationary bicycling, golfing, tennis, skiing, hiking, and using exercise equipment. In addition the effect of orthotics, braces, walking aids, and gait retraining on modulating knee forces will be discussed.

In vivo measured knee forces can be used to enhance existing in vitro models and wear simulators and to improve prosthetic designs and biomaterials as well as guide physicians in their recommendations to patients of "safe" activities following TKA.

# Schedule of the Day

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

# Podium Presentations

## Session 1



## Session 2

# POSTER PRESENTATIONS

## Bone, Cell and Cartilage



## Gait

## Imaging



## Methods and Modeling

## Motor Control



## Osteoarthritis



## Robotic Training





# *Denotes Poster #*

PODIUM PRESENTATIONS

# Session 1

## 1 THE EFFECT OF PROGRESSIVE STRENGTHENING PROGRAMS ON SIT TO STAND MECHANICS AFTER UNILATERAL TOTAL KNEE ARTHROPLASTY: A RANDOMIZED CLINICAL TRIAL

*Ali H. Alnahdi[1,2], Joseph A. Zeni[1], Lynn Snyder-Mackler[1]*

[1]University of Delaware
[2]King Saud University

Objective: During sit to stand task, patients with unilateral total knee arthroplasty (TKA) unload the operated limb and overload the nonoperated limb. This loading asymmetry might be related to the asymmetry between limbs in quadriceps strength. This study evaluated the effects of two progressive strengthening programs on quadriceps strength and lower limb mechanics during sit to stand task (STS).

Methods: Twenty eight subjects who were 6 to 30 months post unilateral TKA participated in a single blinded randomized clinical trial and were randomly assigned to receive either a clinic-based rehabilitation program (n=14) or a home-based rehabilitation program (n=14). Outcome measures were symmetry between limbs in quadriceps strength and symmetry between limbs in STS kinematics and kinetics.

Results: Both groups showed significant improvement in quadriceps strength symmetry (P<0.001), but only the clinic-based group showed a significant improvement in knee extension moment symmetry (P=0.04). Improvement in strength and moment symmetry was caused by improvement of the operated side. The magnitude of change in quadriceps strength was not related to the magnitude of change in STS kinematics or kinetics.

Conclusion: The clinic-based rehabilitation program improved loading symmetry during STS task by increasing the load on the operated knee. Both rehabilitation programs did not reduce the nonoperated knee loading suggesting that they might not reduce the risk of OA progression in the nonoperated knee.

## 2 CORTICAL INHIBITION IS RELATED TO ANKLE LAXITY

*A.R. Needle, J.A. Palmer, T.M. Kesar, S.A. Binder-MacLeod, C.B. Swanik*

Background: The etiology behind ankle instability has eluded researchers as altered proprioception and residual laxity fail to explain complaints of instability. Research suggests that supraspinal changes occur among these subjects; however, cortical influences on mechanical restraint and muscle tone remain unexplored. Objective: To investigate neuromechanical relationships between joint laxity and cortical inhibition using transcranial magnetic stimulation (TMS) among healthy and unstable ankles. Methods: Eleven subjects with no history of ankle injury and eleven subjects with unilateral ankle instability volunteered for this study (21.0±4.1yrs, 171.9±9.4cm, 71.8±18.1kg). Three anterior translations were applied using an arthrometer to measure ankle anterior displacement. Subjects were tested bilaterally for corticospinal inhibition using magnetic stimulation over the primary motor cortex during a 15% pronation contraction while motor evoked potentials (MEP's) were collected from the peroneus longus using electromyography. The cortical silent period (CSP) was determined as the time between the end of the MEP until resumption of normal muscle activity. Asymmetries in anterior displacement (mm) and CSP (ms) were calculated as the difference between sides and compared between groups using t-tests and correlations. Results: No significant group differences were observed for anterior displacement (Healthy: 0.16±2.6mm, Unstable: 0.04±3.2mm, p=0.77) or CSP (Healthy: 2.4±73.5ms, Unstable: -7.0±75.2ms, p=0.59). However, a positive correlation between displacement asymmetry and CSP asymmetry was observed (r=0.650, p=0.002). These correlations were stronger in healthy subjects (r=0.707, p=0.015) than unstable subjects (r=0.623, p=0.07). Conclusions: These data support associations between the central nervous system and mechanical joint properties, suggesting that decreased cortical inhibition is associated with decreased laxity, and therefore may regulate normal muscle tone and joint stiffness. As a weaker correlation was observed in unstable subjects, further research should explore how neuromechanical coupling may be altered following joint injury.

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

## 3 COMPARISON OF TWO COMMONLY USED METHODS OF GRIP FORCE CALCULATION IN STATIC MANIPULATION TASKS

*Mehmet Uygur, Goran Prebeg, Slobodan Jaric*

Previous studies of hand function in variety of manipulation tasks have consistently shown a strong coupling between the grip force (GF) and load force (LF). The coupling has been assessed through the maximum cross correlation ($r_{max}$) between the GF and LF time series close to one and the corresponding time lags close to zero.Therefore, the GF-LF coupling has been considered as an essential index of GF-LF coordination revealing one of the most elaborate neural control mechanisms of our daily motor activities. The purpose of this study was to compare two different GF calculating methods that have been commonly used in various manipulation tasks. In some studies of free manipulation tasks and particularly in robotics GF has been frequently defined as the 'internal force' which corresponded to the minimum of two opposing forces acting upon the hand-held object's surface ($GF_{min}$). Conversely, in other studies and particularly in the static manipulation tasks GF has been also calculated as the average of the two opposing forces ($GF_{avg}$). To our knowledge, there have been no studies that compared GF-LF coupling obtained from two different GF calculation methods on a single data set. Therefore, we calculated GF as $GF_{min}$ and $GF_{avg}$ in a variety of manipulation tasks (such as in those based on different feedbacks, types of the task, or the task frequencies) and, thereafter, compared their coupling. The results systematically revealed higher rmax calculated from $GF_{avg}$ than calculated from from $GF_{min}$. We concluded not only that $GF_{avg}$ should be routinely used in future studies of hand function, but also that $GF_{avg}$ is more likely to be controlled by the CNS than $GF_{min}$.

## 4 ASYMMETRIC MORPHOLOGY OF THE HAMSTRING MUSCLES FOLLOWING ACL AUTOGRAFT RECONSTRUCTION

*Stephen M. Suydam, Kurt Manal, Thomas S. Buchanan*

Common ACL repair techniques include the semitendinosus-gracilis autografts (STG) and allografts (ALLO). ALLO use cadaveric tissue to replace the torn ACL and does not result in patient tendon removal, while the STG procedure harvests tendons from the semitendinosus and gracilis muscles to be inserted as the new ACL. Tendon removal leads to deficits in semitendinosus flexion contributions, which is compensated by hypertrophy of the synergistic biceps femoris short and long heads and semimembranosus. Although overall muscle volume and flexor strength may be recovered, it has not been determined if medial/lateral hamstring volumetric proportions pre-surgery are maintained post-surgery to preserve force balances across the knee. Therefore, the purpose of this study was to compare morphological changes of the lateral and medial hamstrings in patients undergoing STG and ALLO reconstructions with healthy, unimpaired muscle volumes. Thirty-one previously active subjects who suffered a ruptured ACL (ACLD) and 20 healthy controls were included in this study. The hamstrings were imaged and muscle volumes were calculated through IMOD tracing software. The MRI data of the healthy, ACLD, and ALLO cases show strong correlations of the medial/lateral muscle volumes between legs with $R^2$ values of 0.89, 0.86, and 0.91, respectively. The STG group, while displaying compensatory morphological changes in each of the hamstring muscles, showed no correlation of medial/lateral differences between the affected and unaffected legs ($R^2 < 0.01$). While ALLO and ACLD hamstring correlations matched well with the healthy and resulted in similar muscle balance compared to the unaffected side, a shift in medial/lateral hamstring volumes occurred in the STG group. This may result in atypical forces crossing the knee, abnormal joint mechanics, or increased the risk of osteoarthritis.

## 5 LOADING ASYMMETRIES IN ATHLETES WHO DO AND DO NOT MEET RETURN-TO-SPORT READINESS CRITERIA

*E.S. Gardinier, S.L. Di Stasi, K. Manal, T.S. Buchanan, L. Snyder-Mackler*

Altered knee joint loading is related to the development of osteoarthritis after anterior cruciate ligament (ACL) injury, and may also be related to the risk of reinjury following reconstruction (ACLR). The purpose of this study was (1) to evaluate loading symmetry during walking among athletes 6 months after ACLR and (2) to compare symmetry for individuals who met specific return-to-sport (RTS) readiness criteria and those who did not. RTS readiness criteria were: ≥90% quadriceps strength symmetry, ≥90% limb symmetry on 4 unilateral hop tests, ≥90% Knee Outcome Survey Activities of Daily Living Subscale and ≥90% global rating scale of perceived function. Joint contact forces were estimated using an electromyography (EMG) driven modeling approach. In total, 23 athletes were included in this study; 10 had passed RTS readiness (time from injury to surgery = 14±8 wk) and 13 had not passed (18±10 wk). A significant difference in peak tibiofemoral force (pkTC; p=0.03, effect size=0.69) and no differences in peak medial force (pkMC; p=0.06, ES=0.59) or percentage of load borne by the medial compartment (MCshare; p=0.22, ES=0.37) were found between limbs. Those who passed RTS demonstrated small inter-limb differences in loading (pkTC: p=0.57, ES=0.23; pkMC: p=0.28, ES=0.36; MCshare: p=0.86, ES=0.10), while those who did not pass demonstrated moderate/large inter-limb differences (pkTC: p=0.03, ES=1.02; pkMC: p=0.12, ES=0.74; MCshare p=0.10, ES=0.63). Those who did not pass RTS walked with decreased force on their involved limb, resembling post-injury loading patterns. In this study, some athletes walked with loading asymmetries 6 months after ACLR. However, a set of specific RTS readiness criteria showed potential for discriminating between those who load symmetrically and those who do not.



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

PODIUM PRESENTATIONS

# Session 2

## 1 MICRO-SCALE STRAIN TRANSFER IN FIBER-REINFORCED NATIVE TISSUES AND CELL-SEEDED ALIGNED NANOFIBROUS SCAFFOLDS

*W.M. Han[1,2], S.J. Heo[1], T.P. Driscoll[1], R.L. Mauck[1], D.M. Elliott[1,2]*

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

Mechanical signals are essential in regulating cell functions such as viability, differentiation, proliferation, and extracellular matrix (ECM) production in load-bearing tissues. However, the current understanding of how macroscopic tissue level strain is transferred to cells is confounded by the highly variable strain fields that arise within the ECM of both native and cell-seeded nanofibrous scaffolds. Moreover, it is unclear how these transmission mechanisms relate to native load bearing tissues. The current study investigates how applied macroscopic tensile strain is transferred to the intercellular ECM and cell nuclei in meniscus, tendon, single lamellar AF, and MSC-seeded scaffolds. The mean microscopic Lagrangian and principal strains in the loading direction ($E_{22}$ and $e_2$) of all native tissues and scaffolds were attenuated from the applied strains by 50% and 30-40% respectively. In aligned scaffold, a significant correlation was observed between the mean nuclear strain and $E_{22}$ (r2=0.98), where 100% of $E_{22}$ transferred to nuclei. Less pronounced strain attenuation in scaffolds compared to native tissues is likely due to more homogeneous microstructure and lack of ECM. In addition, the presence of pericellular matrix in native tissues, along with dense ECM, may shield and regulate strain transfer from the ECM to the subcellular space.

## 2 TARGETING SUBCHONDRAL BONE DERIVED LEPTIN TO TREAT OSTEOARTHRITIS.

*P.P. Srinivasan, X. Jia, R.L. Duncan, C.B. Kirn Safran*

Osteoarthritis (OA) is the most common chronic degenerative disorder, yet its pathology and etiology are not completely understood. One of the major controversies is whether the subchondral bone changes precede the cartilage damage and its role in OA. Currently, there is evidence that demonstrates that stressed subchondral osteoblasts (OB) secrete pro-inflammatory substances like interleukin 6, cyclooxygenase-2 (COX-2) and prostaglandins that trigger cartilage degeneration. Here we propose that leptin is one of the pro-inflammatory proteins secreted by the stressed OBs that stimulates the secretion of matrix degrading enzymes from chondrocytes leading to OA. Subsequently, leptin inhibitor can be used as a potential therapeutic to slow/prevent the progression of OA. We show that exogenous addition of leptin to primary mouse chondrocytes stimulates the secretion of matrix metalloproteinases (MMPs) and Adamts5 that in turn, cause breakdown of the cartilage matrix components leading to OA. In addition, shear stressed primary mouse OBs secrete higher levels of leptin in the conditioned media (CM) compared to non-sheared OBs. Furthermore, the addition of the CM from the sheared OBs on chondrocytes causes an increase in collagen X (hypertrophy) and a decrease in both aggrecan and collagen II mRNA steady-state levels. We are presently working on showing that the addition of leptin inhibitor can reverse the hypertrophic changes induced by the CM from stressed OBs. Further, we are testing the efficacy of leptin inhibitor as a therapeutic for OA in a surgical knee destabilization mouse model. The translational objective of this project is to show that intra-articular injections of leptin inhibitor can be used as potential therapeutic for OA.

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

## 3 HETROGENOUS COLISION OF PAIR OF CAPSULES IN A SIMPLE SHEAR FLOW: EFFECTS OF UNEQUAL MEMBRANE STIFFNESS

*Rajesh Kumar Singh[1], Kausik Sarkar[1,2]*

[1]University of Delaware
[2]The George Washington University

Many cardiovascular diseases occur due to alteration in the physical properties of the cell membrane in the blood flow. In sickle cell anemia, malaria, the membrane of a red blood cell (RBC) becomes stiffer; eventually RBCs are not able to pass in arteries and microvessels. Deformability of red blood cells also affects hydrodynamic properties of blood and thereby physiological functions. We numerically study the hydrodynamic interaction between a pair of cell-like capsules in a shear flow, using a Front-tracking finite difference method. The elastic membrane is modeled using neo-Hookean and Skalak hyperelastic models. We fixed the stiffness of the one capsule ($C_1$) and varied the stiffness of the other ($C_2$) keeping all other parameters constant. The stiffness of the Capsule $C_2$ has significant impact on the deformation and trajectory of the capsule $C_1$. Maximum deformation of the capsule $C_1$ increases with increased stiffness of capsule $C_2$. The cross-stream deviation in the trajectory of the capsule $C_1$ increases with increasing stiffness of $C_2$. This is due to the change in cross-stream velocity of $C_1$ during the post-collision separation. The present study will be beneficial for design improvement of stiffness based diagnostics of diseases.

## 4 EARLY INTERVENTIONS IN POST-TRAUMA OA WITH ZOLENDRONIC ACID

*Wei-Ju Tseng, Christopher Price, Liyun Wang*

Bisphosphonates, a class of bone turnover inhibitors, have showed success in preventing osteoarthritis progression. Our previous work investigated OA damage after zolendronic acid (ZA)-treatment in the murine destabilization of the medial meniscus (DMM) model of induced OA. Forty, three-month old male C57BL/6J mice were divided into four groups for a two-factor (surgery and ZA treatment) study. Half of the mice had DMM surgery performed on the right knees. Three days after surgery, half of the animals in each surgery group began receiving ZA subcutaneously at a dose of 0.15 mg/kg, twice per week, whereas the rest received the same volume of saline solution (Veh). Three months after surgery, right knee joints were harvested for histological examination. We found that cartilage damage was significantly reduced, back to control levels in ZA-treated OA joints. In this study, we performed immunohistochemistry on the same samples. Our results showed that DMM+Veh group had the lowest area of type II collagen (0.058±0.006 μm2) whereas the area in DMM+ZA group increased approximate 25% (0.071±0.0084 μm2). The normalized aggrecan intensity (aggrecan intensity / growth plate intensity) in DMM+Veh group (1.056±0.41) was approximate 30% higher than the other groups (0.701±0.14). The chondrocyte number decreased significantly in DMM+Veh group (51.00±23.95) compared to sham groups (97.13±13.51) and the ZA treatment prevented this decrease in chondrocyte number (72.4±23.6). Similar trends were observed in chondrocyte density (cell # / type II collagen area). In summary, the DMM surgery seemed to reduce type II collagen expression but increased aggrecan expression in articular cartilage as well as a loss of chondrocytes. ZA treatment seemed to prevent type II collagen reduction and the loss of chondrocytes caused by DMM.

## 5 INHIBITIVE EFFECTS OF LOW INTENSITY ULTRASOUND STIMULATION ON HUMAN BREAST CANCER CELL PROLIFERATION.

*Amit Katiyar[1], Malaya DasBannerjee[1], Matas Smakotinas[1], Kausik Sarkar[1,2], Krishna Pada Sarker[1]*

[1]University of Delaware
[2]The George Washington University

Cancer is characterized by uncontrolled cell proliferation, limiting which is the key to developing novel therapies. We have investigated the effects of near-field low intensity pulsed ultrasound (LIPUS) stimulation on T47D human breast cancer cell proliferation in monolayer cultures. Effects of key ultrasound parameters—intensity, excitation period and duty cycle—are studied by systematically varying them. Cell proliferation was quantified using BrdU and AlamarBlue assays. With 20% duty cycle and 10 min excitation period, we varied LIPUS intensity from 10 mW/cm$^2$ to 100 mW/cm$^2$ to find a gradual decrease in T47D cell proliferation, decrease being strongest at 100 mW/cm$^2$. Varying LIPUS excitation period from 5 min/day to 20 min/day at 20% duty cycle and 100 mW/cm$^2$ showed saturation in its effects on proliferation suggesting habituation response to mechanical stimulation. We varied duty cycle from 20% to 100% (continuous wave). Above 60% duty cycle, T47D cell proliferation decreased drastically. Effects of continuous wave (CW) ultrasound stimulation were further explored by varying intensity and excitation period. These experiments demonstrated that irrespective of the wave form (pulsed or continuous), ultrasound stimulation can inhibit the proliferation of T47D breast cancer cells, and the inhibitive response varies with stimulation parameters.



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POSTER PRESENTATIONS

# Bone, Cell & Cartilage

## 1 RESPONSE OF CHONDROCYTES TO MECHANICAL LOADING AND ZOLENDRONIC ACID IN 3-D CULTURE

*Enoch Cheung, Christopher Price, Liyun Wang, X. Lucas Lu*

Center for Biomedical Engineering Research, University of Delaware

This research project investigates the nature of cartilage damage and osteoarthritis (OA) resulting from traumatic knee injuries (e.g anterior cruciate ligament or meniscal tears). These injuries often lead to altered joint loading mechanics, which trigger cellular/tissue processes that can initiate a "viscous cycle of damage". This results in post-traumatic osteoarthritis (PTOA) several years after injury. Our lab has identified a drug, zolendronic acid (ZA), which can lessen the development of PTOA in a mouse model of surgically induced OA. However, little is known about the drug's mechanism of protection. In this project, we hypothesized that ZA's protective effects on cartilage were mediated directly through chondrocytes, the cells that regulate the development, homeostasis, and repair of cartilage. To study these effects we developed a 3-dimensional cell culture system to study the effect of ZA administration and mechanical loading on the biochemical/molecular properties of chondrocytes. Primary bovine chondrocytes were harvested and seeded into a 3-D hydrogel (agarose) scaffold. A loading device compatible with the in vitro culturing of chondrocyte-agarose constructs plugs was constructed, and used to apply dynamic loads to constructs that were treated with either ZA containing (10uM) or control media. Using this system, we showed sustained viability and proliferation of primary chondrocytes in 3-D culture subjected to either free-swelling or mechanical loading, up to 28-days of culture. Additionally, we identified that ZA administration altered the cell response (i.e. viability, apoptosis, matrix formation/degradation) and sensitivity to both free-swelling and mechanical loading. We will continue to use this system to investigate the direct effects of ZA on chondrocytes and cartilage degeneration, and to explore its clinical application in treating PTOA.

## 2 OSTEOCYTE LACUNAE AND CANALICULI IN CORTICAL AND TRABECULAR BONES

*Xiaohan Lai, Christopher Price, Liyun Wang*

Osteocytes, the most abundant cells in mature bone, are strategically placed to regulate the homeostasis and mechanical adaptation of bone. Interstitial fluid flow and solute transport have been hypothesized to be involved in osteocyte metabolism and mechanosensition. Recent experimental and theoretical studies have shown that the anatomical features of the lacunar-canalicular system (LCS), the fluid pathway in bone, are determining factors of the magnitude of fluid flow and cellular stimulation. Using a newly developed fluorescence recovery after photobleaching (FRAP) approach, we have measured fluid flow and solute transport in the cortex of long bone. To quantify transport characteristics of trabecular bone, the anatomy of the osteocyte LCS has to be determined as previously done for cortical bone. The objective of this study was to characterize osteocyte LCS anatomical features relevant to fluid transport using confocal imaging. Right Femora and L3 vertebrae from C57BL/6J male mice (n = 3, 16 weeks old) were dissected, fixed, bulk stained in basic fuchsin, embedded, sectioned, polished and mounted. Using an inverted confocal laser-scanning microscope, randomly selected lacunae were subjected to 3D high-resolution imaging (200x) to measure size, shape and canaliculi number while lacunar density was measured at 10x magnification. 3D renderings of individual lacunae and canaliculi were reconstructed using VOLOCITY to count canaliculi number while segmentation of lacunae and canaliculi was achieved using AMIRA to measure lacunae volume, surface area and three primary axes lengths. The axial correction factor was also calculated in our system to correct for the distortion of images in this direction. Differences among groups were tested using two-way ANOVA (SAS). The results are crucial for better understanding the role of fluid flow in trabecular bone.

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

## 3 PERLECAN/HSPG2 DEFICIENCY ENHANCES BMP2 EFFECT ON BONE MATRIX MINERALIZATION

*Nadia Lepori-Bui, Dylan A. Lowe, Catherine B. Kirn-Safran*

Perlecan/HSPG2 (Pln) is a large, heparan sulfate proteoglycan abundant in cartilage, where it modulates growth factor bioavailability during development. Pln deficient mice display altered structural properties in bone, including increased bone brittleness associated with increased bone mineral density (BMD). These characteristics are consistent with the symptoms of Schwartz-Jampel patients, who have mutations in the PLN gene. Recently, Pln has been proposed to maintain the lacuno-canalicular system in adult cortical bone by inhibiting mineralization. In the current study, we hypothesize that decreased Pln in the extracellular matrix allows for increased diffusibility of the heparin binding growth factor, BMP2, and enhances its osteogenic effect. To study this, we isolated day 13.5 primary mouse embryonic fibroblasts and day 5 post-natal calvarial osteoblasts from both Pln-deficient and WT mice and cultured them under osteogenic conditions. Osteoprogenitors from Pln-deficient mice displayed elevated differentiation and mineralization potential relative to WT cells, as assayed by alkaline phosphatase and von Kossa staining, respectively. RNA and protein analyses also revealed upregulation of several key mineralization markers in Pln-deficient cells versus WT. This effect was enhanced by the presence of BMP2 in the culture media, suggesting that absence of Pln promotes the osteogenic function of BMP2. Conversely, high amounts of Pln during endochondral ossification may regulate BMP2 signaling by sequestering growth factors from their cognate receptors. Uncovering the mechanism by which Pln influences bone formation will lead to a greater understanding of the events occuring at the bone-cartilage interface during embyrogenesis and in mineralized tissue disorders such as osteoarthritis or injury-induced ectopic calcification.

## 4 SOLUBLE FACTORS FOR DIRECTING MESENCHYMAL STEM CELL FUNCTION FOR LIGAMENT REPAIR

*Matthew S. Rehmann, April M. Kloxin*

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

POSTER PRESENTATIONS

# Gait



# *Denotes Poster #*

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

## 5 METABOLIC COST AND LOWER EXTREMITY MUSCLE ACTIVITY DURING CONSTANT SPEED WALKING AT DIFFERENT STRIDE FREQUENCIES

*Angela Boynton[1,2],Todd Royer[1]*

[1]University of Delaware, Newark
[2]U.S. Army Research Laboratory

At a given speed, individuals tend to select a stride frequency that minimizes energy expenditure. Deviations from preferred stride frequency (PSF) lead to changes in the mechanical work done by the legs and net mechanical efficiency associated with doing that work, resulting in increased metabolic cost. Changes in the mechanical requirements of gait progression may be reflected by modifications in muscle activation patterns. PURPOSE: To quantify changes in metabolic rate (MR) and lower extremity integrated muscle activity (iEMG) associated with walking with normal, high and low cadences at a fixed speed. METHODS: To date, eight healthy males (age: 28.5±5.3 years, body mass: 82.6±20.5 kg) have been recruited from the APG civilian and military population for participation in this study. Subjects walked on a treadmill at 1.34 m/s for 5-minute periods while matching their footfalls to a metronome set at their PSF, PSF+10% or PSF-10%. MR and right leg iEMG were assessed during the final minute of each trial. RESULTS: MR was significantly affected by changes in SF ($p=0.014$), increasing about 7% with a ±10% deviation from PSF. Of the leg muscles evaluated, only tibialis anterior (TA) and medial gastrocnemius (MG) iEMG were significantly affected by changes in SF ($p=0.029$ and 0.030). On average, walking at PSF-10% led to a 26% increase in TA iEMG ($p=0.034$) and 12% increase in MG iEMG ($p=0.035$). CONCLUSIONS: TA and MG iEMG appear to be sensitive to deviations from PSF during walking at a constant speed, but changes in iEMG of individual muscles don't necessarily reflect the increases in MR associated with deviations from PSF.

## 6 LOWER-LEG KINESIO® TAPE APPLICATION REDUCES MEDIAL LOADING IN SUBJECTS WITH MEDIAL TIBIAL STRESS SYNDROME

*M.C. Griebert, A.R. Needle, T.W. Kaminski*

Background: Medial tibial stress syndrome (MTSS) is a common overuse injury characterized by pain in the medial lower leg and increased loading on the medial foot during gait. Despite widespread use, limited research exists on the effect of Kinesio® Tape (KT) on movement strategies in injured populations. Objective: To examine the effects of lower-leg KT on rate of loading in subjects with and without MTSS. Methods and Measures: Twenty subjects with no history of leg injury and 14 subjects with MTSS (20.5±1.8yrs, 73.6±14.1kg, 171.8±10.7cm) volunteered for this study. Subjects walked barefoot across a pressure mat system under 3 conditions: prior to KT application (PRE), immediately following application (KT-I), and following 24-hours of use (KT-24). Tape was applied from the superomedial tibia to the plantar arch at 75% tension. Time to peak force (TTPF, % stance) for each condition was calculated in 6 foot areas: medial rearfoot (MRF), lateral rearfoot (LRF), medial midfoot (MMF), lateral midfoot (LMF), medial forefoot (MFF), and lateral forefoot (LFF). An ANOVA tested differences between groups, across taping conditions, and foot areas. Results: A significant interaction was observed between group, condition, and foot area ($F=2.16$, $p=0.02$). Healthy subjects displayed higher TTPF in MMF at PRE (Healthy: 0.33±0.08%, MTSS: 0.23±0.16%, $p=0.028$). KT application increased TTPF in MTSS subjects' MMF (PRE: 0.23±0.01%, KT-I: 0.30±0.03%, KT-24: 0.29±0.03% $p<0.05$) and LFF (PRE: 0.65±0.02%, KT-I: 0.70±0.01%, $p=0.002$). Kinesio® tape did not alter TTPF in healthy subjects ($p>0.05$). Conclusion: Our data suggest a higher loading rate in the MMF in subjects with MTSS; however, KT application decreased loading rate (increased TTPF) in these subjects. Furthermore, this decrease remained throughout continuous use, indicating it may be beneficial for reducing injurious forces during daily activities.

## 7 LOWER EXTREMITY MUSCLE WORK DURING GAIT AND BONE STRUCTURE IN INDIVIDUALS WITH UNILATERAL CEREBRAL PALSY

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Abnormal gait may be contributing to the underdeveloped bone structure seen in children with cerebral palsy (CP). The objective of this study was to examine the relationship between interlimb differences in muscle work during gait and interlimb differences in structure and strength of the midfemur and midtibia in spastic unilateral CP individuals. Gait analysis of ambulatory unilateral CP individuals (n = 35; 13 to 24 years) was performed with an 8 camera system (Vicon Motion Ltd, UK) and with 2 force plates (Kistler, NY). Cortical volume, medullary volume, total volume and estimates of bone strength [section modulus (Z) and polar moment of inertia (J)] at the middle-third of the femur and tibia were determined using magnetic resonance imaging. The interlimb difference in muscle work only at the knee joint, but not at the hip or ankle joint, was related to interlimb differences in cortical volume ($r = 0.341$, $p = 0.045$), total volume ($r = 0.403$, $p = 0.016$), Z ($r = 0.358$, $p = 0.035$) and J ($r = 0.330$, $p = 0.053$) at the midtibia. No significant relationships were found between interlimb differences in muscle work at the hip, knee or ankle and interlimb differences in structure or strength at the midfemur ($r = -0.214$ - $0.196$, $p > 0.2$). Compared to the unaffected limb, lower work generated at the knee of the affected limb during gait may be a significant contributor to the poor structural development of the midtibia in individuals with unilateral CP.

## 8 ALTERED GAIT KINEMATICS AND STRIDE DETECTION USING THE STEP WATCH™ IN YOUTH WITH CEREBRAL PALSY

*Ameeka George, Nancy Lennon[1]*

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Purpose: Cerebral palsy (CP) is caused by an insult to the developing brain which leads to limited motor function and reduced physical activity throughout the lifespan. Clinicians and researchers need a better understanding of these problems in order to develop effective solutions.

Methods: The StepWatch™ (SW™) is a biomedical device that records stride counts to quantify physical activity performance. At Nemours/AIDHC, we are using the SW™ to examine physical activity in youth with CP. The dual axis accelerometer in the SW™ is designed to detect accelerations during the swing phase of gait. In clinical use, we found that toe drag during gait, which reduces limb acceleration at toe off, was associated with reduced accuracy of the SW™. We also suspected an effect of excess shank rotation and flexion on device accuracy. We examined data from 26 patients with low SW™ accuracy for effects of kinematic deviations on stride detection when using factory settings.

Results: Eight of 26 patients had accuracies <74%. Of these, 6 had knee flexion accelerations less than 700 deg/s2. 17 patients had accuracies <90%. Of these, 11 had excess rotation (> 15° internal or >30° external). 6 patients with < 90% accuracy had excess shank flexion (>44°).

Conclusion: In cases where the accuracy of the SW™ was significantly lower than 90%, a majority of patients had low magnitudes of knee flexion acceleration at toe off. A combination of excess rotation and shank angle also contributed to reduced accuracy.

Significance: Detailed knowledge of SW™ performance will allow us to customize device settings to improve accuracy of stride detection in youth with CP who walk with altered gait kinematics.

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

## 9 SEX DIFFERENCES WITH FUNCTIONAL PERFORMANCE MEASURES FROM BASELINE TO 12 MONTHS AFTER ACL RECONSTRUCTION (ACLR).

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

Background: The ACL is the most commonly injured structure in the knee. Women demonstrate asymmetrical gait and lower self-report after ACL injury compared to men. Little is known about sex differences with functional performance after ACL injury and reconstruction. Therefore, the purpose of this study was to investigate the pattern of functional performance with quadriceps strength and hop test measures between sexes from baseline to 12 months after ACLR.

Methods: Sixty-nine athletes (46 men, 23 women) with an isolated ACL injury received pre-operative and post-operative rehabilitation. Maximum voluntary isometric contractions were used to evaluate quadriceps strength and single leg hop test measures were used to evaluate hop performance at baseline and 12 months after ACLR. Quadriceps index (QI) and hop limb symmetry indexes (LSI) are calculated as the ratio of the performance of involved limb to uninvolved limb x 100. Subjects with missing variables due to complaint of knee pain, effusion or episodes of giving way were not included in test measure analysis. Repeated measures ANOVA were used to determine if limb symmetry differences existed between sexes.

Results: There was a time x sex interaction for single hop LSI ($p= 0.048$ for the interaction). There was a main effect of time for QI, single hop, triple hop, and timed hop ($P< 0.001$). There was no effect of sex for all functional test indexes ($p >0.081$ for all indexes).

Conclusion: Overall functional performance improved considerably over time, irrespective of sex. While LSI uses the uninjured limb as an internal control, which might conceal the sex differences at similar time points, it is likely that ACLR recovery is similar for male and female athletes.

## 10 AVERAGE ANKLE DYNAMIC JOINT STIFFNESS DURING HEEL STRIKE RUNNING

*Charlie Gleason, Alexander Razzook, Richard Willy, Rebecca Fellin, Irene Davis, Steven Stanhope*

Introduction: A passive dynamic ankle-foot orthosis (PD-AFO) is a type of ankle brace that acts like a torsional spring and is commonly prescribed to patients with weakened plantar flexors. Dynamic joint stiffness (DJS) is defined as the instantaneous slope of the ankle moment data plotted as a function of the ankle angle. Recently, PD-AFOs have been prescribed to limb salvage patients and utilized to restore both walking and running function. Therefore, the purpose of this study was to characterize average DJS during running.

Methods: Twenty male and ten female healthy heel-strike runners underwent unilateral instrumented gait analysis while running at 3.35 m/s. Stance phase net plantar/dorsiflexion ankle moments and corresponding ankle angles were calculated using Visual3D. Ankle moments were scaled by subject body weight and body height. Student's t-tests were used to assess gender differences.

Results/Discussion: Female ankle angles at terminal stance ($-21.9^{o}$) were significantly different than males ($-12.5^{o}$) ($p<0.001$). However, there were no significant differences in ankle moments between female and male ankle moments during maximum ankle dorsiflexion ($p=0.506$). Female un-scaled average ankle DJS (10.56 Nm/deg) was significantly different than males (14.76 Nm/deg) ($p=0.009$), however, there was no significant difference once average ankle DJS was scaled for body weight and body height ($p=0.587$).

Conclusion: There was no gender difference in average ankle DJS once scaled by body weight and body height. Consequently, body weight and body height may be used to predict an individual's optimal ankle DJS for running, which may provide an objective basis for tuning PD-AFOs.

## 11 KNEE OSTEOARTHRITIS RESULTS IN KINEMATIC AND KINETIC INTERLIMB ASYMMETRY DURING GAIT

*Tyler Richardson, Jill S. Higginson*

Individuals with knee osteoarthritis (OA) are known to exhibit abnormal gait patterns. However, nearly all prior research has focused only on the OA symptomatic limb in comparison with limbs of healthy subjects. It has been suggested that changes on a more symptomatic limb may lead to altered or increased loading on the contralateral limb which could result in a greater risk of initiation and progression of knee OA. In this study, we used an instrumented split-belt treadmill and an 8 camera motion capture system to collect gait data for 17 OA subjects at their self-selected walking speed. The OA symptomatic limb was determined as the subject's self-described more painful knee and was verified to have a greater medial K-L grade than the contralateral knee. Paired t-tests were used to compare interlimb differences for several kinematic and kinetic parameters for each subject. The results demonstrated that there was diminished knee range of motion during gait on the symptomatic limb compared to the contralateral, however there were no interlimb differences at the hip and ankle. Additionally, the OA symptomatic limb exhibited decreased knee excursion and increased knee flexion at initial contact when compared with the contralateral limb. Significant reductions were also observed in peak vertical ground reaction force and vertical loading rate on the OA symptomatic limb. These findings suggest that individuals with knee OA possess several kinematic and kinetic interlimb gait asymmetries. These asymmetries may reflect a compensation of the contralateral limb to alleviate loading and minimize knee motion on the more painful limb. Future research incorporating healthy controls is necessary to determine how the contralateral limb compares with normal and symptomatic gait.

## 12 GAIT SYMMETRIES IN ACL NON-COPERS RECEIVING PERTURBATION TRAINING AFTER SURGERY, COMPARED TO PERTURBATION TRAINING BEFORE SURGERY

*K. White, S.L. Di Stasi, L. Snyder-Mackler*

Among active individuals, knee injuries commonly occur, with the anterior cruciate ligament (ACL) being frequently injured. Despite reconstruction, second injury rates approach 30%. Risk of a second ACL injury has been linked to lower extremity movement asymmetries. Gait asymmetries are characteristic of ACL non-copers. Before surgery, perturbation training, a neuromuscular training intervention, decreases gait asymmetries. Following ACL reconstruction (ACLR), movement abnormalities and functional limitations often persist. Restoring limb symmetry following ACLR may have implications in preventing second injuries. The purpose of this study is to compare limb symmetry six months after ACLR, via gait mechanics, of non-copers who received pre-operative perturbation training to those who received post-operative perturbation training.

Twenty-eight subjects were included in this study. Both groups received 10 perturbation sessions, one group before reconstruction, the other group after reconstruction. Six months after ACLR, all subjects underwent 3-D gait analysis. Sagittal plane gait variables were evaluated for both limbs.

A limb x group interaction was found for both the hip and knee kinematic measures (hip $p=0.007$; knee $p=0.001$). Subjects receiving perturbation before surgery demonstrated significant asymmetries in hip and knee flexion angles while subjects receiving perturbation after surgery did not demonstrate these asymmetries. The internal knee extensor moment was significantly different between the limbs of all subjects regardless of group ($p<0.001$).

Non-copers who received perturbation after surgery demonstrated less knee and hip asymmetries in the sagittal plane 6 months after reconstruction compared to subjects who received perturbation before surgery. Resolving limb asymmetries prior to returning to sports participation may reduce the risk of second knee injury in ACLR athletes. Future work should evaluate long-term gait adaptations and reinjury rates of ACLR athletes who undergo post-operative neuromuscular training.

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

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

*Kyle N. Winfree[1], Ingrid Pretzer-Aboff[1], David Hilgart[1,2], Rajeev Aggrawal[3], Madhuri Behari[3], Sunil K. Agrawal[1]*

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Subjects with Parkinson's disease often have trouble with ambulation. Some research has shown that auxiliary cueing in the form of visual, auditor, or vibration can improve the gait of patients. We have developed a new vibratory feedback shoe, known as the PDShoe, which builds on existing research. This device can modulate both frequency and amplitude of feedback for the wearer. It is untethered, and thus can be worn during daily activities. Pressure and tactor status data are transmitted wirelessly over a personal area network to a notebook computer. This computer can also control the tactor actuation and stimulation frequency. Our presentation will briefly describe the details of design and construction of the PDShoe. We will discuss in greater depth the results from a preliminary evaluation with four Parkinson's disease subjects and two healthy subjects conducted at the All India Institute of Medical Sciences and at the University of Delaware.

## 14 INVESTIGATING PARTICIPATION IN LEVEL I/II ACTIVITIES BY POTENTIAL COPERS & NON-COPERS 12 MONTHS AFTER ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION

*Victoria Allen, Andrew Lynch, Stephanie DiStasi, Lynn Snyder-Mackler*

The University of Delaware Physical Therapy Department uses a functional test battery to determine a minimum state of readiness for return to sport (RTS), a common success measure for athletes who sustain anterior cruciate ligament injury. Patients complete questionnaires about their perceived knee function, current activity, and what limits their ability to return to their previous level of activity. Recent work showed 78% of non-copers passed Delaware's RTS criteria 12 months after surgery, but the rate of athletes returning to their previous activity level is unknown. Athletes were examined 12 months after ACL reconstruction (ACLR). The purpose was to evaluate the rate of athletes returning to activity; evaluate activity level based on the Marx Activity Rating Scale (MARS); investigate reasons for not returning to the same level of activity, despite meeting clinical RTS criteria. Data were collected from 88 non-copers (n=52) and potential copers (n=36). Athletes to list reasons why they have not returned to the same level of activity. The total pass rate for RTS criteria was 87.5%; return to activity rate was 65.9%, with 77.3% of potential copers and 45.3% of non-copers returning to pre-injury levels. MARS scores frequently indicated higher activity level than the patient-reported, creating an inconsistency. "Fear of re-injury", "too little time to participate" and "not yet cleared from doctor", were predominant reasons for not returning to the same level of activity. Non-copers demonstrate the need for additional evaluation and education to increase their likelihood of participating in higher-level activities. There is a need to intervene with athletes' activity level after injury to increase the percentage of individuals engaging in at least fifty hours of level I/II sports/year.

## 15 BEYOND THE WHEELCHAIR: A NEW PERSPECTIVE ON PEDIATRIC POWER MOBILITY

*C. Ragonesi, H. Huang, M. Schreiber, J.C. Galloway*

Mobility is a causal factor in development. Infants with mobility impairments are at risk for developmental delay. Power wheelchairs are currently used to address one goal: basic mobility. The general purpose of this poster is to re-introduce pediatric power mobility (PPM) as a therapeutic tool far beyond its traditional use. Specifically we will address three new perspectives regarding PPM:

1) PPM can be used to treat a range of therapeutic goals beyond independent mobility. For example, PPM training is a progressive treatment for postural control, strength, coordination as well as cognitive, language and social goals.

2) For maximum effectiveness, PPM training should begin as early as possible and be embedded within the various social settings typical of children. Early, embedded PPM is important such that mobility and socialization skills co-development.

3) Ride-on toy cars (aka 'ride ons') can address the need for early, socially-embedded PPM training to address a range of therapeutic goals. Compared with current PPM devices, ride ons provide a low cost, readily available PPM option. These relatively small sized, lightweight, child-friendly and affordable devices make them more easily used in home, classrooms and outdoor spaces typical of young children. Moreover, electrical and mechanical modifications allow clinicians and families to create a custom fit and dynamic treatment tool that provides the optimal mix of challenge and fun for children with a range of abilities and goals.

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

POSTER PRESENTATIONS

# Imaging

## 16 IS PHYSICAL ACTIVITY PARTICIPATION REDUCED AND INTERMUSCULAR ADIPOSE TISSUE ELEVATED IN CHILDREN WITH OSTEOGENESIS IMPERFECTA?

*Patrick Carter, Brianne Mulrooney, Michael Bober[1], Harshvardhan Singh, Lauren Davey[1], Christopher Modlesky*

[1]Department of Genetics, AI duPont Hospital for Children

Osteogenesis imperfecta (OI) is a genetic disorder associated impaired type I collagen production which leads to low bone mass, poor bone structure and a high rate of fracture. Because of their skeletal fragility, it is plausible that children with OI participate in a lower amount of physical activity. This would be problematic because physical activity is needed for adequate growth and development of bone. Furthermore, reduced physical activity is associated with an increase in the intermuscular adipose tissue (AT) depot which is linked to low bone mass and strength. The objective of this pilot study was to determine whether children with type I OI participate in less physical activity and have a higher quantity of intermuscular AT than typically developing children. Seven children with type I OI and seven typically developing children participated in this study. Magnetic resonance imaging was used to estimate intermuscular AT volume in the mid-thigh and bone structure and strength [i.e., cortical bone volume, polar moment of inertia (J) and section modulus (Z)] in the mid-femur. Physical activity was assessed using activity monitors. There were no group differences in age (p=0.723), height (p=0.179), or body mass (p=0.141). There were also no group differences in physical activity or intermuscular AT volume (p=0.872). Although not statistically significant, children with OI tended to have lower cortical volume (p=0.151), polar moment of inertia (p=0.125), and section modulus (p=0.095). The findings from this pilot study do not support the hypothesis that skeletal fragility is linked to reduced participation in physical activity and elevated intermuscular AT in children with type I OI.

## 17 A THREE-DIMENSIONAL MODEL FOR AVERAGE INTERVERTEBRAL DISC SHAPE AND ITS VARIATION WITH DEGENERATION

*J.M. Peloquin[1], J.H. Yoder[1], N.T. Jacobs[1], S.M. Moon[1], A.C. Wright[1], E.J. Vresilovic[2], D.M. Elliott[1,3]*

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Degeneration of the intervertebral disc is associated with low back pain, which is a prevalent and costly disease. The pathology of degeneration in large part represents altered mechanics and shape of the disc. Shape affects mechanics, and vice versa. However, no published model exists for a population-representative 3D disc shape. Previous studies have used 3D models derived from a single subject, or have published geometric statistics alone. The objective of this study, therefore, was to derive a quantitative 3D model for intervertebral disc shape and identify representative shapes for different stages of degeneration. Magnetic resonance images of 14 L3/L4 discs were used to build the model, and their degenerative state was assessed by Pfirrmann grading. The mean disc shape was calculated using signed distance functions, and principal components analysis was used to re-express the residual variability in an orthonormal basis. The first principal component, which expresses the majority of the population's shape variability, was correlated with degeneration ($R^2 = 0.50$, $p<0.01$). Geometrically, the first principal component represents lateral disc size. None of the other principal components were significantly correlated with degeneration. Overall, these results indicate that degeneration is primarily associated with increased axial area of the disc. The shape model can thus be used to generate population-average healthy and degenerate disc shapes.

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

POSTER PRESENTATIONS

# Methods & Modeling

## 18 CHANGE IN KNEE CONTACT FORCE WITH EXPERIMENTAL AND SIMULATED CHANGE IN BODY WEIGHT

*Brian A. Knarr, Joseph A. Zeni, Jill S. Higginson*

Background: Individuals with knee osteoarthritis typically present with increased body mass compared to age-matched individuals without knee pain. Greater body mass may increase compression forces experienced by weight bearing joints of the lower extremity. It has been suggested that abnormal and increased knee joint contact forces may expedite the rate of or initiate the loss of cartilage in these individuals, although the relationship between change in body mass and change in joint compression forces is largely unknown.

Purpose: The objective of this project is to evaluate the relationship between changes in body mass and changes in knee joint contact forces for an individual using musculoskeletal modeling. Additionally, we plan to compare the model predictions of knee joint contact force when body mass is changed experimentally as opposed within the model only.

Methods: Musculoskeletal simulations were built for two healthy subjects without knee pathology while walking at self-selected speed on an instrumented split-belt treadmill. Seven simulations were generated for each subject representing 100% body weight, +/-30% in 10% increments. A final simulation was built for each subject while they walked with a weighted vest representing a 16% increase in body weight. Regression equations were created for each subject to compare the change in body weight and change in knee joint contact force during the first half of stance.

Results: Significant linear relationships were found for each individual relating change in body mass and change in knee joint contact force. (Slope=2.92 R2=0.96, Slope=1.78 R2=0.99, respectively). The greatest increase in joint contact force occurred at +30% body weight (532N,471N, respectively).

Conclusion: Change in body mass is an important consideration when evaluating knee joint contact forces.

## 19 ARE INTERNAL-EXTERNAL ROTATIONAL MOMENTS IN ACL DEFICIENT SUBJECTS DIFFERENT THAN THOSE IN HEALTHY SUBJECTS?

*Amelia S. Lanier[1], Toran D. Macleod[2], Kurt Manal[1], Thomas S. Buchanan[1]*

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Impairment of the anterior cruciate ligament (ACL) is a common injury causing rotational instability of the knee joint. It is difficult to directly evaluate ACL-deficient patients in internal/external rotations due to risk of further injury. The aim of this study was to evaluate how ACL-deficient patients use internal/external rotational moments to stabalize their knees. We hypothesized ACL injured subjects would exhibit larger external rotation moments during knee extension when compared to healthy subjects. Ten subjects participated in this study; four (2 males, 2 females) had no history of knee injury and six (3 males, 3 females) sustained ACL rupture within 6 months prior to testing. All subjects were regular participants (> 50 hrs/year) in level I and II sports. A standing target matching protocol required subjects to position the cursor on a target consisting of two concentric circles representing anterior/posterior and medial/lateral shear forces and internal/external rotation moments. The limb controlling the cursor was called the mobilizer. The limb not controlling the cursor but still maintaining stability for the subject was called the stabilizer. External rotation, negative transverse knee moment, of the stabilizing limb during knee extension was observed to be higher in ACL-d subjects when compared to healthy subjects. We believe that the standing target matching protocol is effectively challenging ACL deficient subjects in internal and external rotations in a safe and controlled manner. The ACL deficient limb is exhibiting higher external rotation moments during knee extension as a preventative measure in the absence of the passive restraint provided by the ACL.

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

## 20 BIAXIAL TENSILE TESTING AND CONSTITUTIVE MODELING OF HUMAN SUPRASPINATUS TENDON

*Spencer E. Szczesny[1], John M. Peloquin[1], Daniel H. Cortes, Jennifer Kadlowec[2], Louis J. Soslowsky[1], Dawn M. Elliott*

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The heterogeneous composition, collagen fiber organization and mechanical properties of the supraspinatus tendon (SST) offer an opportunity for studying the structure-function relationships of fibrous musculoskeletal connective tissues. The objective of this study was to evaluate the contribution of collagen fiber organization to the planar tensile mechanics of the human SST. This was accomplished by fitting biaxial tensile data with a structural constitutive model that incorporates a sample-specific angular distribution of nonlinear fibers. Biaxial testing was employed to avoid the limitation of non-physiologic traction-free boundary conditions present during uniaxial testing. Samples were tested under a range of boundary conditions with simultaneous monitoring of collagen fiber orientation via polarized light imaging. The experimental data were input into a hyperelastic constitutive model incorporating the contributions of the uncrimped fibers. The model fit the longitudinal stresses well and was successfully validated. The transverse stresses were fit less well with greater errors observed for less aligned samples. Additional strain energy terms representing fiber-fiber interactions are likely necessary to provide closer approximation of the transverse stresses. This approach demonstrated that the longitudinal tensile mechanics of the SST are primarily dependent on the moduli, crimp, and angular distribution of its collagen fibers.

POSTER PRESENTATIONS

# Motor Control

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

## 21 CAN AUDITORY PACING IMPROVE PERIOD STABILITY AND TEMPORAL CONSISTENCY IN CHILDREN WITH AND WITHOUT CO-EXISTING DCD AND DYSLEXIA?

*Daphne Golden, Lynn Liang, Nancy Getchell*

Some of the more common deficits that children with dyslexia and developmental coordination disorder (DCD) exhibit are timing and automatization deficits in motor skills, suggestive of cerebellar dysfunction. Auditory pacing during a motor task as an intervention may aid performance by providing external feedback to augment internal timing representations. Method: Fifty four children (21 typically developing and 33 dyslexic performed a dual motor task (clapping while walking) alone and with a metronome signal. They were divided into sub-groups based on their MABC scores. Stability measures included interclap (ICI) and interheel strike (IHI) intervals across trial blocks. Consistency measures included coefficient of variation of ICI/IHI. Results: Children with co-existing DCD and dyslexia statistically differed from other groups in ICI and IHI period stability. Further, differences existed from pre to post test in IHI for DCD (.03) and DCD at risk (.036) groups, and in ICI for DCD at risk ($p = .0002$). In terms of temporal consistency, group differences existed in ICI ($p = .001$); post hoc tests revealed the DCD group differed from others. Dyslexic groups not at risk for DCD differed between pre and post test on ICI. In IHI, no group differences existed, and two dyslexic groups (>30%tile of MABC and at risk for DCD) changed from pre to post test. These results suggest that the ability to stabilize both arm and leg period across trials may be aided by using an auditory pacing signal. At the same time, a short term auditory pacing intervention does not seem to improve temporal consistency within a trial in individuals with DCD and coexisting DCD.

## 22 TRANSCRANIAL MAGNETIC STIMULATION AS A MEASURE OF LOWER EXTREMITY CORTICOMOTOR EXCITABILITY: TEST-RETEST RELIABILITY AND CHANGES WITH WALKING

*Jacqueline A. Palmer, Trisha Kesar, Stuart A. Binder-Macleod*

Introduction: Transcranial magnetic stimulation (TMS) is a technique that can be used to measure the excitability of the corticospinal connections. We are interested in investigating changes in corticospinal excitability of lower extremity muscles that occur with neuro-rehabilitation interventions such as functional electrical stimulation and treadmill training. As a first step, the aims of this pilot study are to (1) determine the test/retest reliability of TMS-derived measures of corticomotor excitability in able-bodied individuals, and (2) investigate the changes in corticospinal excitability that occur with treadmill walking.

Methods: Able-bodied individuals have been recruited for this study. Input-output curves between the TMS intensity versus peak electromyographic (EMG) responses from bilateral lower extremity muscles (tibialis anterior and soleus) were used to determine 3 TMS parameters: the threshold intensity, recruitment curve slope, and the peak EMG response. ICCs were used to determine test-retest reliability of the TMS parameters collected during two baseline tests (separated by sitting). We also assessed for changes in TMS parameters after 8-minutes of treadmill walking.

Results: Preliminary results show good test-retest reliability of TMS parameters within a session. Our preliminary findings also show a rightward shift in the input-output curves after walking, suggesting a decrease in corticomotor excitability after 8-minutes of treadmill walking.

Conclusions and Implications: Results of this study support the potential use of measuring changes in corticospinal excitability with walking and may help us identify mechanisms for improvements following rehabilitation. Future directions of this study will look at cortical excitability changes with a novel treadmill training intervention in stroke individuals.

## 23 SCAPULAR CONTRIBUTION TO MOTION IN CHILDREN WITH BRACHIAL PLEXUS BIRTH PALSY

*Stephanie Russo, Scott Kozin[1], Dan Zlotolow[1], James Richards*

[1]Shriners Hospital for Children

Brachial plexus birth palsy (BPBP) occurs in approximately 0.4 to 4.6 of every 1000 live births and is categorized by affected nerves (C5-C6: Erb's palsy; C5-C7: extended Erb's palsy). While some infants recover, approximately one third have sustained impairment. BPBP affects development and control of the scapula. The modified Mallet test is used clinically to evaluate function in BPBP patients; however, it provides no information regarding the scapulothoracic (ST) or glenohumeral (GH) contributions to shoulder motion. Shoulder function in 12 children with Erb's palsy, 8 children with extended Erb's palsy and 7 unaffected limbs was analyzed. Markers were placed on the scapula, the upper arm and the torso to create scapula, humerus and trunk coordinate systems. Marker locations were recorded with subjects in a neutral position and each of the modified Mallet positions. Twenty-one ST, GH, humerothoracic and acromion process displacement variables were significantly different ($p<0.05$). Stepwise discriminant function analysis classified subjects into 1 of the 3 groups (Erb's, extended Erb's and unaffected) with 96.2% accuracy using 5 of the 21 significant variables. BPBP subjects utilized increased ST motion to control arm position, but no consistent strategy was identified between subjects. The variations in ST and GH contributions to movement among BPBP subjects suggest that differences in underlying nerve injuries and/or medical interventions produce unique patterns of shoulder impairment. This supports the importance of considering ST and GH function of each patient during treatment planning.

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

POSTER PRESENTATIONS

# Osteoarthritis

## 24 SIT TO STAND MECHANICS AFTER SYMMETRY TRAINING FOR PATIENTS AFTER TOTAL KNEE ARTHROPLASTY

*Sumayeh Abujaber, Joseph A. Zeni, Lynn Snyder-Mackler*

Background: After total knee arthroplasty (TKA), patients typically demonstrate persistent kinetic and kinematic asymmetries. During a sit to stand task (STS), subjects who underwent TKA demonstrated altered movement patterns that unloaded the operated limb and shifted the weight to the non-operated side, leading to excessive loading in the non-operated limb. This loading pattern may predispose the joints of the non-operated limb to OA progression.

Purpose: The purpose of this study was to evaluate the effectiveness of adding symmetry training into post-operative rehabilitation after TKA. The first aim was to examine longitudinal changes in STS mechanics in subjects who received symmetry training along with strengthening exercise after TKA. The second aim was to evaluate the biomechanical differences between subjects who received symmetry training and subjects who only received standard of care after TKA.

Methods: All subjects underwent 3D motion analysis of STS task. Subjects in the symmetry group who received symmetry training were tested before surgery, 3 months, and 6 months post-surgery while subjects in the other group were tested only 6 months after surgery. The outcome measures used were the symmetry ratio of peak sagittal knee moment during standing, peak vertical ground reaction force during standing and sitting movements and vertical ground reaction force while standing.

Results: Subjects in symmetry group had improved symmetry ratios in all outcome variables across time. The Symmetry group was more symmetrical compared with standard of care group at the 6 months-time point.

Conclusion: The improvements in biomechanical symmetry suggest the need to include elements that address the symmetry component in addition to strengthening in the rehabilitation programs for patient after TKA.

## 25 A METABOLOMICS APPROACH TO DISCOVERING NOVEL BIOMARKERS IN THE PROGRESSION OF OSTEOARTHRITIS

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Osteoarthritis (OA) is a common joint disorder with high prevalence in adult populations over the age of 50. Characterized by severe pain and disability, OA not only negatively impacts the quality of patients' lives, but also results in enormous healthcare costs to our society. The progression of OA is complex, in which the critical balance between cartilage synthesis and degradation becomes disrupted, resulting in loss of articular cartilage at diarthrodial joints. Although the failure of normal articular chondrocyte (cartilage cell) homeostasis is believed to play an important role in the loss of cartilage maintenance and degradation, the cellular and molecular mechanisms that shift this imbalance are poorly understood. Additionally, OA is often diagnosed at a stage of late progression, characterized by severe joint destruction, which leaves the patient with limited choices of effective non-surgical treatments that only seek to alleviate symptoms and do not intervene to slow, stop, or reverse the joint damage. Therefore, our OA research is focused on understanding the mechanisms involved in the early progression of the disease through generating chondrocyte metabolic profiles. These studies will not only enhance our understanding of the biochemical pathways involved in the progression of OA, but will also identify non-protein biomarkers that can be used for early detection and diagnosis of OA. Therefore, non-surgical treatments can be effectively administered to patients prior to permanent and debilitating joint damage.

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

## 26 NOVEL INTERVENTION IMPROVES KNEE FUNCTION POST-TOTAL KNEE ARTHROPLASTY

*Portia Flowers, David Logerstedt, Lynn Snyder-Mackler, Joseph Zeni*

Following total knee arthroplasty (TKA), the most common joint to be replaced is the contralateral cognate joint. Adaptations to reduce knee pain due to unilateral osteoarthritis (OA) may lead to increased loading on the contralateral knee, persisting even after TKA and conventional rehabilitation. Abnormal dynamic joint loading is suggested to be a key factor in OA joint disease progression. The objective of this study was to evaluate a rehabilitation protocol that restores symmetrical strength and movement patterns after primary TKA. Sixteen individuals with knee OA scheduled for unilateral TKA underwent gait motion analysis preoperatively and 3 months after surgery. Subjects participated in 4-6 weeks of postoperative physical therapy, 2-3 sessions per week. Ten of the subjects participated in outpatient physical therapy that focused on symmetrical loading during functional activities and progressive strengthening (Symmetry group), while the remaining six subjects received usual care. Interlimb symmetry feedback was provided to the symmetry group by a custom computer program that used a Wii Balance Board as input during functional tasks and during strengthening exercises via leg press machine with dual integrated force plates under each foot. Qualitative comparisons were made between subjects in both groups. After rehabilitation, symmetry ratios for knee flexion excursion, flexion moment, and peak flexion angle improved by 30%, 20%, and 10%, respectively, compared to preoperative values. Symmetry subjects also had greater flexion angles and moments than the usual care group. However, symmetry subjects did not demonstrate a reduction in the adduction moments in the contralateral knee compared to the usual care group. This novel protocol seems to improve the biomechanics of the operated limb and symmetrical movement patterns between both limbs, which are promising developments for rehabilitation protocols following primary TKA.

## 27 DISEASE SEVERITY AND SEX DIFFERENCES IN PATIENTS WITH KNEE OSTEOARTHRITIS

*David Logerstedt, Joseph Zeni, Lynn Snyder-Mackler*

Women are more likely to have and greater severity of knee osteoarthritis (OA) than men. Multiple outcome measures should be measured in patients with knee OA as part of a patient profile. Little is known about disease severity and sex differences on knee function in patients with knee OA. The purpose of this study is to quantify the differences in performance and self-report outcomes between disease severity and sexes.

Methods: A total of 348 patients were assessed for this study: 86 patients who were seeking non-operative management of knee OA (NON-OP), 199 patients who were scheduled for total knee arthroplasty (PRE-TKA), and 63 healthy controls (CON). Similar numbers of men and women were evaluated. Patients were tested using 5 performance and 3 self-report outcomes. Mixed design ANOVA was used to evaluate the interaction between sex and disease severity in outcomes measures. Post-hoc tests were used to determine where the differences occurred.

Results: All performance-based tests showed a main effect of sex ($p=0.039$) and disease severity ($p<0.001$) with women having worse performance than men. PRE-TKA had worse performance scores than NON-OP, who had worse performance scores than CON. For KOS-ADLS and PCS, an interaction between sex and severity ($p<0.032$) was seen. Men had lower KOS-ADLS and PCS scores based on the level of disease severity, while women with knee OA had lower KOS-ADLS and PCS scores than CON.

Conclusions: Men had progressive decrements in performance-based and self-report outcomes as OA disease progressed. Despite progressive decrements in performance measures, women had larger perceived changes in their knee function once they decided to seek treatment for knee OA and had similar perception of their function once they scheduled for TKA.

## 28 ASSOCIATION BETWEEN ISOKINETIC AND FUNCTIONAL QUADRICEPS POWER AFTER TOTAL KNEE ARTHROPLASTY

*A.R. Marmon, L. Snyder-Mackler*

Quadriceps weakness is common in individuals with knee osteoarthritis and is exacerbated in the early period after total knee arthroplasty (TKA). Weakness contributes to the lower extremity functional deficits. To further examine the influence of quadriceps weakness on performance of functional tasks, we examined how the capacity to develop force by the quadriceps is associated with its use during a functional task. Purpose. To examine the associations between peak knee extensor power generation during the stance phase of gait and maximal power generated during isokinetic testing. Methods. Six subjects (women= 2), 6 mos after TKA, were assessed using motion analysis to determine the peak knee extensor power generated during the stance phase of gait. Subject also completed maximal voluntary isokinetic knee extension contractions at three velocities (60, 90, 120 deg/s). Regression analyses were used to assess the association between the peak power generated during the stance phase of gait and during isokinetic testing. Results. The peak knee extensor power generated during the stance phase of gait was best fit using an exponential regression with peak knee extensor power during isokinetic testing (60 deg/s $R^2$= 0.620; 90 deg/s $R^2$= 0.629; 120deg/s $R^2$= 0.775). Conclusions. The peak knee extensor power produced during the stance phase of gait was correlated with the maximal power produced during isokinetic contractions at all three velocities tested. The findings here are clinically relevant because, motion analysis is not readily available or cost effective for functional assessments of individuals with knee osteoarthritis or patients after TKA; however, power production during isokinetic testing is more practical and can provide additional insight into how patients utilize their quadriceps during gait.

## 29 LOADING PATTERNS DURING A STEP-UP-AND-OVER TASK IN INDIVIDUALS FOLLOWING TOTAL KNEE ARTHROPLASTY

*Federico Pozzi[1], Ali Alnhadi[1,2], Joseph Zeni Jr.[1], Lynn Snyder-Mackler[1]*

[1]University of Delaware
[2]King Saud University

Total Knee Arthroplaties (TKAs) successfully reduce pain, but patients continue to exhibit movement asymmetries after surgery. Asymmetrical movement patterns have been found during walking and sit-to-stand tasks, and are partially related to the quadriceps strength of the operated limb. The aim of this study was (1) to compare loading parameters between operated and non-operated limbs in subjects following unilateral TKA during a step-up-and-over task; and (2) investigate the relationship between quadriceps strength and limb loading during the same task. 13 Individuals with unilateral TKA were evaluated for this study. Participants were examined during a step-up-and-over task. Kinematic and kinetic data were collected during the task. Quadriceps strength was measured with an electromechanical dynamometer. Qudriceps strength and kinematic and kinetic parameters were compared between operated and non-operated limbs. The operated limb was significantly weaker and was significantly more impaired than the non-operated limb. The knee of the operated limb had less flexion excursion during the weight acceptance phase ($p = .021$) and lower rate of energy absorption at touchdown. When assessing differences between limbs for the stepping limb, the operated limb presented with less knee flexion moment during the descent from the step ($p = .018$). Poor control of the descent phase by the stepping limb appeared to increase loads on the landing limb. Significant asymmetries were found between the operated and non-operated limbs during the landing and stepping portions of the step-up-and-over task, which may play a role in overloading the non-operated limb. Persistent excessive loading during functional activities might facilitate the degenerative process in the contralateral limb and increase risk of contralateral TKA.



# *Denotes Poster #*

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## 30 RELATIONSHIP BETWEEN HAMSTRING AND QUADRICEPS STRENGTH AND KOOS SCORE IN PATIENTS WITH KNEE OSTEOARTHRITIS

*L.M. van der Post, A.T. Collins, J.S. Higginson*

The quadriceps and hamstring muscles are the major contributors to knee joint stability and play a large role in activities of daily living. While many studies have assessed the relationship between quadriceps strength and knee osteoarthritis (OA), few studies have investigated the connection between hamstring strength and knee OA. To our knowledge, this study is the first to relate pain, symptoms, functionality, and knee-related quality of life as assessed through the Knee Injury and Osteoarthritis Outcome Score (KOOS) to quadriceps and hamstring strength in knee OA. Thirty-four patients with knee OA were studied. To qualify, patients had to have a Kellgren-Lawrence score ≥ 2. Patients completed the KOOS survey and had their quadriceps and hamstring strength evaluated for their test limb using an isokinetic dynamometer. Quadriceps strength (mean=1.38 Nm/kg) on the OA side and KOOS score (mean=65.78) showed a relatively strong correlation ($r=0.51$ $p \leq 0.001$). A correlation between hamstring strength (mean=0.81 Nm/kg) on the OA side and KOOS score was also seen ($r=0.37$ $p=0.023$). Those with stronger quadriceps and hamstring muscles reported less pain and greater functionality on their respective OA limb. In knee OA, the relationship between quadriceps and hamstring strength to KOOS scores is clinically important in that it can provide clinicians with an easily accessible indicator of patient's lower limb strength.

## 31 A MODEL FOR THE CONTACT MECHANICS AND LUBRICATION OF CARTILAGE DURING SLIDING

*B. Henry, E.D. Bonnevie, V.J. Baro, L. Wang, D.L. Burris*

Healthy cartilage provides extremely low friction coefficients and nearly wear-free sliding over decades of continuous use. Although the mechanisms of load support and lubrication remain current topics of debate, it has been established that the unique biphasic structure of the material is a prerequisite for both. In this paper, we discuss the important relationships between tissue structure/composition, mechanics, and lubrication, especially as they pertain to osteoarthritis (OA). We have developed and tested a contact mechanics model for predicting the tribo-mechanical response of tissue with known material properties or extracting material properties from the measured tribo-mechanical response. We will report on the properties of healthy and degraded tissues and discuss the functional consequences of chemical and mechanical degradation. Finally, we place the results within the context of OA research.

POSTER PRESENTATIONS

# Robotic Training

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## 32 DEGREES-OF-FREEDOM OF A ROBOTIC EXOSKELETON AND THE HUMAN ADAPTATION TO TEMPLATES OF NEW GAIT

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

This poster addresses an important question in the field of rehabilitation robotics that can help engineers to develop and optimize future gait training robotic exoskeletons. This question can be posed as follows: Do the exoskeleton's degrees-of-freedom at the pelvis affect human adaptation to new gait templates? More specifically, would additional degrees-of-freedom in the exoskeleton that allow the human trunk to translate and rotate, and the hips to abduct/adduct increase human gait adaptation with an exoskeleton?

We explored these questions using the Active Leg EXoskeleton (ALEX II) which was designed and fabricated at the University of Delaware. Human studies were performed by locking appropriate joints of ALEX~II so that it mimiced the degrees-of-freedom of Lokomat, and the ALEX~I and ALEX~II. Healthy subjects walked at self-selected speeds and were trained with a new gait template, scaled down from their normal template. During the training, they received an 'assist-as-needed' force from the exoskeleton and intermittent visual feedback. The measure of performance used in the study was the error between the actual foot path and the desired foot path following training.

The ALEX~II and Lokomat-like groups showed similar results following the training, while ALEX~I had poorer performance. This result was unexpected as ALEX~I has an intermediate level of freedom allowed at the pelvis compared to the other two configurations of the machine. Further work needs to be done to understand the exact relationship between the degrees-of-freedom allowed at the pelvis and gait training.

# Notes

9th Annual Biomechanics Research Symposium

# Schedule of the Day

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