Welcome students, faculty and friends!

It’s my pleasure to welcome you to the 11th annual CBER day research symposium - my first as the newly-appointed director of the center – and I look forward to seeing friends and colleagues, new and old, and making new acquaintances. As in years past, this symposium puts on display the excellent Biomechanical research being conducted by the students, faculty and research professionals at the University of Delaware.

I am especially pleased to announce that our keynote speaker this year is Dr. Alberto Esquenazi, MD. Dr. Esquenazi is the John Otto Haas Chair of the Department of Physical Medicine and Rehabilitation at Albert Einstein Medical Center, Chief Medical Officer of MossRehab/Einstein, as well as holding numerous other positions at institutes in the southeastern Pennsylvania region. He will speak on the impact and some of the potential obstacles associated with careers in Biomechanics and Bioengineering.

As we continue to celebrate the interdisciplinary and collaborative spirit upon which CBER was founded, I welcome your help and participation in moving the center forward, and navigating the new challenges ahead. I would also like to acknowledge support from the Delaware Rehabilitation Institute, which sponsored the student awards presented at the conclusion of today’s events.

Thank you all for your part in making today another successful CBER day research symposium.

ACKNOWLEDGEMENTS

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Elaine Nelson
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All student awards are sponsored by the Delaware Rehabilitation Institute

Keynote Lecture

“Biomechanics, a window into Medicine”

Alberto Esquenazi, MD

Biomechanics has been linked to the medical sciences since its origins, in my opinion Leonardo da Vinci could be recognized as the first biomechanician because he was the first to study anatomy in the context of mechanics. He analyzed muscle forces acting along lines connecting origins and insertions and studied joint function. He also intended to mimic some of these features in many machines he designed. One example, was the study of birds during flight in his search to find means to help humans fly. The study of biomechanics ranges from the inner workings of a cell to the movement and development of limbs, to the mechanical properties of soft tissue, and bones. In this presentation my aim is to showcase how your chosen career path has positively impacted the lives of many in the field of rehabilitation medicine, also to point at concepts where communication was not clear and the development had limited application or was rejected. The presentation will make use of examples where bioengineering was applied to improve care or has played a key role in developing substitutes to improve human function and maybe plant small seeds for new ideas. I hope to encourage you to collaborate with others in medicine, the potential users and engineering to further advance what is possible as new technology becomes available.

BRIEF BIOGRAPHY

Dr. Esquenazi received his medical degree in Medicine and Surgery from Universidad Nacional Autonoma (the National Autonomous University of Mexico), in Mexico City. He completed his residency in physical medicine and rehabilitation at the Temple University / MossRehab program in Philadelphia, and a fellowship in gait analysis and prosthetic research at MossRehab. Dr. Esquenazi’s research focuses on gait analysis, limb prosthetics, orthotics, and spasticity management. From his extensive knowledge, he has developed electronic educational programs on functional anatomy, spasticity, and muscle overactivity. Dr. Esquenazi has published widely in peer reviewed journals and has authored more than 40 book chapters. His research in spasticity management, gait, orthotics, and limb prosthetics has led him to be an invited speaker at national and international events. Dr. Esquenazi is a member of many national and international professional, educational, and research societies and review panels, including Chaining the National Advisory Board on Medical Rehabilitation Research of the National Institute of Child and Human Development of the National Institutes of Health. He is Past-President of the American Academy of Physical Medicine and Rehabilitation and a member of the board of the International Society of Rehabilitation Medicine. He is the recipient of prestigious national and international awards for his clinical, research and educational efforts and has been recognized for several years among “Top Doctors” in Philadelphia magazine and America’s Top Doctors.
## Schedule of the Day

<table>
<thead>
<tr>
<th>TIME</th>
<th>WHAT</th>
<th>WHERE</th>
</tr>
</thead>
<tbody>
<tr>
<td>8:30</td>
<td>BREAKFAST &amp; POSTER SET-UP</td>
<td>STAR CAMPUS-GLASS ATRIUM</td>
</tr>
<tr>
<td>9:00</td>
<td>WELCOME &amp; INTRODUCTORY REMARKS</td>
<td>STAR CAMPUS-GLASS ATRIUM</td>
</tr>
<tr>
<td>9:15</td>
<td>PODIUM SESSION 1</td>
<td>STAR CAMPUS-GLASS ATRIUM</td>
</tr>
<tr>
<td>10:45</td>
<td>BREAK</td>
<td></td>
</tr>
<tr>
<td>11:00</td>
<td>POSTER SESSION 1 (ODD #S)</td>
<td>STAR CAMPUS-MAIN CONCOURSE</td>
</tr>
<tr>
<td>12:00</td>
<td>LUNCH</td>
<td>STAR CAMPUS-ATRIUM</td>
</tr>
<tr>
<td>1:00</td>
<td>KEYNOTE: DR. ALBERTO ESQUENAZI</td>
<td>STAR CAMPUS-GLASS ATRIUM</td>
</tr>
<tr>
<td>2:00</td>
<td>POSTER SESSION 2 (EVEN #S)</td>
<td>STAR CAMPUS-MAIN CONCOURSE</td>
</tr>
<tr>
<td>3:00</td>
<td>PODIUM SESSION 2</td>
<td>STAR CAMPUS-GLASS ATRIUM</td>
</tr>
<tr>
<td>4:30</td>
<td>AWARDS SESSION</td>
<td>STAR CAMPUS-GLASS ATRIUM</td>
</tr>
</tbody>
</table>

## Podium Presentations

### Session 1

**P.10** WALKING SPEED AND STEP LENGTH ASYMMETRY MODIFY WALKING ECONOMY AFTER STROKE
Louis Ahmed, Jacqueline Palmer, Stuart Binder-Macleod, Ryan Pohlig, Darcy Reisman

**P.10** MOVEMENT ASYMMETRIES DURING SIT TO STAND TASK BEFORE AND AFTER TOTAL HIP ARTHROPLASTY
Sumayeh Abujaber, Federico Pozzi, Joseph Zenz Jr.

**P.11** EVALUATION OF TENDON INJURIES USING VISCOELASTIC PROPERTIES MEASURED VIA ULTRASOUND IMAGING: PRELIMINARY RESULTS
Daniel Cortes, Stephen Supdani, Karin Silbernagel, Thomas Buchanan, Dawn Elliott

**P.11** FINITE ELEMENT PREDICTIONS OF STRAIN ATTENUATION IN PROTEOGLYCAN-RICH MICRODOMAINS
John Deluca, Wajif Han, John Pelizoux, Randy Duncan, Robert Mauck, Dawn Elliott

**P.12** A BIOMECHANICAL-BASED MODEL FOR PREDICTING PROPULSIVE FORCES DURING ABLE-BODIED GAIT
Marloam Ho, Brian A. Kneer, M.S. Higginson, Stuart A. Binder-Macleod

**P.12** PEAK MEDIAL COMPARTMENT CONTACT FORCES (PMCCF) IN THE KNEE AFTER ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION (ACLRI) – 5 YEAR FOLLOW UP

### Session 2

**P.14** ONE-DIMENSIONAL SPATIOTEMPORAL IMAGE CORRELATION SPECTROSCOPY-BASED QUANTIFICATION OF MICROFLUIDIC FLOWS
Brian Graham, Christopher Price

**P.14** KNEE FUNCTIONAL PERFORMANCE AND PATIENT-REPORTED MEASURES AT SIX MONTHS AFTER ACL RECONSTRUCTION PREDICTS RETURN TO PREINJURY ACTIVITY LEVEL AT TWO YEARS AFTER ACLR
Z. Nasravesh, D. Logansted, K. White, L. Snyder-Mackler

**P.15** SYSTEMATIC VARIATION OF MATERIAL AND TRIBOLOGICAL PROPERTIES OF CARTILAGE IN THE BOVINE STIFLE JOINT
Axel Moore, David L. Burris

**P.15** VISION BASED RAPID MODELING OF PERSONALIZED REHABILITATION DEVICES
Qiaosong Wang, Jingyi Yu

**P.16** ASSOCIATION OF JOINT MOMENTS AND CONTACT FORCES WITH EARLY KNEE JOINT OSTEOARTHRITIS AFTER ACL INJURY AND RECONSTRUCTION
J. Wellnacht, E. S. Gardner, K. Manal, M. J. Kee, T. Buchanan, L. Snyder-Mackler

**P.16** DYNAMIC STABILITY DURING DUAL-TASK TREADMILL WALKING IN HEALTHY ADULTS
Pei-Chun Kao, Kelly Seymour, Morgan Kamanidze, Christopher Higginson, JF Higginson

Denotes Podium #
Bone, Cell and Cartilage

Poster Presentations

P.18 THE EFFECT OF DELAYED LOADING ON IN VITRO MICROFRACTURE MODEL
Mirre Park, Mandepura Charttey, Anna Gonye, Brandon Zimmermann, Lynn Snyder-Mackler, X. Lucas Lu

P.18 BISPHOSPHONATE RESCUE ARTICULAR CARTILAGE FROM TRAUMA DAMAGE
Mirre Park, Yiu Zhou, Liyun Wang, X. Lucas Lu

P.19 QUANTIFYING DIFFUSION IN POROUS VISCOELASTIC MATERIALS USING CORRELATION SPECTROSCOPY
Jancy Shen, Christopher Price

P.19 IS THERE A RELATIONSHIP BETWEEN ADIPOSITY OF THE LOWER LIMB AND TRANSMISSION OF A HIGH-FREQUENCY, LOW-MAGNITUDE VIBRATION ACROSS THE TIBIA AND FEMUR IN CHILDREN WITH SPASTIC CEREBRAL PALSY?
Nishant Singh, Danal Whitney, Freeman Miller, Christopher Modlesky

P.20 SPONTANEOUS CALCIUM RESPONSE OF IN SITU CHONDROCYTE AND RELATED PATHWAYS
Yiu Zhou, Jie Ma, Liyun Wang, X. Lucas Lu

P.20 EFFICACY OF BOUNDARY LUBRICATIONS ON TMJ DISC AND CONDYLAR CARTILAGE
Brandon K. Zimmerman, David L. Burns, X. Lucas Lu

P.21 IMAGING AND QUANTIFYING MUSCLE-BONE CROSSSTALK THROUGH INTRACUTANEOUS PERIOSTEUM
Xiaohan Lai, Christopher Price, X. Lucas Lu, Liyun Wang

P.21 SEMITENDINOSUS TENDON ELASTICITY RECOVERY POST ACL RECONSTRUCTION
Stephen M. Suydam, Thomas S. Buchanan

P.22 MECHANICAL FUNCTIONS OF SUPERFICIAL ZONE IN TAIWAN CONDYLAR CARTILAGE
Lehanon Ruggiero, Kelsey Devlin, Brandon Zimmerman, X. Lucas Lu

P.22 IN VIVO RESPONSE OF TYPE 1 DIABETIC BONE TO MECHANICAL LOADING DEPENDS ON GENDER AND/OR DISEASE SEVERITY
Aruh Panjali, Xiaoyu Dave Gu, Xiaohan Lai, Hong Zhang, Mia Lao Thi, Christopher Price, Liyun Wang

P.23 FUNCTIONAL PROGRESSION AND RETURN TO ACTIVITY AFTER ACL IN SOCCER AND NON-SOCCEER ATHLETES
Amelia Arundale, Lynn Snyder-Mackler

P.23 TRENDS IN PEAK LOWER EXTREMITY JOINT POWERS DUE TO CHANGES IN WALKING SPEED AND BODY WEIGHT SUPPORT
Anush Elbahrami, Seryn R. Goldberg, Steven J. Stanhope

P.23 FUNCTIONAL STATUS AND RETURN TO SPORT RATES FOR POTENTIAL COPIERS AND NON-COPIERS 2 YEARS AFTER ACLR
Matt Failla, David Logerstedt, Lynn Snyder-Mackler

P.24 PRE-OPERATIVE PREDICTORS OF CONTRALATERAL TKA FOLLOWING UNILATERAL TOTAL KNEE ARTHROPLASTY
Portia Flowers, Joseph Zeri, Jr., Lynn Snyder-Mackler

P.24 CAN FREE MOMENT BE USED TO EFFECTIVELY CHALLENGE SUBJECTS’ ROTATIONAL LOADING AT THE KNEE?
Amelia Lanier, Kurt Mansel, Thomas Buchanan

P.25 FUNCTIONAL KINEMATIC CHANGES IN GAIT DUE TO DUAL-TASKING
Kelly Seymour, Morgan Karmadze, Christopher Higginson, Jil Higginson

P.25 THE RELATIONSHIP BETWEEN FEAR AND FUNCTION IN THE ACL DEFICIENT KNEE
Ryan Zarychansky, Matthew Fialka, David Lagrue et al

P.26 KINETIC AND KINEMATIC CHANGES IN GAIT DUE TO ANKLE PLANTAR FLEXORS DUE TO AGE AND SPEED
Amy Bucha, Jil Higginson

P.26 EFFECTS OF ARM PROXIMAL AND DISTAL MUSCLES FATIGUE ON FORCE COORDINATION IN MANIPULATION TASKS
Nicolai Emge, Mehmet Uysal, Mandy Bakirov, Thomas Kaminski, Todd Royer, Shoahban Jari

P.27 PHYSICAL THERAPY TREATMENT IMPROVES PATIENT PERCEIVED KNEE FUNCTION AFTER ACL INJURY
Kevin Lapham, Kathleen White, Lynn Snyder-Mackler

P.27 SHORT TERM EFFECT OF EXERGAMING ON PHYSICAL ACTIVITY LEVELS AND EXECUTIVE FUNCTION IN CHILDREN WITH AND WITHOUT AUTISM SPECTRUM DISORDER: PRELIMINARY RESULTS
Daphne Golden, Danielle Brambley, Nancy Getchell

Gait

P.28 OSTEOPOROSIS: BONE LOSS IN EARLY POST-TRAUMATIC OSTEOMALLICITY; IMPLICATIONS FOR PHARMACOLOGICAL TREATMENT
Michael David, Christopher Price

P.29 TISSUE, CELLULAR, AND MOLECULAR EFFECTS IN EARLY POST-TRAUMATIC OSTEOARTHRITIS; IMPLICATIONS FOR PHARMACOLOGICAL TREATMENT
Michael David, Christopher Price

P.29 KNEE STIFFNESS REGULATION CHANGES WHEN STARTED AT DIFFERENT TIMES
L. Wu, C. S. Sevani, B. L. Walsh

P.30 NEUROMUSCULAR IMPROVEMENTS FOLLOWING A SPEED-BASED CYCLING INTERVENTION
Mario Bellumori, Christopher A. Knight

Osteoarthritis

P.31 STRATEGIES TO IDENTIFY NOVEL BONE BIOMARKERS FOR EARLY DETECTION OF OSTEOARTHRITIS
Radhaj P. Srivastava, Angela R. Segmüller, Randall L. Duncan, Catherine K. Safar

P.31 THE TRADE-OFF BETWEEN HIP FLEXORS AND ANKLE PLANTAR FLEXORS DUE TO AGE AND SPEED
Amy Bucha, Jil Higginson

Motor Control
PODUM PRESENTATIONS // SESSION 1

Session 1

**Stroke and Brain**

**P.38** THE BASELINE ACTIVITY IN THE PREFRONTAL CORTEX IN HEALTHY PARTICIPANTS: THE EFFECTS OF EYES CONDITION
Ling-Yin Liang, Jia-Jin Jason Chen, Patricia A. Shewokis, Nancy Getchell

**P.38** A STRENGTH ENHANCEMENT PARADIGM FOR PRESCRIPTION OF PASSIVE-DYNAMIC ANKLE-FOOT ORTHOSES FOR INDIVIDUALS POST-STROKE
Elisa S. Arch, Darcy S. Reisman, Steven J. Stanhope

**P.39** THE RELATIONSHIP BETWEEN THE SPATIOTEMPORAL GAIT ASYMMETRIES AND WALKING ACTIVITY IN INDIVIDUALS POST STROKE
Menki Chen, Kelly Daniels, Tamara Wright, Margaret Roos, Evan Matthews, William Farquhar, Darcy Reisman

**P.39** CHANGES IN MUSCLE CONTRIBUTION TO SUPPORT AND PROPULSION POST GAIT-RETRAINING IN STROKE VICTIMS
Reza Khoeilar, Jill S. Higginson

**P.40** THE RELATIONSHIP BETWEEN WALKING SPEED AND INTENSITY OF DAILY WALKING ACTIVITY IN INDIVIDUALS POST-STROKE
Brian A. Knarr, Margaret A. Roos, Darcy S. Reisman

**P.40** CHANGES IN FUNCTIONAL ROLES OF POST-STROKE HIP MUSCLES BETWEEN HOUSEHOLD AND COMMUNITY AMBULATORS
John Ramsay, Thomas Buchanan, JKL Higginson

**P.41** FACTORS THAT ATTRIBUTE BODY WEIGHT THROUGH A TREADMILL TRAINING INTERVENTION IN POST-STROKE INDIVIDUALS
Claire Buthevat, Tamara Wright, Louis Awad, Darcy Reisman, Stuart Binder-Macleod

**P.41** LINEAR ACCELERATION OF THE HEAD DURING PURPOSEFUL HEADERS IN MALE AND FEMALE COLLEGIATE SOCCER PLAYERS
Nathaneal Roud, Jocelyn Gaccese, Thomas Kaminski

**Robotics**

**P.43** DESIGN AND CONTROL OF BIO-INSPIRED LEGGED ROBOTS
Alex Revell, Konstantinos Karydis, Prasanna Kinnappan, Herbert Tanner, Ioannis Poulakakis
A higher energy cost of walking poststroke has been linked to reduced walking performance and participation in the community. To inform future rehabilitation efforts and facilitate the development of targeted gait interventions, this investigation sought to identify gait deficits that, when improved, result in less energy expended during walking. Specifically, the contribution of improvements in walking speed and spatiotemporal gait asymmetries to the reduction of poststroke walking economy after intervention were tested. Methods: 42 subjects with chronic stroke were recruited to participate in 12 weeks of walking rehabilitation. Walking economy and speed, as well as step length, swing time, and stance time asymmetries were calculated pre- and posttraining. Sequential linear regression analyses tested the pre- to posttraining changes (posttraining - pretraining) relationships between walking economy versus walking speed and each measure of asymmetry. Secondary analyses were conducted to determine the influence of pretraining asymmetry on this relationship. Results: Pretraining walking speed (β = 0.05) and swing time asymmetry (β = 0.403) predicted pretraining walking economy (adjR² = 0.713, F(2,7) = 34.055, p < 0.001). Change in walking speed (β = 0.338) and change in step length asymmetry (β = 0.531) predicted change in walking economy (adjR² = 0.447, F(3,3) = 10.7, p < 0.001). However, change in swing time asymmetry did not. Moderation of this model by the direction or magnitude of pretraining asymmetry was not present. Conclusions: These findings suggest that poststroke interventions that target deficits in walking speed without regard for walking asymmetry may be inadequate to produce optimal improvements in walking economy.

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2. Physical Therapy, University of the Sciences

Total hip arthroplasty (THA): effective management of pain and improve function in patients with end-stage hip osteoarthritis. However, patients after THA demonstrate movement asymmetries in various motor tasks. During sit to stand (STS) task, patients rise from a chair with general unloading of the operated side and shifting the weight to the non-operated side, and with reduced motion and moments in the operated hip joint. However, outcome studies that have analyzed the STS biomechanics in the THA population were cross sectional studies. The pre- to postoperative biomechanical changes after THA have not been evaluated.

To determine how THA changes the biomechanics of STS task. Therefore we aimed to identify the interlimb movement differences during STS performance before and after THA, and to document the pre- to postoperative biomechanical changes in each limb.

Twelve subjects scheduled for unilateral THA completed 3-dimensional motion testing during STS task, 2-4 weeks before and 3 months after THA. Average vertical ground reaction force (VgRF), peak hip flexion moment (HFM), and peak knee flexion moment (KFM) were computed for each limb.

Before THA, interlimb differences were found in all variables. Preoperative interlimb differences in all variables showed considerable improvement by 3 months after surgery exemplified by significant increases in the KFM in the operated limb and reduced VgRF in the non-operated limb. However, interlimb differences in VgRF and KFM still persisted after THA. THA improves movement symmetries during STS performance, but doesn't completely restore symmetrical movement. These results emphasize the need for investigating the factors that contribute to persistent movement asymmetry, which will lead to develop targeted rehabilitation to maximize movement symmetry after THA.

1. Louis Awada, Jacqueline Palmera, Stuart Binder-Macleod, Ryan Pohlig, Darcy Reisman


Daniel Cortesi1, Stephen Sudaman1, Karin Silbernagle2, Thomas Buchanan2, Dawn Elliott2

1. Biomedical Engineering, University of Delaware
2. Mechanical Engineering, University of Delaware

Tendon injuries, such as tendinopathy or rupture, often result in decreased mechanical properties and abnormal collagen fiber structure. Since tendon structure and composition are difficult to quantify non-invasively, changes in viscoelastic properties can be used as equivalent biomarkers of tendon health and function. The objectives of this study are to develop a method for the measurement of viscoelastic properties of tendons (continuous Shear Wave Elastography, cSWE), to validate cSWE by comparing measurements of wave speed with those obtained using Magnetic Resonance Elastography (MRE), and to present preliminary measurements in human Achilles tendons in vivo. The viscoelastic properties (elasticity, and viscosity) were calculated using the Voigt model. Comparison of wave velocity measurements between cSWE and MRE showed an excellent agreement for agarose gels of different concentrations (1%, 1.5% and 2%). Preliminary data on healthy volunteers (n = 7) showed that it is feasible to measure the viscoelastic parameters in the middle portion of the Achilles tendon. A strong viscoelastic effect was observed for the Achilles tendon for which the shear wave speed increased 2-fold when the vibration frequency was increased from 200 to 1000 Hz. The viscoelastic properties at the middle portion of the tendon were 71.7±49.2 kPa and 64.6±13.3 Pa. The advantage of the proposed technique is that maps of viscoelastic properties of the Achilles tendon can be measured. Therefore, our technique can be used to quantify changes of viscoelastic properties at the tendinopathy lesion and surrounding tissues, to evaluate the healing process of Achilles ruptures, and to compare the effectiveness of different treatments for tendon injuries.

The mechanics of fiber-reinforced tissues such as the annulus fibrosus and meniscus are governed largely by highly organized collagen structure. However, recent studies have shown that proteoglycan-rich deposits, or microdomains, that are interspersed within the collagen structure alter the strain transfer from the tissue down to the cells. Specifically, the local matrix within the proteoglycan-rich microdomains (PG μ-domains) experiences significant less strain compared to the fibrous region of the tissue, resulting in a heterogeneous strain field. It remains unknown how the structure-function relationships in the tissue result in the observed heterogeneous strain fields and what the associated stresses are. The objectives of this study were to implement PG μ-domains into a finite element model, compare with experimental data, and determine the strain fields at multiple physiological loading levels. Strain transfer from the tissue level to the local matrix level was taken from our recent experimental studies. A histological image was used to determine a representative shape of the PG μ-domains for the finite element model. Using a custom MATLAB code, the finite element model with PG μ-domain was implemented in FEbio, an open source software package developed for biological tissue modeling. A Holmes-Mow matrix with fibers that follow an exponential power-law was used to represent the fibrous domain, and a Holmes-Mow matrix with no fibers but with an osmotic swelling component was used to model the PG μ-domain. The finite element model produced 30-40% strain attenuation in the PG μ-domains as compared to the fibrous region, which was consistent with the mechanical testing data. These results have important implications in the mechanobiology of soft fibrous tissues, as cells will respond according to the mechanical signals within their microenvironment.
A BIOMECHANICAL-BASED MODEL FOR PREDICTING PROPULSIVE FORCES DURING ABLE-BODIED GAIT
HaoYuan Hsiao1, Brian A. Knarr2, J.W. Hoggenson3, Stuart A. Binder-Macleod1,4
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3Department of Mechanical Engineering
4Department of Physical therapy, University of Delaware

Current rehabilitation for individuals post-stroke focuses on restoring walking ability because it is strongly correlated with quality of life. A major factor required for translating the body forward during normal gait is the ability to generate propulsive force. Previous studies with regression-based model have pointed out the critical factors that are related to propulsive force in both healthy and post-stroke populations: ankle plantar flexor muscle strength and trailing limb angle (tLA). However, these relationships do not provide quantitative information regarding the relative potential of each of these factors to improve the propulsive force. Quantifying the impact of these biomechanical factors on propulsive force during gait would allow for the design of rehabilitation strategies for improving propulsive force in individuals post-stroke.

The primary purpose of this study was to develop a mathematical model to quantify the contribution of ankle moment and tLA on propulsive force. Twenty healthy individuals walked at their self-selected and 120% of self-selected walking speed on the treadmill. Independent groups of subjects were used for model development and validation. Using a generic equation for the ankle moment obtained through inverse dynamics analysis, we identified the key clinically accessible parameters that determine propulsive force. Our main findings were (1) Peak ankle moment and peak tLA have similar potential to facilitate peak propulsive force, and (2) Healthy individuals utilize more tLA than ankle moment adjustment to modulate propulsive force. These findings provide a biomechanical basis for the development of targeted pathological gait therapies.

Comparing pMCCF in the involved versus uninvolved limb using a neuromusculoskeletal (NMS) model can confirm whether asymmetric loading and decreased loads prevail after ACLR.

Ten active subjects (5 females, 5 males, Age: 32 ± 12 years) with unilateral knee injuries underwent ACLR, rehabilitation, gait trials and electromyography (EMG) analysis. Kinematic and kinetic parameters were recorded using an 8-camera video system and force platforms respectively. Surface-EMG recordings were collected from the following 7 muscles crossing each knee joint: medial/lateral vasti, rectus femoris, semitendinosus, long head of biceps femoris, and medial/lateral gastrocnemius. pMCCF were computed using a validated Hill-type EMG-driven NMS model, which was anatomically scaled and calibrated for each subject. pMCCF obtained were normalized to body weight (BW) for each trial. 3 trials per subject were averaged for each limb. Two way analysis of variance was used to examine changes in pMCCF in each limb at three time points (Factors: Limb – Involved/Uninvolved, Time Points – Baseline/2 years/5 years post-operatively).

pMCCF was significantly lower in the involved limb at baseline (2.34 BW vs. 3.04 BW, p=0.02), but this asymmetry did not exist at 2 and 5 years. Also, pMCCF in both limbs were significantly lower at 5 years, compared to the earlier time point (p=0.04). In subjects with a unilateral knee injury, an asymmetric loading pattern was observed prior to surgery. These loading asymmetries did not exist after ACLR and rehabilitation, which is encouraging. However, pMCCF were also lower at 5 years, indicative of unloading. While not directly proven yet, it is possible that unloading may result in cartilage deconditioning, thinning and ultimately OA.
Fluorescence correlation spectroscopy (FCS) is an imaging approach that has been used successfully to optically measure the convection of fluorescent particles in solution, but has limited applicability to very slow and fast velocities. A novel analogue of FCS, which we term one-dimensional spatiotemporal image correlation spectroscopy (1-D STICS), has the ability to quantify fluorescent particle velocities over a much wider range than FCS.

In 1-D STICS, as opposed to FCS, we repeatedly and rapidly capture a raster-scanned data line within the microfluidic system, creating a “data carpet” in which fluorescent particle transport results in pixel intensity fluctuations. We then perform cross-correlation among different points in the scan using Fourier methods to generate a spatiotemporal correlation map. If, on average, line scanning is performed faster than the time it takes for a fluorescent particle to traverse the length of the scan line, a streak will appear in the correlation map. We isolated streaks from the correlation maps using image segmentation techniques, then used a weighted central moment calculation to calculate streaks using image segmentation techniques, then used a map. we isolated streaks from the correlation maps it takes for a fluorescent particle to traverse the length of different points in the scan using Fourier methods to determine which combination of KPF and PRM 6 months (6m) after ACLR contributes to the ability to RPLA 2y after ACLR. Therefore, the aim of this study was to determine which combination of KPF and PRM 6m after ACLR predicts RPLA 2y after ACLR.

Sixty athletes who were regular participants in level I/II activities underwent ACLR and completed KPF tests (four single-legged hop (SLH) tests: single hop (SHP), crossover hop (XHP), triple hop (THP), and 6-meter timed hop (TimHPI)) and a PRM (International Knee Documentation Committee 2000 (IKDC2000)) 6m after ACLR. Two years after ACLR, athletes were asked if they had RPLA or not. Binary logistic regression was used to evaluate which combination of SLHs and IKDC2000 scores predicted RPLA 2y after ACLR.

Forty-one athletes (68.3%) RPLA 2y after ACLR. All SLHs and IKDC2000 scores were significant individual predictors (p<0.01) of RPLA. SHP and TimHPI were the strongest predictors and individually predicted 33.4% and 31.6% respectively of the variance of RPLA 2y after ACLR. When all SLHs and IKDC2000 scores were entered into the regression model, they significantly predicted 54.4% of the variance (p<0.001).

Athletes who demonstrate functional limb symmetry and score higher on PRM 6m after ACLR are more likely to RPLA 2y after ACLR. Athletes who failed to achieve functional limb symmetry and scored lower on PRM at 6m are not likely to RPLA 2y. Athletes who had functional limb asymmetry 6m after ACLR might choose to modify their activities to avoid multidirectional activities.
Knee osteoarthritis (OA) is common following anterior cruciate ligament (ACL) injury. Abnormal joint loading is one key mechanism in the development of OA. This study’s purpose was to determine whether knee moments and contact forces after injury were associated with OA 5 years after reconstruction (ACL-R).

Seventeen patients (7 F, age 34.7 ± 11.8) undergoing ACL-R completed standard motion gait analysis with electromyography (EMG) prior to (baseline) and after 10 pre-operative rehabilitation sessions (post-training), 6 months after ACL-R (6 months), and 2 years after ACL-R (2 years). Stance kinetic measures of interest included peak knee adduction moment (PkmA) and knee adduction moment impulse (KAmI).

Medial compartment contact forces were derived using an EMG-driven Hill-type musculoskeletal model.

Weight-bearing posterior-anterior 30° radiographs were taken 5 years after ACL-R, with OA defined as a Kellgren-Lawrence grade ≥ 2.

Fisher’s exact test and independent t-tests tested differences in demographics, PkmA, PkmC and KAmI between those with and without OA in the medial compartment (OA, nonOA).

Six subjects had involved knee OA, 11 did not. No demographic differences existed.

There were no group differences in PkmC at baseline or post-training. The OA group had significantly lower PkmA at 6 months (p = 0.046, nonOA: 2.90 ± 0.55 BW, OA: 2.10 ± 0.69 BW) but not at 2 years.

Significant kinetic differences occurred only at baseline in PkmA (p = 0.043, nonOA: 0.29 ± 0.08 BW, OA: 0.17 ± 0.04 BW) and KAmI (p = 0.037, nonOA: 0.087 ± 0.025 BW, OA: 0.049 ± 0.018 BW).

Patients with OA had lower joint contact forces 6 months after ACL-R, with loading becoming similar between groups at 2 years. This unloading followed by reloading may be a perfect storm for the development of OA after ACL-R.
THE EFFECT OF DELAYED LOADING ON IN VITRO MICROFRACTURE MODEL
Miri Park, Monideepa Chartterjee, Anna Gonye, Brandon Zimmerman, Lynn Snyder-Mackler, X. Lucas Lu

Microfracture is an arthroscopic surgery to promote the repair of a cartilage lesion with subchondral bone marrow. However, quality of the repaired tissue in microfracture is often inferior to the surrounding cartilage. Improvement of surgical procedure or rehabilitation protocols requires animal or clinical studies, which could be expensive with ethical limitations. In this study, we proposed to investigate the effect different mechanical loading profiles on the outcome of microfracture surgery using an in vitro culture model.

Cartilage-bone cores were harvested from tibia plateau in knee joints of 3-month-old calves. An artificial cartilage lesion was made in the center of an explant by removing cartilage tissue. Subchondral bone marrow was harvested from the same joint and filled in the lesion. Using this model, we have shown that bone marrow cultured in the lesion of cartilage-bone explants can generate cartilaginous tissue with the supplement of proper medium and growth factors. Two different loading profiles were utilized: one with immediate stimulation from day 1 or a 2-week delayed stimulation each for 6 weeks.

Using this innovative in vitro microfracture cartilage-bone co-culture model, we examined the effects of growth factors and mechanical stimulation. The addition of TGF-β3 showed a significant increase in the stiffness, biochemical content and chondrogenesis gene expression in repaired cartilage. Mechanical loading of both direct and delayed profiles improved the quality of the newly generated tissue compared to groups with no loading. Delayed mechanical loading was beneficial for new tissue generation from bone marrow.

BISPHOSPHONATE RESCUES ARTICULAR CARTILAGE FROM TRAUMA DAMAGE
Miri Park, Yilu Zhou, Liyun Wang, X. Lucas Lu

Zoledronic acid (ZA) is a bisphosphonate drug approved by FDA for osteoporosis treatment. We found that ZA can efficiently suppress the development of post-traumatic osteoarthritis in a Destabilization of meniscal mouse model. However, little is known about the chondroprotective mechanisms of ZA. In this study, we hypothesized that ZA can directly regulate the metabolic activities of chondrocytes. The objectives are to prove that ZA treatment can 1) rescue the trauma damage on cartilage allografts and 2) promote the beneficial effects of mechanical loading during in vitro culture of cartilage.

Cartilage allografts from calf knee joints were cultured in serum-supplemented medium for 1 week to simulate trauma damage on cartilage during joint bleeding. The allografts were then cultured with or without 1 μM ZA for 4 weeks. Mechanical stimulation was applied daily with 10% preload and ±3% dynamic loading.

For damaged cartilage with 1-week serum exposure, the Young's modulus of allografts increased more than 200% after 4-week rescuing culture in medium containing ZA, while the non-ZA group showed a 56% increase. In the non-ZA group, 19% of chondrocytes showed spontaneous calcium responses within 15 minutes of imaging, and the value remained constant for 4 weeks. ZA treatment also significantly improved tissue stiffness of cartilage cultured with mechanical stimulation, as well as the cell viability and spontaneous calcium signaling. Expression levels of type I, II collagen and aggrecan genes were significantly higher in the ZA group.

Treatment with ZA can rescue the mechanical integrity of cartilage after trauma damage induced by serum exposure and promote the beneficial effects of mechanical stimulation during in vitro culture. We showed that the chondro-protective effect of ZA is correlated with the intracellular calcium signaling of chondrocytes.

QUANTIFYING DIFFUSION IN POROUS VISCOElastic MATERIALS USING CORRELATION SPECTROSCOPY
Janty Shoga & Christopher Price

An early sign of osteoarthritis (OA) is the loss of proteoglycans from the cartilage matrix. Due to the multiphasic and viscoelastic nature of cartilage, this loss can alter interstitial fluid flow behavior. Thus, measurement of fluid flow within the tissue could not only inform cartilage biology, but also be diagnostic for OA. The goal of this study was to demonstrate the application of correlation spectroscopy to the study of the equilibrium microfluidic environment of articular cartilage through in situ quantification of diffusion. Samples included agarose gels of three different concentrations, and bovine cartilage from the medial femoral condyle at different zonal depths.

Samples were cut into cylindrical plugs (1-mm high, 3-mm diameter) and soaked in dilute solutions of various molecular weight fluorescent tracer molecules. Samples were axially loaded, in unloaded compression, to 0, 10, 20, and 30% strain and the diffusion coefficients of various tracers were determined using fluorescence correlation spectroscopy (FCS). Increasing solute size, matrix density, and compressive strain resulted in decreased tracer diffusivity in agarose at equilibrium. In cartilage, increasing solute size also resulted in decreased diffusivity. In the superficial cartilage zone, diffusivity decreased with increased strain. In the middle and deep zones no consistent trend with respect to strain, was observed among diffusivities.

These results demonstrate that FCS can be used to accurately quantify variations in diffusivity in agarose and cartilage. Raster image correlation spectroscopy (RICS) data, acquired simultaneously under the conditions described, is being analyzed to demonstrate effectiveness in the 2-D micro-scale mapping of diffusivity within cartilage. Additionally, ongoing work, building upon these techniques, strives to develop methods of quantifying dynamic, load-induced convective fluid/solute flows within cartilage using advanced spatiotemporal image correlation spectroscopy (STICS) techniques.
In this study, roles of nine signaling pathways in calcium signaling were identified. The calcium signaling is one of the earliest responses of many cells. Various pathways have been identified to regulate calcium signaling. In this study, roles of nine signaling pathways in calcium signaling were studied. These pathways include extracellular calcium source, intracellular calcium stores, ATP-IP3 pathway, gap junction, and voltage-gated calcium channel. The spontaneous calcium signaling relies significantly on the extracellular calcium source. The calcium response also relies on the extracellular calcium source. The spontaneous calcium signaling rate, however, impeding the gap junction has no significant effect. Interestingly, hydrolysis of extracellular ATP has no effect on the spontaneous calcium oscillation. Blocking stretch-sensitive channels can significantly reduce the responsiveness of healthy tissue. The mechanism behind the lubricating ability of HA appears to be metabolic rather than mechanical. It has been proposed that HA protects lubricating phospholipids from lysis by PL2, indirectly maintaining low friction, and the results of the present study support this, as HA was not seen to be an effective boundary lubricant.

Efficacy of Boundary Lubricants on TMJ Disc and Condylar Cartilage
Brandon K. Zimmerman, David L. Burni, X. Lucas Lu*

Calcium signaling is one of the earliest responses of many cells. Various pathways have been identified to regulate calcium signaling. In this study, roles of nine signaling pathways in calcium signaling were studied. These pathways include extracellular calcium source, intracellular calcium stores, ATP-IP3 pathway, gap junction, and voltage-gated calcium channel. The spontaneous calcium signaling relies significantly on the extracellular calcium source. The calcium response also relies on the extracellular calcium source. The spontaneous calcium signaling rate, however, impeding the gap junction has no significant effect. Interestingly, hydrolysis of extracellular ATP has no effect on the spontaneous calcium oscillation. Blocking stretch-sensitive channels can significantly reduce the responsiveness of healthy tissue. The mechanism behind the lubricating ability of HA appears to be metabolic rather than mechanical. It has been proposed that HA protects lubricating phospholipids from lysis by PL2, indirectly maintaining low friction, and the results of the present study support this, as HA was not seen to be an effective boundary lubricant.
Mechanical Functions of Superficial Zone in TMJ Condylar Cartilage

Leonardo Ruggiero, Kelsey Devlin, Brandon Zimmerman, X. Lucas Lu

Mandibular condylar cartilage (MCC) in temporomandibular joint (TMJ) is characterized by a unique superficial zone which is composed of highly aligned type I collagen bundles with little proteoglycan content. The middle- and deep-zone cartilage covered by this fibrous layer exhibits a similar structure with hyaline cartilage in other diarthrodial joints (Fig 1A). The effects of the unique superficial fibrous zone in the daily functions of MCC, such as load bearing and lubrication, are barely known. In this study, we propose to: 1) determine the biomechanical properties, including permeability and tensile and compressive moduli, of both fibrous and middle-deep zones in MCC, and 2) build a 3D finite element (FE) model based on mixture theory to simulate the nonlinear inhomogeneous structure of MCC and determine the biomechanical effects of the superficial zone in MCC daily functions.
Soccer places unique demands on an athlete’s lower extremities as it requires moving the ball while simultaneously supporting the body. Soccer also has a higher incidence of anterior cruciate ligament (ACL) injury. These factors could cause the trajectory of recovery after ACL reconstruction (ACLR) for soccer athletes to be different from other athletes. Thus, the purpose of this study was to determine if soccer players are unique in their functional progression through the first year after ACLR.

234 athletes were followed for one year after unilateral ACL tear. Demographic information and function measures were collected after ACL injury and re-evaluated at 6 and 12 months after surgery; as well as return to pre-injury activity level (RTA). Chi-squared and repeated measure two-way ANOVA were used to analyze the differences between soccer and non-soccer athletes. There were significant differences in RTA at 6 and 12 months (p=0.006 and 0.05 respectively). There was a significant time x group interaction (p=0.032) for the IKDC2000 with soccer athletes having a smaller change in score over the three time points. There were no interactions or main effects for the single leg hop tests, however there were main effects for group and time for the KOS-ADLS (group p=0.004, time p=0.0001) and GRS (group p=0.003, time p=0.0001). These results indicate that soccer athletes perceive their knee function to be lower than non-soccer athletes. Such lower perceived level of function may be reflected in the smaller number who returned to pre-injury activity level at 6 and 12 months. A further implication is that the single legged hop tests may have a ceiling effect in soccer players.

FUNCTIONAL PROGRESSION AND RETURN TO ACTIVITY AFTER ACLR IN SOCCER AND NON-SOCCKER ATHLETES
Amelia Arcadate, PT, DPT, SCS, and Lynn Snyder-Mackler PT, ATC, SCS, ScD
University of Delaware, Hofstra University

TRENDS IN PEAK LOWER EXTREMITY JOINT POWERS DUE TO CHANGES IN WALKING SPEED AND BODY WEIGHT SUPPORT
Anathid Ebrahim, Saryn R Goldberg*, Steven J Stanhope;

The purpose of this study was to characterize changes in lower extremity peak joint powers across a range of body weight support (BWS) levels and walking velocities in a normal population. We hypothesized that powers would follow the same general trends as joint moments. Previous research from SR Goldberg and S1 Stanhope, 2013 found that ankle and hip peak joint moments linearly decreased with slower walking velocities and with greater BWS, while knee moments did not decrease linearly with slower walking velocities and were insensitive to BWS. Eight adult subjects walked at three walking velocities (0.4, 0.6, and 0.8 statures/s) on an instrumented treadmill, each with three BWS conditions (0%, 20%, and 40% of body weight supported). Six degree of freedom joint powers were calculated using methods from FL Bukcelk, et al., 1994. Differences in peak joint powers were determined using a multiple regressions model (p<0.05). In general, peak joint powers did not follow the same trends as joint moments. While looking at the effect of BWS at a certain walking velocity, peak powers did not significantly decrease with greater BWS except at 0.8 statures/s for both the ankle and hip, nor at 0.6 statures/s for the hip. However, as observed with peak joint moments, peak knee powers did not significantly differ between BWS levels within a walking velocity. All three peak joint powers were significantly less at 0.4 statures/s compared to at 0.8 statures/s. Future studies may find comparing trends in net joint work to be useful in further understanding the differences in peak joint moment and power patterns on the mechanics of gait.

Functional Status and Return to Sport Rates for Potential Copers and Non-Copers 2 Years After ACLR
Matt Failla, David Logerstedt, Lynn Snyder-Mackler

Classification of potential copers and non-copers after ACL injury has long been established. Potential copers and non-copers show no difference in function 1 year after surgical reconstruction. The purpose of this study is to examine the functional status of potential copers and non-copers 2 years after ACL reconstruction.

Fifty nine subjects after unilateral ACL rupture. Subjects were screened to determine potential coper or non-coper status. All subjects underwent ACL reconstruction, and returned for testing 2 years after surgery. Data collected included isometric quadriceps strength index (Q), 4 single-legged hop symmetry indexes, Knee Outcome Survey Activities of Daily Living Scale (KOS-ADLS), Global Rating Scale (GRS), International Knee Documentation Committee 2000 (IKDC 2000), Tampa Scale for Kinesiophobia (TSK 11), and the Marx Activity Rating Scale (Marx). T-tests and chi-square were used for statistical analysis.

No differences were seen between groups in Q (p=0.62), KOS-ADLS (p=0.911), GRS (p=0.719), IKDC 2000 (p=0.317), TSK 11 (p=0.991), or Marx (p=0.90). All non-copers returned to sport, and 97% of potential copers returned (p=0.088). 29% of potential copers did not return to their pre-injury sport level while 28% of non-copers did not return to pre-injury level (p=0.86). Potential copers were significantly more symmetrical than non-copers during the single hop (p=0.005) and triple hop (p=0.046), but not crossover hop (p=0.236) or timed hop (p=0.136).

There were no differences in return to sport or level, or functional differences between potential copers and non-copers 2 years after ACL reconstruction. While single hop and triple hop were statistically different, both group symmetry indexes were above 95%, and therefore are likely not clinically important. Potential copers or non-coper classification after ACL injury does not affect outcomes 2 years after ACL reconstruction.

Pre-Operative Predictors of Contralateral TKA Following Unilateral Total Knee Arthroplasty (TKA)
Portia Flowers, Joseph Zeni, Jr., Lynn Snyder-Mackler

To identify predictors of future contralateral TKA in persons who underwent unilateral TKA at baseline. We hypothesize that bilateral impairments and joint biomechanics will be predictors of contralateral TKA. Seventy seven subjects who underwent unilateral TKA were evaluated and grouped according to contralateral TKA status (YES or NO). Initial testing was performed 6mos, 1yr, or 2yrs after TKA with at least a 2.5 year follow-up to determine incidence of contralateral TKA. Patient reported outcomes of knee function and pain, quadriceps strength, active knee extension range of motion, knee flexion moment at peak knee flexion, and peak knee adduction moment (PKAM) were assessed and analyzed bilaterally.

Hierarchical logistical regression models were used to determine predictors of contralateral TKA. Limb-by-group differences were determined using 2x2 ANOVA. Descriptive comparisons were made to historic pre-operative and healthy individuals. There were significant main effects of group and limb, with the YES group having bilateral weakness. There were no significant predictors of contralateral TKA for either limb. However, the addition of operated limb strength to the model improved the significance of the model and was nearly a significant addition to the model. With the YES group being weaker than the NO, pre-operative, and healthy groups, these results suggest that quadriceps weakness may play a role in discriminating contralateral limb OA progression. Future work should evaluate rehabilitation protocols that not only restore operated limb strength to pre-operative levels, but exceed it. Although PKAM is predictive of OA progression, current results did find it to be predictive of contralateral TKA. However, previous literature suggests that non-normalized PKAM may be a more clinically relevant measure when analyzing knee OA progression. Therefore, future analyses of incidence of contralateral TKA may include non-normalized PKAM.
Impairment of the anterior cruciate ligament (ACL) is a common injury leading to significant financial burdens. While tibial translation is most commonly indicated as an injury mechanism, tibial rotation also contributes and can lead to rotational instability. Understanding mechanisms and consequences of rotational instability can inform therapists in designing rehabilitation. ACL tears typically occur when landing and/or changing directions and so the run cut and pivot landing tasks are typically used as research tools. Studies exploring kinetics of the knee during running and cutting maneuvers found significant external rotation moments generated during sidestepping tasks (Besier et al. 2001). It is difficult to directly evaluate ACL-deficient patients in internal and external rotations using certain pivot landing tasks due to risk of further injury. In an effort to actively test subjects in internal and external rotational loading without risking injury our lab developed a task to use the free moment as an indicator of ‘rotational challenge’. Subjects stood barefoot approximately hip-width apart on two force plates, a separate force plate for each foot. Subjects, 5 healthy males with no history of ACL injury, generated 10, 50, and 80% of their maximum free moment in both the internal rotation (IR) and external rotation (ER) directions. Kinematics and kinetics of the lower limbs were recorded throughout the data collection. We found that as the free moment effort increased the rotation angle of the hip also increased. Additionally, transverse knee moments increased as free moment effort increased. We found increased transverse knee moments during the ER versus the IR condition. Our results indicate we are able to challenge patients in rotational loading using the free moment measure.

KINETIC AND KINEMATIC CHANGES IN GAIT DUE TO DUAL-TASKING
Kelti Seymour1, Morgan Kamenetz1, Christopher Higginson, Ph.D.,2, Jill Yaggion, Ph.D.2
1University of Delaware
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Although historically considered an automatic process, gait control has been shown to consume attentional demands. Identifying the impact of cognitive tasks on motor tasks could detect increased fall risk and lead to prevention strategies. The impact on kinetics, kinematics, and spatial parameters due to dual-tasking is currently unknown. The objective of this study is to identify how dual-tasking impacts motor task performance in healthy adults compared to younger adults.

Participants completed a neuropsychological assessment consisting of various cognitive tests to define a baseline measure of cognitive abilities. Three tasks were then repeated during treadmill walking: a working memory task (Paced Auditory Serial Addition Test, PASAT), a processing speed task with components of visual attention (Symbol Digit Modalities Test, SDMT), and a visual attention and fine motor skills task (cellular phone dialing task, Phone). Three walking conditions were used for dual-tasking: self-selected, fast (120% of self-selected), and fast speeds (induced by the split-belt treadmill with one belt moving at self-selected and fast speed).

Changes in stride length and width means and standard deviations as well as peaks and variances of lower extremity kinematics between younger and older adults indicate that all types of dual-tasking have an impact on gait. Changes in gait performance with the addition of a cognitive task show that gait is not fully automatic. Furthermore, dual tasks may increase fall risk in older adults because some gait changes such as stride width variability, and peaks and range of motion for knee flexion, hip extension, and ankle plantarflexion are often indicative of a fall. Future implications include developing prevention strategies for older adults at risk of falls.

THE RELATIONSHIP BETWEEN FEAR AND FUNCTION IN THE ACL DEFICIENT KNEE
Ryan Zarzycki, PT, DPT, Cert MDT (UD BIOMS); Matthew Fakla, PT, MSPT, SCS (UD BIOMS); David Logerstedt, PT, PhD, MPT, MA, SCS (UD Physical Therapy Department)

The Tampa Scale for Kinesiophobia (TSK-11) is a valid and reliable measure of fear of movement and re-injury in the ACL deficient population. Previous research has found the TSK-11 to be related to self-reported function and ability to return to sport. The purpose of this study is to evaluate whether a significant change in TSK-11 score, after a neuromuscular training program, correlates with functional performance and self-reported function in ACL deficient subjects.

Eighty Level III subjects after isolated ACL rupture were included in this analysis. All patients performed quadriceps strength testing (QS), single-legged hop testing (single hop, cross-over hop, triple hop, and 6-m timed hop), a global rating scale (GRS) measure, TSK-11, and the International Knee Documentation Committee Subjective Knee Form (IKDC) before and after a neuromuscular training program. The change scores from pre-treatment to post-treatment were calculated for all the aforementioned tests. Correlations were performed between change score in TSK-11 and change scores in all other measures. SPSS 21 was utilized to run bivariate correlations. P value was set at p<0.05.

Significant correlations were found between change score in TSK score and change score in GRS (r=-.298, p=0.008), IKDC (r=-.425; p<0.001), single hop (r=-.360, p=0.003), cross-over hop (r=-.308; p=0.013), triple hop (r=-.335, p=0.006), and timed hop (r=-.273; p=0.048). No correlation was found between change in TSK score and QI (r=-.013; p=0.913).

Small correlations were found between the change in TSK and all hop tests and self-reported measures. A subject's change in TSK score is minimally related to a change in other self-reported or functional measures.
A HYBRID EMG-DRIVEN COMPUTED MUSCLE CONTROL METHOD TO ESTIMATE HIP MUSCLE FUNCTION IN HEALTHY CONTROLS

John Ramsay, Thomas Buchanan, Jill Higginson

Computed muscle control (CMC) is a powerful method for estimating muscle forces during complex dynamic tasks. One of the major benefits of CMC is the ability to estimate forces for a high number of muscles. To solve the muscle redundancy problem, the algorithm uses a proportional-derivative controller to estimate muscle activations that satisfy the current kinematic state of the musculoskeletal model. At each time step, the muscle forces are optimized by minimizing the sum of the activations squared for all muscles in the model. However, CMC has been shown to overpredict muscle activations and forces in subjects with impaired activations or changes in muscle properties, such as stroke. To address this limitation, we have developed a hybrid method that uses an existing EMG-driven model to estimate subject-specific muscle properties and muscle activations from surface EMG of a subset of muscles and uses CMC to predict the remaining muscle activations and forces. The purpose of this study was to evaluate the difference in estimated hip muscle function between the default CMC method and the hybrid method in healthy controls during swing. Kinematic, kinetic, and EMG data from two healthy subjects walking at their self-selected speeds were used as input into both simulations. Muscle function was defined by individual muscle moment for hip flexion/extension and abduction/adduction. We found that for both methods, while the predicted role of each muscle was the same, the default CMC method had lower muscle moment magnitudes. By including the known neural command and estimated muscle properties from the EMG-driven model, tuned simulations of pathological gait may produce more realistic measures of muscle function.

PRELIMINARY ASSESSMENT OF A NEW MUSCULOSKELETAL MODEL OF THE SHOULDER AND UPPER EXTREMITY

R. Tyler Richardson, Robert G. Quinton, Kristen F. Nicholson, and James G. Richards

Musculoskeletal modeling possesses the capability to estimate internal muscle forces that cannot be directly measured. However, the validity of the results must first be assessed to ensure that the model is sufficiently robust to recreate the mechanics that occur in vivo. In an effort to overcome significant limitations of previous upper extremity models, a new shoulder model (UDSM) has been developed for preliminary evaluation. Following adequate assessment, this new model will ultimately be used to estimate muscle forces and activation patterns that characterize an individual patient’s muscular deficits, and to provide clinicians with previously unavailable patient-specific data to inform clinical and surgical interventions. A motion capture system recorded the kinematics of the trunk and upper extremity segments during shoulder abduction for one healthy subject. Muscle forces were computed using the static optimization tool. The model estimations of muscle forces were evaluated qualitatively by comparing the timings and relative magnitudes with the expected anatomical actions of each muscle. The deltoid produced the largest forces followed by the trapezius and serratus anterior which both generated moderate forces. The supraspinatus and infraspinatus produced small to moderate levels of force in the middle and end of the trial respectively. All other muscles were minimally active. The results of this initial evaluation demonstrate that the relative magnitudes and timings of the muscle forces estimated by the UDSM for shoulder abduction qualitatively agree with the expected anatomical actions. These promising preliminary results indicate that future studies are warranted to provide further validation for the UDSM.
KNEE STIFFNESS REGULATION CHANGES WHEN STARTLED AT DIFFERENT TIMES
An YW, Swanik CB, Walls BL

Altered neuromuscular control (NMC) is a contributor to the high incidence of non-contact joint injury mechanisms. Recent studies have shown that unexpected, starting events alter preparatory (feed-forward) and reactive (feedback) systems necessary for maintaining knee stability. However, it remains unclear how the timing of starting episodes may interrupt stiffness regulation strategies necessary for functional stability. Sixty-six males and females with no history of knee injury participated in either Short Startle Delay (SSD, 36 subjects) or Long Startle Delay (LSD, 30 subjects) for testing joint stiffness and muscle activity (Quadriceps, Hamstrings) on a custom-built device. Subjects were instructed to relax and immediately provide maximum resistance to a perturbation from 30-degree to 70-degree flexion. Perturbations were randomly applied in 2 different conditions: control and acoustic startle (100dB, 50ms duration, 100ms). The time of startle was 100ms for the SSD group and 1000ms for the LSD group. Short-range (0-4°) and the total-range (0-40°) normalized knee joint stiffness (Nm/°/kg) was compared across groups (2-levels) and conditions (2-levels) by using 2-way repeated-measures ANOVAs. Muscle activity (timing and amplitude) was compared across groups (2-levels), conditions (2-levels), and muscles (4-levels) by using 3-way repeated-measures ANOVAs. The results revealed the acoustic startle condition produced higher short-range stiffness than the control condition. LSD group showed greater total-range stiffness than SSD group under the acoustic startle condition. LSD group also had higher peak EMG activity, 150ms before and 250ms after perturbation in both the quadriceps and hamstrings. Our results may suggest that the timing of startling events may interrupt NMC and stiffness regulation strategies and that startling events preceding a knee load by 100ms may be more adverse to knee stability than those occurring 1 second before a perturbation.
Muscle torque shows a decline with age, evident in both men and women. The hip flexors and ankle plantar flexors propel the body forward; therefore, a decrease in ankle plantar flexor torque is consistent with a decrease in gait speed of elderly subjects seen by Winter. In previous studies, a trade-off was found between hip flexor muscles and ankle plantar flexor muscles, suggesting that the hip muscles form an adaptation to make up for the decreased torque production in plantar flexor muscles during aging. The purpose of this study was to determine whether a relationship exists between the hip flexor and ankle plantar flexor muscle forces for (1) older and younger subjects and (2) self-selected and fast walking speeds.

The preliminary data shows that, while walking with an increase in speed, younger subjects show a decreased hip/ankle ratio, while older adults show an increased hip/ankle ratio, implying that the older adults are relying more on their ankle plantar flexors with an increased speed while the older adults rely more on their hip flexors.

A better understanding of the different trade-offs between ankle plantar flexors and hip flexors for older and younger adults can be used to design a rehabilitation technique to compute muscle forces in the ankle plantar flexors and hip flexors.

### Effects of Arm Proximal and Distal Muscles Fatigue on Force Coordination in Manipulation Tasks

Nicholas Emge, Mehmet Uygur, Mandi Radvan, Thomas Kaminski, Todd Royer, and Slobodan Jaric

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| Biomechanics and Movement Science Graduate Program, University of Delaware |

Effects of muscle fatigue on force coordination and task performance of various manipulation tasks are explored. Grip force (GF; normal force component acting at the digits-object contact area) and load force (LF; tangential component that lifts and holds objects) were recorded prior to and after fatiguing the distal arm muscles (DAM; i.e., GF producing) and proximal arm muscles (PAM; LF producing). Results reveal a deterioration of GF scaling (i.e., averaged GF/LF ratio), GF-LF coupling (their correlation), and task performance (ability to exert a prescribed LF pattern) associated with DAM, but not PAM fatigue. Deteriorated force coordination clearly increases the likelihood of dropping an object, however, the observed selective effects of DAM and PAM fatigue represent a novel finding deserving of further research.

### Title: The Short Term Effect of Exergaming on Physical Activity Levels and Executive Function in Children With and Without Autism Spectrum Disorder: Preliminary Results

Daphne Golden, MPT, DPT, Danielle Brumbley, and Nancy Getchell, Ph.D.

The purpose of this research is to investigate the effect of exergaming on physical activity (PA) level achieved, executive function and perceived enjoyment in boys with and without Autism Spectrum Disorder (ASD). Method: Repeated measure design with 2 groups and 3 physical activities. Participants: 15 boys (8-11 years) with ASD and 15 age and BMI matched neurotypicals. Equipment: Actical Accelerometer for testing of physical activity level, Inquisit Computer Children’s Flanker Task of executive function, and 3 Point Scale of Enjoyment. Gaming unit is an Xbox 360 for the sedentary videogame with a Kinect unit for the exergame. Physical activity level measures are physical activity count (AC) and percent time in moderate to vigorous physical activity (MVPA). Executive Function measures are number correct, and the response time on the Flanker. Enjoyment measure is enjoyment level. Protocol: Day 1 inclusion testing. Day 2 the executive function and physical activity level pretest data are collected. Days 3-5 are randomly assigned condition. Testing includes a period of 5 minutes rest. Then physical activity is performed for 20 minutes. Followed by a 15 minute rest period. Enjoyment level measured after physical activity and then executive function post condition data is collected. Statistical Analysis: A repeated measure MANOVA will be used between group and condition. Currently, 6 ASD and 2 typical boys have met inclusion criteria and results will be reported from these participants.
Post-traumatic osteoarthritis (PTOA), an accelerated form of osteoarthritis (OA), is an insidious disease of progressive diarthrodial joint articular cartilage degeneration that results directly from traumatic joint injury, e.g., meniscus or ligament tears, and is common in athletes and military service members. Approximately 50% of those who experience a ligament tear develop OA within 15 years. Unlike other causes of idiopathic OA, such as chronic joint loading or ageing, with PTOA the initial timing of the disease is known. Interestingly, previous work at UD using systemic administration of Zolendronic Acid (ZA), a FDA-approved bisphosphonate used to treat bone loss, demonstrated histologically the long-term prevention of cartilage damage and PTOA. However, in that study, and many like it, the early cellular and molecular mechanisms involved in PTOA-related cartilage damage and drug-mediated protection remain unknown. We hypothesize that immediately following injury changes in chondrocyte metabolism and fate determination precipitate the vicious cycle of cartilage degeneration in PTOA. By targeting these early changes pharmacologically with intra-articular injection (i.a.) of ZA, the development of PTOA can be prevented or hindered. To address this hypothesis, a murine joint instability injury model of PTOA (destabilization of the medial meniscus) is being utilized to study the early structural, compositional, cellular, and molecular changes associated with trauma-induced PTOA. In this study we will present histological and immunohistochemical analyses of non-treated, control and injured knees across a wide range of post-surgical time points at 3-, 7-, 14-, 36-, 84- and 112-days post-injury. Ultimately, this study will identify early mechanisms in injury-related cartilage degeneration and determine the efficacy of targeted drug delivery systems, such as i.a. ZA, to prevent the onset of PTOA.
Subchondral bone sclerosis in joints is associated with late stage osteoarthritis (OA). Recent studies showed that during the early development of the disease soluble metabolites released from mechanically stressed subchondral osteoblasts are responsible for induction of cartilage degeneration. The goal of this project is to identify novel bone biomarkers for early detection of OA. We subjected the MC3T3-E1 pre-osteoblastic cells to Fluid Shear Stress (FSS ~ 3.5 dynes/cm²) for 2 hours. A significant increase in the cyclooxygenase (COX2) and osteopontin (SPP1) mRNA levels were observed in cells subjected to FSS relative to static cells. In addition, western blot analysis showed upregulation of COX2 protein levels. To test the effect of factors released by FSS osteoblasts on cartilage cells, we used conditioned media (CM) from the FSS osteoblasts to treat primary mouse sternal chondrocytes cultured in micromasses. Gene expression profiling of micromasses cultured in the presence of FSS osteoblast CM for one week, showed a significant increase in the mRNA levels of collagen X, alkaline phosphatase and MMP13 relative to control micromasses. In contrast, no significant changes were observed for cartilage matrix proteins such as aggrecan and collagen II. This data supports the idea that the CM from the FSS osteoblasts contains metabolites capable of activating catabolic pathways in chondrocytes. To identify these factors, our current approach is to isotopically label static and sheared osteoblasts with either carbon-12 or carbon-13, respectively, and assess their intracellular and extracellular metabolic profiles using a mass spectrometry-based Isotopic Ratio Outlier Analysis (IROA). Ultimately, this work will help develop effective diagnostic tools and therapeutics aimed at lessening progression of OA.
**THE BASELINE ACTIVITY IN THE PREFRONTAL CORTEX IN HEALTHY PARTICIPANTS. THE EFFECTS OF EYES CONDITION.**

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The prefrontal cortex (PFC) plays an important role in cognitive process related to executive functions. It activates not only when individuals perform executive function-related tasks but also in resting states. Brain activity during resting states provides a baseline for interpreting task-induced brain activities. Both eyes open and eyes closed condition are commonly used baseline conditions. However, brain activity in eyes open condition is different from activity in eyes closed condition. The aim of this study was to examine differences in brain activity between eyes open and eyes closed conditions during resting states to provide a rationale of proper selection of baseline condition. Total of 36 participants in 3 age groups were recruited in this study including twenty-four adults, 5 12-15 years old children, and 7 8-11 years old children. Concentrations of oxygenated hemoglobin (oxy-Hb) and deoxygenated hemoglobin (deoxy-Hb) were obtained using functional near-infrared spectroscopy (fNIRS) in eyes closed and eyes open conditions, 3 minutes each. Contrasts were tested to compare the differences of concentrations of oxy-Hb and deoxy-Hb between eyes open and eyes closed conditions. A significant higher concentration of oxygenated hemoglobin (oxy-Hb) and deoxygenated hemoglobin (deoxy-Hb) was found in eyes closed condition indicated a higher activity in the PFC that could interfere with interpretation of task-induced activity.

**A STRENGTH ENHANCEMENT PARADIGM FOR PRESCRIPTION OF PASSIVE-DYNAMIC ANKLE-FOOT ORTHOSES FOR INDIVIDUALS POST-STROKE**

Elisa S Arch, Darcy S Reisman, Steven J Stashhope

In healthy gait, the plantar flexors act eccentrically to provide dorsiflexion resistance during the second rocker of the stance phase of gait. Passive-dynamic ankle-foot orthosis (PD-AFO) bending stiffness is believed to be able to replace lost plantar flexor function. We previously developed and demonstrated feasibility of a strength substitution paradigm, in which PD-AFO bending stiffness substituted for a prescribed percentage of a healthy individual’s peak plantar flexion moment. Thus, for individuals with plantar flexor weakness we hypothesized a strength enhancement paradigm, in which PD-AFO bending stiffness is prescribed to account for the plantar flexion moment deficit, would be effective. The purpose of this pilot study was to evaluate the strength enhancement paradigm for individuals post-stroke with plantar flexor weakness. First, baseline kinetic and kinematic movement analysis data were collected as subjects post-stroke (n=2) walked on a split belt instrumented treadmill at their self-selected velocity without any AFO, if possible. Scaled plantar ankle joint moments were compared to scaled, velocity-matched ankle joint moments from our normative database, and percent differences in peak plantar flexion moments were calculated. Customized PD-AFO bending stiffness was prescribed as the difference in peak plantar flexion moments divided by the average normal ankle excursion during the second rocker of stance. Subjects then walked while wearing the stiffness-customized PD-AFOS. Results supported feasibility of the strength enhancement paradigm, with the percent difference in peak moments decreasing from the baseline to PD-AFO conditions. (Subject A: 25.5% to -3.7%; Subject B: 31.1% to 14.9%). Additionally, step length ratio became more symmetrical (Subject A: 0.78 to 0.92; Subject B: 0.91 to 1.00). Overall gait function may improve even more with training or long-term use of the customized PD-AFOS.

**THE RELATIONSHIP BETWEEN THE SPATIOTEMPORAL GAIT ASYMMETRIES AND WALKING ACTIVITY IN INDIVIDUALS POST STROKE.**

Menki Chen, Kelly Daniki, Tamara Wright, Margie Rossi, Evan Matthews, William Farquhar, Darcy Reisman,¹

¹Department of Physical Therapy
²Program in Biomechanics and Movement Science, Introduction. Daily walking activity in individuals post stroke is very low, well below that of sedentary adults (<1,000 steps/day). Spatiotemporal irregularities in gait are caused by spatiotemporal asymmetries related to hemiparesis after stroke. The purpose of this study was to examine the relationship between daily walking activity and spatiotemporal gait asymmetries post-stroke. We hypothesized that individuals with the greatest asymmetries would show the greatest impairment in daily walking activity. Methods: To obtain a measure of activity level, twenty-five persons with chronic stroke wore a StepWatch Activity Monitor for at least 4 days. Steps per day (SPD) was averaged across the wear period. Gait asymmetry was measured as subjects walked at their self-selected speed across the Galil that instrumented walkway. Following the collection of 5 runs with 3 strides each, the descriptors of gait asymmetry were averaged and used to analyze the relationship to SPD. Descriptors of gait asymmetry included: step length asymmetry (SL), stance time asymmetry (Stt), and swing time asymmetry (Swt). Results: The combined variables of spatiotemporal asymmetry are significantly related to SPD (r=0.598, p<0.023). Individually, there is a trend for a relationship between Swt asymmetry and SPD (r=0.418, p=0.052). Conclusions: These results suggest that in persons poststroke, there is a relationship between spatiotemporal asymmetry and decreased walking activity. To better understand this relationship, future studies should examine whether there is a relationship between improvements in swing time asymmetry and walking activity with rehabilitation after stroke.

**CHANGES IN MUSCLE CONTRIBUTION TO SUPPORT AND PROPULSION POST GAIT-RETRAINING IN STROKE VICTIMS**

Reza Khoeliar, Jiv S. Higginson

Mechanical Engineering

Stroke is a leading cause of disability in US and often leads to gait impairment. The complexity of the human musculoskeletal system enables fine motor control but makes treatment difficult. Understanding the underlying mechanisms and individual muscle contributions to pathological gait is essential for designing optimal treatments. The objective of this study was to use computational simulations to help elucidate the functional roles of muscles in stroke gait and detect how rehabilitation has affected individual muscles. Stroke patients were recruited and divided evenly to undergo two forms of gait-retraining, Body Weight Supported Treadmill Training (BWStt) and Active Leg Exoskeleton Training (ALEX), which uses assist as needed paradigm. Subject specific 3D simulations were built using motion capture data and ground reaction forces before and after training sessions. Analysis were performed to detect changes in muscle force, muscle potential-a quantitative measure of muscles ability to accelerate center of mass based on posture alone and muscle induced acceleration. Preliminary results for BWStt indicate an increase in the contribution of Gastrocnemius to support in stance phase as well as increased support in persons post-stroke (n=2) walked on a split-belt treadmill at their self-selected velocity and kinematic movement analysis data were collected. Following the collection of 5 runs with 3 strides each, the descriptors of gait asymmetry were averaged and used to analyze the relationship to SPD. Descriptors of gait asymmetry included: step length asymmetry (SL), stance time asymmetry (Stt), and swing time asymmetry (Swt). Results: The combined variables of spatiotemporal asymmetry are significantly related to SPD (r=0.598, p<0.023). Individually, there is a trend for a relationship between Swt asymmetry and SPD (r=0.418, p=0.052). Conclusions: These results suggest that in persons poststroke, there is a relationship between spatiotemporal asymmetry and decreased walking activity. To better understand this relationship, future studies should examine whether there is a relationship between improvements in swing time asymmetry and walking activity with rehabilitation after stroke.
Understanding the factors limiting speed progression and the compensatory mechanisms utilized to achieve higher walking speeds is important for stroke rehabilitation. The purpose of this study was to use a hybrid simulation method to determine hip muscle compensatory mechanisms utilized by fast walkers that may be used as therapeutic guidelines for facilitating an increase in walking speed for slow post-stroke walkers. Kinematic, kinetic, and electromyography (EMG) data of 6 post-stroke subjects, split into two ambulatory speed groups (3 household and 3 community), were used for this study. The hybrid simulation method utilizes an EMG-driven model to estimate subject-specific muscle activation patterns and individual muscle parameters for fourteen knee and ankle muscles. Muscles were constrained by these updated parameters and activation patterns and computed muscle control was used to estimate the remaining hip muscle activations and muscle forces. Resultant individual hip flexion/extension and abduction/adduction muscle moments were estimated during swing. In general, we found that muscle function becomes less specialized for community ambulators. Neuromuscular constraints when comparing gender differences.

### Changes in Functional Roles of Post-Stroke Hip Muscles Between Household and Community Ambulators

**John Ramsay, Thomas Buchanan, Jill Higginson**

In general, we found that muscle function becomes less specialized for community ambulators.
Legged robots have a distinct and significant advantage over wheeled robots when faced with rough terrain and other obstacles, as would be present in a search-and-rescue mission or reconnaissance operation.

The intent of this design project was to create an inexpensive, easily assembled walking sensory platform that can overcome rough terrain and small obstacles.

The final design features a crank-driven leg linkage invented by Theo Jansen. Eight legs are driven by two DC metal gearmotors via a geared transmission system. This differential drive robot is largely constructed from 3D printed components, in order to reduce weight, cost, and machining time.

An on-board computer primarily controls the robot using Wi-Fi, with additional components such as a motor driver, power regulator, and USB hub. Three lithium ion batteries power the two motors and the on-board electronics. The two sensors that were placed on the platform for testing were a laser scanner and HD webcam. In addition to the open space on the baseplate, a lid was added to provide a mounting surface for the sensors and USB hub.

Including electronics, the final design weighed 4.6 lbs and cost less than $400 to assemble. The approximate dimensions are as follows: 14" long, 8.5" wide, and 7" tall. Further evaluation is ongoing, and several tests are planned to assess various capabilities of the robot. Some of the tests include measuring maximum linear speed on a few different surfaces, finding the maximum obstacle height that the robot can climb over, and examining the steepest incline that the robot can traverse.

The potential of walking robots is still being uncovered, and this platform will be a useful tool for further improving what they are capable of.
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