ME Student Research Abstracts- Bioengineering Research

Student: Narek Akopyan
Professor/Sponsor: Professor Liwei Lin
Mentor: Dr. Ryan Sochol
Research Project Title: Micropost Traction Force Quantification

Abstract:
Microfabricated posts were designed to advance cell handling techniques, which is useful for research in biology. By creating stiffness and interpost spacing gradients along the micropost array, bovine aortic endothelial cells (BAECs) were observed to unidirectionally migrate. The cells migrated in directions of increasing micropost stiffness and decreasing interpost spacing. The goal was to quantify the forces that the cell pushed or pulled on the microposts in order to move in one direction. These forces were calculated by taking microscopic images of the immovable bottom of the micropost array which was stuck to the substrate and the top of the micropost array which moved due to the forces applied by the cell. By applying the general Hooke’s Law, forces were related by the displacement each micropost moved since each cantilever could be approximated as a spring. With aid of image processing software, micropost traction forces were quantified, and the edges of the cells were found to pull more strongly on the microposts compared to the center of the cell. The forces were found to pull inwards towards the center of the cell causing unidirectional cellular migration due to the variable stiffness and spacing gradients.

Student: Connor Benton
Professor/Sponsor: Professor Tony Keaveny
Mentors: Megan Pendleton and Alex Baker
Research Project Title: Design and Implementation of an Apparatus for Flexural Testing of Trabeculae

Abstract:
The purpose of this research is to identify the most efficient and precise method of measuring the strain-stress properties of trabecular bone tissue at a very small scale. The heterogeneity inherent in bone tissue across different people suggests that there is value in large-scale testing in order to better understand how factors such as age, disease, and disease treatment impact the material properties of the bone itself. We first evaluated the differences between strain tests and their feasibility in regard to testing specimens of our ideal size, eventually coming to the conclusion that three-point flexural testing was the best approach. We designed a test bed for this research, using high-resolution micrometers and actuators in order to give us the control we desired, and fabricated the apparatus in the student machine shop. In order to verify the accuracy of our solution, we conducted material tests of aluminum samples with known strain-stress properties. Our test bed is a compact, accurate, easy-to-use platform that provides the means to test large quantities of specimens and establish a better understanding of their material properties. This research will be built upon by our team in future testing and evaluation of different impacts on the strength of trabecular bone tissue.

Student: Matt Cameron
Professor/Sponsor: Lisa Pruitt
Mentor: Cynthia Cruz
**Research Project Title:** Improved Method for Specified Motion Monitoring While Conducting Wear Testing on Biomedical Thermoplastic Polycarbonate-Urethane

**Abstract:**
In current medical devices, cobalt chromium (CoCr) and ultra-high molecular weight polyethylene (UHMWPE) materials are used to minimize fatigue and wear of joint replacements while in vivo. However due to the nature of the polymer, UHMWPE particulates can wear off and be released into the body and subsequently loosen the implant with the potential to fail. A new polycarbonate-urethane material, Bionate®, is considered to have little to no wear compared to UHMWPE [1]. Studies have only focused on Bionate® 90A and 55D. DSM, Inc. is looking at the application of Bionate® 80A and 75D in the shoulder, yet no studies focused on the wear characteristics of these specific Bionate® chemistries. Hence, the Medical Polymer Group has a Multi-Directional Tribo-System (ELVIS), which will conduct wear testing on the 80A and 75D Bionate® material.

ELVIS is a converted CNC mill controlled by a custom a National Instruments LabVIEW Virtual Instrument (VI). The VI controls the type of motion, speed, and amount of translation and rotation to conduct wear tests as well as mimic motions within a joint. The VI simultaneously monitors the position of the point of contact, the temperate and electric current of the CNC motors, and cycle information. In preparation for the Bionate® wear testing, improvements were made to how the VI monitors cycle count and cycle time. This was achieved by adding new features to the motion code in addition to timing functions that execute when motion parameters change. This allows for more accurate testing and estimation for how long the test will take. The revamped VI in combination with other adjustments will allow ELVIS to accommodate samples of the new material and then the wear characteristics of Bionate® 80A and 75D can be established. Future studies will use ELVIS to mimic the gait cycle in a shoulder joint, which has translation, abduction/adduction, and elevation all at varying rates within one motion cycle. This would be a better model at predicting the wear in the shoulder joint.


**Student:** Joe Felipe  
**Professor/Sponsor:** Professor Grace O’Connell

**Research Project Title:** Design of Large Scale Waterbath For Mechanical Testing of Soft Tissue

**Abstract:**
Mechanical testing of the intervertebral disc requires that the soft tissue maintain hydration for accurate and meaningful results. The aim of this project was to build a large scale waterbath compatible with the lab’s MTS machine for usage in soft tissue biomechanics. Prior to using a bath for mechanical testing, experiments that were performed could only be executed for 2-3 hours before samples of bone-disc-bone segments no longer maintained proper hydration. A new testing configuration was to be implemented in which the load cell was to be moved from the bottom to the top of the MTS machine. Grips were prepared to hold samples of bone-disc- bone segments in place for testing. With this new configuration, the bath and grips could be used for all sorts of mechanical testing such as compression, tension, and torsion. A 3-D model of the bath was made in Solidworks prior the machining of the bath. The implementation of a waterbath has greatly improved the accuracy of our results. Studies in the O’Connell lab have been focused on understanding the mechanical function of the healthy, injured and degenerated disc with the goal of developing viable repairment strategies. It is essential to have
accurate and repeatable data to meet this goal. For example, a recent study "Osmotic loading environment alters intervertebral disc mechanical function" focused on comparing the mechanical properties of the intervertebral disc when soaked in a 1X vs 20X (.1M or 2M) saline solution. The difference in salinity would mimic two different states of hydration experienced in diurnal loading. Prior to the bath, bone-disc-bone segments were soaked overnight and then tested for only 2.5 hours. A prediction model was used in MATLAB which determined the samples would take about 16 hours until they reached equilibrium (no longer displacing during creep). With the implementation of the waterbath, results will no longer need to be "predicted" based off the limited data that could be collected. The next study using the bath will be on understanding the effects of space flight on spine biomechanics.

Student: Landon Henson  
Professor/Sponsor: Lisa Pruitt  
Mentor: Cynthia Cruz  
Research Project Title: Polishing UHMWPE for use in experiments  

Abstract:  
The purpose of our current research is focused on various aspects of ultra high molecular weight polyethylene (UHMWPE) and Bionate® as it relates to wear, life and early failure in orthopedic implants. It is well known in the orthopaedic community that UHMWPE in combination with cobalt chromium (CoCr) are good counter bearing materials for joint replacements. However, UHMWPE does have a finite life expectancy. Historically wear and damage of UHMWPE has affected the longevity of orthopaedic implants. Thus, it is our goal to gain a better understanding of how the wear characteristics of Bionate® compares with the wear characteristics of UHMWPE. It has been proposed that Bionate® 80A and 75D should be used as a counter bearing material for CoCr in the shoulder joint by DSM, inc.

In order to run experiments and thus get a better understanding of how the wear characteristics of Bionate® and UHMWPE effect the life of implants, we must reproduce as close as possible a medical grade finish that manufacturers achieve on their implants. One such property is the "smoothness" or roughness average (Ra) number of the sample to be used in experiments. Ra is the measure of the texture of a surface. To quantify the surface roughness we use a profilometer to measure the profile of the UHMWPE surface.

Previously in our lab, UHMWPE samples were polished to an Ra number of approximately 0.2~.4 µm. To achieve this finish with repeatability a new SOP for polishing was needed. The new process is a two-part wet sanding procedure. Once the appropriate geometric tolerances are obtained from machining the samples, they are polished. Optimal conditions for polishing show that abrading the sample with 800-grade sandpaper followed by 1200-grade result in consistent Rₐ of .2~.3 µm.

Student: Divya Kulkarni  
Professor/Sponsor: Professor Tony Keaveny  
Mentor: Shashank Nawathe  
Research Project Title: Influence Of Typical Population-Variations In Tissue-Level Ductility On The Femoral Strength  

Abstract:
The strength of the whole bone is widely known to have a direct correlation with aging, disease and treatment. However there is not much work on the effect of tissue level ductility on whole bone strength. It makes sense that a change in individual tissue ductility would affect the overall failure of the bone whether it be the femur or the vertebrae. There have been studies in the past for which the tissue level ductility is manipulated to be either fully ductile or fully brittle and the effect of these cases on the strength of the whole bone are studied. In the real world case such extreme behaviors would most likely not be seen. In our study, we focus on human proximal femurs to study the whole bone strength and varying values of ultimate strain for the bone tissue ductility. The distinction between cortical and trabecular bone is made to find a deeper correlation between tissue level ductility and femoral strength. Relating the tissue level ductility on a micro scale with whole bone strength will be vital in understanding the cause of hip fractures and its risk-assessment.

Four cadavers are chosen to test various values of ultimate strain for both trabecular and cortical tissues of these bones. The values used are based on the previous studies of general ultimate strain values in the human population. It was assumed that ultimate strain values in tension and compression were equal. We performed our non-linear finite element analyses using the iterative quasi-nonlinear technique that has also been previously used in our fully brittle analyses.

The femoral strength was determined from each set of ultimate strains on both the cortical and the trabecular bone. This strength was determined using the force strain curve for a structure-level and calculating the 0.2% offset. Tissue level failure included both yielding and fracture. It seems as though during a sideways fall, only about 10% to 12% of the femoral strength is actually affected by the changing tissue ductility. The trabecular bone seems to have a larger effect on the entire bone strength. It seems the cortical bone ductility only plays a large role when the trabecular bone ductility is already low.

Student: Ruben Maldonado  
Professor/Sponsor: Professor Tony Keaveny  
Mentor: Arnav Sanyal  
Research Project Title: Multi-Axial Strength Testing of Human Femoral Trabecular Bone

Abstract:
Since multiaxial stresses can develop in trabecular bone during falls and at bone-implant interfaces, multiaxial strength behavior is of fundamental relevance to a number of orthopaedic problems. Building on the work of other student researchers in the lab who developed a 3D multiaxial failure criterion for human trabecular bone, the goal of this research is to extend the work to low-density trabecular bone and subsequently validate it using experiments. The experimental results will be used to validate the finite element models.

Student: Audrey Martin  
Professor/Sponsor: Lisa Pruitt  
Mentor: Farzana Ansari  
Research Project Title: Evaluation of Damage on Retrieved Humeral Head Prostheses

Abstract:
**Introduction:** Over 53,000 patients in the United States each year receive a Total Shoulder Replacement (TSR), a synthetic metal-polymer bearing system that serves to reproduce the function of a diseased or injured glenohumeral joint [1]. On average, 10 percent of these patients will undergo a risky and costly revision due to premature wear, loosening, and fracture of the ultrahigh molecular weight polyethylene (UHMWPE) glenoid component [2]. Studies have shown that there is a strong correlation between the presence of UHMWPE-wear debris and bone loss (osteolysis) which can induce loosening of the glenoid component [3, 4]. The purpose of this ongoing study is to analyze the relationship between damage on Cobalt-Chrome (CoCr) humeral head prostheses and glenoid component wear. The goal for this term was to collect more scoring data for and prepare for a counter-bearing wear analysis.

**Methods:** The Medical Polymers Group (MPG) houses a collection of retrieved humeral head prostheses, many with matching glenoid components. Samples were prioritized for scoring based on the presence of (1) a matching glenoid component, (2) a damage evaluation for the glenoid component, and (3) an orientation marking on the CoCr component. Three undergraduates were trained in a previously developed, detail-oriented scoring methodology to evaluate damage on the retrieved humeral heads. The scoring methodology segregates damage modes into six categories: hairline scratching, curvilinear abrasion, pitting, dimpling, striated scratching, and linear abrasion. The data was analyzed by determining the percent of samples exhibiting each damage mode and the percentage of identification variation between scorers as compared to previously collected scores. Preparations were also made for a counter-bearing wear analysis by evaluating the capabilities of MPG's custom multidirectional tribological-system and designing fixtures for testing.

**Results:** In total, seven new scores were collected. Striated scratching continues to be the most commonly found damage mode with 100% of samples exhibiting this damage mode followed by curvilinear abrasion at 94.1%. Dimpling was found to be the least common at 61.8%. At least 88% of scorers per sample showed agreement on the presence of a particular damage mode for n > 2 scorers. The test parameters for the counter bearing analysis were determined. Given the current capabilities of the test frame, a 200/20N load profile was deemed appropriate for preliminary testing.

**Discussion and Conclusions:** MPG's scoring methodology continues to yield consistent results. With striated scratching and curvilinear abrasion being the most commonly found damage modes, these would be appropriate parameters to isolate for upcoming counter-bearing analyses. Future work will include performing these wear analysis using a sample with an isolated region of striated scratching, and abrasion as compared to an unused sample with no damage.

**Student:** Robin Parrish  
**Professor/Sponsor:** Lisa Pruitt  
**Mentor:** Farzana Ansari  
**Research Project Title:** Analysis of Stresses in Glenoids

**Abstract:**

*Introduction:* Ultra high molecular weight polyethylene (UHMWPE) is the most commonly used bearing surface in total joint arthroplasties. However, failure of the UHMWPE component is a common cause of device failure. Therefore, novel materials are being developed in an attempt to increase the life of these devices. This study set out to determine stresses in the bearing surface used in total joint arthroplasty as a function of material, geometry, and loading conditions.
Methods: This study was carried out computationally using the simplified elasticity solution and focused on the glenoid component of total shoulder arthroplasties. The following parameters were varied to determine their effects on stresses: elastic modulus of material used, backing material, and radial mismatch. Glenoid radius of curvature was also investigated for consideration of its effects on stresses in the glenoid.

Results and Discussion: It was shown that stresses in the glenoid increase as the modulus of elasticity of the glenoid increases. Glenoid stresses also increase with decreasing radial mismatch between the glenoid and humeral components. However, due to the increased contact area associated with lower moduli, effects of conformity are minimized in systems containing glenoids with lower moduli. Finally, it was shown that for any given geometric configuration, there is a polynomial relationship between modulus and maximum stress. This relationship was used to isolate the effects of backing thickness and humeral geometry and to demonstrate that increasing backing thickness increases the effective modulus and maximum stress in the glenoid. Finally, our findings suggest that biomaterials with lower moduli may be able to decrease stresses in the glenoid, subsequently reducing wear rates and leading to lower device failure rates.

Future Work: Finite element analysis (FEA) will be performed, and results from the simplified elasticity solution will be compared to the results of the simulation. Following the validation of this FEA model, a glenoid with variable radius of curvature will be investigated. Finally, conclusions will be drawn concerning the efficacy of novel biomaterials.

Student: Robin Parrish
Professor/Sponsor: Lisa Pruitt
Mentor: Farzana Ansari
Research Project Title: Finite Element Analysis of Crack Propagation in UHMWPE

Abstract:
Introduction: Ultra high molecular weight polyethylene (UHMWPE) is commonly used as a bearing surface in total joint arthroplasties. However, failure of the UHMWPE component is a common cause of device failure. Several material modifications can be made to increase wear resistance, fracture resistance, and oxidative resistance. However, each compositional change has trade-offs. We are interested in characterizing the structure-property relationships that govern crack propagation because fracture is a common cause of catastrophic device failure.

Methods: This study was carried out computationally in conjunction with mechanical crack-propagation tests. A crack test specimen was modeled in Abaqus FEA software (Dassault Systèmes Simulia Corp), and various loading conditions were applied. The radius of the notch tip was varied, and a side-groove was added to the model. Complementary mechanical tests were carried out with the same set-up as the Abaqus model.

Results and Discussion: The conclusions that were drawn from the results of the simulations are as follows: (1) Stresses near the notch tip increase with decreasing notch radius. (2) Stresses near the notch tip increase with movement through the depth of the sample into the center. (3) Sharper notch radius results in lower stresses away from the notch tip. (4) Stresses at the surface and in the center do not change proportionally with movement away from the notch tip.
Future Work: Material data is being collected on the specific formulations of UHMWPE that are of interest to us. Connections are being drawn between the FEA model and the mechanical tests. We will calculate the size of the plastic zone in front of the notch tip to better design the mechanical tests to result in cracking rather than yielding.

Student: Joanna Scheffelin  
Professor/Sponsor: Professor Tony Keaveny  
Mentor: Arnav Sanyal  
Research Project Title: Multiaxial Failure Criterion of Trabecular Bone

Abstract:  
This semester I worked with Arnav Sanyal on the "Multi-axial Strength Criterion" project in which micro-CT scans of trabecular bone cube specimens were crushed in FE simulations by applying displacements in the x, y, and z directions. Data was collected for failure (Principal stress at failure) for all 3 directions. The ultimate goal is to fit this data to a closed ellipsoid in which the failure stresses in each direction are superimposed to create a super ellipsoid to show failure criteria of the bone specimen. I wrote various algorithms in MATLAB to fit this code to a closed surface. The best fit is a quartic ellipsoid translated and rotated by 3 Euler angles and with an additional variable term to alter the fit. The fit is done using the "fmincon" function in MATLAB with 10 variables.

Student: Colin Shanahan  
Professor/Sponsor: Professor Lisa Pruitt  
Mentor: Farzana Ansari  
Research Project Title: Compression Testing of Cross-linked Vitamin E Enriched Ultra High Molecular Weight Polyethylene

Abstract:  
Vitamin E enriched Ultra-high molecular weight polyethylene (UHMWPE) is growing in popularity as a material for knee and other joint replacements due to its anti-oxidation properties. However, there have not previously been any studies done on its compressive properties which greatly determine its quality as a material in joints such as the knee. Using a methodology developed in previous tests which was based off of ASTM standard D695 for compressive testing of rigid plastics a series of tests were performed using an Instron machine. Conventional GUR 1020 UHMWPE was tested for baseline comparison purposes, both cross linked and non-cross linked. The same was performed for GUR 1020 UHMWPE enriched with Vitamin E, both cross linked and non-cross linked. Also of interest was the orientation of samples cut from stock material to confirm isotropy. Results so far have not shown any clear correlations and so further testing is required.

Student: Amelia Swan  
Professor/Sponsor: Lisa Pruitt  
Mentor: Farzana Ansari  
Research Project Title: Comparison of Scratching and Abrasion Damage on Retrieved Cobalt Chrome Humeral Heads

Abstract:
The in vivo damage observed on the counterbearing cobalt chrome (CoCr) surface of total joint replacements (TJR) can increase the volume of wear debris released from the ultra-high molecular weight polyethylene (UHMPWE) glenoid surface. Consequently, osteolysis and implant loosening can occur [1]. The previous study investigated metallic damage on a microscale, scanning retrievals for striated and hairline scratches with a Phasesshift 3D Optical Profilometer. MapVue and Vision 32 software were used to retrieve 2D profiles of the surface. Matlab uses this data to gain values for average roughness (Ra), minimum valley depth (Rv), maximum peak height (Rp), skewness (Rsk), and kurtosis (Rku) [2]. This investigation applies the same methodology to scratches within abrasion patches found on the CoCr surface. The abrasion data will be compared to scratch data to determine if damage modes have different severities. Additionally, after testing different profiling methods in Vision 32, a more global abrasion analysis has also been developed. This analyzes a whole patch of abrasion as opposed to just one of its components. Future studies will include a comparison of the damage found on shoulder retrievals with that of hips and knees using the same procedures, as well as examining damage trends on CoCr surfaces of total arthroplasties versus hemiarthroplasties. Thanks to the principle investigator Lisa Pruitt, graduate mentor Farzana Ansari, and the Biomedical Nanotechnology Center for the use of their optical profilometer.


Student: Amelia Swan
Professor/Sponsor: Lisa Pruitt
Mentor: Farzana Ansari
Research Project Title: Development of Roughness Parameter Analysis for Retrieved Humeral Heads

Abstract:
Once retrieved, total shoulder replacements display damaged counterbearing cobalt chrome (Co-Cr) humeral heads. This damage varies in geometry and severity, from hairline and striated scratching to curvilinear and linear abrasion. It is theorized that this damage accelerates the wear of the bearing ultra-high molecular weight polyethylene (UHMWPE) surface in vivo. These wear particles can lead to implant loosening and an inflammatory response called osteolysis [1]. Previous studies in the lab have developed a macroscale damage scoring system, as well as a damage analysis method that determines roughness parameters over 2D profiles of the microscale surface. [2] The study shows that scratching has a higher peak height, kurtosis (peak sharpness), and average roughness compared to abrasion, although abrasion has higher skewness. It is likely that the third-body wear mechanisms differ between the damage modes. The large peaks from scratch profiles likely generate larger UHMWPE particles, but their negative skewness indicates that some peak material may be worn away over time. Abrasion with a linear geometry commonly occurs at the center of the humeral head, which experiences the largest contact stresses; this explains the reduced peak heights and kurtosis values found for this damage type. Meanwhile, curvilinear abrasion has blunter, shorter peaks and positive skewness but covers a large portion of the head's surface area. This could generate smaller wear particles but a larger overall volume of wear debris, which can worsen the immune response. [3] The study is currently ongoing. Future steps include increasing the sample size for statistical analysis; comparing damaged surfaces from different fixation methods, implant geometries, and causes of failure; coupling the damage between UHMPWE and metal surface; expanding the roughness analysis to hips and knees; and testing retrieved implants to see how scratch morphologies change after wear testing. Thank you to Professor Lisa Pruitt, graduate mentor Farzana Ansari, the employees of the Mechanical Engineering Student Machine Shop, and the
Medical Polymers and Biomaterials Group for their advisement and facilities, as well as the Biomedical Nanotechnology Center for the use of their optical profilometer.


Student: Amelia Swan
Professor/Sponsor: Lisa Pruitt
Mentor: Farzana Ansari
Research Project Title: Damage Analysis of Cobalt Chrome Humeral Head Retrievals using 3D Profilometry

Abstract:
After a total shoulder replacement is retrieved, damage is observed on both the bearing glenoid surface and the counterbearing humeral head. These are made of ultra-high molecular weight polyethylene (UHMWPE) and cobalt chrome (Co-Cr), respectively. The damage accelerates UHMWPE wear debris generation when the two surfaces articulate in vivo. This can lead to implant loosening and a painful immune response called osteolysis [1]. Previous studies have used a Phaseshift Optical Profilometer to scan the surface of the Co-Cr component, and MapVue and Vision 32 software to collect 2D surface profiles. Matlab imports this data and calculates average roughness (Ra), minimum valley depth (Rv), maximum peak height (Rp), skewness (Rsk), and kurtosis (Rku) [2]. This methodology has been applied to different severity levels of hairline scratching, striated scratching, and linear abrasion patches. It has been shown that certain damage modes and severities have some significant differences in roughness parameter values. Logically, it follows that the differing roughness values on the Co-Cr surface generate variably-sized UHMWPE wear particles [3]. However, a macroscale analysis should also be considered, as the damaged area’s size and density will also affect the volume of wear debris. A multi-directional tribotester will be used for preliminary wear testing of retrieved Co-Cr humeral heads against UHMWPE disks. The tests will focus on comparing results from contact areas covered by varying damage modes and severities. This will illuminate the volume of UHMWPE debris that is worn away based on damage mode, and how metallic damage modes change after articulation against UHMWPE disks. Future studies will include additional roughness parameter statistics, the continuation of wear testing, and the expansion of this analysis to hip and knee retrievals.