BIOMEDICAL ENGINEERING RESEARCH DAY 2026

Wednesday, April 8, 2026 | Pearl Sullivan Engineering (PSE) 2317

Presentation Abstracts

UNIVERSITY OF WATERLOO
FACULTY OF ENGINEERING

SESSION 1

Investigating the response of early and late tear polymorphonuclear neutrophils to bacterial challenge: development of an in vitro infection model of the closed eye environment

Genevie Tran, MASc student
Supervisor(s): Dr. Maud Gorbet

Abstract
The ocular surface is considered an immune-privileged site: immune activity is restricted to protect from inflammatory damage. As such, potential immune responses are often overlooked in ophthalmic biomaterial design. However, hundreds of thousands of tear polymorphonuclear neutrophils (tear PMNs) accumulate on the ocular surface during prolonged eye closure overnight. As tear PMNs are phenotypically distinct from blood-derived PMNs, their interactions with bacteria and biomaterials are poorly understood. To provide insight into ocular homeostasis and immunomodulatory biomaterials, this research aims to develop an in vitro infection model of the closed-eye environment to investigate the response of tear PMNs to bacteria in the presence of contact lenses.
Methods: To identify a material suitable for a bacterial infection model, live Staphylococcus epidermidis was incubated in tissue culture polystyrene (TCPS) wells or polypropylene tubes for 60 minutes, then plated on agar to quantify colony-forming units (CFUs). To compare late versus early tear PMNs, participants collected tear PMNs using a gentle eyewash technique after 2 and 7 hours of sleep (ORE#43743). Phagocytosis was assessed by incubating tear PMNs with fluorescent, inactivated Escherichia coli for 60 minutes (1:10 PMN:bacteria), then internalized bacteria were quantified using flow cytometry. Tear PMNs were also challenged with live S. epidermidis (1:1 ratio) for 60 minutes on a contact lens (Lotrafilcon A), followed by plating and CFU enumeration.
Results: Recovery of S. epidermidis CFUs was inconsistent after incubation on TCPS (0-7 CFUs, n=4), but successful on polypropylene (≥3 CFUs, n=4). Significantly more 7-hour tear PMNs phagocytosed inactivated E. coli compared to 2-hour tear PMNs ($p<0.005$, n=6). Co-incubation of live S. epidermidis with 7-hour tear PMNs resulted in fewer CFUs than 2-hour tear PMNs, but this difference was only significant when co-incubation occurred on Lotrafilcon A ($p<0.05$ with lens, $p>0.06$ without lens, n=3). Eyewash collection samples plated on agar alone yielded fewer than two CFUs (n=4).
Conclusion: Bacteria incubation in polypropylene provides more reliable recovery. Our results suggest that prolonged exposure to the closed eye environment affects tear PMNs antimicrobial activity; 2-hour tear PMNs may more accurately recapitulate tear PMN functionality in a closed-eye in vitro model. Current results highlight that the presence of a contact lens may affect the killing ability of 2- and 7-hour tear PMNs differently. Future work includes increasing sample size for live bacteria experiments and investigating the effects of various contact lens materials on tear PMN-bacteria interactions.

Semantic-lexical adaptation to adverse noise conditions

Polina Stepanenko, MASc student
Supervisor(s): Dr. Ewen MacDonald

Abstract
Conversational dialogue is not only shaped by acoustic features and timing but also by the evolving semantic content exchanged between interlocutors. While prior work, such as Ellag et al. (2024), demonstrated that background noise alters turn-taking dynamics, it did not consider what speakers say. Yet, semantic cues have been shown to play a critical role in speech perception, especially under adverse listening conditions, where contextual predictability can facilitate intelligibility. In this study, we analyze the recordings collected in Ellag et al. (2024) to examine the semantic structure of dialogues between native-English speakers in both quiet and noisy environments during free-form and task-based interactions. Our goal is to understand how noise and task demands influence semantic coherence, alignment, and predictability across conversational turns. Using natural language processing techniques, we analyze phrase-level embeddings and word predictability to explore how meaning shifts within and between speakers under different conditions. This approach allows us to investigate whether noise leads to more constrained or elaborative speech, and how it affects the alignment of semantic trajectories across interlocutors. Together, these findings will offer new insights into how environmental challenges influence both the structure and coherence of conversational interaction.

In-vitro model of bone remodeling: studying osteoblast and osteoclast response to novel nanocomposite biopolymers

Mariya Peskova, MASc student
Supervisor(s): Dr. Maud Gorbet, Dr. Thomas Willett

Abstract
Bone is a dynamic tissue that is maintained by a balance of activity of bone resorbing osteoclasts and bone forming osteoblasts. Ideally, biomaterials used in grafting/implant applications should match the mechanical and physical characteristics of the bone environment, withstand and not exacerbate the immune response, and integrate with bone. In my thesis I will improve existing methods for the culture of immortalized osteoblasts (dMC3T3-OB) and the differentiation and culture of immortalized macrophages (RAW 264.7) into osteoclasts on novel 3D printed nanocomposite biopolymer specimens in-vitro. In my preliminary work, I have explored several assays that can act as predictive metrics for bone matrix deposition by immortalized osteoblasts, such as alizarin red staining and alkaline phosphatase to determine mineralization, and hydroxyproline concentration to determine collagen deposition. Additionally, by staining cells with tartrate resistant acid phosphatase (TRAP), I have confirmed that culturing immortalized macrophages in medium supplemented with macrophage colony-stimulating factor (M-CSF) and receptor activator of nuclear factor kappa-B ligand (RANKL) leads to osteoclast differentiation. I successfully isolated primary osteoblasts and osteoclasts from mouse and rabbit bones, which will support in vitro biocompatibility experiments with primary cells. I have also examined the potential of bovine bone specimens treated with supercritical CO_2 (sCO_2) as a positive control. Before the end of the year, I will continue improving current protocols, propose a new positive control using calcium phosphate mineralization, identify and test ways to determine osteoclast resorption pits, and include an oxidative stress model for testing protective properties of biomaterials.

Towards better understanding of trimester specific gait kinematics during pregnancy

Alyson Colpitts, PhD student

Supervisor(s): Dr. Elise Laende

Abstract
Current understanding of biomechanical changes during pregnancy and post-partum is limited. The objective of our study was to investigate kinematic changes over pregnancy and the feasibility of capturing data these changes using accessible markerless motion capture. Data were collected using 8 synchronized Sony video cameras and processed with markerless motion capture software (Theia3D, Kingston, ON). Exercises included walking, fast walking, balance, and lifting and carrying tasks. Participants had decreased maximum hip sagittal plane angle between trimester 1 (37.6+/-0.9 degrees) and trimester 3 (36.2+/-2.0 degrees) and increased maximum knee flexion angle from trimester 1 (64.5+/-1.4 degrees) to trimester 3 (68.2+/-3.1 degrees; Figure 1). This work demonstrated initial feasibility of using a novel markerless motion capture approach to track kinematics in a pregnant population, enabling high throughput and minimizing participant burden which will support ongoing research in this understudied area.

Quantum sensing for sperm oxidative stress analysis

Rahul Menon, PhD student

Supervisor(s): Dr. Veronika Magdanz

Abstract
I will be discussing the biological and pathological role of Reactive Oxygen Species (ROS) in the context of sperm cells and describing the experimental protocol I will be using to test the validity of using ESR as a measurement tool for ROS in sperm cells.

Magnetic microrobots for targeted blastocyst delivery

Mu Yun Zhang, PhD student

Supervisor(s): Dr. Hamed Shahsavan, Dr. Veronika Magdanz

Abstract

Infertility affects 1 in 6 adults worldwide over their lifetime. In the past decade, in vitro fertilization (IVF) has become the leading assisted reproductive technology. However, implantation remains a major bottleneck limiting per-cycle live birth rates below 35%. Current embryo transfer techniques use ultrasound to guide catheter tip position for depositing the embryo in the uterus, but lack control and tracking of the embryo's final location, despite evidence that uterine site and stable embryo-endometrium contact influence implantation success. This project proposes using magnetic microrobots during embryo transfer to enable targeted and trackable blastocyst delivery, aiming to improve implantation rates by guiding embryos to optimal uterine regions and promoting confined contact. Initial experiments will characterize magnetic actuation of blastocyst-scale carriers in in vitro models to demonstrate precise positioning capability, followed by validation of biocompatibility and adhesion in endometrial culture systems. This microrobotics approach aims to provide a novel solution for precise, reproducible embryo placement in the IVF process.

Characterization of strontium-substituted calcium phosphate apatite mineralization

Alyson Ranger, PhD student

Supervisor(s): Dr. Liza-Anastasia DiCecco, Dr. Maud Gorbet

Abstract

Motivation: Additively manufactured porous titanium (Ti) implants are increasingly used in orthopedic and dental applications for their ability to mimic trabecular bone architecture. However, in conditions such as osteoporosis (OP), Ti’s bioinert nature limits bone-implant integration. Calcium phosphate apatite (CaP), the primary mineral in bone, provides structural rigidity and connection between bone and implant. OP disrupts bone remodelling, altering CaP crystal size and lattice organization, which compromises mechanical integrity and integration. Incorporating ions like strontium (Sr^{2+}) can substitute into the CaP lattice and stimulate bone formation while reducing bone resorption. The mechanisms by which Sr alters CaP nucleation, growth, and lattice structure remain unclear. Understanding these processes at the nanoscale is essential for the design of Sr-modified biomaterials, such as porous Ti implants, which are rising in popularity as a future bioactive component.

Objectives: The key objectives of this research are to (1) understand the substitutional behaviour of Sr in CaP mineralization and (2) determine the optimal CaP:Sr^{2+} ratio that improves CaP crystal characteristics and mechanical behaviour.

Methods: A hyper-mineralized saliva model was used to study early CaP mineral

formation with 0–20 mol% Sr^{2+} substitution under physiological conditions. Reactions were sampled at 0–4 h, with aliquots deposited onto lacy carbon 400-size copper grids, after which the grids were rinsed in methanol to halt mineralization and rinse samples. High-resolution transmission electron microscopy (TEM) results will be shared, used to assess crystal morphology, size, and lattice organization. Selected area electron diffraction (SAED) distinguished amorphous CaP from crystalline HAP and revealed lattice distortions due to Sr. Energy-dispersive X-ray spectroscopy (EDX) provided elemental mapping, while inductively coupled plasma optical emission spectroscopy (ICP-OES) quantified Sr solubility over time.

Conclusion: This multiscale characterization approach highlights the effects of Sr substitution on nanoscale CaP crystal development, guiding the design of Sr-doped coatings for porous Ti implants.

Intelligent autonomous navigation to restore independence in assistive mobility

Taha Liaqat, PhD student

Supervisor(s): Dr. Jim Wallace, Dr. James Tung

Abstract
Mobility is a fundamental aspect of independence and quality of life. However, many people with severe motor impairments such as those with amyotrophic lateral sclerosis (ALS) are unable to control their powered wheelchairs in a safe and reliable manner. Although their cognitive abilities are generally intact, the progressive loss of motor control reduces a user's ability to provide the continuous low-level (e.g., go forward, left, right) control typically required by wheelchairs for navigation in complex indoor spaces. Thus, safe and efficient movement should be increasingly supported by the wheelchair itself, rather than relying on continuous user control. However, removing decision making entirely from the user would undermine trust and agency. This highlights a central challenge, how to reduce cognitive and physical burden while ensuring the user remains meaningfully in control. This creates a critical need for a shared-autonomy navigation system that can restore meaningful mobility while operating under sparse, high-level goals while the system handles the low-level navigation steps to reach the goal.

SESSION 2

Bilateral external knee adduction moment during cycling in people with and without knee pain from osteoarthritis

Dan Currie, PhD student
Supervisor(s): Dr. Monica R. Maly, Dr. James Tung

Abstract
Introduction: Knee osteoarthritis (OA) is one of the most common chronic conditions in Canada [1]. Commonly, the pain caused by knee OA is unequal between knees, which can lead to asymmetry of movement in daily activities. External knee adduction moment (KAM) is linked to the progression and severity of knee OA [2]. The effect of seat height and workload on KAM during cycling has been explored in a single leg analysis in healthy adults [3]. Bilateral analyses are rare. The objective of this secondary analysis is to compare KAM during the pedaling cycle between seat heights, workloads and knees (more versus less painful knee; or dominant versus non-dominant when there was no knee pain or the same pain intensity in both knees) in people with and without symptomatic knee OA.

Methods: Twenty-six participants aged 45-75 years, with and without symptomatic knee OA completed six cycling bouts at three seat heights and two workloads on a commercial fit-bike (Pro 1, Purely Custom, USA). Each bout was performed for 2 minutes at a cadence of 60 rpm. Self-reported knee pain on the Numeric Pain Rating Scale (NPRS) was recorded before the first and after each bout. Synchronized three-dimensional kinematics and kinetics were collected with a commercial motion capture system (Optotrak Certus, NDI, Canada) and a commercial instrumented 3-axis pedals (Science to Practice, Slovenia). The KAM waveform for both knees was calculated in Visual3D (HAS-Motion, Canada). From the full waveform, a 1-minute portion was selected and averaged to 1 pedal cycle. A three-way repeated-measures analysis of variance was conducted in a statistical parametric mapping (SPM) analysis to compare the external KAM values in the average pedal cycle.

Results: A dominant significant effect of workload was found ($p < 0.001$) where KAM was greater with greater workload. Significant, but minor differences in KAM were also observed between seat heights and between knees ($p < 0.05$).

Discussion: The KAM is similar in both knees in this bilateral task The increase in demand from the higher workload appears to increase the external KAM. This result is in line with previous research [3].

References:
[1] Bombardier C. et al. (2011). The Impact of Arthritis in Canada.
[2] Miyazaki et al. (2002). Dynamic load at baseline can predict radiographic disease progression in medial compartment knee osteoarthritis. Vol.61(7); p. 617-622
[3] Hummer et al. (2021). Does saddle height influence knee frontal-plane biomechanics during stationary cycling? Vol.29; p. 233-240

Investigating the regulation of speech level during conversations in noise

Ben Masters, PhD student
Supervisor(s): Dr. Ewen MacDonald

Abstract
The Lombard effect describes the adaptation of speech production based on the acoustic environment (e.g., increased speech level in noise). Although it's been suggested that the manifestation of this effect during conversation may be partially driven by the monitoring of a partner's voice, we expect that the effect remains primarily driven by the monitoring of one's own voice in the environment. This study investigates this by examining whether receiving an attenuated version of a partner's voice during a conversation elicits adjustments in speech or communication behavior. Pairs of university-aged, typical hearing talkers held conversations in adjacent sound booths in either a quiet reference condition, or in the presence of a 70 dBA speech-shaped background noise. During the noise condition, one of three gain settings was applied to the speech signals: unity gain or a 3 dB attenuation of either talker's voice. Talkers always heard their own voice at unity gain. We discuss results which evaluate differences in speech acoustics, speech content, and communication behavior across gain settings to determine if the received level of a partner's voice affects one's own speech production.

Anti-cancer drug loaded magnetized alginate beads for active targeted delivery in the female reproductive tract

Motahareh Shabani Dargah, PhD student
Supervisor(s): Dr. Veronika Magdanz

Abstract
This study presents magnetic, drug-loaded alginate beads as a targeted drug delivery platform for the treatment of gynecological cancers in the female reproductive tract. Conventional cancer therapies often cause severe side effects due to the non-specific distribution of drugs throughout the body. To overcome this limitation, alginate beads containing iron oxide nanoparticles were fabricated to allow magnetic guidance toward specific tumor locations. The loading capacity of the anticancer drug doxorubicin (DOX) was evaluated for beads with different sizes and iron oxide concentrations to assess their drug cargo and navigation capabilities. The results showed that 1 mm beads containing 30 mg/mL iron oxide were able to load approximately 13 µg of DOX within 120 hours. In vitro drug release experiments demonstrated a sustained and stable release of doxorubicin over a period of 10 days, leading to an effective cytotoxic effect on uterine sarcoma cells as early as four days after treatment. Furthermore, magnetic actuation experiments conducted both in a test tube and in a uterus phantom confirmed that the beads could be effectively controlled in media with varying viscosities. Overall, magnetized alginate beads represent a promising strategy for targeted and controlled delivery of doxorubicin for the treatment of gynecological cancers.

Biomechanical analysis of the backhand drive in disc golf players

Bianca Simone, PhD student

Supervisor(s): Dr. John McPhee

Abstract

Disc golf backhand drives involve rapid, high-impact rotational movements of the torso, shoulder, elbow, and wrist, often leading to upper-extremity injuries due to their repetitive nature. Despite the sport's growing popularity, biomechanical research on disc golf remains limited. This study addresses that gap by analyzing the kinematics and dynamics of the backhand drive in nine participants with skill levels ranging from intermediate to expert, classified by their Professional Disc Golf Association (PDGA) ratings. Higher-rated players demonstrated smoother, more coordinated joint kinematics and torque patterns, suggesting greater upper-body control and a more efficient kinetic chain from the torso to disc release. These findings offer valuable insights for coaches, athletes, and sports medicine professionals, with potential applications in performance optimization, injury prevention, and the development of evidence-based training programs.

SESSION 3

Development of an integrated virtual twin lumbar intervertebral disc model for a spinal loading simulator

Claire Thompson, PhD student

Supervisor(s): Dr. Stewart McLachlin

Abstract
This presentation will be a continuation from the previous BME research day. It details a novel methodology to use the unique capabilities of the AMTI VIVO virtual constraints to create a model of the passive stabilization of the lumbar spine.

Development of an integrated virtual twin lumbar intervertebral disc model for a spinal loading simulator

Elizabeth Diederichs, PhD student

Supervisor(s): Dr. Thomas Willett

Abstract
Skeletal trauma, infection, and cancer are significant clinical issues that can result in substantial bone loss; poorly treated fractures and defects can result in reduced patient outcomes and can present a large economical and clinical burden. Large structural bone defects are an area of concern as their current methods of treatment, such as allografts and metal prostheses, are associated with a host of clinical and practical issues. Due to these concerns, synthetic bone grafts are becoming increasingly popular for the reconstruction of skeletal defects. The Waterloo Composite Biomaterial Systems Lab has developed a 3D printable composite composed of functionalized biopolymers and hydroxyapatite nanoparticles for this purpose. These biopolymer nanocomposites have exhibited promising mechanical and biological properties; however, development is still needed to improve their interactions with biological environments, their degradability, and their resulting mechanical performance. Material optimization is ongoing to improve these biopolymer nanocomposites' mechanical robustness under physiologically relevant environments and degradation potential. Strategies to develop the material system include optimizing the matrix composition to improve its response to aqueous environments and modulate its response to oxidative environments. This proposed research should generate significant advances of this biomaterial system towards the eventual goal of creating a robust and resorbable material compatible with repairing structural defects in bone.

Averaging material parameters in hyperelastic models: impact of model type, deformation range, data source

Arya Amiri, PhD student

Supervisor(s): Dr. Thomas Willett, Dr. Tais Sigaeva

Abstract

Hyperelastic constitutive models are mathematical expressions that relate deformation to stress in soft biological tissues. Each model has one or more parameters that are identified by fitting the model to experimental stress-deformation data. For a group of specimens, a single set of parameters is often reported to represent the average behavior. While linear algebra properties like “additivity” and “homogeneity” can predict when averaged parameters yield an average response, it is generally thought that nonlinearity of these models prevents this. The objective is to investigate whether average parameters can reproduce the population’s average responses for several commonly used models and to assess any discrepancies. Three polynomial (Mooney-Rivlin, Yeoh, and Polynomial) and three exponential models (Fung, Holzapfel-Gasser-Ogden, and Four-Fiber-Family) were investigated. Uniaxial data was used for the first four models, and equibiaxial data for the last two. Two approaches, algebraic and statistical, were employed for the analysis. The normalized root-mean-square error (NRMSE) was used to quantify the discrepancy between the predicted responses from averaged parameters and the actual averaged responses. Both algebraic and statistical results show that constitutive models can be classified into two categories: polynomial and exponential. For polynomial models, average parameters reproduce the average response, despite their nonlinear behavior. In contrast, for exponential models, the deformation level affects how well average parameters predict the average response. A new finding that has not been previously reported is that for polynomial models, average parameters reproduce the mean mechanical response without any discrepancy, suggesting that model type, not nonlinearity alone, is the key factor. Even for exponential models, average parameters can predict the mean response of the population with an NRMSE as low as 2.5% at typical experimental stretches, although the discrepancy increases at higher stretches. These results clarify the behavior of various constitutive models and support using average parameters to represent a population when appropriate. As a limitation of this study, it should be noted that although the algebraic approach allows generalization to all constitutive models, only six models under uniaxial and equibiaxial testing protocols were investigated.

Fractographic analysis of collagen denaturation on human cortical bone using machine learning

Corin Alexander Seelemann, PhD student

Supervisor(s): Dr. Thomas Willett

Abstract

Bone material is a composite primary composed of collagen (protein), calcium hydroxyapatite (mineral), and water. These components are organized hierarchically, creating a 3D structure that gives rise to 'toughening mechanisms'. These include crack deflection, collagen fibrils spanning over the growing crack, and the formation of a microdamage process zone, rather than lengthening a single crack. However, in cases with aging or chronic oxidative stress (such as chronic kidney disease) bone can lose its ability to resist fracture and become fragile. The role of collagen in supporting bone fracture resistance, and how it can lose the capability to contribute is not fully understood. The present research applies machine learning techniques to examine images of human bone fracture surfaces, stained to detect denatured collagen. This allows analysis of how collagen contributes to fracture resistance.