MIE498H1: Research Thesis 2025-2026

Supervisor	Axel Guenther
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Number of Positions	2
Open to	Mechanical Engineering Students
Term Offered	Full-year
Research Area	Materials
Research Topic	Angle-Ply Collagen Structures for tissue Engineering Applications

Project Description

Angle-ply structures are the most frequently transplanted tissues worldwide, surpassing organ transplantation over tenfold. Despite their critical physiological functions, these tissues have limited regenerative capacity once damaged, and there are currently no readily available substitutes with biomimetic microarchitecture. While some researchers have attempted to engineer angle-ply grafts as replacements, these efforts were limited by poor biomechanical performance, inadequate interfacial adhesion, and excessive composite thickness.

This study aims to establish a quantitative experimental framework for evaluating engineered angle-ply structures composed of collagen, with applications in tissue engineering. Using our patented microfluidic wet-spinning technology [1][2], we fabricate collagen sheets 2 microns thin – thinner than a strand of human hair, yet comparable in strength to household plastic wrap. These biomaterials exhibit anisotropic organization and are designed to mimic the mechanical behaviour of load-bearing angle-ply multilamellar composites. Most notably, cardiovascular tissue such as the wall of blood vessels.

You will perform bi-axial biomechanical tensile testing on engineered angle-ply collagen structures. Key objectives include:

1. Conducting uniaxial tensile tests to quantify the adhesion strength between aligned collagen sheets and various apron substrate materials. As a control, perform the same tests using a hyperelastic substrate material with welldocumented biaxial properties (e.g., silicone sheet) to assess baseline adhesion performance.

2. Design and fabricate custom tensile testing apron structures for biaxial evaluation of angle-ply materials. Using AutoCAD and/or SolidWorks, you will design a mounting apron that minimizes stress concentrations and prevents premature rupture at the gripping interface. Finite element analysis (e.g., ANSYS) will be used to simulate 2D stress-strain fields, with particular focus on the regions surrounding the apron interface.

3. Fabricate apron prototypes using carbon-dioxide laser ablation and attach them to single-layer or multilamellar angle-ply collagen structures. Mounting experiments will be conducted to evaluate the effectiveness of the design, ensuring that samples can be securely fastened to the hooks of a commercial CellScale tensile testing apparatus [3]. The biomaterial structures must remain free-standing, wrinkle-free, and intact in a hydrated environment without premature rupture.

4. Students will conduct repeat biaxial tensile tests (N = 5 biological replicates per biomaterial condition using the same apron shape and material, including a control group with a hyperelastic substrate). Graphite particles will be incorporated into the biomaterial structures to enable 2D displacement field tracking during testing. Raw force and displacement data will be collected to generate stress-strain curves and evaluate mechanical performance under multiaxial loading.

5. Using experimental data from the hyperelastic reference material and finite element analysis, you will quantify the error introduced by different apron designs [4]. A comparative analysis will be used to justify the selection of the optimal apron configuration.

6. You will process raw data into biaxial stress-strain curves and extract key biomechanical metrics, including elastic modulus, ultimate tensile strength, and failure strain. These results will be compared against benchmark values reported for native vascular tissues.

Additional Information

On site. This project potentially allows for co-authorship in a journal publication. Experimental work will be conducted at the Center for Research and Applications in Fluidic Technologies (CRAFT), a renowned open access research facility specializing in microfluidics and biomaterials, supporting over 220 scientists, and housing more than 55 advanced instruments [5]. Prior design experience with CAD software (e.g., SolidWorks, AutoCAD), and simulation tools (e.g. COMSOL, ANSYS) is required.

Application Instructions

Please submit CV and unofficial transcript to Prof. Axel Guenther (axel.guenther@utoronto.ca) and PhD student Chantel Briana Campbell (chantelbriana.campbell@mail.utoronto.ca)

References

[1] Zhang, Y. et al. Adv. Mater. Technol.; 2401810:1-9, 2025. Click here to read.

[2] Malladi, S.*; Miranda-Nieves, D.* et al. ACS Biomater. Sci. Eng., 6, 4236−4246, 2020. Click here to read.

[3] CellScale Biomaterials Testing - BioTester 5000. Click here for specifications.

[4] Di Leonardo et al. Journal of the Mechanical Behavior of Biomedical Materials, 150, 106291, 2024. Click here to read.

[5] Center for Research and Application in Fluidic Technologies (CRAFT). Click here for more details.