Project Title: Design of Subcutaneous Magnetic Blood Pump for Infants and Young Children

Participating Labs/Departments: Biomedical Engineering (CMU); Cardiology (AGH); Cardiac Surgery (AGH)

Location: CMU (90%): Scott Hall; AGH(10%): Allegheny Health Network Cardiovascular Institute, 320 East North Avenue

Primary Investigator: James F. Antaki, PhD

Research Description: Up until recently, heart-assist devices for infants have been so large that there is more blood outside of the patient than inside! These devices are gradually becoming smaller, but are still too big to fit inside the body of a young infant, and must therefore be connected by tubes through the skin to a pump outside the body.

This project is an exploratory investigation of an entirely new concept that could revolutionize the field of circulatory support for infants and young children.

The summer project will involve some theoretical design work, engineering analysis as well as hands-on testing of a prototype. Our collaborators will include a cardiologist and a cardiac surgeon from Allegheny Health Network. The student working on this project will gain experience and develop skills in: design of an electromechanical device; cardiology and hemodynamics; cardiac anatomy; in-vitro testing; computer-control; literature research; technical writing; and possibly an introduction to intellectual property (patents).

Clinical Exposure (Required for SURP in BME at CMU): Because this project is in very early stages, I am not entirely sure of the extent of clinical interaction beyond occasional meetings with the physicians. I believe that one or two shadowing sessions would be valuable. If permissible, I would like the student to witness a cardiac surgery procedure.

Major/Course/Skill Prerequisites: mechanical engineering: general design skills; knowledge of electrostatics (introductory, undergrad level); hands-on skills for constructing and testing bench-top prototypes. Experience with CAD (e.g. SolidWorks), computer control, robotics (e.g. Arduino) would be very helpful.
**Project Title:** Evaluating Patient Values and Regret when considering a Left Ventricle Assist Device Implant

**Participating Labs/Departments:** Biomedical Engineering (CMU); Cardiology (AGH); Cardiac Surgery (AGH); Cardiology (University of Colorado-Denver)

**Location:** CMU, Scott Hall (90%); AGH (10%)

**Primary Investigator:** James F. Antaki, PhD

**Research Description:** Left ventricular assist devices (LVADs) are used in patients with end stage heart failure to either bridge them to a heart transplant or as destination therapy. It is a final effort treatment modality, with medical management of symptoms as the only other option. When considering receiving an LVAD, patients are often scared and overwhelmed and frequently defer the decision to their cardiologist or family members. This can lead to intense regret and dissatisfaction with the LVAD among patients.

This project is to capture the fears, regrets, and values of LVAD patients and their caretakers after receiving and LVAD. The information will be analyzed to help build a patient counselor, an educational tool for patients when deciding if an LVAD is right for them.

The summer project will involve analysis of a preliminary value capture survey, design and testing of new survey questions, and preliminary design of material for the patient counselor application. Our collaborators will include a cardiologist and a cardiac surgeon from Allegheny Health Network and a cardiology nurse from UCD. The student working on this project will gain experience and develop skills in: interviews; survey design; statistical analysis; cardiology and heart failure; end of life decision making; literature research; technical writing; and human-computer interface design.

**Clinical Exposure (Required for SURP in BME at CMU):** The student will participate in meetings with the cardiology team at AGH and interview patients and caregivers about their LVAD implant experience.

**Major/Course/Skill Prerequisites:** Statistics (SPSS, R, SAS), Medical or technical writing, Medical Device Design, Human Computer Interfaces, Programming (Java, HTML, Angular JS) would be helpful.
Project Title: Computer Modeling of Cardiovascular Impedance

Participating Labs/Departments: Cardiology

Location: AGH Cardiac MRI Lab

Primary Investigator: Robert W.W. Biederman, MD

Research Description: We have developed a measure of cardiovascular impedance that indicates that the blood ejection from the heart exhibits multiple resonance conditions. These resonance conditions were not previously suspected, and as far we are able to discern, this represents a distinct departure from previous understanding of the heart. The student’s project would be to develop a computer model that would explain the essential features of the system that we observe in clinical and research data.

Clinical Exposure: The student will have exposure to the clinical cardiovascular magnetic resonance imaging suite.

Major/Course/Skill Prerequisites: Matlab or similar preferred
**Project Title:** Synthetic actin filaments for studying sarcomeric biomechanics

**Participating Labs/Departments:** Taylor Lab

**Primary Investigator:** Rebecca Taylor, PhD.

**Location:** CMU

**Research Description**
The Taylor Microsystems and Mechanobiology Lab in Mechanical Engineering at CMU is interested in the creation of biomimetic, synthetic biosystems that aim to recapitulate the emergent properties of the cardiac sarcomere. Our lab is developing actin-mimicking filaments for use in biophysical contractile assays and novel nanoscale sensors and actuators. Summer research opportunities include (1) the nanomechanical design of DNA origami platforms using nanoscale CAD tools and finite element analysis, (2) fluorescence imaging analysis of biomachines in action, and (3) 3D printing or other macroscale modeling of DNA-protein constructs for macro-scale structural investigation of compliant biomachine elements.
**Project Title:** Nonrigid Image Registration Based Cardiac Motion Tracking for Clinical Applications  
**Participating Labs/Departments:** Computational Biomodeling Lab (CMU MechE) and the Allegheny Singer Research Institute  
**Location:** Wean Hall and Allegheny General Hospital  
**Primary Investigator:** Jessica Zhang  
**Research Description:** Our lab has built a parallel computational framework of multiscale geometric modeling and mesh generation for cardiac biomechanics applications (the PI’s NSF CAREER grant), with several efficient and accurate nonrigid registration techniques developed. In this proposal, we seek research funds to support 1-2 undergraduate students to explore clinical applications of nonrigid image registration. Possible summer projects include 1) parallelization and code optimization of our 3D image registration technique using truncated hierarchical B-splines; 2) cardiac motion tracking using nonrigid image registration; and 3) atlas-based patient-specific geometric cardiac model construction with quantitative study. Students will select a specific project based on their personal interests, and also directly interact with clinical collaborators to gain the first-hand experiences.  
**Clinical Exposure (Required for SURP in BME at CMU):** Research rotations as required by the Carnegie Heart Program  
**Major/Course/Skill Prerequisites:** The ideal student will study BME, Mechanical Engineering, Computer Sciences or Mathematics
Project Title: Parallel Wire Robot for Epicardial Interventions  
Participating Labs/Departments: Surgical Mechatronics Lab, Robotics Institute  
Location: NSH A406  
Primary Investigator: Cameron Riviere (camr@ri.cmu.edu) / Michael Passineau (AHN)

Research Description

1.1. Project Overview
Gene therapies have emerged as a promising treatment for congestive heart failure, yet the lack of a method for minimally invasive, uniform delivery. To address this need, we have developed Cerberus, a planar parallel wire robot for minimally invasive myocardial injections, shown in Fig. 1(a)-(c). The device is inserted using a subxiphoid approach that accesses the heart while avoiding the lungs. Flexible arms then allow the device to expand into a triangular shape and adhere to the surface of the beating heart with suction on its three bases, providing a stable platform with no motion relative to the heart. Wires from each base connect to an injector head that moves within the triangular support structure by changing the wire lengths. This design has the typical advantages of parallel wire robots, namely a large workspace and the ability to move quickly within this workspace. These advantages give the device the potential to deliver multiple injections accurately within the entirety of the workspace to the beating heart.

1.2. Prior Work
Work to date on this project has focused on the design, construction, and demonstration of prototype end-effectors and control hardware as well as the development of a hybrid control architecture that controls position and force simultaneously. While the device has been successfully demonstrated in live animal porcine models, there exists a significant need for the further development of the hybrid control scheme. Although the heart is a curved and dynamic surface, the previous control scheme assumed that the device is planar. This control scheme was developed and demonstrated on a benchtop setup (Fig. 1(d)).

1.3. Proposed Student Research
The next step in moving this device towards clinical relevancy is to develop and tune a feedforward/ feedback control system that correctly models the non-planar kinematics and performs parallel force/ position control for accurate placement of injections on the curved surface of the heart. In the curved scenario, friction with the epicardial surface is likely to be much more significant than it was in the planar case, since the tensioned cables pull the injector head into tighter contact with the surface; this will be taken into account in developing the control system. Validation will be carried out on a modified desktop set-up that must be designed and manufactured. These experiments will compare the performance of the curvature-compensating controller with the performance of assuming that the device is planar. Porcine or ovine hearts ex vivo, obtained from the abattoir, will also be used for testing, since they simulate more closely the compliance and wetness of the epicardial surface in vivo.

2. Major/Course/Skill Prerequisites: Matlab, CAD, control systems

![Fig. 1. Triangular manipulator for rapid accurate myocardial injection for gene therapy. (a) The manipulator collapses for endoscopic insertion and removal. (b) After insertion, it deploys in triangular shape, with its three corners grasping the epicardium with suction. By pulling the 3 cables, injections can be rapidly and accurately placed anywhere within the dotted triangle. (c) Modified Cerberus geometry enables access to the entire left ventricle by placing distal suction bases on the anterior and posterior surfaces of the heart. (d) Desktop set-up with three bases fixed on a platform, where the left and right base can be set to various lengths, and a mounted camera.](image-url)
Project Title: Apical Torsion Device for Circulatory Support

Participating Labs/Departments:
1. Circulatory Support Lab, Biomedical Engineering Dept., Carnegie Mellon Univ. (CMU)
2. Cardiothoracic Surgery Dept., Allegheny General Hospital (AGH)

Location: Carnegie Mellon University & Allegheny General Hospital, Pittsburgh, PA

Primary Investigators:
Dennis R. Trumble, PhD (Asst. Research Professor, CMU)
Walter E. McGregor, MD (Director, Robotic & Minimally Invasive Heart Surgery, AGH)

Research Description:
The technology under development is called an Apical Torsion Device (ATD), which is designed to enhance the pumping action of a failing heart by effectively ‘wringing’ blood from both the right and left ventricles concurrently. This is accomplished by attaching a rotary actuator to the apical aspect of the heart so that the apex can be turned counterclockwise (as viewed from the apex) with respect to the base of the heart. The applied torsion serves to restore the natural wringing motion observed to occur in healthy hearts—a contractile trait that is far less prominent in diseased hearts. The rotary actuator is placed on the epicardial surface of the heart so as not to contact the blood and can be used to provide supra-normal torsion (20 degrees or more) to improve ventricular emptying. Device actuation coincides with the systolic phase of the cardiac cycle and will increase ventricular ejection fraction directly by mechanical means and indirectly by lowering myocardial wall stress. The actuator can conceivably be powered electrically, pneumatically, or by low-volume hydraulics.

The primary objective of the research to be performed during the course of this Fellowship Program is to design a second-generation prototype device with special emphasis on optimizing cardiac interface surface characteristics (i.e., device fixation) and developing a minimally invasive transcostal deployment system.

Clinical Exposure:
During the course of this work the Fellowship recipient will have the opportunity to participate in the following clinical activities:
1. Open heart surgery observation to develop a technical appreciation of surgical methods, application of cardiopulmonary bypass, echo technology for cardiac imaging, and anesthesia technology for patient monitoring.
2. Patient rounds in the ICU to gain exposure to critical care technologies and also up-close encounters with ventricular assist devices, extracorporeal membrane oxygenation (ECMO), and cardiac transplantation.
3. Patient rounds on the floor to reinforce the human side of surgical medicine and medical device development.

Major/Course/Skill Prerequisites:
Fellowship recipients must have a firm understanding of global cardiac mechanics and a strong
Project Title: A low-volume aortic compression device for muscle-powered circulatory support

Participating Labs/Departments:
3. Circulatory Support Lab, Biomedical Engineering Dept., Carnegie Mellon Univ. (CMU)
4. Cardiothoracic Surgery Dept., Allegheny General Hospital (AGH)

Location: Carnegie Mellon University & Allegheny General Hospital, Pittsburgh, PA

Primary Investigators:
Dennis R. Trumble, PhD (Asst. Research Professor, CMU)
Jooll Han, BS (PhD Candidate, CMU)
Walter E. McGregor, MD (Director, Robotic & Minimally Invasive Heart Surgery, AGH)

Research Description:
Short-term use of left ventricular assist devices (LVADs) has been shown to reverse the effects of congestive heart failure, a devastating condition that will ultimately afflict one in every five Americans. When used for permanent support however, LVAD therapy has been limited by serious complications caused by percutaneous drivelines and blood contacting surfaces. Here we propose to assemble and test a non-blood-contacting muscle-powered counterpulsation system that avoids the limitations of current heart assist devices and so could potentially represent a major advance in the treatment of congestive heart failure. As a first step toward this goal, we have developed an implantable muscle energy converter (MEC) capable of transforming contractile energy into hydraulic power. The objective of this project is to assemble and test a non-blood-contacting aortic compression device powered by the MEC. The aims of this research project are to: 1) complete a computational analysis of the design space to determine the effect of various design specifications (i.e., design configuration, materials) on device performance; 2) manufacture promising device prototype designs selected in aim #1 via advanced 3D printing methods using durable elastomeric filaments; and 3) perform in vitro testing of elastomeric device prototypes to determine the configuration best suited to compress the aorta using the LD/MEC power source. At the conclusion of the project, we expect that the viability of a fully-functional, implant-ready prototype will have been demonstrated via in vitro evaluation of a complete muscle-actuated ventricular assist system.

Clinical Exposure:
During the course of this work the Fellowship recipient will have the opportunity to participate in the following clinical activities:
1. Open heart surgery observation to develop a technical appreciation of surgical methods, application of cardiopulmonary bypass, echo technology for cardiac imaging, and anesthesia technology for patient monitoring.
2. Patient rounds in the ICU to gain exposure to critical care technologies and also up-close encounters with ventricular assist devices, extracorporeal membrane oxygenation (ECMO), and cardiac transplantation.
3. Patient rounds on the floor to reinforce the human side of surgical medicine and medical device development.

Major/Course/Skill Prerequisites:
Fellowship recipients must have a firm understanding of global cardiac mechanics and a strong background in Computer Aided Design (CAD) and 3D printing techniques.
Project Title: Non-invasive, cuff-less blood pressure estimation

Participating Labs/Departments: Kainerstorfer Lab, BME

Location: Scott Hall

Primary Investigator: Jana Kainerstorfer

Research Description
Continuous blood pressure monitoring can provide invaluable information about individuals’ health conditions. Recently, devices have been developed which are cuff-less and can monitor blood pressure continuously. Of such devices, the Pulse Wave Velocity (PWV) based method is the most common one, where PWV is the velocity of the pressure wave propagation in the blood vessels. Often, Pulse Transit Time (PTT), the time interval between a heartbeat and its transfers to a body periphery, is used for PWV estimation. A relationship between PTT and blood pressure is then established. Here we propose a new cuff-less, all optical method based on near-infrared light to estimate PTT and hence blood pressure. The student will be responsible for data collection on healthy volunteers as well as data analysis under guidance from the PI and graduate students.

Clinical Exposure (Required for SURP in BME at CMU): none – healthy volunteers only

Major/Course/Skill Prerequisites: Basic knowledge of Matlab and signal processing
Project Title: Artificial Lungs for Destination Therapy

Participating Labs/Departments: Cook lab (CMU BME) and the Allegheny Singer Research Institute

Location: Scott Hall and Allegheny General Hospital

Primary Investigator: Keith Cook

Research Description: Our lab is developing an artificial lung for destination therapy. The major factor limiting this development is clot formation on the artificial surfaces of the device, specifically the bundle of hollow fibers that acts as the gas exchange membrane. Possible summer projects involve i) testing novel zwitterionic surface coatings that limit coagulation, ii) development of drug eluting components for the inside of the fiber bundle, iii) developing new means of mapping micron scale clot development at fiber surfaces, and iv) testing novel anticoagulants that limit coagulation within the artificial lung but not within the patient. Specific project selection will be done through discussion with the student, gauging their interests and skill set to find a good fit. Most projects will involve in vitro laboratory testing using blood samples, but the work may include in vivo testing in a surgical setting.

Clinical Exposure (Required for SURP in BME at CMU): Research rotations as required by the Carnegie Heart Program

Major/Course/Skill Prerequisites: The ideal student will study BME as well as either mechanical engineering, material science, or chemical engineering.
**Project Title:** Engineering 3D Human Cardiac Muscle Using Induced Pluripotent Stem Cells

**Participating Labs/Departments:** Feinberg lab, Biomedical Engineering, Materials Science and Engineering

**Location:** Scott Hall

**Primary Investigator:** Adam Feinberg

**Research Description:**
The goal of this project is to develop an improved 3D engineered cardiac muscle tissue using human induced pluripotent stem cells. The eventual application of this tissue is to create an in vitro model of human heart muscle for drug discovery and toxicity screening. Previous work in the Feinberg lab has developed technologies to engineer 3D cardiac muscle and also has established human iPS culture and differentiation into cardiomyocytes. The proposed research will combine these technologies in order to tissue engineer human heart muscle with defined structural and functional properties. To do this we will use 3D printed molds to cast collagen gels embedded with these cells and culture them for defined periods to form muscle tissue. Students will fix these tissues, label the cytoskeletal and then image in 3D using the confocal and multiphoton microscopes. Contractility experiments will also be performed where students measure the force generation of these engineered tissues. The anticipated endpoint is to have produced a function human cardiac tissue over the summer research period. The undergraduate student will work in close collaboration with graduate students to learn how to culture human iPS cells and will be trained in the required tissue engineering techniques.

**Major/Course/Skill Prerequisites:** Cell culture, microcontact printing, immunofluorescent staining, confocal imaging, image analysis