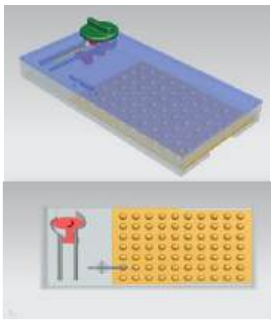
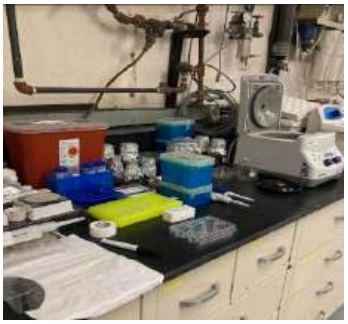
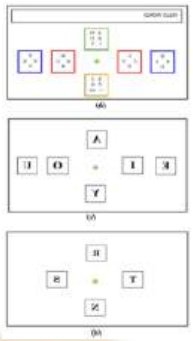
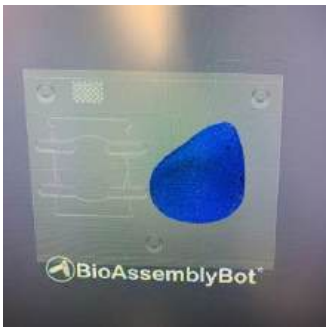
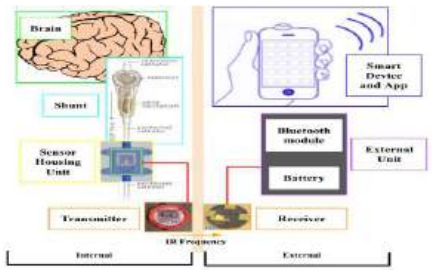
Biomedical Engineering Department

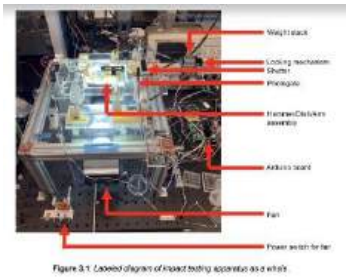
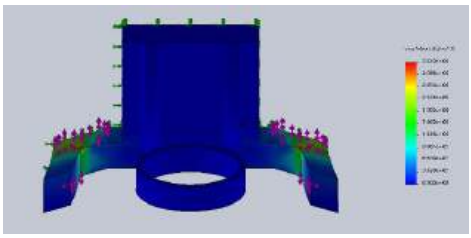
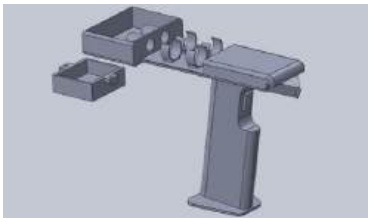
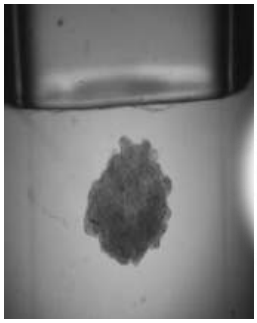
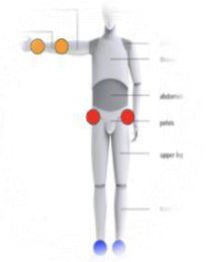
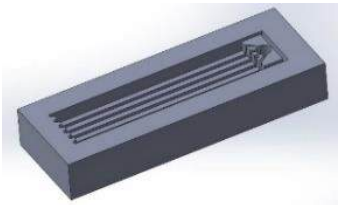
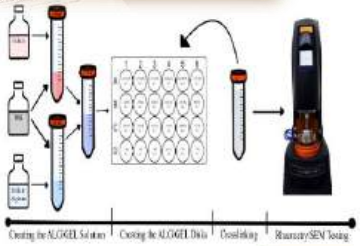
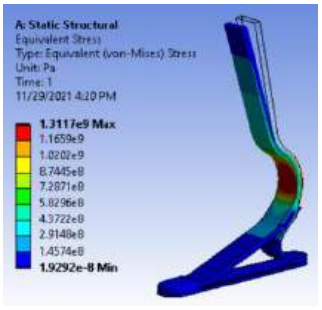
Senior Design Projects

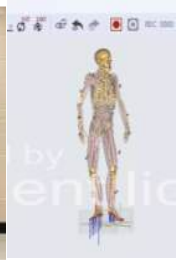
Spring 2022

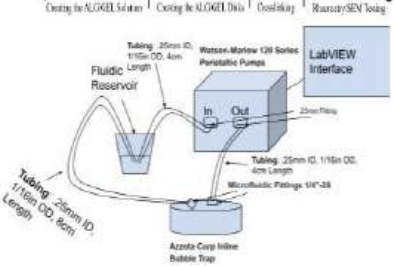




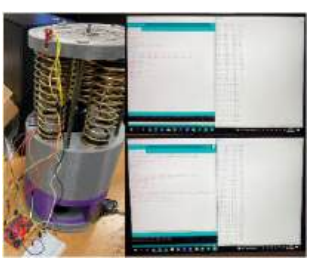







BME Senior Design Project at UCONN

On behalf of the faculty, staff, and students of UCONN's Biomedical Engineering (BME) Department, we would like to welcome you to our annual Demo Day in April 29th 2022. The BME Department hosts this event to recognize the accomplishments of our BME undergraduate students. These project demonstrations and presented brochures of abstracts represent year-long efforts by our undergraduate students on their *Senior Design Projects.*

The BME Senior Design at UCONN course is intended to engage students in a meaningful experience by bringing together concepts and principles learned in the biomedical engineering curriculum, extending this theory to practical application, then planning and constructing a finalized product. Our BME students advance their proficiency and practice innovation and application during a two-semester, senior-year course sequence in biomedical engineering design, where students are immersed in a design experience. An emphasis is placed on learning the design process within the framework of an engineering team with a focus placed on the creation of a functional prototype. The experience is comprehensive and reflects all aspects of the engineering design process as well as common industry practices. Problem-solving for an open-ended, complex, and sometimes incompletely defined system is the ultimate challenge faced within this experience and, in its successful completion; the design is often viewed as a student's first professional BME achievement.

We hope that you enjoy your visit to the Demo Day event in Gampel Pavilion and we look forward to meeting you in person. If you have questions about any of our tracks or courses, please feel free to contact us directly.

Sincerely,

Professors: Patrick Kumavor, Krystyna Gielo-Perczak, Guoan Zheng, Fayekah Assanah, Yu Lei, Liisa Kuhn, Yupeng Chen, Kazunori Hoshino, Syam Nukavarapu, Sabato Santaniello

Teaching Assistants: Kia Golzari, Mahdi Pirayesh Shirazi Nejad

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Device and Mobile App for Retinal Imaging Diagnosis

Team 1

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***Abstract* – The purpose of this design project is to build a smartphone-based non-mydriatic device that can capture and diagnose a fundus image for diabetic retinopathy and other ocular diseases. The device will consist of a smartphone and an adapter that will include a 45 degree mirror that will be used along with a solid core fiber optic cable to make the smartphone camera and the light coaxial. The image is captured through a 20D lens that magnifies the retina. An Android smartphone application provides a simple UI that allows for image capturing and diagnosis using a trained deep learning image classification model.**

Keywords – Non-Mydriatic, Fundus Imaging, Retinal Imaging, Diabetic Retinopathy, Deep Learning

1. Introduction

Retinal imaging provides ophthalmologists with a mode of evaluating a patient's optical health and early detection of dangerous ocular diseases. For people and communities with limited access to an ophthalmologist, an affordable and user-friendly retinal imaging device will increase early treatment of preventable eye disease or injury. Our goal is to design such a device with a smartphone interface for an accessible method of retinal imaging and diagnosis, with emphasis on the diagnosis of diabetic retinopathy (DR).

It is estimated that 347 million people have diabetes globally, with 29 million of those in the United States [1]. These values are estimated to rise to 552 million by 2030 [1]. Diabetic retinopathy (DR) causes semi or complete loss of vision due to "damage to small blood vessels in the retina" [2], yet it is easily treatable if caught early. A study estimating the magnitude of visual impairment found that "low-income countries carry approximately 90% of the burden of visual impairment, and 80% of this can be prevented or cured" [2]. Unfortunately, modern retinal imaging (ophthalmic) devices are expensive, bulky, and require training to use. Therefore the development of a portable, easy-to-use, and cost-effective smartphone-based retinal imaging device with machine learning diagnosis would allow for greater access to early detection of ocular diseases which could save the vision of low-income populations.

2. Methods

The device consists of a smartphone integrated UI and a smartphone adapter that will house all the necessary components to capture a retinal image. The adapter couples a 4mm solid-core fiber optic cable to the smartphone flashlight which then reflects off of a mirror to coaxially project the light with the camera sensor to illuminate the retina. A 20D disposable ophthalmic lens is used to focus and magnify the image for the camera. The smartphone is used to acquire an image and the Android application then uses a deep learning image classification model to classify the image for retinal diseases and returns a disease classification to the user.

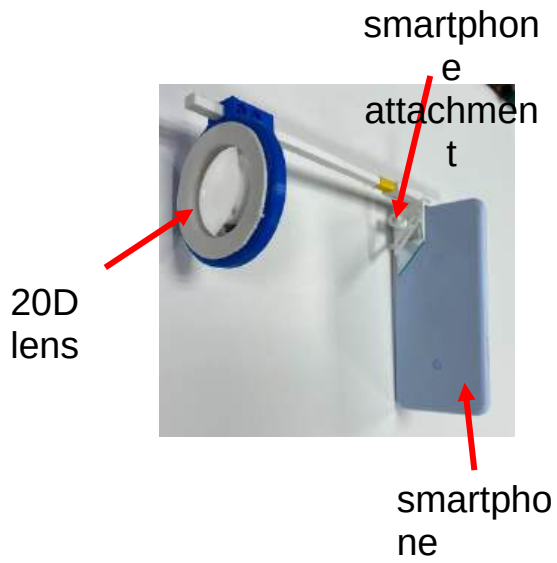

Figure 2 *– Retinal imaging smartphone adapter.*

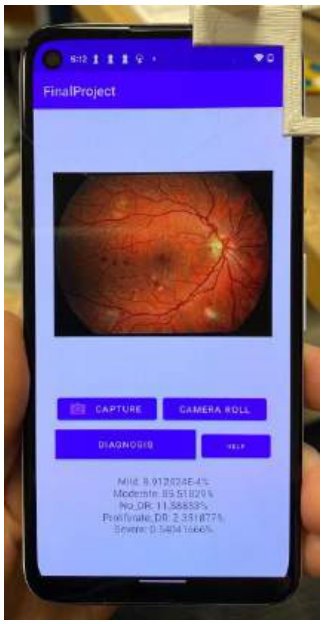

Figure 3 *– Retinal image diagnosis app developed on Android Studio.*

A convolutional neural network or deep learning image classification model is trained and tested using a large dataset of healthy and damaged or diseased retinal images obtained from an open-source database. The code for this model is written in Python using TensorFlow.

Our deep learning model is implemented in our Android smartphone application, which is written in Java using Android Studio. The application connects to the deep learning models to return a multitude of retinal diagnosis.

3. Simulations/Expected Outcomes

The design of the device consists of the smartphone application and the smartphone imaging adapter. These two components are tested utilizing different methods.

The illumination ability of the smartphone adapter is thoroughly tested and all possible eye safety protocols will be taken into account. The device specifications will not exceed that of International Organization for Standardization (ISO) restrictions for ophthalmic devices to ensure patient safety.

The deep learning models are tested using a dataset of varying severity of diseases to ensure that the model functions as expected. Testing of the model will be done utilizing testing modules in Python and TensorFlow. The application has models for DR, Macular Degeneration, Glaucoma, and Cataracts, which can return a positive or negative diagnosis recommendation with over 90% accuracy when applied to novel retinal images.

The smartphone application UI is also thoroughly tested for functionality and ease of use.

4. Future Work

A possible future improvement is that infrared light may be used to focus the camera with less discomfort to the user, as it does not cause pupil constriction, and visible light will be used to illuminate the eye to capture the final image. Because most smartphones include a filter that block infrared light, this would require modifications to the smartphone itself or the inclusion of an additional camera that can focus using infrared light.

Other possible improvements are to implement other retinal disease or damage diagnostics. A more important improvement would be to make adapters for a variety of smartphones, including other models of Google Pixels. The application is also only functional on Android devices, so a useful future improvement would be to develop an IOS version of this application.

5. Acknowledgments

We would like to thank our sponsor, the UCONN Biomedical Engineering Department (https://www.bme.uconn.edu/) for providing us with the resources to complete the project. Testing, realistic constraints, and device design were aided by Dr. Guoan Zheng. Optical system support and access to specialty materials provided by Dr. Patrick Kumavor.

6. References

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Opioid Misuse Prevention Packaging

Team 2

Vlad Ilies, Yuan Wang

Patrick Kumavor, Ph.D.

Biomedical Engineering Department
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***Abstract* – The purpose of this design project is to propose a novel, affordable, and effective design to replace current opioid packages/containers with enhanced child-resistant and senior-friendly features in an effort to curb the opioid epidemic in the United States. The focus is on refining and improving the child-resistant features of current opioid packaging techniques while at the same time discouraging opioid misuse and abuse in adults using a novel self-closing and dose-controlling opioid packaging design.**

Keywords – Opioid Epidemic, Opioid Misuse/Abuse, Opioid Packaging, Child Resistant, Self-Closing, Dose Control

1. Introduction

In The United States of America, an opioid epidemic, largely driven by over-prescription of medication for 'treatment' of chronic noncancer pain (CNCP), has escalated such that the US Government declared it a public health emergency as of October 16, 2017 [1]. The abuse/misuse of opioids, resulting in a nearly fourfold increase in overdose deaths from 1999 to 2008 and over 64,000 deaths in 2017 alone [1], is occurring in parallel with a distinct increase in opioid prescriptions for people with chronic noncancer pain, or CNCP [2]. In fact, around 21 to 29% of people prescribed opioids for chronic pain (CP) misuse them, 8 to 12% of patients using an opioid for CP develop an opioid use disorder. Furthermore, roughly 80% of heroin users first misused prescribed opioids [3]. In sum, a strong association can be made between opioid overdose-related deaths and opioid prescribing patterns [4], making it clear that this public health crisis can be controlled and steered in the right direction

Children are at an increasingly higher risk of opioid intoxication from both accidental and non-accidental reasons [5], with nearly 10,000 children dying from opioid poisonings within the last 20 years in the United States alone [6]. Young children remain at the highest risk and so most are most vulnerable to accidental and/or non accidental opioid poisoning. Toxic doses can lead to potentially lethal acute leukoencephalopathy, and in young children, this has a preference for the cerebellum with severe implications [4].

Currently, the US Department of Human Health and Services has five priorities to address this opioid crisis: improving access to recovery services and treatment, promoting overdose-reversing drugs, improving our understanding of the opioid epidemic via public health surveillance, supporting research on chronic pain and addiction, and furthering the advancement of pain management practices [3]. These priorities do not focus on reevaluating and redesigning current opioid packaging techniques, and they barely, if at all, address the demographic which is most vulnerable to opioid accidental and non accidental opioid poisoning--children. A novel approach to opioid packaging, one which can discourage opioid misuse in adults and prevent opioid poisoning in children, is required.

2. Methods

The design consists of the *self-closing* and locking mechanism to prevent children from misusing the opioid drugs, which are made up of a knob and a constant spring. The knob will control the opening and locking of the blister and the constant spring will bring the blister back to its original place to activate the self-closing mechanism.

"Constant Force" flat springs are inexpensive, and already commonly used in a variety of medical devices such as auto-injectors, inhalers, and surgical staplers. Their fatigue life is in the thousands of cycles, ensuring their reliability in a self-closing package of limited pills. As Constant Force springs do not obey Hooke's Law, their smooth uniform pulling force seems well suited to this type of application. They can be shaped to be machine loaded in a package and anchored to capture a blister-card of medication inserted either by machine, or by hand at a pharmacy. These features unique to Constant Force springs make them ideal for this unique self-closing packaging.

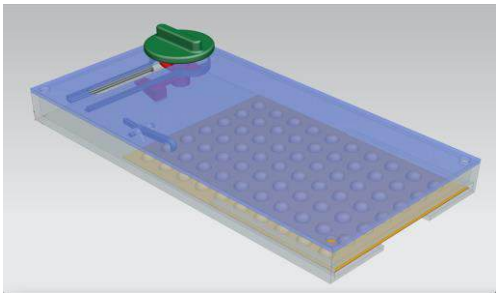

Figure 2 *– CAD representation of the track system design (with knob).*

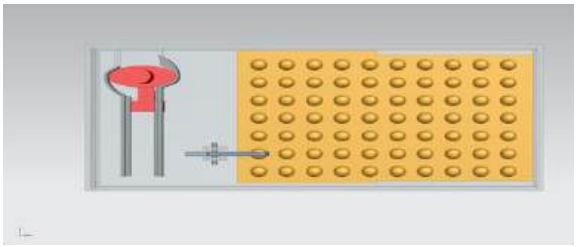

Figure 3 *– CAD representation of the top-view of the track system design (no knob).*

3. Simulations/Expected Outcomes

The design needs to pass the child-resistant tests and senior-friendly tests. For the child-resistant tests, up to 200 children aged between 42 and 51 months, working in pairs, try for five minutes to open the pack. They then witness a silent demonstration by the test supervisor and try again for another five minutes. To pass, 85% must fail to open it before the demonstration and 80% must fail to do so after the demonstration. For the senior-friendly test, one panel of test subjects will be between ages 50 and 59 (50/50 male/female split) and another panel will be between ages 60 and 70 (not necessarily evenly spread). After handling a familiarization pack, they have one minute to open and reclose the test pack, one that has not been opened before. With a good pack, most panel members open and close it in a matter of seconds [7]. Once packaging is applied into the market, we need to be able to see the reduction of the number of children opioid misuse/abuse-related poisonings/deaths.

4. Future Work

A prototype of the track system design will be finished and a procedure will be created to accurately operate the packaging. The prototype will be made using old cardboards and 3D printed parts in order to demonstrate and refine the mechanical proof of concept, after which the design will be scaled down to real size. The child-resistant and senior-friendly tests will be conducted through the laboratory outside the campus. Any revision and improvement will be added after the tests.

A refined mechanical design of the dosage control design will be developed and proceed through the same steps as the track system design.

5. Acknowledgments

We would like to thank our sponsors, Dr. Jeff Holland and Dr. Nathaniel Rickles, and Dr. Patrick Kumavor for providing us with the resources to complete the project and for assisting with device design, testing, and realistic constraints.

6. References

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Genetically Modified Yeast as a Novel Viral Detection Mechanism for Bovine Viral Diarrhea Virus

Team 3

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University of Connecticut; Storrs, CT 06269 USA

***Abstract* – The purpose of this project is to establish a proof of concept for Yeast (*Pichia Pastoris)* as a host organism for Bovine Viral Diarrhea Virus (BVDV). Yeast is chosen as the host organism because Yeast cultures can be easily grown in vitro and the cultures are stable for prolonged periods of time, with a quick replication rate compared to mammalian cells. To get maximal cell growth of yeast, we will use Yeast Peptone Dextrose (YPD) broth as a nutrient rich media for growing yeast [1]. In order to determine if the yeast will be able to uptake BVDV, the colonies will be observed under a light microscope for the presence of a Cytopathogenic Effect (CPE), which includes shrinking, swelling, rounding, and congregation of yeast cells within the colony, due to lysis from the virus [2].**

Keywords –*Yeast, Bovine Viral Diarrhea Virus, YPD Broth, Cytopathogenic Effect*

1. Introduction

There are several methods used for point of care testing for viruses, including Polymerase Chain Reaction (PCR) and molecular antigen testing [3]. However, these testing methods have significant shortcomings; they require highly trained personnel to collect the sample, distribute it, and run the sample in the laboratory. With this level of expertise required, there are higher associated costs for the patient especially when they are not covered by insurance [3]. In addition to these rapid point of care techniques for viral testing, there exist traditional methods of viral detection through mammalian cell culture. Although highly accurate, for most viruses it takes 5-10 days to get results, and with some viruses up to even 30 days [2]. Yeast cells have the potential to improve the traditional and highly accurate cell culture method, by greatly reducing the time required for results to be obtained. Yeast has been shown to divide much faster than mammalian cells, doubling the size of its colony every 90 minutes [4].

2. Methods

To culture the yeast cells, the initial procedure involves the inoculation of the Yeast Peptone Dextrose (YPD) Broth with yeast cells. A singular yeast colony forming unit collected from a cultured yeast source will be added to the YPD containing tube. The tube will then be placed in the shaken incubator for up to 18 hours to allow for optimal colony proliferation. After this amount of allotted time, there should be enough yeast cells present to be able to begin visualizing the cells under a microscope.

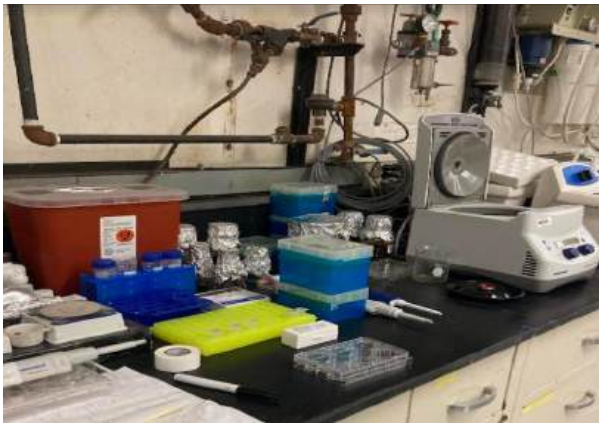

Figure 1 *– Laboratory set up of the staging area for storage materials picturing; centrifuge (right), aluminum covered YPD flasks (background), and micropipettes (foreground).*

The cells are then removed from the YPD media, cleansed, and placed under the microscope to track their morphological appearance. The next procedure involves the yeast cells being transfected with BVDV. To track whether the virus was successful in infecting the yeast cell, the light microscope will be utilized to observe the CPE of the yeast. If the BVDV successfully infects the yeast, then there will be an apparent change in its appearance. Additionally, as the yeast gets infected the lysing of the cell can be observed in real time. Once it can be determined with confidence when an infection has taken place, future viral detection methods will become significantly simpler because of the visual detection.

3. Simulations/Expected Outcomes

This new viral detection method requires the following functions: detection of specific viruses and can be quantified in a liquid culture. The device should provide a qualitative result of either positive, if the virus is present, or negative, if the virus is not present. The yeast is positive for the virus if we see that the yeast cells are lysing. This is an important function since the user should receive a result that is easy to understand.

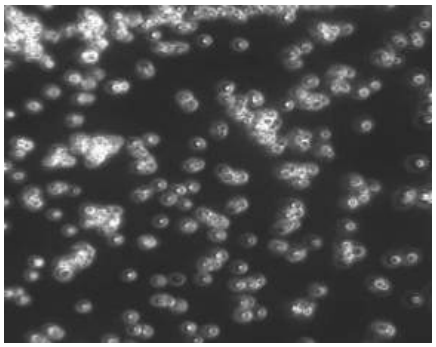

Figure 2 *– Image from light microscopy of yeast cultured in liquid YPD Broth. Single white dots represent a single yeast cell, and double white dots signify a dividing yeast cell into two daughter cells.*

The cultures should be quantifiable, this can be done through a standard plate count or spectrophotometric analysis [5]. The standard plate count is performed by counting the cells via recognition of colony forming units (CFU). Spectrophotometric analysis method measures the capacity of structures to absorb light of various wavelengths to determine the quantity of structures [5]. The optimal range is between 40 and 400 colonies per plate, if there are too many or too few there will be a larger number of discrepancies [6]. A Compound Light Microscope is also used to observe the growth of yeast in YPD Broth culture as seen in Figure 2.

4. Future Work

By February 2022 the team will have access to the genetically modified yeast and active bovine viral diarrhea (BVD) virus to determine proof of principle. A test plan authored by the team will be implemented to conduct sensitivity studies on the cell cultures in Dr. Yu Lei's lab. The presence of CPE will be observed via a light microscope to determine if the yeast possesses the ability to take up the BVDV. The group is also looking at ways to incorporate fluorescent stains as a means of determining the presence of BVDV. To do this, it is possible to use stains that detect the presence of oxidative stress in the yeast cells, such as the Dihydroethidium (DHE) stain, which is proportional to the presence of virus. [7] Stains like these will complement using the CPE to further validate the presence or absence of virus. This study will discern if genetically engineered yeast can become hosts to enveloped mammalian viruses. The resulting viral detection method will be effective, inexpensive, scalable, and relatively quick; allowing it to be available to broader markets. This work aims at being applied to many other viruses, through the addition of further surface markers into the genetically engineered yeast, to rapidly and cost effectively test human patients for viruses.

5. Acknowledgments

We would like to thank our sponsor, Robust Product Development LLC (*https://opencorporates.com/companies/us_ct/1285646*) for providing us with the resources to complete the project. Testing, realistic constraints, and project design were aided by Dr. Fayekah Assanah and Dr. Yu Lei, as well as a lab space and instrumentation training taking place in Dr. Yu Lei's lab.

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Personalized 3D Printed Breast Forms

Team 4

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***Abstract* – The purpose of this design project is to develop improved breast forms for women who have gone through a single or double mastectomy. After a mastectomy, breast cancer survivors are left with scars from the procedure [1] where their breasts once were. This can leave patients with a feeling of being noticeably different and impact their overall self-esteem. Current breast forms are commercially available and come in a myriad of materials and styles, however, they all encompass the same issues: lack of natural symmetry with patients' chest walls, uncomfortable fit, and a heavyweight that acts as a reminder of the breast forms' existence [2]. Through the use of a bioprinter, a more suitable breast form will be designed. The durability and comfortability of these forms will be tested through the use of each prototype on the patients. Compression strength tests and feedback from the patient will allow for the breast form to be put under conditions the patients may experience in their day-to-day lives.**

Keywords – Personalized, comfortable, biocompatibility, durability, elastomer, silicone, water-resistant, deformation-resistant

1. Introduction

After a mastectomy, breast cancer survivors are left with a reminder of their bravery and their battle with such a debilitating disease: scars from the procedure [1]. The absence of one or both breasts can have a monumental effect on the self-esteem of these survivors, so many of them seek out some form of external breast prostheses in an effort to remedy this.

Unfortunately, the current breast forms seem to lack many features that these women are looking for, such as the comfort and symmetry of both breasts. Many times these breast forms are heavy, noticeable, and can

cause women discomfort. These obstacles not only limit viable options for survivors but also contribute to their adversities after recovery [3].

With that being said, these patients need breast forms that are personalized, comfortable, durable, lightweight, and biocompatible. This project is looking to provide these women with an option that makes them feel confident knowing they look great and feel as though they do not stand out for looking different. Volunteers will wear them and provide important feedback after each prototype they receive.

2. Methods

The design consists of a personalized breast form made out of a 3-D printed elastomer material resulting in a durable, lightweight structure that is comfortable for the patients.

2.1 Materials

There are several different types of elastomers and silicones that can be used for these types of breast forms. After successfully printing full forms with three elastomers, there has been one that proves to get the best feedback and printing results. However, some patients have said this material can begin to smell funny after wearing it for a few days. Tests will be done with a vacuum oven to see if the smell can be eliminated.

2.2 Printing Process

For the creation of the.STL file that is sent from the computer to the bioprinter, an app is used to scan the patient's chest walls to provide a template for the contour of the side of the form that will be against the patients' skin. The scan also provides the shape of their existing breast if they only had a single mastectomy. The scans are then transferred to a computer software called mesh mixer by AutoCAD, where they can be manipulated to better fit the patient, or match the existing breast depending on the patient and their condition.

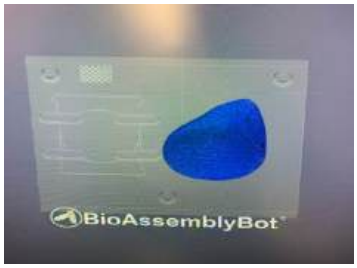

Figure 1: *This displays the top portion of the breast form in mesh mixer. This gets sent to the bioprinter.*

During the print of the grid structure, the pressure of the elastomer leaving the tube and the speed at which the tube travels can be manipulated to vary the overall consistency and feel of the breast form. Speed and pressure of the print determine how close each layer of print is, and where each layer is in contact with the next.

Figure 2: *The top part of a breast form. The grid and cross-sections used to develop a soft and durable feel are displayed.*

3. Results

3.1 Determining the Best Elastomer

The type of elastomer used in printing as well as the pattern of the print is critical to the durability and comfort of the breast form. A single-step elastomer material was chosen in order to eliminate the mixing process and premature curing of the material. Some important parameters of the elastomer product chosen were elongation until the break, durometer, creep, cure rate, and tensile strength. After receiving feedback that the forms creased over time, compression tests were done to ensure the material can bounce back to its original shape. To avoid excess compression, custom cases were created for the forms.

3.2 Patient Reviews

Each prototype is given to the patients to gather feedback, and examine the breast form after use. The forms are in direct contact with the skin, so patients are given test bracelets before they receive the full form to ensure no skin irritation. When choosing the elastomer, it was also important to ensure it is safe.

3.3 Final Breast Forms

Currently, five successful breast forms have been made for patients– three of those being double mastectomies. There has been more difficult with patients who have had a single mastectomy because of the weight discrepancies between the forms and a natural breast. Heavier forms are being tested.

4. Future Work

There have been many successes as well as some concerns throughout the feedback process. The current form is too light to match a natural breast in single-mastectomy patients, so the spacing of the print, and the inclusion of a heavier center are being tested. Some have complained the design looks strange, so there may be the integration of a soft cover to go over the forms. There are also going to be some future tests to ensure the form does not smell strange including putting the form in a vacuum oven after curing. More bracelets will be made in order to see if the smell is affected by that process.

5. Acknowledgements

We would like to thank Dr. Kuhn for developing this project and being so positive about the process of experimenting with different prototypes. We would also like to thank the Berkley Family Foundation and Connecticut Breast Health Initiative for helping fund this project. We are also working in collaboration with Dr. Stevenson, assistant professor of surgery in the department of medicine, as she has brought in seven cancer patients who are looking for better breast forms and are willing to try ours. Special thanks to Nathaniel Keri for teaching us how to use the bioprinter in the lab and continuing to print forms throughout the week.

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Design of Microfluidic Systems via 3D Printing

Team 5

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***Abstract* – The purpose of this project is to design and fabricate a microfluidic chip to model disease development for preclinical studies of osteoarthritis. A microfluidic chip made from polydimethylsiloxane (PDMS) is used to culture cells from joints and replicate the conditions during which osteoarthritis develops. The process of replicating the condition of osteoarthritis involved putting forces on the cells using a pneumatic or mechanical actuator to replicate the condition in which articular cartilage develops osteoarthritis. The microfluidic chip includes channels to culture and deliver drugs and essential substances to nurture the cells, substances enter the chip into the channels using a microfluidic pump. The result of this project is to provide a realistic in vitro environment to study about osteoarthritis and to do preclinical tests for drugs.**

Keywords – Microfluidic Chip, Tissue-On-a-Chip, Biomechanics, Osteoarthritis, Preclinical Test

1. Introduction

The process of bringing a drug from research to market requires multiple preclinical animal studies as well as four clinical trials. As a whole, this process costs an average of $2.5 billion [1] and takes an average of twelve years to complete [2]. Efficacy and safety seen in animal studies generally does not translate to human trials due to clear anatomical differences due to the fact that the average rate of successful translation from animal models to clinical trials is 8% [3]. Overall, this causes a waste of both money and time.

Microfluidic systems have recently been utilized to mimic the function of human organs [4]. These "tissue chips" allow for different cell types in the tissue to communicate as they would in the body through the microchannels. Furthermore, tissue chips can be designed to model disease development; potentially transforming the early stages of the drug development process as microchips may be utilized for drug screening and safety testing [4]. The objective of this project is to design and fabricate a microfluidic device that successfully models the development of osteoarthritis (OA) that can be used for more effective drug screening and safety testing when compared to current animal models.

2. Methods

The tissue chip design consists of six channels. Four of the channels hold cells and the other two channels are used for fluid circulation. The channels from left to right on the chip design are: media circulation, bone cells, articular cartilage (AC) cells, synovial fluid circulation, synovial membrane cells, and the other media circulation connected with the first. These are specifically aligned to mimic the anatomy of the knee joint and cell signaling with osteoarthritis. The circulation channels are being circulated using automated pumps outside the system that push the nutrients around the chip for all the cell channels. Two options being tested to optimize the mechanical component of the chip: mechanical actuator and pneumatic actuator. A mechanical pressure actuator is applied on top of the AC cell channel to portray the mechanical stresses that cause osteoarthritis. A pneumatic actuator design consists of a vacuum chamber surrounding the AC cell channel to create stretch and pressure forces that stimulate the stresses on the tissue as osteoarthritis develops. Each cell channel is about 1 mm in width and the entire chip fits onto a 75mm x 25mm glass slide.

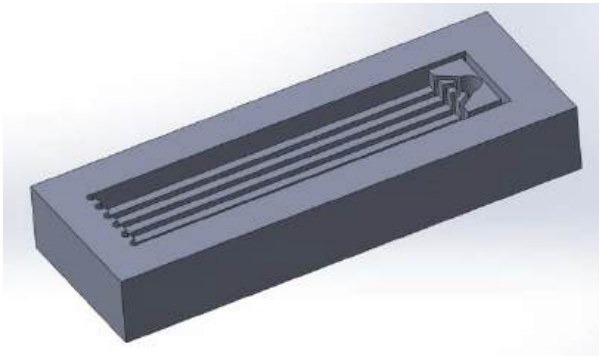

Figure 1 *– SolidWorks design of microchip to model osteoarthritis*

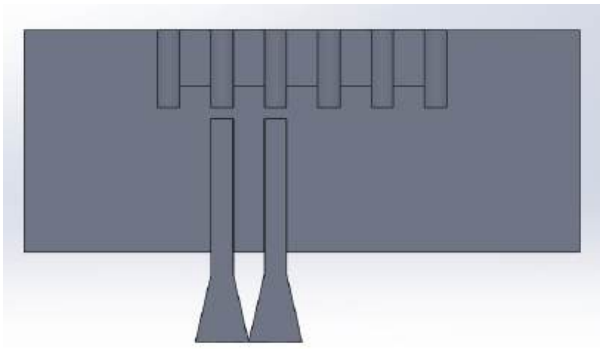

Figure 2 – Cross section of microchip design created on Solidworks. The cells in the channels are as follows (from left to right): culture media, bone, articular cartilage, synovial fluid, synovial membrane, and culture media. Mechanical actuators apply pressures to the bone and articular cartilage cell channels.

A 3D printer will print the negative mold of the SolidWork design using polylactic acid (PLA) filament. PDMS, a clear liquid silicone material, will be used to create the actual mold of the chip. This material allows the cells to signal to each other when they are inserted inside the channels.

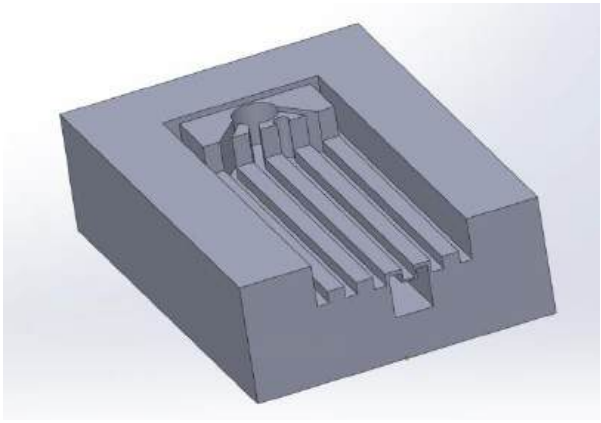

Figure 3 – Cross section of microchip design with channels for a pneumatic actuator. The cells in the channel around the actuator contain articular cartilage cells.

3. Simulations/Expected Outcomes

Mechanical actuator is very critical to the design of the testing because it will mimic the forces that induce osteoarthritis in the knee joint, causing the cells to release the signals that are comparable to those in the disease state. A PA-07 Micro Linear Actuator was chosen for the actuator because of its size, limited space and minimal force. Mechanical actuator will apply forces only to the bone cell channels and cartilage cell channels. Nonlinear simulations were performed on the microfluidic chip design using Solidworks to test the design resilience and fluid flow under applied stresses and deformations. The simulation ensures that fluid motion under set mechanical loading is going to induce osteoarthritis and the channels are not going to get clotted. Stimulations and characteristics of fluid motion proved that PTFE Tubing with dimensions of 1/16" at outside diameter and 1/32" in the inside diameter would be ideal to withstand pressures up to 3 bar. These simulations were essential to confirm the performance of the device considering the steady fluid motion.

4. Future Work

The prototype for the fully functional microfluidic chip will be completed by the end of April 2022 and would allow for the user to model osteoarthritis. Additionally, the mechanical actuator for the chip will be developed from scratch to better model the environment of osteoarthritis. In the immediate future, the current design will be tested and altered depending on the performance of the previous iterations of the microfluidic chip to produce the most optimal design. In the extended future, the chip can be modified to test various stages of the disease as well as potential treatments. For example, the researcher's interest could vary from how arthritis is developed through the interaction between articular cartilage and the synovial fluid or a potential drug could be added to the media circulation channels to test the effect on the various cell types. This microfluidic chip will help researchers conduct more accurate preclinical research on potential drugs to treat osteoarthritis.

5. Acknowledgments

We would like to thank our advisor Dr. Yupeng Chen for providing us with the guidance to complete the project. We would also like to thank Anne Yau for guidance and constant support throughout our design process.

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In Vitro Study of Spinal Cord Injury

Team 6

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***Abstract* – The purpose of this design project is to perform experiments on spinal cord cells to test how the applied force, speed affects the damages on the spinal cord cells, utilizing the testing system built for the study of Traumatic Brain Injury from previous research. The testing system consists of Arduino, camera, fan, dish, hammer with arm, locking mechanism, shutter, various weights, and spring. The Arduino is coded from the previous senior design team [1], it controls the switch to turn on the lights for the camera, using sensors to measure the magnitude of the forces, and trigger the camera to take pictures when the locking mechanism is triggered; the fan is to keep the temperature consistent for the camera; testing tissue is placed in the dish that is assembled with the hammer and the arm; the applied force is vary by the weight and spring used, and the distance between the edges to the beginning of the shutter. The result of this project provides the number of forces applied and the damages to the tissues with changes in force.**

Keywords – *In Vitro*, Tissue Culturing, Spinal Cord Injury, 2-D Cell Culture, 3-D Cell Culture

1. Introduction

An in vitro model that can be used to study the different injuries like the spinal cord injury, or the traumatic brain injury, it's to mimic the hitting and damaging process to the tissues as it is in real time accidents. It provides engineers and researchers the real time feedback and data as a real accident with the force measurements, high resolution real-time images, total time of the damaging process, then being able to analyze the speed of hitting and the effects on tissue.

For spinal cord injury, there's no defined cure once the damage has happened[2], as scientists and engineers trying to develop better treatment for this injury, it is essential to see how the injury influences human's tissue in a real time with the opportunity to analyze images and data from experiments.

The current limitation for this project is that the goal of this project is to build and utilize this model in vitro, there is error in the environment of tissue even though the parameter of the sample in the dish can be changed to the most likely environment. However, in order to move the project forward in the future, in vitro experiments are necessary. The objective of this design project is to use the device to perform experiments with various parameters to find multiple sets of parameters to test cultured cells, then analyzing the damages on tissues with different applied force from the hammer. The output data will be compared using Microsoft Excel, ImageJ, and other necessary software.

2. Methods

On this device, the locking mechanism will be released, using the motion from the spring to hit the hammer/dish/arm assembly producing an impact on the cultured tissues placed in the dish. As the shutter on the locking mechanism moves through the photogate, the camera is triggered to take photos. Photos are taken at the desired rate set in the program. In the case of this experiment the pictures are taken at an acquisition frame rate of 831 in combination with an exposure time of 1000.0 us. Recording a total of 51 frames once the trigger is activated. The light under the dish where tissues are placed allows the camera to take clear pictures of the damages in real time for analyzing. The built-in fan is to prevent the thermal energy produced by the light from killing the tissues and to keep the device in a regulated temperature range. The fan needs to be turned on manually with the power switch as the light turns on. The Arduino board will be properly set up with a serial monitor open before the testing starts. The data retrieved from the experiment comes from the attached Arduino reading the numbers generated from the force plate. This data is then analyzed utilizing excel to produce graphs for easier viewing.

A custom setting within Pylon Viewer in tandem with the use of Arduino will ensure activation of the camera after activation of the switch as well as the number of

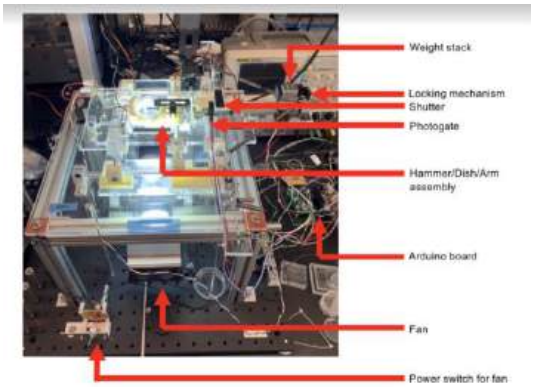

Figure 1 *– Device for testing damage in tissue cultures through imagery and force applied*

frames captured. The data the Arduino retrieves from the force will appear in the serial monitor to be transferred into excel for further analysis. The images captured will automatically go into the folder chosen via the Pylon Viewer platform for easy retrieval and further analysis utilizing measuring programs such as ImageJ.

$$Frame\ time\ (t) = \frac{Total\ time\ for\ 51\ frame}{51} \quad (1)$$

$$v = \frac{x}{t} \quad (2)$$

In equation 2, v is speed of the hammer,

x is the distance that the hammer moved between 1 frame measured from ImageJ,

t is frame time.

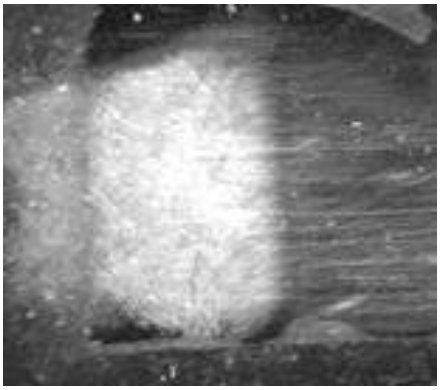

Figure 2 *– One of the pictures taken in the 51 frames of the sponge.*

In addition, a mold is designed to build a container for cultured testing tissues. Spinal cord tissues will be placed in those containers during experiments.

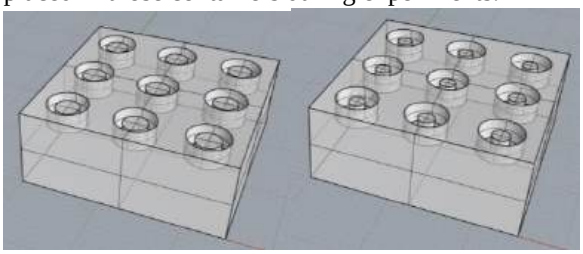

Figure 3, 4 *– Mold design for the spinal cord tissue container. The inner diameter is 3mm for the left, 2mm for the right.*

3. Simulations/Expected Outcomes

To simulate the experiment before utilizing tissues within the dish, a sponge was used to simulate the sample. This sponge was 5mm by 5mm. The experiments performed with the sponge were to calibrate the force needed to act upon the sample without causing complete destruction to the sample. Experiments were conducted with just the sponge in the dish receiving the impact as well as the sponge in water receiving the force of impact from the hammer. The trials for each of these conditions, dry and in water, were conducted by changing the distance between the shutter and photogate. Trials were also conducted to find the optimal force by changing the weight used along with spring length and number. These simulations were essential in ensuring the integrity of the neuronal samples that will be used in the actual experiment conducted for spinal cord injury research.

4. Future Work

Utilize the modified hammer designs and cell culture mold in testing. Utilize the different hammer shapes, round, flat, triangular (design shown below in figure 5, 6, 7), to further the testing and better understand the effects of types of impact and force distribution on the spinal cord.

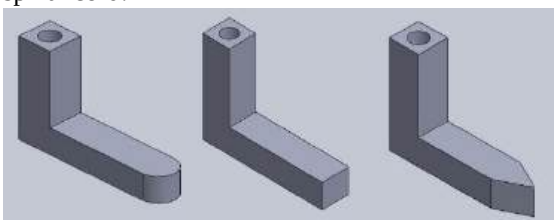

Figure 5, 6, 7 *– 3 different designs of the hammer, round, flat, triangular, to further stimulate the damage that could happen to the spinal cord.*

5. Acknowledgments

We would like to thank our project advisor Dr. Kazunori Hoshino for helping us in the lab during testing and teaching us about the device. We would also like to thank our sophomore helper, Juliana Rush, for the aid in cell culturing.

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Two-Layer Tubular Structure for Three-Dimensional Cancer Cell Culture and Microtissue Analysis

Team 7

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***Abstract* – The purpose of this design project is to fabricate an *in vitro* three-dimensional two-layer tubular cell culture structure through the usage of alginate and agarose hydrogels as an environment for tumor cell growth. MCF-7 breast cancer cells will be embedded within the inner layer of the hydrogel structure, and the outer layer will serve as an outer tissue layer. The design of such a structure lends itself to the study of cancer cell migration and invasion. The interactions between material, biological substances, and tissue behavior in relation to active tumors will be studied. By modeling the environment of a tumor in three dimensions, more accurate data of *in vivo* conditions can be obtained when combined with therapeutics for the treatment of diseased tissue. The result of this project provides valuable information to pharmaceutical companies, cancer patients in addition to researchers as it expands on cancer research on an *in vitro* scale and provides more knowledge on the interaction of drugs with tissues outside the body.**

Keywords – Cell Culture, Three-Dimensional, Hydrogels, Cancer, Microtissue analysis, Biomaterials

1. Introduction

The current technology used by drug developers and clinicians to test and observe the efficacy of drugs on cancer relies heavily on the use of traditional cell culture models in a two-dimensional setting, followed by the use of animal models, before being used in the healthcare setting. Most of the research done studies the effects of cancer drugs when they are delivered systemically, even when they need to reach a specific target state such as a tumor. It is very hard to predict the effects of a drug when considering the formulation alone, numerous tests are done using *in vivo* animal models, at the cost of time and valuable life. Cancer itself is also a constantly evolving disease, it can be very difficult to introduce in life subjects let alone control its spread when measuring drug interactions. The development of an *in vitro* model that mimics the behavior of cancer as well as its interactions on a three-dimensional level is useful to accurately gauge its response when in the presence of pharmaceutical drugs used to treat cancer [1]. The use of hydrogel as a vessel *in vitro* harnesses the advancements of three-dimensional cell culture and allows for a more controlled approach to studying the effects of drugs while using very little material and saving on costs. As a result, the overarching goal of this project is to design and fabricate a multi-layered, three-dimensional, tubular structure that serves as a microenvironment to further study the interaction of cancer drugs *ex vivo*.

2. Methods

The selected design involved creating two layers of hydrogel material in a tubular structure as seen in Figure 1. The first inner layer encapsulates a tumor spheroid consisting of approximately 3000 cells of the MCF-7 breast cancer cell line. This layer consists of a mixture of agarose and CollaGel, a collagen supplemented hydrogel used in place of Matrigel, a hydrogel which mimics *in vivo* basement membrane matrix in cancer cell experiments hydrogels. The outer layer consists of sodium alginate which is a naturally-occurring hydrogel. The inner layer is created by introducing spheroids into an agarose and CollaGel hydrogel suspension and is piped into small pillars using a microcapillary pipette which encases a spheroid in this hydrogel suspension. The outer "tissue" layer is then created by micro-dipping these small pillars in sodium alginate and allowing them to cross-link. The structure is then complete and is placed in media to allow the spheroid to proliferate and invade from the inner layer into the outer layer. Through this process, we are aiming to maximize hydrogel structure while minimizing size.

3. Simulations/Expected Outcomes

One of the most critical aspects of creating the tubular structure's design is the choice of material used. It was important to prioritize the ease of producing the final product as well. Agarose is a well-researched polymer that requires minimal steps to create a firm, yet flexible environment for cells to reside in [2]. For this reason, a

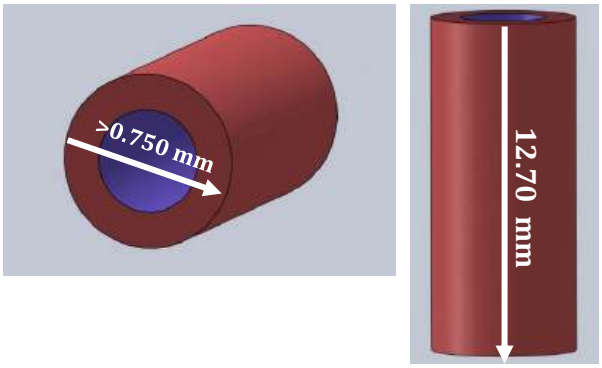

Figure 1 *– SolidWorks prototype of a two-layer three-dimensional structure for cancer cell culture with an inner layer (purple color) created by incorporating MCF-7 tumor spheroids with CollaGel, and agarose micro-dipped in a sodium alginate hydrogel outer layer (red color).*

double-layered structure was desirable to mimic. The expected outcomes for this two-layer structure are to allow for ample cancer cell proliferation to be able to run further drug testing in addition to microtissue analysis. Figures 1 and 2 illustrate the early prototypes created, highlighting the tubular structure with the proper layers and colored portions distinguishing between each layer. Figure 2 illustrates an early prototype of our inner layer which consists of CollaGel, agarose, and a tumor spheroid. Encasing this structure in sodium alginate will complete our two-layer tubular structure for three-dimensional cancer culture and microtissue analysis. We hope to distinguish the two layers and spheroid through the usage of cell dye, which will aid in tracking cell proliferation.

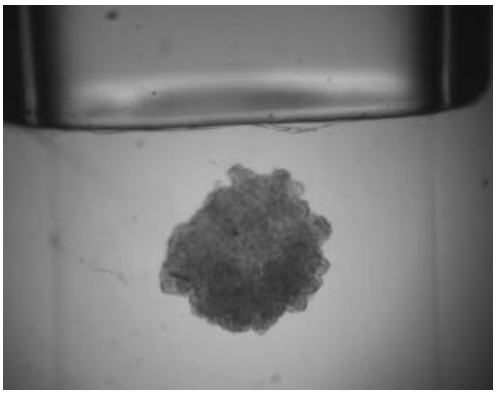

Figure 2 *– Early prototype of the inner layer consisting of a tumor spheroid, CollaGel, and agarose without the incorporation of the sodium alginate outer layer*

To test the mechanical strength of the tubular structures through microtissue analysis, a piece of equipment called micro-tweezers will be used. This will allow further analysis of the forces present in the tissue, material stiffness, and indicate how the tubular structure reacts to an applied force. [2] From the data extracted from this process, an understanding of the cancer cell proliferation, migration, invasion and tumor microenvironment characteristics can be achieved which can be further used to conduct corresponding research with the hope to aid cancer patients.

4. Future Work

If a sustainable three-dimensional cancer cell culture environment is achieved, our short-term goal is to observe the behavior of the cells as they proliferate. These morphological changes in cells can be observed through various cell viability and proliferation assays, such as live-dead assays can all be used to track and quantify cell death that occurs after seeding and track cell proliferation on a daily basis. It is our hope that we can mimic different stages of cancer by varying the size of the tumor spheroids. Additionally, by conducting microtissue analysis, the effects of cancer and the tumor microenvironment can be studied in relation to the stiffness of the extracellular matrix. A long-term goal would be to introduce therapeutic agents into the environment to observe their effects *in vitro.*

5. Acknowledgments

We would like to thank our faculty advisor, Dr. Kazunori Hoshino, for all his support and assistance on the design of our project. In addition, a special thank you to Dr. Kumavor for being approachable and answering our relentless questions.

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Design of a Smart Shunt System

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***Abstract* – The purpose of this design project is to further develop an interface to non-invasively monitor cerebrospinal fluid (CSF) flow in commercially available cerebral shunts. The two main components of this interface system are the internal, implanted sensor unit, and the external unit. The main goal of this project is to provide an improved quality of life for patients with hydrocephalus. A smaller sensor housing unit will improve patient comfort, while the addition of a spectrophotometer will detect contaminants in the CSF and provide more information to the patient. Using Bluetooth transmission, CSF flow rate and CSF quality data will be sent to the patient's smart device which will display real-time information and alert the patient if necessary. The wearable external unit will be redesigned for optimal patient comfort for continuous monitoring. Providing the patient with real-time data will reduce the number of unnecessary hospitalizations for hydrocephalus complications and will provide the patient with piece-of-mind that their shunt is functioning properly.**

Keywords – Hydrocephalus, Cerebral Shunt, Flow Rate, Cerebrospinal Fluid (CSF), Implantable Monitor

1. Introduction

Hydrocephalus is a condition in which the ventricles in the brain fill up with an abnormal amount of CSF, causing increased brain pressure and, if left untreated, will lead to brain damage and death in 50% of patients [1]. There is currently no cure for hydrocephalus; however, there are two main therapies available to manage symptoms. Choice of treatment is mainly dependent on the diagnosed type of hydrocephalus, the cause, the age of the patient, and the treatment history.
In patients of all ages, shunt surgery is commonly used to treat hydrocephalus by providing a route for CSF to be absorbed in a different part of the body. This treatment requires a commercially available shunt to be surgically implanted under the skin of the patient's skull. The system consists of a proximal catheter that directs CSF into the shunt valve and a distal catheter that drains the excess CSF. Proper placement of the proximal and distal catheters is crucial and individualized for each patient. Typically, the proximal catheter is placed in the ventricles, while the distal catheter is in the peritoneal cavity.

Commercial shunts fall into two different categories, fixed-resistance valves, and variable resistance valves. Fixed-resistance valves have a single valve setting. The valve will open when intracranial pressure is greater than the set opening pressure (low, medium, or high) and abdominal pressure to allow CSF to flow out of the ventricles. If the opening pressure needs to be changed, a new shunt will need to be surgically implanted. With a variable resistance valve, the opening pressure can be adjusted using a magnetic device and no additional surgeries are needed. The ability to adjust the opening pressure can prevent over drainage and helps patients better manage symptoms. However, small exposures to external magnetic fields may require a physician to ensure proper CSF flow [2].

There are many risks associated with shunt surgery. A shunt is classified as a failure if it needs a revision or needs to be completely replaced. A revision may be needed due to infection, disconnection, blockage, and or over drainage. A collection of studies shows that, "the overall shunt failure rate requiring shunt revision(s) was 46.3%, and the majority of shunt revision occurred during the first 6 months after shunt placement" [3]. Due to the high shunt failure rate, frequent monitoring is needed to ensure the shunt is operating optimally. To check shunt function, surgeons will sample CSF and patient blood to analyze flow rate and possible infections [2]. Headaches are a common symptom of a shunt malfunction causing patients to make frequent hospital when experiencing any type of head pain. "In 2017, there were an estimated 16,376 Emergency Department (ED) visits for suspected shunt malfunction" in the United States [4]. Additionally, a study done from 2010-2013 found that "60.5% of patients presenting to the ED for suspected shunt malfunction were discharged home," spending an average of 3.29 hours per ED visit [4]. The high number of hospital visits shows the uncertainty of the patient regarding the functionality of his/her shunt.

A device that can provide the patient with real-time information on shunt function can reduce costly ED visits as well as put the patient at ease.

2. Methods

A. Overview

The design consists of an internal sensor housing unit which is connected to the distal catheter of the cerebral shunt. The sensor housing unit contains a photosensor

to measure CSF flow rate and a spectrophotometer to detect contaminants in the CSF. Using IR communication, data from the sensor is received by the external unit. A Bluetooth module then sends this data to a database where the data is stored. The smart phone application can display the processed data in a way that is easy for the patient to understand. An overview of the entire system can be seen in Fig. 1.

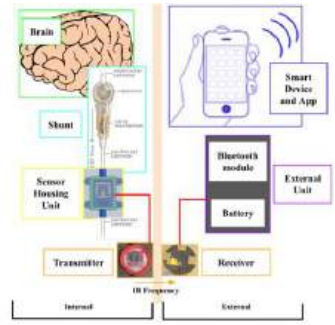

Figure 1. Diagram of Smart Shunt System

B. Sensor Housing Unit

The sensor housing unit consists of four main components: the bottom piece, top piece, cantilever flow sensor, and silicone seal. The four components can be seen in the exploded view shown in Fig. 2.
This improved housing unit has approximately a 40% decrease in volume compared to the previous design. A lip/groove connection on the top and bottom pieces and a silicone seal were added to prevent leaking.

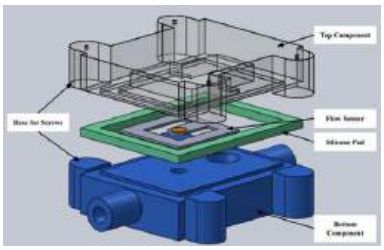

Figure 2. SolidWorks Sensor Housing Unit Exploded View

CSF flow through the sensor housing unit is used to measure flow rate and detect obstructions. The flow rate mechanically bends the cantilever beam with a gold tip. A parallel light source provides a changing level of deflection of the gold tip. This deflection photonically excites a photosensor with high gain. The amplified signal is transmitted by IR wavelengths by an ADC pin connected to an IR diode. The ADC pin samples the analog current signal and sends the information in bits. Because CSF is a clear liquid in healthy conditions, we can claim it is colorless in nature. Using a bi-color LED, as our parallel light source, alternating between the red and green wavelengths, the presence of red spectra within the CSF can be detected. This is due to the differences in the absorbance spectra of red vs green light. This information can then be leveraged as a method of hemoglobin detection within CSF.

C. Wireless Charging System

The smart shunt system is powered using the principles of electromagnetic induction. Alternating current in the external coil creates a changing magnetic field. This changing field generates an emf in the receiving internal coil. The generated emf is rectified, filtered, and regulated to provide power to operate the device. Currently, an adafruit inductive charging set is utilized. This transmitter/receiver set is modeled in Fig. 1. In the future increased powering efficiency will be achieved using a Qi charging module.

D. External Unit

The external unit is in the process of being modified to be made thinner and to incorporate a Bluetooth module. A model of the next iteration of the external unit is shown in Fig. 1. Utilizing smaller, rechargeable batteries provides longer operating time and allows for a smaller unit which could be made to fit in the patient's pocket. The Bluetooth module will send the raw data received from the IR receiver to a database which will process the data.

3. Future work

The next steps of the design project are focused on the data collection. We will run experiments to determine an experimental equation to convert raw data to a meaningful flow rate. We will also work on data processing methods for the spectrophotometer. A smart device application will be developed to provide the patient with information on the operation status of his/her cerebral shunt. The design of the external unit will be wearable based on cochlear implant designs. This design will decrease the visibility of the device and increase patient comfort.

4-Acknowledgments

We would like to thank our advisor, Professor Hoshino, for assisting with developing improvement goals and modeling system components.

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Handheld Device for in situ Bioprinting

Team 9

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***Abstract* – The goal of this design project is to develop a handheld bio-printing device that can be used in tissue defect repair and regeneration. This device would be used for *in situ* bio-printing, which is a novel technique of tissue repair where tissues are fabricated and/or repaired directly on the intended anatomical location of the defect, using the body itself as a bioreactor [1]. The handheld bio-printing device includes two syringes, one for the desired bio-ink and the other for the intended crosslinker, two servo motors, and a multichannel nozzle. The motors operate to extrude both the bioink and crosslinker into the tip, where they will be crosslinked. The bio-ink will then extrude out of the multichannel nozzle allowing for a more homogenous distribution of the bioink across the defect site. The result of this project will aid the current research on how direct bio-printing could be used in tissue defect repair/regeneration.**

Keywords – Bio-printing, tissue regeneration, tissue repair, *in situ*, extrusion

1. Introduction

There are numerous types of diseases or accidents that can occur which lead to defect sites forming in all types of human tissue. Clinicians need a more optimal bioprinting-based treatment strategy than the currently available *in vitro* models. The current *in-vitro* models mostly revolve around implanting a prefabricated scaffold into the defect site itself [2]. Issues that come along with pre-fabricating the scaffold include difficult repeatability between patients and controlling the properties of the scaffold. By altering properties like the degradation rate, the porosity of the material will change, which in turn affects the mechanical properties of the scaffold leading to mechanical failure [1].

Current research is taking place on *in situ* bio-printing, which works to fabricate or repair living tissues at a defect site in a clinical setting [2]. There are two different approaches to *in situ* bio-printing, a robotic arm approach and a handheld approach [2]. This design project focuses on handheld *in situ* bio-printing. With this approach, biomaterials can be deposited onto a defect site in a direct-write fashion [2]. This approach has multiple advantages over the robotic arm approach including flexible printing for time-dependent wound conditions, the ability to deposit the bio-ink into crevices of the defect site that the CAD did not account for, ease of sterilization and overall movement out of the clinical location, and lower cost [2]. Ultimately, the objective of this design project is to fabricate a handheld bio-printing device, which can be used *in situ* to repair and regenerate tissue in a defect site.

2. Methods

The design considerations of our handheld gun-shaped bioprinting system emphasizes ergonomics and portability, as well as the homogeneity of the print. The device contains a motorized extrusion system, a bioink cartridge, a silicon wheel, and a multichannel nozzle, operated by a portable battery. The bioink cartridges and nozzle will be detachable to allow for an easier process loading the bioinks and a more personalized nozzle accommodating the tissue type being printed on. The encasement of the device will be 3D printed out of acrylonitrile butadiene styrene [3].

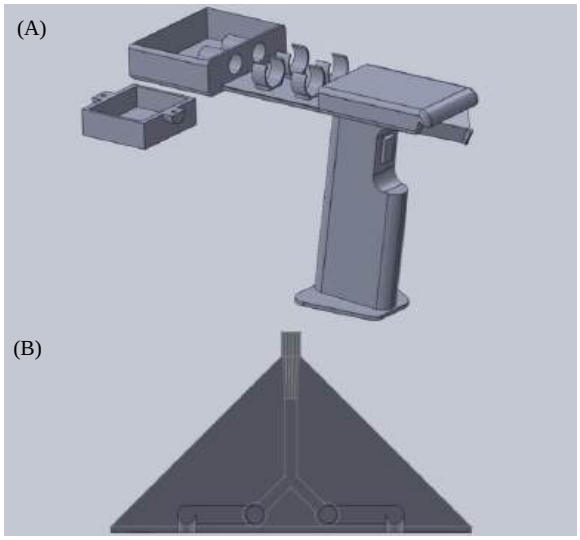

Figure 1 *– (A) SolidWorks prototype of the handheld bioprinter. (B) SolidWorks prototype of the handheld bioprinter's tip.*

A custom code will control the speed at which the motors act on the syringes, impacting their flow rate. The individual values for the bioink and crosslinking syringes will be inputted prior to printing. As the bioink and crosslinking agents are being extruded from their individual syringes, they will meet right before being expelled from the nozzle. The crosslinked form that will result is ideal for cell proliferation, adhesion, and overall tissue regeneration within the defect site as it mimics the ECM of the tissue. The crosslinked bioink is then extruded from the 5-channel tip allowing for greater coverage of the defect site, which increases the speed of the procedure and results in a more homogenous distribution of the bioink.

3. Simulations/Expected Outcomes

The bio-ink resides inside of BD Plastics Luer Lock syringes, which are clipped into place on top of the device. These syringes are connected with internal PVC tubing to the tip of the printer. The tip, consisting of SS316 stainless steel, allows for satisfactory sterilization between patients. The low nickel content of the tip also reduces the capability for a negative immune response. In the rear of the device, twin 20 kg-cm servo motors are connected to ⅜'' diameter aluminum rods. These rods depress the syringe plunger. The torque produced by these rods exceeds both the plunger-stopper break loose force (the force required to take the plunger out of static friction) and the dynamic gliding force (the force required to continue the depression) of similar syringes [4]. The bio-ink travels through the internal PVC tubing and into the tip. For testing purposes, sodium alginate will be used in the printer. Allevi, a prominent bioprinting corporation, has set guidelines for appropriate parameters at which alginate should be printed [5]. Allevi recommends either a 2% or 5% alginate at a 6 millimeter per second speed with pressures of about 51.7 kPa and 103.4 kPa, respectively, out of a 30 gauge needle. In order to maintain the same extrusion force in our 0.40 mm tips, a pressure of 19.65 kPa must be implemented for the 2% alginate, and 39.30 kPa must be used for the 5%. Thus, the servo motor force will be modified to create such a value. As seen in Figure 3 below, the pathway for alginate extrusion as highlighted in blue and yellow begins in sterile syringes, which are loaded into the bioprinter prior to printing onto a surface. As these syringes compress, the two alginate samples pass through internal tubing and extrude through the tip onto the desired surface. Then, the bio-ink is treated with a calcium chloride solution to crosslink the sample. Figure 4 depicts the mixing process of the two syringe contents, which will be useful for other bio-inks that require a crosslinking agent to be thoroughly blended in order to provide structure.

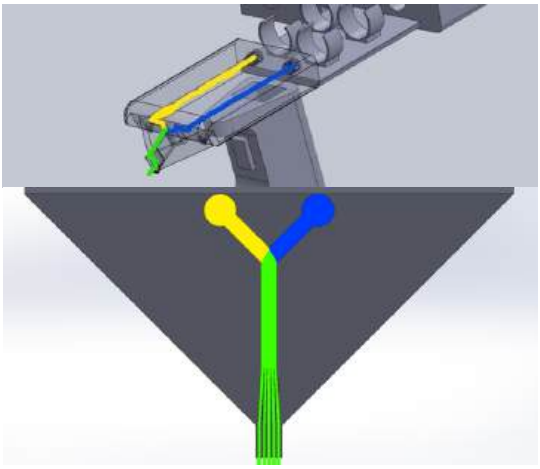

Figure 2 *– SolidWorks simulation showing extrusion of alginate bioink (blue & yellow highlights) and the mixing of the two channels as well as their extrusion through the five tips.*

4. Future Work

The bioprinted scaffold will be tested to examine the accuracy of the printer, comparing it visually and mechanically to other scaffolds which are clinically used.

5. Acknowledgments

We would like to thank Dr. Syam Nukavarapu for his guidance as our team advisor for this project, as well as our TA for the fall semester, Trevon Graham, and our TA for the spring semester, Mahdi Pirayesh Shirazi Nejad, for their advice and the help they both provided our group throughout the entire process. Dr. Krystyna Gielo-Perczak and Dr. Patrick Kumavor also served as sources we could turn to for general questions about the project so we would like to thank them as well. Finally, we would like to thank the several people who helped us carry out the fabrication of the different parts of our bioprinter prototype.

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Drone and Weather Balloon-Augmented Reduced Gravity Simulator for Field Environments

Team 10

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***Abstract* – The purpose of this design project is to design an apparatus using a weather balloon and a drone to simulate the reduced gravity conditions on Mars on Earth by offloading some of the weight of the user. This apparatus will consist of a drone attached to a weather balloon. A gimbal made from a lightweight steel frame fabricated with aluminum anchoring arms will be secured to the user, equipped with accelerometers and XSens motion capture sensors [2] that communicate with the drone for positioning. The system will offload the weight of the person using it, as well as make sure to be always over their center of gravity. The result of this project provides an effective and efficient system capable of being used in field environment testing for the National Aeronautics and Space Administration (NASA).**

Keywords – Gravitational acceleration, Gravity simulation, Gimbal, Accelerometer, Angular velocity and acceleration

1. Introduction

As space exploration programs, such as the National Aeronautics and Space Administration (NASA), look to sending astronauts to space, proper methods of training are essential to ensure that working in space will not be too difficult. However, sending astronauts to environments with less than 1 g-force requires special facilities that can mimic the effects of low gravity. NASA has developed the Active Response Gravity Offload System (ARGOS) and Neutral Buoyancy Laboratory (NBL) to simulate these conditions.

The current limitation with the NBL is that while it is currently the best method of no gravity simulation, the astronauts still feel the weight while in their suits, and while for ARGOS, low to no gravity simulation is possible, the greatest limitation to the system is that it is static and confined by space [1]. The objective of this design project is to develop a system for offloading a suited subject to simulate reduced gravity by offloading the subject's weight while safely attached to the system and performing a range of activities. The goal for offloading is to mimic the gravitational pull on Mars, but it is allowed to do less offloading than required, as long as the method of offloading is scalable.

2. Methods

The design consists of a drone that is attached to a weather balloon. The drone will steer the weather balloon to follow the subject. The suited subject will then be tethered to the balloon while wearing a gimbal that consists of a frame that is fastened to the subject's back through straps holding the subject on the shoulders and around the waist, and a harness to support the lower body. The goal of the gimbal is to safely tether the subject to the system while allowing for different positions and movement from the subject.

***Figure 1**: SOLIDWORKS model of gimbal design*

The drone will also follow the subject by using accelerometers placed on the hips of the subject and one in the backpack. The method used to track motion will be using motion capture sensors, which give

orientation, magnetic fields, and accelerations, which will be used to detect movement [2].

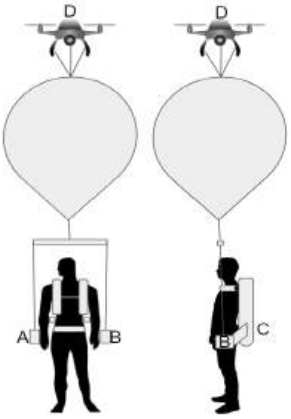

Figure 2: *Front and side view of drone-weather balloon and gimbal design with accelerometers (sensors) A, B, C, and D*

The sensors are small wearable devices that output roll, pitch, and yaw. The inertial sensors can also give altitude information, which can then be paired with the altitude of the drone, so that the distance between the person and the drone will always be constant in the *y*-direction, which in this case is the vertical direction pointing towards the sky. The *x*- and *z*-direction will be determined by taking the rotational matrices from the roll, pitch, yaw. With the rotational matrices, the relative *x* and *z* positions to the drone can be determined. The drone will follow the subject based on these sensor outputs through movement commands.

3. Simulations/Expected Outcomes

The design needs to be able to withstand an upward tensile force applied to the arms on either side of the gimbal. In order to predict how the design will react under expected conditions the use of a SOLIDWORKS simulation was conducted. The simulation was done under the following assumptions: the part is constructed from a mild steel alloy, the part has a force of 100 lbf applied to each of the arms, and finally that the back of the gimbal is fixed. The simulation resulted in the following stress and strain diagrams.

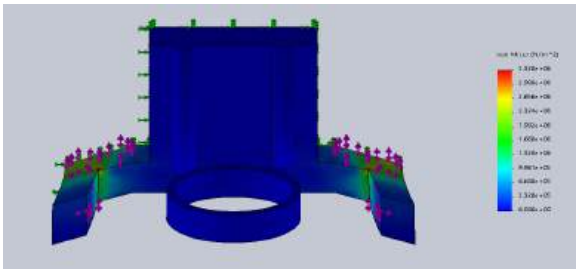

Figure 3: *SOLIDWORKS stress analysis heat map.*

The overall results of this heat map show that the design can currently withstand the expected loads it will experience. Further optimizations to the design would likely be reducing the angle of the elbows to a gradual curve and cutting sections of the back plate for weight reduction.

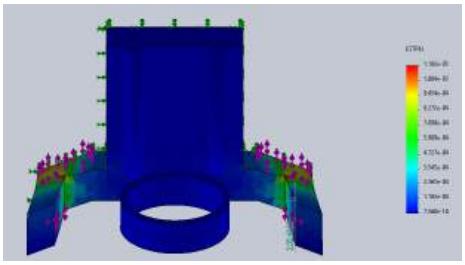

Figure 4: *SOLIDWORKS strain analysis heat map*

Figure 4 shows the strain analysis of the gimbal under normal operating conditions.

4. Future Work

In early April 2022, the gimbal assembly will be fabricated and implemented into the design. The code that extracts data from the sensors will be finalized to take the current accelerations and translate them into positional data, which can then be sent to the drone. This code will be paired with the code that controls the drone itself. Further testing on the durability and comfort of the gimbal will be performed as well as testing the drones following capabilities and full assembly functionality. Testing the gimbal and its design with the drone-weather balloon system will occur in late April.

5. Acknowledgments

We would like to thank our sponsor, NASA for providing us with the resources to complete the project. We would also like to thank Aquiline Drones for providing the drones as well as assistance with the drone technology. Information regarding the motion capture sensors and their compatibility with this project was provided by XSens.

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Joystick Operated Ride-On Device for Children with Cerebral Palsy

Team 11

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***Abstract* – The purpose of this design project is to redesign and optimize a motorized ride-on cart to be used during physical therapy to help children with cerebral palsy. Children with cerebral palsy (CP), a neurological disorder caused before or during birth, have mild to severe issues with movement, motor control, and posture [1]. One of the most powerful tools that doctors have for improving these symptoms is physical therapy, with early intervention proven to improve gross motor function [2]. The goal of the design is to improve the functionality of the existing ride-on cart such that children with varying severities of cerebral palsy and varying ability to use different sides of their body can participate in physical therapy to help improve their motor function, hand-eye coordination, and hand strength. This will be done by using an Arduino microcontroller to modify the existing cart for accessibility, added safety, and comfortability. The progress of the patients participating in the physical therapy will be tracked by recording the path and distance traveled over the course of the physical therapy sessions. The result of this project will be a fun, engaging, dynamic, and accessible ride-on cart that can be used by physical therapists and families with children who have cerebral palsy.**

Keywords – Cerebral Palsy, Physical Therapy, Arduino, Ride-on Cart

1. Introduction

Cerebral palsy is a non-progressive, permanent neurological condition that causes a wide range of mobility and motor control problems. CP is caused by damage in the cerebral cortex which consists of the entire outer layer of the brain that controls our most complicated mental capabilities. Although there is no cure for CP, there are a number of therapy options that can help individuals improve motor coordination, speech and language skills, and learn to work around their physical and mental limitations.The goal of this study is to create a locally and remotely controlled ride-on cart that can be used as a form of physical therapy for children with CP, with reconfigurable joysticks and remote tracking capability to test the hypothesis that driving such a cart will stimulate the children's muscles and help improve their motor control.

2. Methods

The design consists of a repurposed Power Wheels ride-on cart, an Arduino Mega microcontroller, two MegaMoto Arduino shield motor drivers, a bluetooth module, two ultrasonic sensors, and two configurable joysticks. The ride-on cart will be stripped of its existing microcontroller and joysticks and only the frame, 12V battery, and existing wheels will be utilized.

Figure 1 *– The ride-on cart with new reinforced joystick controls*

The Arduino will take the place of the existing microcontroller and control both signal processing from the joystick to the driver as well as track the cart's path and distance traveled. The MegaMoto drivers will take information from the Arduino via two pulse width modulation (PWM) digital outputs and output a varying voltage to the DC motors based on the input from the joysticks.

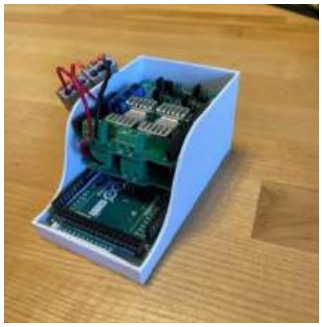

Figure 2 *- Arduino Mega microcontroller, and two MegaMoto Arduino shield motor drivers in parallel*

The bluetooth module will be used to send data to a computer or phone about the path and distance traveled and receive commands to stop the cart and change the joystick configuration between dual and single joystick use. As shown in Figure 1, the joystick mounts have been custom designed

and 3D printed to be reinforced and allow for ease of use by Cerebral Palsy patients.

The Arduino and MegaMoto drivers will be wired as shown below in Figure 3 such that the two drivers are stacked on top of the Arduino. They are wired in parallel with the battery. The joysticks are controlled via analog input, and Bluetooth and ultrasonic sensors controlled via digital inputs.

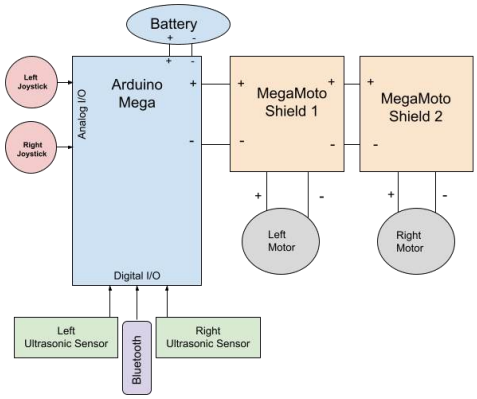

Figure 3 – *Circuit diagram for Arduino Mega and MegaMoto driver*

3. Simulations/Expected Outcomes

Testing was done to configure the ultrasonic sensor to track the cart's distance traveled and to calibrate the code. Each trial consisted of applying a voltage to rotate the wheel five times and observing the number of notches counted by the ultrasonic sensor. The wheel measuring surface contained four notches, giving eight depth changes in a single rotation. Ideally, after five full rotations the sensor would read 40 depth changes, thus allowing wheel rotations to be counted. Tests were conducted at high and low speeds, as either extreme could be a source of error.

Ultrasonic Sensor Testing					
Trial 1		Trial 2		Trial 3	
Fast	Slow	Fast	Slow	Fast	Slow
6	66	39	41	40	40
20	116	39	43	40	40
---	---	37	43	40	40

Figure 4 *- Ultrasonic sensor testing results*

Trial 1 set a baseline result. Trial 2 occured after updating the placement of the sensor and updating the code behind sensor tracking. Trial 3 occured after zeroing the code in to be more accurate. The number of rotations was counted with a high accuracy and repeatability by this time. Error occurs when the wheel turns and the sensor does not pick it up because it turned less than a full notch in the wheel-covering. Increasing the frequency of height changes in the wheel-covering would allow for more precise data. A redesigned wheel-covering was created to make a more accurate measuring surface for the ultrasonic sensor as shown below in Figure 5.

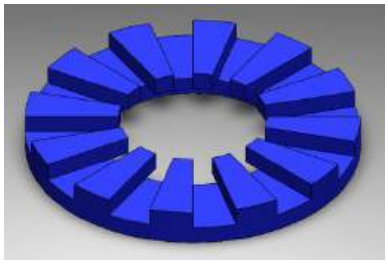

Figure 5 *– Wheel well covering with added notches*

4. Future Work

Upon completion of the first cart, the second cart, the Huffy Green Machine Vortex, will be outfitted with a similar Arduino and Joystick configuration. This newly acquired cart will receive the same modifications with the addition of full ultrasonic tracking and bluetooth control capabilities for data acquisition and remote access. Additional support and comfort modifications will be made to allow for use with larger children while still being usable for small children. While this second cart is constructed, the first cart will simultaneously be tested in the REINVENT-PT lab where the team can observe and make necessary modifications to the second cart in real-time.

5. Acknowledgments

We would like to thank our sponsor, Dr. Sudha Srinivasan of UConn's REINVENT-PT lab for providing us with the resources, background, and motivation for this project. We would also like to thank our project advisor Dr. Patrick Kumavor for his previous research and guidance throughout the project. Testing was aided by our undergraduate project intern Naysa Joseph-Gabriel.

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EOG-based Communication System for Patients with Locked-in Syndrome

Team 12

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***Abstract* – This project aims to develop a computer interface that allows individuals with Locked-in Syndrome to spell words by using eye movements. The design includes a wearable system with up to five electrodes for electrooculographic (EOG) measurements interfaced with a virtual keyboard and a spelling algorithm on a PC. The EOG measurements captures both vertical and horizontal eye movements and are streamed to the PC for real-time analysis. The spelling algorithm processes the EOG time series to track the position of the eyesight on a virtual keyboard and detect eye blinking, which is used to encode letter selection. The keyboard is designed as a hierarchical sequence of menus with a subset of letters per menu, where the location and number of letters per menu is optimized to reduce detection errors and minimize the spelling time.**

1. Introduction

Locked-in Syndrome (LIS) was first described in 1966. It was defined by quadriplegia, lower cranial nerve paralysis, and mutism, including preservation of consciousness, vertical gaze, and upper eyelid movement [1]. LIS is caused by damage to the midbrain, most often by an infarct in the pons [2]. It can also be the result of an occlusion in the mid-basilar artery [2]. The patient is "locked in" their body as they have very limited motor ability. The result of this paralysis is a lack of effective ways in which the patient can communicate with their surroundings. To aid their communication, computer interfaces with spelling keyboards controlled by EOG signals have been created.

Currently in the literature on EOG-based spellers, there are two general divisions: those using only blinks and winks, and those that also include saccades. As blinks and winks are faster than saccades, previous EOG-spellers that use only blinks and winks [3][4] have shown a faster character selection time than those also including saccades [5][6]. In addition, spellers using only blinks and winks have shown a higher character classification accuracy. Another divide can be made based on the GUI design. GUIs can be "grouped", where characters on the main menu are grouped together and a system of submenus are used to select a single character. Conversely, there are also "singular" GUI spellers where there is only one menu consisting of many possible single character targets. On average GUIs using multiple menus [4][5] have a higher classification accuracy than those using a single menu [3][6].

Our aim is to create an EOG-based speller using blinks and saccades that has a faster character selection time than previous spellers using the same eye movements. To achieve this, we will use a GUI will multiple menus, as this has been proven to produce a higher classification accuracy. Our GUI design will be optimized by grouping letters by their frequency of use in English words. A similar design was created in [6] on a "singular" GUI menu, in which strategically placing commonly used letters closer together resulted in a faster selection time and accuracy than a standard QWERTY keyboard. Therefore, we believe combining this letter-placement method with multiple GUI menus will produce a faster, more accurate EOG-speller that improves communication for patients with LIS. Its efficacy will therefore be measured by speed and accuracy metrics.

2. Methods

2.1 Hardware Setup

This overall design focuses on developing a hardware and computational component. The first step for receiving EOG signals consists of a 5-electrode setup utilizing silver chloride electrodes to track eye movements. A pair of electrodes will be placed on the sides of both eyes near the temples to measure a horizontal movement signal. Another pair will be put above and below one eye in order to produce a vertical movement signal that can record blinks as well. A single electrode will be placed on the forehead in between both eyes to act as a reference. The complete electrode setup can be seen in Fig. 1(a). The two measured signals will be amplified and filtered through an amplifier circuit [7]. A bandpass filter will be utilized in order to produce a signal in the frequency range of 0.1-16 Hz to extract eye movements. The signals will be received and sent to a personal computer through a USB connection utilizing an Arduino UNO board.

2.2 GUI Design and Control

The GUI in this design includes three menus as shown in Fig. 1(b-d). This GUI has been designed to group commonly used English letters together. Placing commonly used letters closer to one another decreases the time needed for word spelling [6]. To choose a target, the user will be instructed to perform a saccadic movement to the desired target group on the main GUI menu. The target group chosen will be highlighted. If the

correct group is highlighted, a double blink will confirm the selection and open the corresponding submenu. If the highlight

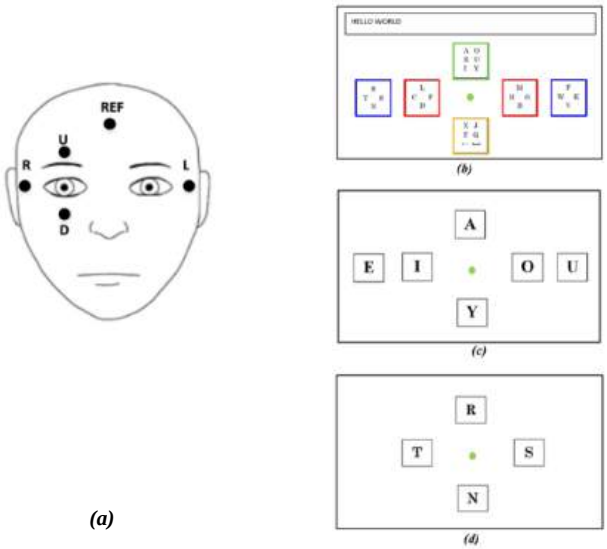

Fig. 1 *– Electrode placement for horizontal and vertical eye movements (a), and GUI design including the main menu (b), and (c) and (d) two possible Submenus*

is incorrect, another saccade can be performed before the double blink, and the new group will be highlighted. The same process will occur in the submenus. However, once a double blink is used to confirm the desired single target, the submenu will close, allowing the main menu to be reopened with the new character displayed at the end of the text in the textbox.

2.3 Saccade and Blink Detection

Both EOG signals, the vertical signal (EOGV) and the horizontal signal (EOGH) will be searched for features corresponding to saccadic and blink eye movements. Two preprocessing steps, down-sampling and derivation will be performed on EOGV and EOGH. The resulting vectors will be referred to as *H'* and *V'*. Down-sampling removes minor fluctuations in an EOG signal [4], while taking the first-order derivative of the signal allows for more pronounced peaks and therefore easier peak detection [4][5]. An example of a saccade in a raw versus differentiated EOG signal is shown in Fig. 2.

The thresholds used in this algorithm are similar to those used in a study conducted by Barbara et. al. [5]. Here, 7 amplitude thresholds will be used: near right and left, far right and left, up, down, and blink. These values will be referred to as NR, NL, FR, FL, U, D and B. NR and NL will be detected in H', while U, D and B will come from V'. NR and NL thresholds will be used to detect the boxes highlighted in red in Fig. 1(b). Thresholds FR and FL will be used for the boxes in blue. The U threshold will be for the green box and the D threshold will be for the yellow box. The B threshold is not for specific boxes, as it will be used to confirm a choice target for classification.

Once the thresholds are determined, if a peak in *H'* or *V'* surpasses a corresponding threshold, this will cause a highlight or group/character selection to occur on the GUI.

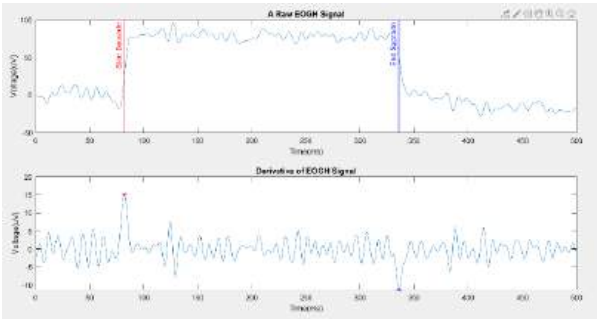

Fig. 2 *- The top plot shows an example of a left-directed saccade in a raw, horizontal EOG signal. The beginning of the saccade is marked by a red line, and the end by a blue line. The bottom plot shows the first-order derivative of the same signal. The start of the saccade is marked by a red star and the end marked by a blue star. The amplitude and position of the stars were found using the MATLAB findpeaks function [8].*

2.4 Threshold Determination

To find the values of NR, NL, FR, FL, U, D and B, training sessions will be done before the spelling sessions begin. During the training, experimental amplitude values will be collected for each of the 6 possible target positions and blink movements. These experimental data will be used to calculate the 7 thresholds for the classification algorithm.

3. Conclusion

The purpose of this project is to create an EOG-speller device that outperforms similar systems with respect to character selection speed and accuracy. We have designed a novel GUI menu system and classification algorithm that draws on optimal aspects of previous spellers, including character grouping and letter arrangement. With all elements combined, we expect high accuracy and fast character selection.

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Reduced-Gravity Simulator for Field Environments: Mobile Frame System

Team 13

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***Abstract* – The purpose of this design project is to create a mobile reduced gravity system to provide a more accurate and versatile training scenario for astronauts. A system of trusses, pulleys, and counterweights, similar to systems used in stage performances, is providing the reduced gravity functionality of this project. Mobility is achieved through the use of servo motors, drivers, gearboxes, and Mecanum omnidirectional wheels [1]. Through the use of wearable and inertial sensors made by XSens, astronauts' movements will be recorded as inputs to automate the movement of the mobile frame system [2]. A Jerk Vest Suit Harness that allows for multiple attachment points, as well as even weight distribution, will allow for realistic gravitational offloading [3]. The result of this project will provide NASA with an affordable and dynamic training system that can later be refined and improved for complex environments similar to that of Earth's moon or Mars. The deliverable for this project consists of a dynamic-scaled and stationary model that displays automated movement through the use of sensors and a reduced gravity effect, respectively.**

Keywords – Reduced Gravity System, Mobile Frame, Mecanum Omnidirectional Wheels, Wearable Motion Tracking Sensors, Inertial Sensors, Jerk Vest Harness, NASA

1. Introduction

Reduced Gravity Simulators provide astronauts, scientists, and engineers a way to replicate the gravitational environments in space that can be used for training, research, or testing equipment. Currently one of the best systems that provide this function is NASA's Active Response Gravity Offload System (ARGOS) [4]. This system is very similar to an overhead bridge crane. It uses an inline load cell to continuously offload the subject's weight and provides for a variety of dynamic movements that an astronaut may experience.

The objective of the mobile frame system design project is to build an automated mobile system using wearable and inertial sensors that can communicate with the Mecanum wheels-motor circuit to provide mobility all while utilizing a pulley system-jerk harness concept to successfully offset the bodyweight of the subject, to more accurately and inexpensively simulate Lunar, Martian, or microgravity environments.

2. Methods

2.1 Frame (Stationary)

The stationary design will consist of a 15'x15'x15' Mod-truss frame that serves as the support for the reduced gravity system. Within the frame, X-Y axis mobility will be achieved using a frictionless rail track system. The main pulley is attached to this track system which allows the subject to move within the bounds of the frame and provides for dynamic mobility.

2.2 Harness (Stationary)

The other component of the stationary design is the use of a Jerk Vest Harness that allows for gravitational reduction and dynamic mobility. The reason a Jerk Vest Harness was chosen is because of the force distribution and attachment point feasibility. Most harnesses utilize minimal straps which allow for simplicity, however for this design, the more body surface area that is supported, the better the disbursement of weight will be causing even lifting and comfortability.

***Figure 1** – Jerk Vest Harness with thigh attachments and leg stirrups*

The current design incorporates two attachment points on each hip as well as the incorporation of thigh cuffs and leg stirrups for further weight disbursement. It is important to use the hips as the two attachment points because this location is the closest to a person's center of gravity. As improvements and developments of the design occur, attachment points to the elbow and wrist

body, not just the torso. will be included to allow gravity reduction on the full

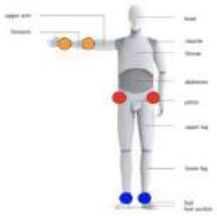

Figure 2 – *Attachment points on harness*

2.3 Mobility and Sensors (Dynamic)

Automated mobility is achieved by using a combination of real-time motion capturing sensors and electrically powered wheels. First, mobility itself is achieved using a servo motor system with attached Mecanum wheels.

Figure 3 *- Inertial MTi-7 GNSS/INS sensor (left) and MTw Awinda wearable sensor (right).*

The integration of an inertial navigation system and wearable sensors then allows for automated movement causing the system input to be the movement of the subject. The inertial sensor being utilized for this design is the MTi-7 from XSens. The MTi-7 is a self-contained global navigation satellite/inertial navigation system that uses advanced sensor fusion algorithms to synchronize the inputs from the module's onboard accelerometer, gyroscope, and magnetometer [5]. Three MTw Awinda wearable sensors will be placed on the subject using velcro straps. The sensors will be located in the thoracic, dorsal and head regions. The wearable sensors will track the subject's movement and initiate chassis mobility. The communication between the MTi-7 and MTw wearable sensors continuously monitor if the subject is located within the origin of the chassis and initiate movement, if necessary, to maintain the subject's position within the chassis.

The output voltages are read and recorded using XSens's MT Manager User Interface and then sent to a custom python program that can communicate with the motor circuit to then move the rig.

3. Expected Outcomes and Future Work

The Biomedical Engineering team is primarily focused on the mobility of the rig and harness design. Now that the harness has been assembled with all its attachments, fitted, and tested using a simple pulley system, it can begin to be altered for additional attachment points on the elbow and wrist. This will be achieved using fabrication techniques that turn the harness into a makeshift suit which will be achieved in conjunction with the dramatic arts team. This design allows for further weight disbursement and additional attachment points. The expectation is that along with the main body/torso, limbs can also experience reduced gravity using the counterweight pulley system.

The automated mobility of the design is achieved through the use of sensors as inputs directs the movement of the rig to keep the subject at the origin of the rig's bounds. The main focus of this team's efforts is to ensure that the sensors properly communicate with the motor circuit and the torque of the motors is adequate to move the weight of the dynamic-scaled system. Minimal alterations will be made if this functionality is achieved.

The current focus of this project is the fabrication of both dynamic and stationary systems which will then transition into testing and delivery.

4. Acknowledgments

We would like to thank our sponsors, NASA (www.nasa.gov) and Advanced Motion Controls (www.a-m-c.com) for providing us with the resources to complete this project. Prototyping, testing, realistic constraints, and overall design were aided by Dr. Patrick Kumavor, Dr. Jason Lee, Dr. Vito Moreno, Edward Weingart, and Chris Sancomb.

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Stress of Patients under Compression of Hologic Paddle Designs for 3Dimensions™ Mammography System

Team 14

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Abstract – Mammograms are procedures that are recommended for all females and various males to detect breast cancer and other tumors but are widely understood to be both mentally and physically taxing on patients. The project explores the physiological responses expressed by a patient during two different mammogram procedures to quantify the relative amount of stress and pain induced in each environment. Made by simultaneously measuring various biophysical signals, the model consists of indices derived from electrocardiogram (ECG), electromyography (EMG), galvanic skin response (GSR) and center of mass (COM) data sets, all of which have previously been shown to be relative and reliable metrics of stress, pain, and focus. In collecting these signals for four different paddle compressions, both for a traditional flat paddle design and a novel curved paddle designed to induce less pain, a snapshot of a subject's response is created. Analysis conducted on the resulting data will provide a list of indices from each respective signal allowing for a comprehensive comparison to be made between the two paddle designs as well as an overarching empirical-based conclusion on general mammography-related stress/pain.

Keywords – Mammography, Women's Health, Electrocardiogram, Electromyography, Galvanic Skin Response, Center of Mass

1. Introduction

Hologic's SmartCurve Breast Stabilization System improves comfort in 93% of patients who reported moderate to severe discomfort with standard compression. However, previous studies have only required women to self-report their personal experiences rather than capturing a quantitative characterization. Additionally, only 35% of women globally get mammograms as typically the anticipation of the pain associated with the procedure prevents many women from scheduling regular breast imaging appointments [1]. To help increase interest in and ultimately the use of mammograms, an intensive analysis of the current stand for breast imaging must be done to reduce such fear and anxiety associated with the process.

In this study, such an analysis is proposed using a typical mammogram machine as well as a novel design. In particular, the patient's comfort is analyzed when under examination by Hologic's SmartCurve System and their traditional flat paddle. To measure both the physiological and psychological response the human-machine interaction invokes, various biological signals are monitored. These include electrocardiogram (ECG), the measure of the electrical activity of the heart, electromyography (EMG), the measure of electrical activity in innervated muscles, galvanic skin response (GSR), the measure of skin conductance representative of sympathetic tone, and center of mass (COM), the quantitative representation of physiological models. All of these signals have each respectively been shown to be a metric of the amount of pain, stress, fatigue, and/or focus in various settings and collectively, can provide a comprehensive snapshot of subject response to the designed protocol [2]. In order to compile a comprehensive history relating the subject to their respective performance, a questionnaire is presented to the patient asking a variety of questions before and after the examination, dealing with their apprehension

Fig.1 – Hologic's 3Dimensions™ Mammography System with SmartCurve Paddle

towards the procedure, their history with mammograms, and details such as diet, and sleep before the exam. Using multimodal non-invasive measurement techniques, the patient's experience will be quantified to compare two different paddle designs.

2. Methods

The study was designed to analyze various aspects of the mammogram experience that are stressed or disrupted during the procedure. A total of 19 leads are placed across the subject on prepared skin to collect the EMG, ECG, GSR, and COM signals mentioned above.

For the EMG preparation, the Delsys Trigno system is utilized to collect data from 14 different muscles, those

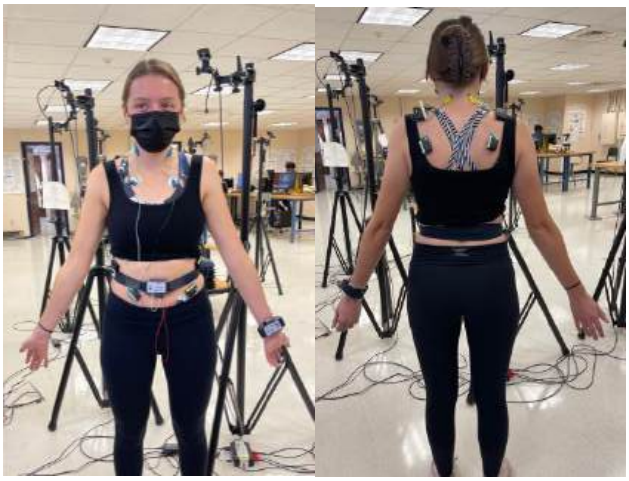

Fig.2 – Placement of EMG, GSR, and ECG on subject

including the sternocleidomastoid, trapezius upper fibers, deltoid, serratus anterior, teres minor, external oblique, and infraspinatus of both the left and right sides of the subject.

For the ECG and GSR preparations, the BIOPAC MP36R system is used. Two leads for the GSR unit are attached to the subject's fingers while three leads for the ECG unit are attached to the subject's chest and abdomen.

For the COM preparation, the AMTI Force Platform Accusway RS-232 is utilized, requiring no subject leads to measure the patient's center of pressure, moments, and velocities.

A questionnaire is administered before and after the procedure in order to acquire a self-reported measure of their experience.

Before any data collection, a questionnaire is administered to understand the subject's history, bias, and lifestyle. Their grip strength is also measured to provide insight into their natural strength. Then signal acquisition begins.

The subject undergoes two 3-minute baselines both in an initial as well as the mammography room to observe the effects of the environment and procedural anticipation. Once complete, the subject then undergoes four compressions, one flat and one angled for each breast, using a traditional flat paddle. Continuous EDA and ECG data are taken, marking the onsets of each compression while segmented windows of COM and EMG are taken centered around those same time points. Another control is taken while the machine is fitted with the SmartCurve paddle and the same procedure is repeated.

A second questionnaire is administered to gain insight into how the patient's experience was during the study and receive their comparison of the two paddle types.

Data analysis where signal indices used for comparison are derived is done using AMTI Netforce, EMGWorks Analysis, and BIOPAC Student Lab software, with additional processing being executed using a custom MATLAB code.

3. Current Results and Expected Outcomes

The preliminary data collected throughout trial experiments are encouraging as they show elevated mean muscle activity during compression and scanning along with reported stress and fatigue. An increase in COM tail values also has shown that subjects balance and equilibrium are greatly disrupted, complementing increases in skin conductance levels from GSR readings. Official data collection will begin in the Spring of 2022 which will be more revealing as accurate pressure will be used in the official experiments in comparison to the weak pressure applied for the trail runs during the fall semester.

4. Conclusion

The results of this study will serve to inform the Hologic Team as well as other interested researchers on which comfort and patient experiences are affected by mammography options and provide quantitative information beyond simple self-assessment.

5. Acknowledgments

This study was supported in part by Hologic®. Testing and methodology design were aided by Dr. Krystyna Gielo-Perczak. We would like to thank the University of Connecticut Department of Biomedical Engineering and Dr. Patrick Kumavor for providing the BIOPAC® System.

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Multi-System Approach in Evaluation of Leg Exo-Skeleton

Team 15

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Abstract -**The purpose of this design project is to develop an exoskeleton brace that facilitates the sit to stand process. This process involves creating new motion capture markers that promote organic motion, and designing the exoskeleton itself that does not limit any range of motion or degrees of freedom in the knee while also implementing the use of a microcontroller to assist the motion of the leg. This exoskeleton brace is then to be tested on patients to see if it does indeed reduce the workload of the knee joint. This should be done by testing the brace by going from sit to stand without assistance, sit to stand with constant velocity provided by a motorized seat, and sit to stand with constant acceleration also provided by a motorized seat, using no brace as a control. This test is to be performed combining motion capture software with musculoskeletal modeling software in order to develop a complete picture of the effects of this exoskeleton on the lower extremity. Ultimately, it is believed that using the process to test the exoskeleton will result in a device that is able to facilitate the sit to stand process.**

Keywords – Motion Capture, Biomechanics, Exoskeleton brace, Sit to stand, Musculoskeletal modeling

1. Introduction

Lower extremity exoskeleton braces can be used to improve the mobility of the joint. Many patients experience an injury that prevents them from using their muscles to create adequate motion in the joint. Therefore, often exoskeleton braces have an electrical component that assists the patient in moving their leg. When somebody undergoes an injury or has some condition that results in the loss of control or the reduction of performance of the leg muscles, the muscles begin to break down and become weaker. If the muscle becomes too weak, it can result in the inability to perform simple everyday tasks, such as sitting down and standing up. By using the assistance of a lower extremity exoskeleton, a patient can continue to work their muscles and prevent the deterioration of those muscles while also performing the sit-to-stand motion with much greater comfort and ease.

Some of the current issues that come with designing and producing lower extremity exoskeletons are the time that it takes to produce the exoskeleton, the cost of production, the adjustability of the exoskeleton, the balance between structural support as well as flexibility, along with the range of motion that the exoskeleton allows. The objective of this design project is to use motion capture software, SolidWorks, and ANSYS software to design and produce a lower extremity exoskeleton that optimizes all of these constraints and provides the best assistance possible during the sit-to-stand motion..

2. Methods

The design of the leg exoskeleton incorporates 3 different pieces for the upper thigh: the left upper thigh piece, right upper thigh piece, and a metal strip used to connect the two. Separating the exoskeleton into multiple parts allows greater adjustability as the exoskeleton can fit and contour properly to the patient's thighs. The upper thigh pieces connect to the lower thigh pieces via the knee connector depicted in the prototype below. The knee connector piece can click into the slot

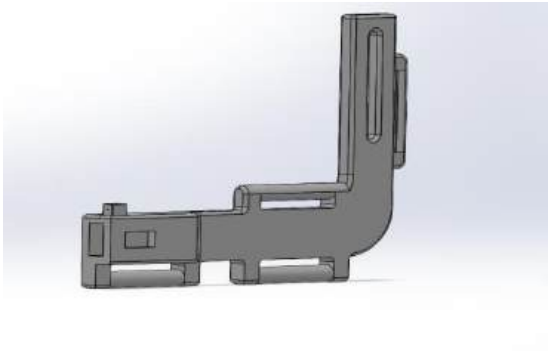

Figure 1 *– SolidWorks prototype of Leg-Exoskeleton*

and allow the lower leg portion to remain attached to the upper extremity and allow for full range of motion of the patient's leg. The leg-exoskeleton is used in conjunction with 8 3D printed motion capture markers that the team designed. The markers are necessary for the software to initialize each portion of the subject's body as a rigid body. EMG sensors are then placed on the various muscles of the patient to record muscle activity while the patient completes multiple sit-to-stand trials with and without the leg-exoskeleton

***Figure 2** – Motion Capture markers and EMG sensor setup on test patient*

3.Simulations/Expected Outcomes

Simulation of the exoskeleton was performed using ANSYS, which is an engineering simulation and 3D modeling software that allows users to apply forces to static and dynamic systems to test for breaking points. As stated previously, the exoskeleton is designed to work in conjunction with the knee without inhibiting it's multitude of degrees of freedom. In order to properly simulate this, multiple bending and rotation forces need to be applied and run through the meeting point of the lower leg exoskeleton and upper leg exoskeleton. The goal of the simulations is to prove the expected outcome, which is that the exoskeleton provides the necessary stability to the knee to develop EMG measurements but is not inhibitory to the point that it creates a great error in these measurements.

4. Future Work

By April of 2022, a working exoskeleton brace prototype will be produced and used in clinical testing of the sit to stand motion. The frame of this exoskeleton brace will be 3D printed and then attached to the controller, and the jointing mechanism (attaching the upper exoskeleton to the lower). Patients will be tested with and without the exoskeleton going from sit to stand on their own and in an assisted manner (applying constant velocity, and then constant acceleration from a motorized seat). Then using the motion capturing software (OptiTrack) and the program AnyBody, this brace's ability to reduce the forces and moments acting on the knee joint will be tested. Ultimately, it is believed that with using motion capture and the AnyBody software to test the exoskeleton, we will have a device that is able to facilitate the sit to stand process.

5. Acknowledgments

We would like to thank our faculty advisors Dr. Krystyna Gielo-Perczak and Professor Alexandros Mathioudakis for helping us design, create, and test our 3D printed motion capture markers and leg-exoskeleton prototype.

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Inverse Dynamics Analysis of a Lower Extremity Sit-to Stand Exoskeleton

Team 16

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***Abstract* – The purpose of this design project is to use the state-of-the-art software, AnyBody Technology, to analyze the mechanical effects of the use of an exoskeleton in sit-to-stand motion. In comparison to other motion capture analysis tools, AnyBody Technology software provides features such as: custom calibration, musculoskeletal analysis, force/moment-dependent kinematics, motion prediction, and visual simulation that allow us to both quantitatively and qualitatively determine how the exoskeleton influences natural motion. [1]. Motion capture data collected from a variety of subjects performing the sit-to-stand motion both with and without the exoskeleton is first configured for simulation accuracy. Complex data analysis then outputs time-dependent force and moment values corresponding to specific locations of the body. The result of this project will provide valuable feedback to biomechanical engineers on the effectiveness of exoskeleton designs, as well as subject-specific treatment information.**

Keywords – Exoskeleton, Biomechanics, Musculoskeletal, Kinematics, Human body models

1. Introduction

An exoskeleton is defined as an anthropomorphic mechanical device that surrounds a user's body and works in coordination with natural movement [2]. Exoskeletons are generally used to assist soldiers, workers, trauma patients, paraplegics, individuals with spinal cord injuries, elderly people, and for rehabilitation purposes. The potential of this technology is rapidly evolving and is even being used for healthy individuals who would gain physical assistance in carrying out certain tasks [2].

Although the effectiveness of the lower-extremity exoskeleton can be studied by surveying the user's experience directly, the benefits of the device can only be quantified using higher-level processing. The objective of this design project is to apply AnyBody software to our design system to numerically, visually, and graphically output data regarding the physical advantage of the exoskeleton in terms of variable force, moments, energy, and strain associated with every motion.

2. Methods

Our method in conducting an inverse dynamics analysis of an exoskeleton in sit-to-stand motion consists of multiple procedures: data collection, data configuration, and data analysis.

Data collection is performed by having a subject wear reflective markers on their body in specific regions that are associated with labeled markers in the AnyBody software code. Photos are taken of the subject from multiple viewpoints for manual calibration purposes. Motion capture videos are recorded, detecting the location of the markers in real-time for trials with and without the exoskeleton.

Figure 1 *– Subject preparation for motion capture data collection.*

In order to successfully analyze the recorded motions using AnyBody, the parameters of the actual situation must match those written into the software code. For instance, the height, weight, and limb lengths of the individual performing the sit-to-stand motion must be altered in AnyBody's code. The markers are defined at a specific location in the Anybody code. The markers on the subject are manually adjusted by comparing the markers in the code and the limb lengths of the subject. A three-dimensional motion software, Mokka, is used to create a simulated motion that is implemented into

Anybody. After the parameters are entered into the software, the code will run without error.

After acquiring the data for the forces of the lower body joints for each of the 6 trials, we configure the data by percent body weight. The equation for this normalization is presented below, where x, y, and z represent the forces in the x, y, and z directions at a given time interval, m represents the participants mass (in kilograms) and g represents the acceleration due to gravity ($9.8\,m/s^2$). This data is multiplied by 100 to obtain a percent value.

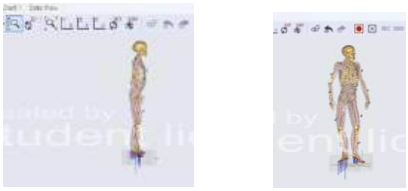

***Figure 2** – Anybody model window displaying final position in which two markers (red and blue) are matched up.*

$$Normalization\ Eqn. = \frac{\sqrt{x^2 + y^2 + z^2}}{mg} \times 100$$

After the data is normalized we will be able to directly observe the impact of the exoskeleton and sit-to-stand platform on the magnitude of the forces experienced at the ankle, hip, and knee.

3. Simulations/Expected Outcomes

A complete run of the simulation outputs a large mass of data organized by side of the body, body segment, measurement type, etc. For the purposes of our study, we focus on force measurements over time in the hip, knee, and ankle joints. The data is configured using the previously mentioned normalization method. This allows us to observe the impact of the exoskeleton on the magnitude of the forces at the lower body joints during sit to stand motion. For instance, we would assume that an effective exoskeleton would result in smaller magnitudes of force and moment. In turn, we can suggest changes to the design of the exoskeleton, for example, adding more support to a certain joint to lower expended force. Examining differences between simultaneous motion of the left and right sides of the body can give us insight into the symmetry (or lack of symmetry) of the subject's movement, allowing us to investigate specific events involved in sit-to-stand motion. Integrating all our analyses of various sets of data will provide a holistic analysis of the human-exoskeleton interaction in sit-to-stand motion.

After data normalization, we see some key differences in the AnyBody simulation results regarding the impact of the sit to stand assistance platform on the magnitude of the force experienced by lower body joints. Figure 5 demonstrates the force percent of body weight at the ankle joint without the use of the exoskeleton or sit to stand assistance platform (control), while the ankle force data for Figure 6 was recorded using the constant acceleration sit to stand assistance platform.

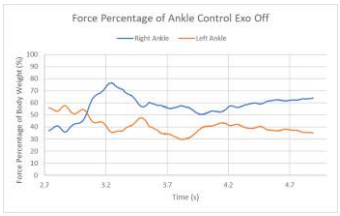

Figure 5 - Normalized force percent of body weight at the ankle (control exoskeleton off)

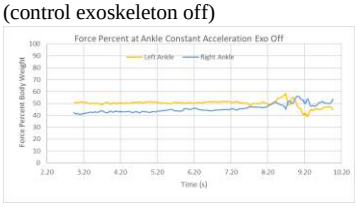

Figure 6 - Normalized force percent of body weight at the ankle (constant acceleration exoskeleton off)

This analysis allows us to directly compare the change in the magnitude of the force at a given joint as a result of experimental changes. This particular comparison demonstrates that the constant acceleration sit to stand platform decreases the magnitude of the forces experienced at the ankle. Although this conclusion is relatively obvious, our normalization method will be beneficial during the analysis of future trials.

4. Future Work

By mid-April 2022, we will implement a force platform and a chair into AnyBody to account for the reaction forces and have a more accurate measurement. We will also attempt to incorporate the exoskeleton into AnyBody onto the model. This will allow us to have the data from the motion capture with the exoskeleton on the subject represented in the simulation.

5. Acknowledgments

We would like to thank our sponsor, the University of Connecticut Biomedical Engineering Department for providing us with the resources to complete the project. Project activities are aided by Dr. Krystyna Gielo-Perczak and Alexandros Mathioudakis. In addition, this project is in collaboration with Senior Design group 15.

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Esophageal Testing Model for Orvil Deployment

Team 17

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***Abstract* – The purpose of this design project is to create an anatomically accurate three-dimensional model of the oropharynx, larynx, and upper gastrointestinal regions of the human body in order to test Medtronic's Tri-Staple Orvil device. In order to create a useable physical model, a simplified CAD model is designed to determine the relevant anatomy with the correct dimensions of a 50th percentile female so that the model represents the constraints of a majority of the adult United States population. Imitation esophageal tissue from LifeLikeBio will be used due to its similar mechanical properties to real human esophageal tissue. Uniaxial, biaxial, and inflation testing will be performed on sample LifeLikeBio tissue and compared to results from tests done on porcine tissue samples to validate the properties of the tissue used for the model. The LifeLikeBio tissue will be attached to the 3D printed CAD model creating a life like mucosa for the esophageal model. Both aspects of the three-dimensional model will create an anatomically and biomechanically accurate human model. The results of this project will allow Medtronic to begin testing their stapling device on a model that is as close to humans as possible, providing valuable insight on the device's effects on human anatomy for the rollout of their surgical device, while also aiding in the testing of newer and better technologies for future projects.**

Keywords – CAD Model, Biomechanics, Tissue testing, Esophagus, Oropharynx, Orvil, LifeLikeBio

1. Introduction

Medtronic's state of the art Tri-Staple Orvil device is an essential tool for surgeons to use during various procedures. Currently there is no human model for this device to be tested on by designers as well as surgeons practicing. This limitation greatly affects feedback given by the potential users of the device. As the goal of this design project is to create a model for testing of the product, the creation of it will provide valuable information for future iterations.

The model being produced by the team is a combination of both a CAD model along with tissue samples. The CAD model which is a group of three different sections that are 3D printed and assembled will provide a life-like and accurate human model shell. Tissue samples will then be attached inside the model in order to create a life like esophagus to show engineers and surgeons practicing how the Orvil device will operate. Different tissue samples will be testing by using tensile and inflation testing methods. The data from the testing will be cross-referenced with known measurements and data of esophageal tissue in order to find the best possible alternative to an actual esophagus.

2. Methods

The design consists of an model representing the oropharynx, larynx and other upper gastrointestinal elements, along with the epiglottis, and esophagus and trachea. The opening of the model will be encapsulated in a jaw thrust mechanism, allowing the user to modify the jaw opening and model different positions of the patient on the operating table. All dimensions of this model will be researched to be as anatomically accurate as possible, for a 50th percentile female individual of the US population.

Table 1 *– Selected Esophageal Model Dimensions*

Section	Units
Esophagus Inner Diameter (avg)	25.00 mm
Esophagus Outer Diameter (avg)	29.34 mm
Esophagus Wall Thickness (avg for females)	4.34 mm
Trachea Wall Thickness (avg)	1-3 mm
Trachea Length (avg)	100-120 mm
Trachea Coronal Diameter (avg females)	10-21 mm
Tracheal Sagittal Diameter (avg females)	10-23 mm
Tracheal Ring Height	4 mm
Larynx Length (avg)	40-50 mm
Larynx Diameter (avg)	40-50 mm (slightly shorter anterior-posterior)
Epiglottis Length (avg)	7-9 mm
Epiglottis Thickness (avg female)	2.34 +/- 0.13 mm
Tracheal Angle	70 +/- 20 degrees

The model will be enhanced with the selection and application of synthetic materials that simulate human biomaterials. Porcine materials will be used to conduct

appropriate mechanical testing to gather data, but final materials will be gathered from LifeLike BioTissue [1] a Canadian based company specializing in synthetic biomaterials for medical device testing. These materials will be attached to the model to further increase realism and application for the users and will have the ability to be replaced when worn out, in a modular capacity.

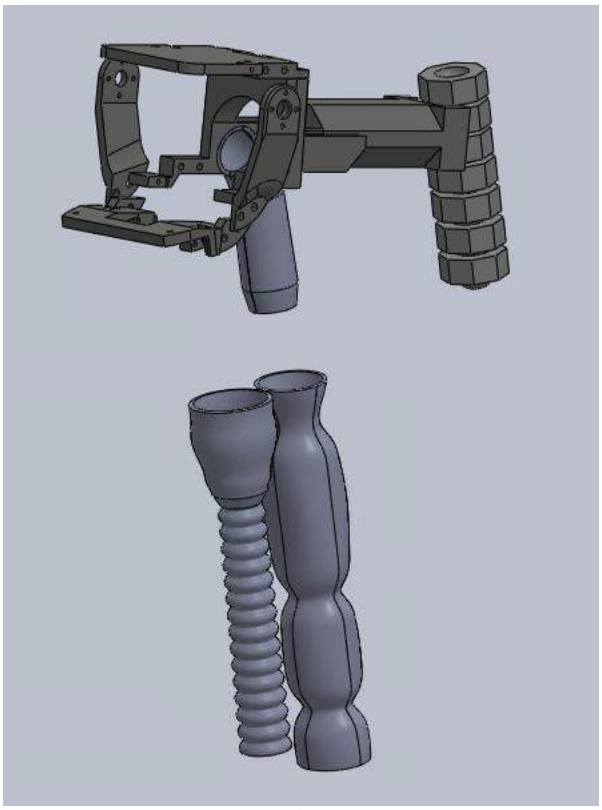

Figure 1 *– Current CAD Model of Testing Device*

3. Simulations/Expected Outcomes

By the spring semester of 2022, the goal of this project is to have an esophageal model that is made up of two components: a physical, 3D printed template and a coating of tissue very comparable to that of the inside of the human esophagus. Having this elaborate and accurate diagram of the inside of the human esophagus and other associated features will allow for the deployment of the Orvil device with as much respect to a human patient as possible. There will be multiple testing methods used to evaluate the effectiveness and accuracy of our model. These include uniaxial and biaxial tensile tests along with inflation testing. Using a variety of testing methods will allow for the user to account for any discrepancies in the LifeLike Bio tissue being used and will determine if any areas of the model need to be adjusted in any way. The LifeLike Bio tissue, as mentioned before, is very similar to human tissue. Thus, the way the LifeLike Bio tissue reacts to the deployment of the Orvil device should be very similar to how a human patient's tissue would react. Because of the close similarities of these tissue types, it is expected that if the angles and dimensions of the 3D model are appropriate and the LifeLike Bio tissue is not damaged when the Orvil device is passed through, the Orvil device will perform safely and successfully on a human patient.

4. Future Work

The Esophageal Model prototype is planned to be created in the spring semester of 2022. The future iterations of model will include additional features of the oropharynx that may affect inserting the Orvil device such as the tongue, uvula, and epiglottis. These would be added to the cad model and potentially extra LifeLike Bio tissue to simulate the properties. The neck and face muscles will be examined using a Delsys EMG system and analyzed with EMGworks Analysis. The muscle activity during rest and swallowing will be measured and the model will be adjusted or added to based on the results such as adding simulated muscle tissue to the model or changing the material properties of the existing tissue.

5. Acknowledgments

We would like to thank our sponsor, Medtronic, for providing us with the resources to complete this project. Special thanks to Haley Strassner (Senior Biomedical Engineer), Drew Seils (Human Factors Engineer), Amy Kung (Development Engineer) and Alex Caulk (Tissue Mechanics) for providing resources, dimensions, data and support. Mentoring support provided by Dr. Krystyna Gielo-Perczak and Dr. Patrick Kumavor.

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Design & Fabrication of Soft Hydrogels to Mimic Brain Matter to Model Traumatic Brain Injuries

Team 18

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***Abstract* – The purpose of this project is to design and fabricate a hydrogel that mimics the mechanical properties of brain matter. This will provide an accurate *in vitro* brain model to study traumatic brain injuries. The design being considered is a natural and biocompatible gelatin-alginate based hydrogel. In this study, the concentrations of both gelatin and alginate are varied to fabricate a hydrogel that mimics the linear and non-linear viscoelastic properties of the brain matter as studied in the literature. Rheology testing will validate the mechanical properties of these hydrogels to that of the brain matter. Thus, this design will provide an accurate three dimensional (3D) *in vitro* brain tissue model that can be utilized by future researchers to study the cellular response of the brain when subjected to forces comparable to the ones that cause traumatic brain injuries.**

Keywords – Hydrogel, Gelatin, Alginate, Traumatic brain injury (TBI), Mechanical Properties, Mechanical testing, Rheology, Scanning Electron Microscopy (SEM)

1. Introduction

Traumatic brain injuries (TBIs) are "one of the leading causes of morbidity, disability and mortality across all ages with more than 50 million individuals suffering from TBIs each year" [1]. These statistics present a huge clinical problem and display a gap in understanding TBIs between the engineering and medical fields. TBIs may affect any individual, irrespective of age, occupation, or any other categorical factor and there is little understanding how the brain tissue is altered after enduring a TBI. Analyzing the neural cellular response to the blunt forces endured during TBIs is crucial to developing proper imaging techniques and clinical treatments. Although literature shows many *in vivo* TBI models, there are very few *in vitro* studies to understand the propagation and types of forces endured during TBIs and how such impacts may result in various cellular responses [2]. Developing an accurate *in vitro* TBI model through the production of cell-encapsulated hydrogels is crucial to further understand how cells respond to mechanical loading at the interfaces of the material.

Recently, hydrogels have shown promise to mimic different extracellular matrices. Hydrogels are biocompatible, have a high-water content, and are easily fabricated. The mechanical properties of hydrogels can be easily altered to match the tissue of interest [5]. Therefore, hydrogels are an excellent candidate to imitate brain matter because of their structural similarity to the extracellular matrix of the brain. They "can assist structural and functional restoration of damaged tissues by providing mechanical support and navigating cell fate", making them a prime material for creating a hydrogel that will be used to study TBIs [3]. Therefore, this project aims to design a hydrogel that accurately replicates the mechanical properties of brain matter under conditions consistent with cell culturing to provide an *in vitro* brain model to use to study TBIs.

2. Methods

During the fabrication process, the concentrations of alginate and gelatin will be altered in order to determine which ratio yields a hydrogel that most closely mimics the *in vivo* mechanical properties of brain matter. The amounts of gelatin, alginate, and PBS that are to be used for each of the four iterations of the design are provided in Table 1. Figure 1 displays the fabrication process. Once the specific amounts of sodium alginate and porcine gelatin (Type A, 300 bloom) are properly measured, they are separately dissolved in PBS. After the solvents and PBS resemble a homogenous solution, the separate alginate and gelatin solutions are combined in equal ratios. 300 µL of the combined solution is pipetted into the divets in the top of the well plate (n=6).

Table 1 *- Test Matrix for Gelatin-Alginate Hydrogel Fabrication*

ALG/ GEL (w/v%)	Alginate Amount (g)	Gelatin Amount (g)	Total PBS Amount (mL)
0.5/0.5	0.05	0.05	9.90
1.0/1.0	0.10	0.10	9.80
0.5/1.0	0.05	0.10	9.85
1.0/0.5	0.10	0.05	9.85

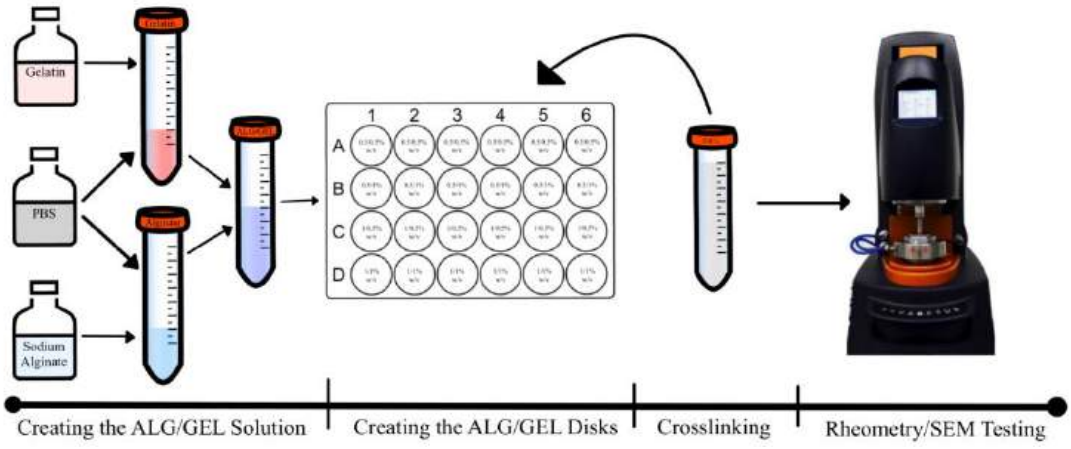

Figure 1 *- Schematic of Fabrication and Testing Methods [3]*

Separately, 0.16647g of $CaCl_2$ is mixed with 15mL of dH_2O to create a 0.1M calcium chloride solution which serves as the solution to physically crosslink the alginate. A 10% transglutaminase solution is used as a second crosslinker to chemically crosslink the gelatin. The $CaCl_2$ crosslinking solution is sprayed onto the gels and allowed to sit for 1 hr at 25ºC. The gels are then lifted and placed in petri dishes where they sit for 24 hrs in the TG solution at 37ºC [4].

After the samples are incubated for 24h at 37ºC in PBS, accounting for the mechanical conditions of the samples similar to 24 h after incubation during *in vitro* cell culture, they will be subjected to mechanical testing. [4]. Both rheology testing and SEM will be used to analyze the different alginate-gelatin hydrogels.

*3. Simulations/Expected Outcome*s

It is expected that by varying the concentration of the alginate and gelatin solutions, the resulting 3D alginate/gelatin hydrogel will be tuned to match the mechanical properties of brain matter. The rheology testing will provide details about the viscosity, storage/loss modulus, and other critical features that aid in the hydrogel's ability to mimic brain matter. The SEM imaging will be used to determine porosity of the hydrogel samples. It is expected that the storage modulus will be approximately between 2.7 kPa and 3.2 kPa [5]. The loss modulus will be approximately 2.5 kPa [5]. The elastic modulus will be 70 +/- 44 MPa and the maximum strain will be 11 +/- 3% [6]. The hydrogel samples must be porous to allow for future studies focusing on cell encapsulation/ migration.

4. Future Work

With an initial prototype hydrogel that would accurately imitate the mechanical properties of the brain, a following step would be to incorporate cell encapsulation. Encapsulation of neurons in these optimal hydrogel systems would assist in an accurate *in vitro* TBI model. Then, deformation and force experiments could be applied to mimic TBIs and study the effects of loading and hydrogel deformation on brain cells. Understanding the cellular response of neurons within the brain to such forces or impacts during TBIs in the *in vitro* system will further aid in the design and development of better treatment and imaging modalities of TBIs.

5. Acknowledgements

We would like to thank our sponsor and BME advisor, Dr. Assanah, for providing us with the resources to complete the project. Testing, realistic constraints, and hydrogel design were also aided by Dr. Assanah. UCONN Facilities provided the technology for rheology testing and SEM imaging. Special thanks to Joshua Beres for assistance in the lab.

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Defibtech Mechanical Human Thorax Model for Automatic and CPR Device Testing

Team 19

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Abstract – **The purpose of this design is to create a mechanical thorax model used during CPR training and automated device testing that accurately reflects a human chest's mechanical behavior. Current devices lack proper representation of the human thorax and do not reflect how a chest compresses and recoils during CPR. As sudden cardiac arrest is the leading cause of death in the United States, we seek to engineer a design that promotes proper training for and simulation of CPR [1]. The design strategy was to use a previous group's design to build upon to our standards. The device was structurally re-engineered to increase the stability and improve measurement precision and accuracy. The force plate and ultrasonic sensor were also implemented and tested to ensure proper functioning of the sensors. These data are then fed into the stepper motor, which adjusts recoil resistance accordingly to model a human thorax. Stemming from the original design plan and considering alternative designs, our final design was generated using SOLIDWORKS the encompasses design functions and our desirable means and specifications. The result of this project yields a more accurate CPR device or tool used in automated device testing that promotes optimal chest compressions and increases the chances of sudden cardiac arrest resuscitation and patient outcome.**

Keywords – Human Thorax, Biomechanics, Cardiopulmonary Resuscitation, Compression, Recoil, Live Feedback, Dampening

1. Introduction

Cardiopulmonary resuscitation (CPR) devices provide healthcare workers and lay people with training and simulation scenarios that may be applied to the real world. While CPR is a fairly recent medical development and protocols are still changing due to research and patient outcome studies, training devices have not had the same upward progression. While devices accurately portray a typical human thorax physical appearance and dimensions, they do not portray proper chest behavior [2]. This results in CPR certified providers (or even automated devices such as the LUCAS) administering compressions too deep, shallow, or fast, not allowing full chest recoil. This is problematic because inadequate recoil does not allow the atrium and ventricles to refill with blood, therefore providing ineffective compressions. This can be assessed in the real-world by analyzing a patient's end-tidal carbon dioxide, or EtCO2. Devices provide real-time feedback on compression rate and depth, but not recoil nor force. They also assume that chest behavior is linear, which is incorrect [3].

Therefore, not only is there a structural flaw in current devices and their lack of human thorax mechanical behavior, but the feedback system is also insufficient. By implementing a force plate, ultrasonic sensor, and dynamic stepper motor, chest recoil and force can also be calculated in addition to compression rate and depth. Arduino coding and additional software are used to interpret and display the data. The objective of this project is to not only design and develop a device that accurately portrays chest behavior, but also use LabView software to provide real-time feedback so the user can correct their compressions to increase a sudden cardiac arrest patient's chance of survival in the field.

While this device does not include the mannequin itself and focuses on human biomechanics, it can easily be implemented into a mannequin or used as a stand-alone training device.

2. Methods

The design consists of an external structure that is lightweight, but mechanically strong and able to withstand long durations of a vertically applied force. An ultrasonic sensor and force plate are mounted to the exterior and top plate of the structure, respectively. It's essential the devices are tightly mounted to reduce error. The stepper motor is then mounted internally within the structure itself and attached to the top plate of the device.

A SparkFun electronics RedBoard and Arduino breadboard/software are used to continuously monitor data and extend that to the LabView program.

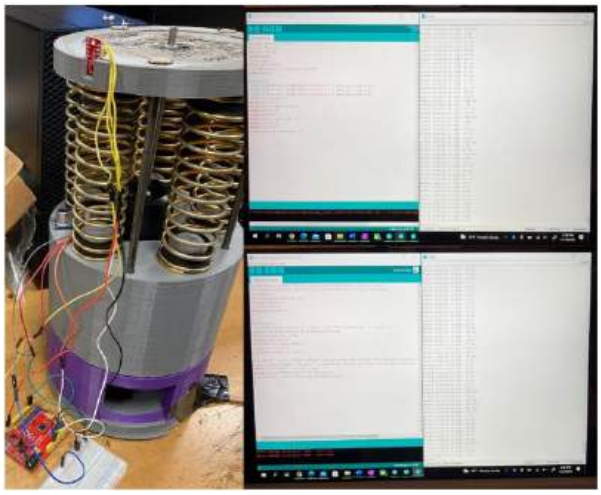

Figure 1 *– A previous year's design improved to meet our group's functions and specifications. Displayed is live feedback from the accelerometer and ultrasonic sensor.*

Below is the SOLIDWORKS representation of our planned design. This design improves upon the simplicity, stability, fatigue resistance, and accuracy of the mechanical thorax model.

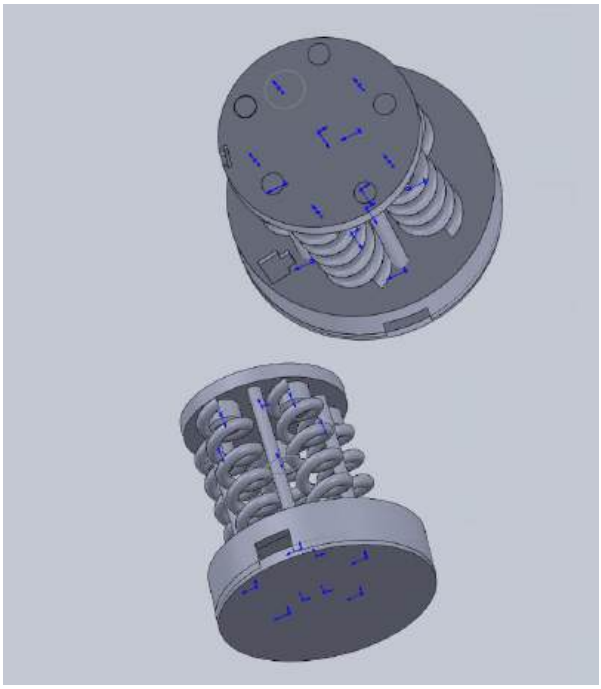

Figure 2 – *SOLIDWORKS representation of planned design.*

3. Simulations/Expected Outcomes

Possibly the most significant component of our design is the stepper motor. The motor creates a dampening effect providing improved accuracy of human thoracic behavior. This device also creates the realistic non-linear relationship during chest compression and recoil, something current models lack [3]. While our design proved to be structurally sound under a vertical force during simulations, it is extremely difficult the test the stepper motor and it's dampening effect on SOLIDWORKS. This is because the stepper motor pulls live data from the force plate and ultrasonic sensor to adjust the dampening affect accordingly. Our team plans to adjust the Arduino code accordingly to achieve the desired values for accepted chest behavior.

4. Future Work

By April of 2022 the latest, our design prototype will be complete, along with several testing procedures to ensure the accuracy, stability, and durability of the device. Our team has the optimal mechanical thorax model designed and components tested, our next focus is the actual development. Our team has decided to use 3D-printed PLA or ABS plastic as the material due to its low cost, high durability, and lightweight properties. Additionally, the LabView program is in development to provide the data in a more simplistic and interpretable fashion. Our team has limited our spending in the early months to ensure the budget permits the goals of our design. Once completed, this device will be accurate, reliable, and provide possible insight into future development of CPR testing and training.

5. Acknowledgments

We would like to thank our sponsor, Defibtech for providing us with the design problem and financial support to complete the project. Additionally, we are appreciative of Dr. Kumavor's insight and resources within his lab to conduct design creation, implementation, and testing. Lastly, we acknowledge Ph.D. candidates Fatemah Delavari and Mahdi Pirayesh Shirazi Nejad for their technical assistance and professional feedback throughout our design process.

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Automatic Shear Device for Biopharmaceutical Process Development

Team 20

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***Abstract* - The purpose of this design is to accurately apply the desired shear rate to a biopharmaceutical to model the purification process during manufacturing. To do this, a peristaltic pump is connected in series with a bubble trap and microfluidic device. The microfluidic device can apply shear rate as a function of the flow rate determined by the pump and adjoined interface [1]. The resulting substance is then collected and evaluated for particulate formation. The results of this project provide information to biopharmaceutical manufacturers on the effective shear rate during purification has on the particulate form of the product.**

Keywords - Biopharmaceutical, Microfluidic, Shear rate, Particulate

1. Introduction

The particulate formation is very detrimental to the development of biopharmaceuticals and can result in an unaccounted immune response [1]. One culprit for particulate formation is the shear rate indirectly applied during the purification processes i.e. bioreactors. However, there are currently no laboratory-employed, turn-key systems for modeling a specific shear rate for the desired duration on a biopharmaceutical to examine particulate formation.

Current researched shear rate models have limitations that need to be overcome. The first is they are not user-friendly, and in turn, need to be operated by a specialist. Secondly, current models do not have a uniform shear rate distribution, resulting in a poor model.

2. Methods

The design consists of a peristaltic pump connected to the inlet of the sample. This pump has an adjustable flow rate to control the applied shear rate. This then pumps the substance through a bubble trap to get rid of any air pockets. This is necessary because air pockets will add variability and in turn create a less accurate model. This is then run through a custom-made microfluidic device, with a cylindrical channel with known dimensions. Through equation modeling, we can use these known dimensions to make the shear rate only a function of the flow rate in which the substance is passed through.

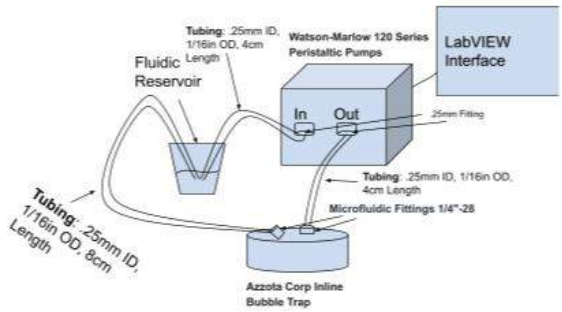

Figure 1 - Design of the model (not to scale)

The substance coming from the other side of the microfluidic device is then cycled into the original substance. This tube is under a constant vortex, creating a homogenous solution. This homogenous solution is then passed again through the solution for the total duration.

Shear rate and duration are controlled through a custom-made LabVIEW program. In this program, the user can enter the desired shear rate and duration, and the program will adjust the flow rate of the pump and turn off the pump accordingly. Additionally, the program instructs the user to remove the inlet tube so the solution may fully exit the system.

3. Expected Outcomes

The dimensions and shape of the microfluidic channel are critical when designing this device as this channel is applying the fluidic shear rate to the sample. A cylindrically shaped channel with a diameter of 276.5µm and a length of 10cm was chosen to produce the desired maximum simulation shear rate of 100,000s^{-1}. The cylindrical shape of the channel was chosen to maximize the uniformity of the shear rate throughout the sample. The repetitive cycle of the fluid through the vortex bed and back through the device allows for the user to customize the duration of the shear rate. The shear rate can be modified by increasing the flow rate through the microfluidic channel, which, along with the duration of shear stress applied, will be controlled through a LabVIEW controller. The temperature of the device can be controlled through the warming or cooling of the device, as the device can be cooled by a freezer or heated by a hotplate if the simulation needs to take place at a specific temperature. This allows for a greater range of biopharmaceutical production and purification processes to be modeled by this microfluidic device.

4. Future Work

By the spring of 2022, a working prototype of this device will be developed and tested to ensure proper function. The LabVIEW program will be created and implemented into the design by the team members, and it will allow for the tunable duration and shear rate applied from the device. Since there isn't a reliable method to experimentally test shear rate, the team will have to rely on equational modeling present in the current literature. The LabVIEW program will allow for a simple and user-friendly interface. The samples run through this prototype can be studied via microscopy to observe particle formation on the surface of the biopharmaceutical.

5. Acknowledgements

We would like to thank our sponsor Boehringer Ingelheim (https://www.boehringer-ingelheim.com), and Dr. Patrick Kumavor and Dr. Krystyna Gielo-Perczak for guiding us in the creation of this project.

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Utilizing 3D Motion-Capture to Optimize Prosthesis for K3 and K4 Amputees

Team 21

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***Abstract* - The purpose of this design project is to fabricate a part that can be attached to a K4 prosthesis to convert its functionality to that of a K3 prosthesis. Essentially, an individual would be able to add or remove this part to allow the switch between running, walking, or hiking modalities. The main functions associated with the design are in relation to the ease of use and overall accessibility to switch between K3 and K4 modalities. Additionally, the device design aims to assist in weight shifts and balance of the user, while providing the full range of motion in the joints. It also aims to normalize step cadence and return of power across the modalities. Analysis of relevant data will focus on rollover shape testing, comparing center of pressure for the prosthesis in both K3 and K4 modes to a non-amputee individual. The result of this project provides beneficial information to prostheses manufacturers and production teams by introducing an alternative hybrid device design.**

Keywords - Prostheses, Biomechanics, Force Platform, Treadmill, Motion Capture, SIMI

1. Introduction

Approximately 185,000 amputations occur every year in the United States and it is predicted that over 3.6 million people will be affected by limb loss by the year 2050 [1]. Utilizing a prosthesis often helps to tackle both the issue of limited mobility due to limb loss and the side effects that come along with the limb loss process. The biomechanics of running, walking and hiking have been thoroughly researched and analyzed for performance in amputee individuals. However, many prostheses are unable to incorporate a design aspect dedicated to all three modalities. There is much room for improvement and a need to create prostheses and attachments that allow for individuals to manually modify their respective prosthesis in order to achieve the different mobile tasks. In collaboration with UConn Institute for Sports Medicine, we were able to utilize SIMI Reality Motion Systems as the method of motion capture to help with the design of a prosthesis that addresses all the mentioned modalities. This data allowed us to explore the biomechanical and design properties needed for modifying an existing prosthetic device to achieve different mobile tasks through the form of an additive component.

2. Methods

The design consists of a standard K4 running blade which was procured under the stipulation that it remained undamaged. Lightweight carbon fiber was chosen as the material for the K4 running blade due to its favorable strength, stiffness, and lightweight characteristics and this decision was backed by current devices on the market. Carbon fiber would be used in production for the K3 attachment, but aluminum will be used in prototyping, as it has a similar elastic modulus at a much cheaper cost. The two pieces are attached with a bolt and latch system that is low profile for minimal protrusion in both the K3 and K4 modes and does not damage the blade, as required by the blade donors.

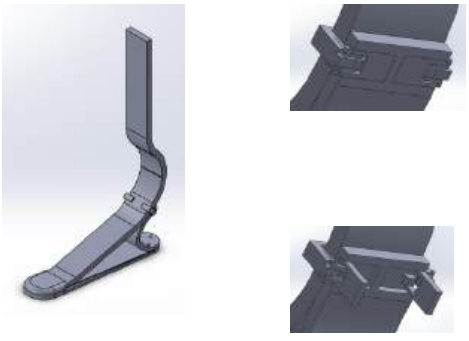

Figure 1 *- Solidworks prototype of a hybrid K3/K4 prosthetic leg.*

3. Simulations / Expected Outcomes

The two most critical parts of the design are the curve of the blade and the connections between the K3 and K4 components. As mentioned earlier, carbon fiber was chosen as the material for these two components due to its favorable characteristics. While the rest of the design was made from carbon fiber, the latch bolts were chosen to be stainless steel. This decision was due to the durability of stainless steel through the constant wear which will occur during the changing of modes. A very basic static structural, isotropically elastic simulation was done in Ansys with the Solidworks model to test the viability of the material choice and design during loading. A force of 6500 lbf was applied downwards on the top face of the blade. This force was chosen based on research which found that a force of about 10 times the body weight was applied during running, the average body weight of the USA is about 800 N, and a factor of safety of 3.0 [3]. The sole of the K3 foot was fixed as a boundary condition.

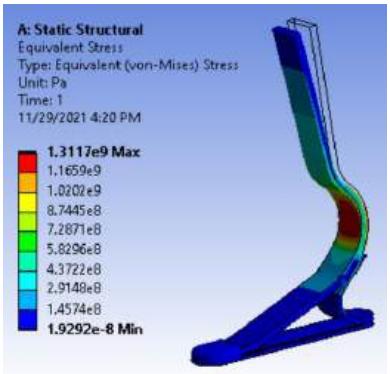

Figure 2 *- Ansys simulations showing the equivalent stress on the prosthetic leg during loading.*

The maximum stresses on the blade were found through the simulation to be 1311.7 MPa and were compared to the strength of the carbon fiber and stainless steel parts, which were 3900 MPa and 3100 MPa, respectively. This data indicates that the latching system and heel design will comfortably carry the required load and gives a basis for which physical tests in the lab can be compared to.

4. Future Work

The exploration of this design would be enhanced by more advanced simulations being run to analyze the system under torsion and compression, which would be closer to real life conditions. Further device testing will be completed at the UConn Institute for Sports Medicine, UConn Human Performance Laboratory, and UConn Biomedical Engineering Laboratory. The main test method will be rollover shape testing, which is commonly used in industry to analyze prosthesis gait by locating the center of pressure in various loading states. Rollover shape testing will be conducted by adding a weight to the knee area of the prosthetic foot/blade and rolling it over a force platform in order to measure effective foot length ratio and other metrics of interest during single limb stance phase of walking [4]. The resulting metrics of interest will be analyzed in comparison to normalized data for current market prototype designs across data for the three modalities of mobile tasks. This device will improve prostheses development, performance, and the related manufacturing process.

Figure 4 *- Andrew Christenson testing 2D gait analysis on SIMI motion capture system at UConn Institute for Sports Medicine, Storrs, CT.*

5. Acknowledgements

We would like to thank our advisors, Dr. Krystyna Gielo-Perczak and Dr. Patrick Kumavor for their continued support and guidance throughout this project. We would also like to thank Dr. Laurie Devaney for the use of her Motion Capture equipment and lab space. A special thanks to Prof. Stephen Charry and Prof. Duffy Felmlee from the University of Hartford for their networking support and expertise in the field of prostheses. Lastly, we would like to thank Robert Kistenberg and Prosthetic Hope International for the loan of the running blade and their prostheses resources.

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