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Development of an Upper Extremity Fracture Model

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Abstract

An upper extremity fracture model should be created to enable medical school residents to learn how to apply and remove casts from a forearm fracture. After researching available sensors and applied force systems, the group found devices that could be modified for function and serve as a solution to the problem. Through brainstorming and design matrices, the team decided on a final product incorporating a wooden dowel incorporating a hinge system, small Force Sensitive Resistors, an arduino microcontroller, Processing as the development environment to create live bar graphs and Platsil as a tissue representation. The final design is an effective training tool that will determine the forces applied and allow for a modular resistance in the fracture. In the future, data will be collected from an experienced orthopedic surgeon to prove precision by repetition and baseline data from three other orthopedic surgeons will be collected. The data will be averaged across each sensor to provide an accepted pressure range for to utilize while training on the device. The visual display on the computer will be improved to include the baseline data and a visual representation of the forearm with color.

Introduction

Dr. Matt Halanski of orthopedics and rehabilitation at the UW School of Medicine and Public Health submitted this project to the University of Wisconsin-Madison Biomedical Engineering Department. He will serve as the experienced orthopedic surgeon to complete the precision testing.

Fractures are common in pediatrics, representing a major public health problem. Between 0 and 16 years of age, 42% of boys and 27% of girls experience at least one fracture and 84% of those fractures are upper limb fractures [1].

Currently there are not any commercially available models to teach medical school residents how to properly apply and remove a cast from a fracture. The most serious complication of casting is compartment syndrome which is a condition of increased pressure within a closed space that impairs blood flow and tissue perfusion. Thermal injuries to the skin can also occur due to high temperatures reached during molding of the cast. The most common related problem is skin breakdown which may be caused by pressure from a wrinkled, unpadded or under-padded area of the arm [2].

Pediatric bone is less brittle, has a higher ultimate strain than adult bone and is stronger in tension than compression. Growth plates are unique in pediatrics since it is weaker than bone in torsion, shear and bending which allows for injury at or through the growth plate area. The plates are cartilaginous and vary in thickness and location. Ligaments are generally stronger than bone in children which explains the greater fracture rate in pediatric patients [3].


Figure 1: Distal radius fracture in pediatric patient

Forearm injuries are very common, counting for 40% of all pediatric fractures. The peak occurrence is when the child is greater than 5 years of age when the bone is weakest due to velocity of growth. The radius is a curved bone in the proximal third that is flat distally. The ulna has a triangular shape throughout, with an apex in the proximal third. The two bones are stabilized distally and proximally by the triangular fibrocartilage complex and the annular ligament [3]. Most forearm fractures occur in the radius but sometimes can be both a radial and ulnar fracture. Distal radius fractures account for 75% of all forearm fractures in children. Often distal radius fractures, seen in Figure 1, are accompanied by a wrist fracture because of contact [4]. Forearm fractures can be caused by indirect or direct contact. Indirect contact involves a fall in which a flexion injury causes dorsal angulation and an extension injury causes volar angulation. Direct contact involves trauma to the radial or ulnar shaft [3]. In distal fractures, the proximal part will be in neutral or slight supination. The weight of the hand and the pronator quadratus pronates the distal fragment [5].

The goal is to create a radius-only distal fracture that allows varying resistance. It would be beneficial to mimic a greenstick fracture since it is the most common fracture found in children. From research, the team has decided these criteria would benefit the largest population of pediatrics. It is important to allow traction, angulation and rotation in order to create an acceptable learning tool for residents to assist them in various types of fractures that they will experience.

Materials and Methods

Experimental Model


Figure 2: Platsil arm model and wooden dowel fracture system

The first iteration of the final design consisted of a modular resistance system, a soft tissue representation, and circuitry and programming component. A hinge system, as seen in Figure 2, composed of a wooden dowel was used to represent the modular resistance system. The wooden dowel was used as a proof of concept, as well as to provide the team with a working representation of a fracture for testing the pressure sensors. The soft tissue representation was created by a past BME design team and was made using Platsil Gel-10. The tissue representation was molded from the arm of a female pediatric patient. The measurements of the pressure along the forearm fracture model were accomplished by force sensitive resistors (FSRs). Ten half inch diameter FSRs were placed on the model based off recommended locations from the client. The output voltage for each resistor was sampled using an Arduino Mega2560. This device was programed to read the voltage at each analog input, and form them into an array. A Java extension called Processing was used to display the data from the FSRs in a color-coded graphical representation shown in Figure 3.

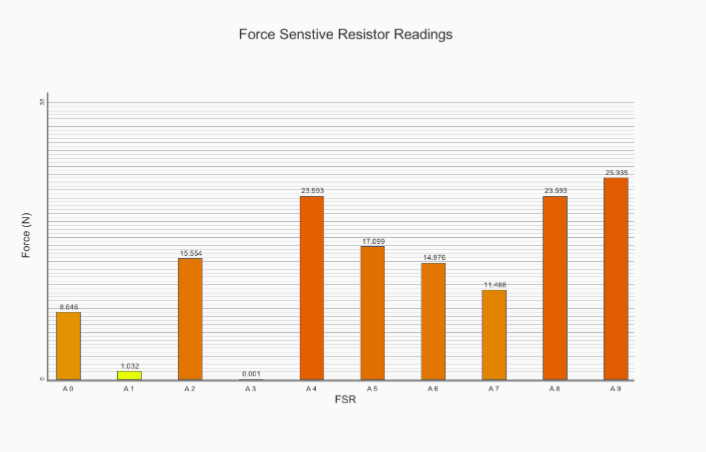

Figure 3: Processing displaying live bar graphs with force output for each sensor

Model Validation

Two tests were conducted to verify the accuracy of the sensors and prove the variable resistance capabilities of the fracture. The first test used a 100 gram weight to apply point loads to various locations on the FSRs; this helped to show that by placing rubber stoppers on the FSRs that the force can be evenly displaced across the entire FSR as seen in Figure 4. The second test that was done was varying the tightness of the modular resistance system. By varying how tight the system was secured at the hinge, the torque needed to reduce the fracture could be varied; however, this method did not prove to be fully reliable and consistent as seen in the data table in the Appendix. Due to the change in direction of the project, the second iteration of the final design will not be using any of the components of the first iteration. The second iteration will have a fracture model professionally developed by a separate

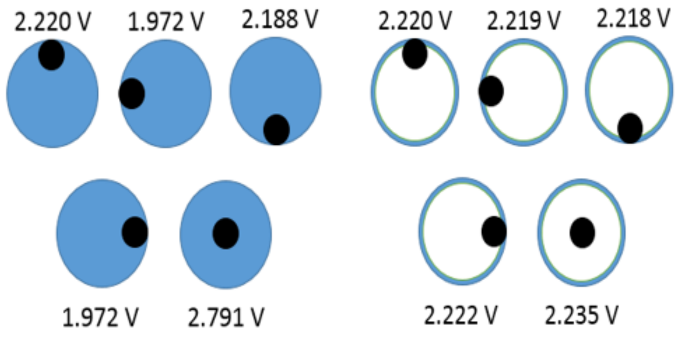

Figure 4: Test with (right) and without (left) bumpers to determine force output when loads were applied at various locations on the sensor

company while the focus of the project is now to develop a mobile pressure mapping system that will form fit to any model.

Model Modifications

Since the client has moved to other sources for bone and tissue representation in this model, the scope and focus of the project has been altered. The main goal is now to create pressure mapping hardware and software for use on multiple limb fracture models of varying sizes and shapes. This new scope required a complete retooling and rethinking of the design of the pressure gathering and graphing system. The new model can be broken into two distinct sections: the hardware system and corresponding software to create an intuitive visual display of the data gathered.

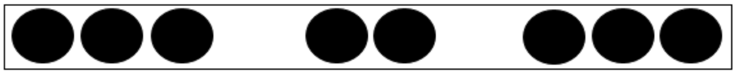

Figure 5: Metal tray with most sensor coverage on distal and proximal ends due to hand placement during reduction

The new hardware system will utilize a flexible, elastic fabric with four metal trays, seen in Figure 5, containing FSRs slid in between layers of fabric. The fabric will allow near universal use of the device on different limbs of different thicknesses because of the ability to reversibly deform. The FSRs will have a sensing area (0.375 inches) with a force range of 0-100lbs. They will be covered with a half-spherical rubber piece that will have a reduced vertical profile compared to the last design. This rubber piece will act to direct forces in all directions onto the center of the FSR and increase efficacy and accuracy of the data gathering technique. There will be multiple FSRs on each tray, with clustering near the distal and proximal ends based on standard hand positioning for fracture reduction. To reduce the number of FSRs necessary, there will be another metal piece on top of the FSR extending to a neighboring FSR. Using simple rigid beam equations, the exact location and magnitude of the force can be determined over a large section based on the reaction forces experienced by the FSRs.

The software aspect of the design also needs an aesthetic revamp to include a three dimensional model of the arm with color display changing based on pressure applied to the arm. Based on the voltage outputs of the FSRs, a corresponding force will be calculated at each location and displayed live on the model as a color coded heat map. This software must also include the ability to store data and display deviance from an accepted value, as determined by the testing values gathered from practicing physicians.

Testing Design

Dr. Matt Halanski, an orthopedic surgeon at the University of Wisconsin-Madison Hospital, will reduce the fracture of the prototype a total of 15 times. The subject will be blind from viewing his individual results, eliminating any chance for bias. The completion of the test is when Dr. Halanski believes that the force being applied is enough to reset the fracture. The average force across all of the sensors will be collected and evaluated for each of the 15 trials. The mean and standard deviation of Dr.

Halanski's trials will be the baseline data that will be used. Three more orthopedic surgeons will be tested in the exact same manner.

Data Analysis

The three doctors trials will be tested individually against Dr. Halanski's trials with an unpaired t-test, $n=15$ and $\alpha=0.05$. The null hypothesis is that there is no significant difference of the means across doctors and the alternative is that there is a significant variation of means. If there is sufficient evidence that the null hypothesis is true, $\alpha>0.05$, it can be concluded that prototype is capable of predicting the correct range of pressure values to reduce a fracture. If there is evidence to reject the null hypothesis, $\alpha<0.05$, this proves that the mean pressures applied between orthopedic surgeons is significantly different, and the prototype and pressure system must be re-evaluated.

Source of Funding

The funding for this project will come from the client, Dr. Matt Halanski and the Department of Orthopedics and Rehabilitation at the University of Wisconsin-Madison Hospital. As of now, there is no limit for funding as long as the purchases are approved by the client.

Results

Discussion

Since the direction of the project has changed from last fall, the team will have to improve the sensor and computer interface in order to give an accurate output of the forces applied to individual sensors. Also, this system must be easily transported since the goal is to be used on any type of model. This is important since this project is now a collaboration of three different universities or groups. One group is focusing on the design of a fracture model composed of bone-like material and the other group has been working on a temperature sensing system. The design team will move forward with re-designing the sensor and computer system and finish by the end of March in order to move forward and gather testing data during the month of April in order to integrate the accepted range into the display in the software system.

Acknowledgements

The design team would like to give special thanks to Professor Mitch Tyler and the UW Madison Biomedical Engineering Department for guidance and input throughout the entire design process thus far. Additionally, special thanks to the client Dr. Matt Halanski for providing the team with the existing prototype and insight on future work.

The team would like to thank Professor John Kao for helping with biomaterials research. It is important to recognize Gabe Bautista and Professor Tom Yen of the design team last year for meeting with the team to discuss past progress. The team would like to thank Shlomi Laufer and Dr. Carla Pugh's lab for information regarding sensors and microcontrollers. Also, it is important to acknowledge the College of Engineering Student Shop for providing assistance with the fabrication of the hinge system. Lastly, special thanks go out to Michael Bauer for assistance with programming and understanding of Processing and the arduino code.

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Appendix

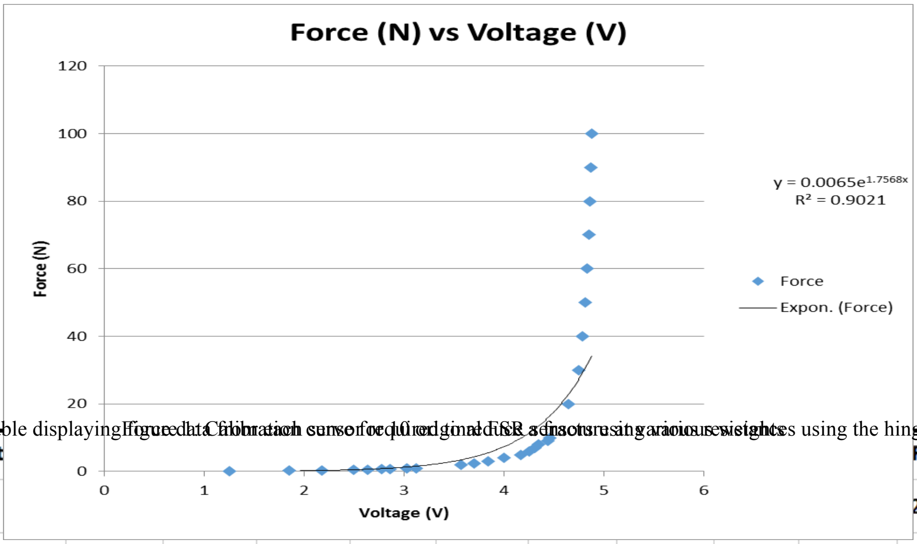

Figure 2: Table displaying [illegible] Figure 1: Calibration curve for [illegible] FSR sensors using various weights [illegible] using the hinge to tighten

# of turns from t										FSR 10	Average
0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	25.935	14.183
0.25	6.759	3.891	13.512	0.0256	18.416	14.463	10.513	9.463	17.156	10.163	10.436
0.50	6.846	4.315	8.546	0.001	12.56	9.463	12.456	5.11	8.61	5.163	7.307

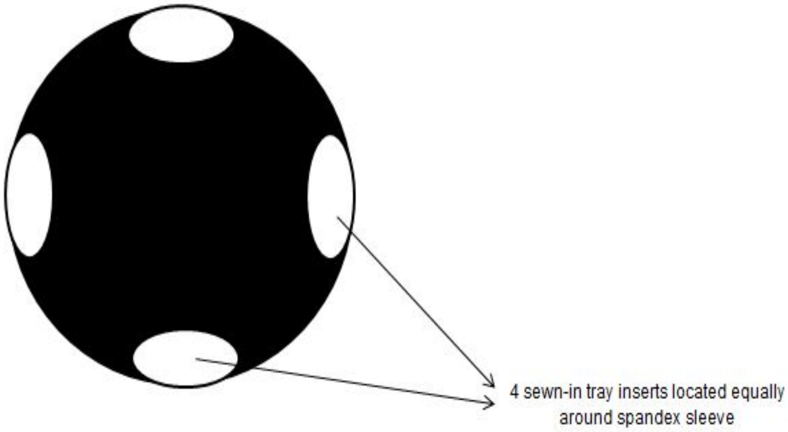

Figure 4: Dr. Halanski's hand placement while reducing a fracture using previous model