Development of an Upper Extremity Fracture Model

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Abstract

The objective of this project is to create an upper extremity fracture model 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, ten 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, a conductive rubber cord will be implemented as an alignment sensor, baseline data from experienced orthopedic surgeons will be collected, a temperature recording system will be developed and the visual display will be improved to include the baseline data.

Client

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 requested that a design team continue to engineer an upper extremity fracture model that records and displays pressure and temperature, creates modular resistance in the fracture and represents a true pediatric forearm.

Problem Statement

To develop a pediatric forearm fracture model that provides temperature, skin surface pressure, and bone alignment feedback for use by medical school residents in order to practice and learn safe, effective casting techniques.

Introduction and Project Motivation

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. Even though genetic or systemic illnesses can cause fractures, the majority of children with fractures are healthy. Bone mass, bone mineral density, low calcium intake, high body mass index (BMI) and consumption of carbonated beverages have been associated with fractures in children because of decreased bone strength [1].

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]. Currently there are not any commercially available models to teach medical school residents how to properly apply and remove a cast from a fracture.

As seen in Figure 1, the current model that Dr. Halanski uses is made primarily of PVC pipes connected to a wood board. The PVC pipes make an L-shape with the distal end representing the forearm. A thin layer of copper foil represents the skin of the forearm. The residents practice applying and removing casts on the copper-coated PVC pipe. If the copper is damaged during removal of the cast, the user will know they cut too deep. The cast saw has sensors on the blade that track temperature by passing data to a capture and logging system displayed on a computer. The client's current model is useful for recording the cast saw blade temperature and showing the user whether they have cut too deep. Ideally, the model should have the ability to display fracture alignment, applied pressure, and skin surface temperature.

Figure 1: Client's current forearm model including the copper coated PVC pipe to represent the forearm and computer system which records temperature.

Background Research

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 2: Buckle fracture at metaphyseal-diaphyseal joint

Figure 3: Radial and ulnar greenstick fracture in a child

Figure 4: Monteggia fracture in ulna and radius in a child

Pediatric fractures are a result of compression, torsion or bending moments because they occur at a lower energy than adult fractures. “Buckle” fractures are compression fractures that occur at the metaphyseal-diaphyseal intersection and can cause angular deformity. As seen in Figure 2, the top layer of bone on one side of the bone is compressed causing the other side to bend away. This is a stable fracture and broken pieces have not been displaced. Bending moments can cause a greenstick fracture seen in Figure 3, which results in a deformity on the concave side of the fracture since the bone is incompletely fractured. Bending moments can also cause microscopic fractures in which there is deformation of the bone but no visible fracture lines. The Galeazzi fracture is a middle or distal radius fracture with an unaffected ulna. This is rare in children since it disrupts the distal radio-ulnar joint [3]. The Monteggia fracture affects both the radius and the ulna. As depicted above in Figure 4, there is a fracture in the ulna and the top of the radius is dislocated. This injury requires immediate care. Growth plate fractures are unique to pediatrics in that the fracture occurs at or across a growth plate of the radius near the wrist as displayed below in Figure 5. This is also called a physeal fracture [4].

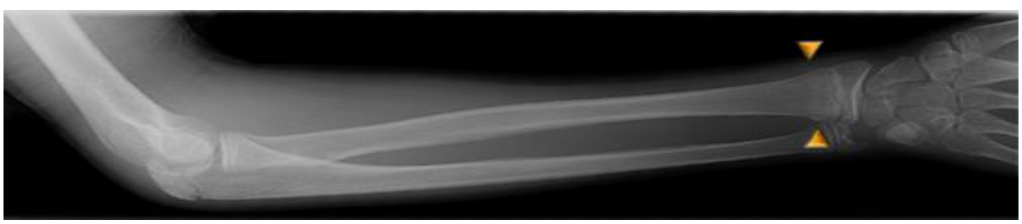

Figure 5: Growth plate fracture across radial growth plate

Figure 6: Distal radial 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 as seen in Figure 4. Distal radius fractures account for 75% of all forearm fractures in children. Often distal radius fractures, seen in Figure 6, are accompanied by a wrist fracture because of contact [5]. 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 [6].

Incomplete fractures are treated by completing the fracture and returning the bones into the original position. Most fractures can be reduced by rotating the palm toward the deformity. After reduction, the arm should be immobilized into the position that corrected the fracture. Distal radius fractures are reduced with angulation and rotation of the palm in the direction of the angulation. As long as angulation and rotation are reduced, it is okay to leave some fragments overlapping. All fractures are eventually casted with the elbow at 90 degrees. Both anterior and posterior pressure is applied over the interosseous membrane (fibrous tissue that separates bones in the body) to mold casts. This separates bones and increases the cast stability. After reduction and immobilization, patients return for a follow up x-ray 1 or 2 weeks after the injury. If there is re-angulation, the cast is removed and reduction is performed once again. If there is no angulation, the cast is removed after 6 to 8 weeks of healing [6].

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.

Previous Team Prototype

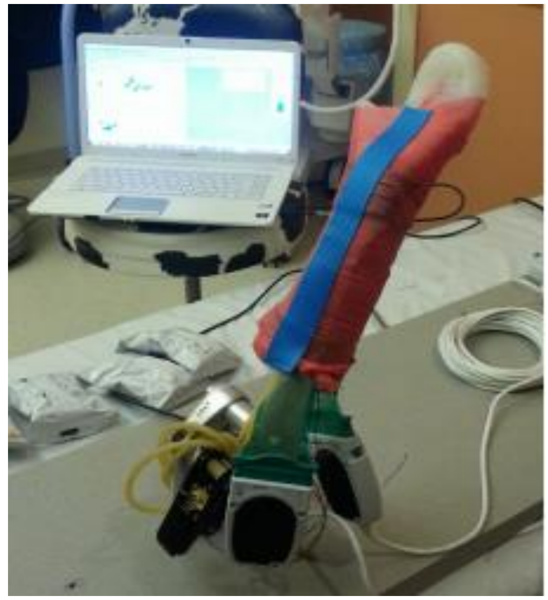
Figure 7: Photo of past BME design team's model

This project is a continuation of the development by a previous BME design team. The past team delivered a model capable of detecting pressure, temperature, and alignment along a forearm model. However, the past team's model had several limitations. The primary issue with the model is the lack of usability. The client was not capable of setting up the model and software independently. Other issues with the past team's model included the pressure mapping system, poor accuracy with the alignment sensors, fracture location, lack of a modular fracture resistance system, and no protection for hardware. Due to cost issues and time constraints, the past team went with a foot pressure mapping system. This is not ideal due to compromised accuracy, closed source software, expensive force sensing components, and the fact that the packaged software displays an outline of a foot in the program. The system for detecting the alignment of the fracture reduction only operates in one plane; therefore, it does not account for bone twisting. The model has the simulated fracture in the middle of the forearm. In order to accurately portray the most common pediatric forearm fractures, the fracture must be moved distally. The past team used latex surgical tubing to create resistance for the fracture, which did not allow the user to vary the pressure needed for reducing the fracture. Lastly, the group did not have time to develop a system for protecting the hardware from the cast saw and heat during the casting procedure.

The major concerns are listed above; however, there are several other aspects of the design that have not been discussed. The past team modeled the bones of the forearm as a single ¼-PVC pipe which is much smaller than the diameter of pediatric forearm bones. Thermisistors were used for detecting temperature along the model, which can be inconsistent and inaccurate. Figure 7 displays a photo of the past team's completed model.

Design Specifications

In this section, the key design upgrades to the previous team's model will be summarized. The client has specified that the initial upgrades should be for the usability, pressure mapping system, alignment detection, location of the fracture, and modular resistance. The client is unable to set up the current model on his own; therefore, the future model should have a fully integrated software package that would allow the client and residents to simply insert a USB cable into a computer, which would launch the program automatically. Ideally, the pressure mapping system will be upgraded from the foot system to a less expensive but accurate system for detecting force applied during casting. A new system for detecting the alignment of the fracture reduction must be developed. The system should account for the angle of separation of the fracture. Finally, the fracture must be moved distally, and modular resistance needs to be added to the model. Moving the fracture distally will include revamping the mechanism for causing the fracture and allow for a newly developed system for varying resistances to be added.

There are several secondary upgrades that should be made to the system once the aforementioned upgrades have been made. The following systems should be upgraded or added to the system: temperature detection, protection for hardware, and realistic representation of the skin tissue in a pediatric forearm. The client has noted that the temperature detection system is not a priority at the moment, and its development can wait until the primary issues have been resolved. Before the model experiences wide use, a system for protecting the hardware will need to be developed in order to lengthen the life expectancy of the model. Lastly, the model should be as anatomically correct as possible to provide the users with the best representation possible of a fractured pediatric forearm.

Design Considerations and Decision Matrix

Pressure Mapping System

An important component of the design considerations is the pressure mapping system which is used to record the pressure applied to the fractured bone during the casting process. The pressure mapping system should be able to accurately calculate the amount of pressure that is applied to the bone and cover the entire casting area. It is important for the system to be specific to the forearm to enable high precision and accuracy. Another important consideration when deciding between mapping system is cost, since the different mapping systems range from $5,000 to $50,000. This deserves attention when evaluating the $5,000 budget of the prototype. The designs considered were evaluated based on accuracy, data output, usability, cost, and safety.

Table 1: The design matrix for the pressure mapping system.

Design Criteria	Weight	TekScan (Foot)		TactArray		Custom Forearm Sensors	
Accuracy	30	2	12	3	18	3	18
Data Output	25	3	15	3	15	3	15
Usability	20	2	8	4	16	3	12
Cost	15	3	9	1	3	2	6
Safety	10	4	8	4	8	4	8
Total	100	52		62		59	

The TekScan pressure mapping system is actually a foot pressure mapping system, seen in Figure 8, which can superimpose onto the forearm. This system was used in the previous prototype and is not ideal, however, the price was acceptable and it can record pressure readings. This device received a low score in accuracy and data output as displayed in Table 1. The mapping system is in the shape of a foot, therefore, when placed on the forearm model, some gaps were present between the sensors and forearm and pressure data was missing. The software for the mapping system is not user friendly since the programs do not launch and display automatically, which explains the low scores in usability. Ideally, a customized software system should be implemented for the system in order to better display the pressure and temperature readings that the user requires [7].

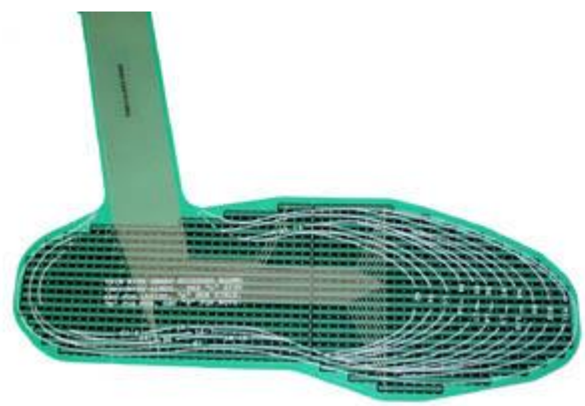

Figure 8: TekScan foot pressure mapping system currently being used

The TactArray pressure mapping system is a cutting edge technology developed by Pressure Profile Systems Inc. The company has a pressure mapping system, seen to the right in Figure 9, which is stretchable and ideal for a pediatric forearm, since the sizes are customizable. The device is constructed with a padded material that allows the system to stretch for a close fit on the most complex shapes, including the human body. The previous team also looked into using this design. However, the cost of the system inhibited the purchase and implementation of the TactArray into the design. If the product cost did not have any effect, this design would be ideal. Understanding this, the final pressure system chosen should have similar properties to this advanced system [8].

Figure 9: Tact Array sensor

The team had to conduct research and receive consulting to gain information regarding a custom pressure mapping system design. Due to the current system using a foot pressure mapping system and the TactArray sensor exceeding the budget, the client has proposed a custom pressure mapping system made by Dr. Carla Pugh at the University of Wisconsin-Madison Hospital. According to the client, the custom system can be made to fit any area of the body and should not exceed the price limit for the prototype. After discussing the custom system, the software licensing might be an issue since it is both expensive and exclusive. Also, there are concerns regarding the placement of the sensors in that they will not always be on a flat surface which can be damaging.

Modular Fracture System

Another component of the design that requires re-evaluation is the fracturing system used to displace the bone. The fracture modular system must be comparative to an actual radial fracture, with the ability to vary resistance. The range of variability can demonstrate the different types of breaks, regarding amount of pressure needed to realign the bone. The structure will consist of a representation of both the radius and ulna made of PVC piping. Considering the ulna will be fixed in the upright position and the radius will be the bone that displaces, the fracture system will be mounted onto the ulna and extend part of the radius bone. There are three different designs that could potentially be used for this process: elastic bands, a mechanical system or a pneumatic system. They were evaluated on resistance variability, usability, manufacturability, cost, and safety.

Table 2: The design matrix for the modular fracture system.

Design Criteria	Weight	Bands		Pneumatic System		Mechanical System	
Resistance Variability	30	2	12	5	30	4	25
Usability	25	2	10	4	20	3	15
Manufacturability	25	4	20	3	15	3	15
Cost	10	5	10	3	6	4	8
Safety	10	4	8	4	8	4	8
Total	**100**	**60**		**77**		**71**	

The previous team working on the project used elastic surgical bands to induce the forearm fracture. These type of bands are easily accessible, therefore low in cost as displayed in Table 2. The bands were hooked through the PVC pipe that represents the bone. The bands were tied to a mechanical system at the base of the forearm and a crank could be used to tighten or loosen the bands, therefore producing a deviation to simulate a fracture. This system was able to create a displacement, however, it was hard to tell exactly how much the bone had displaced. This explains the low score in the resistance variability and usability category. The prototype must have a more sophisticated mechanism in order to produce a more realistic simulation of a fracture, create various fracture types and to produce more accurate displacement data.

One plausible option for creating variable bone displacement is a mechanical system displayed in Figure 10. The design would consist of a spring connected to the fixed ulna bone that pushes against the radius. The force that the spring creates on the radius is determined by the change in length of the spring. Therefore, to increase the force on the radius, a crank system would move the spring, causing a decrease in spring length and increase in force. This provides the user with a range of forces that may be applied to the

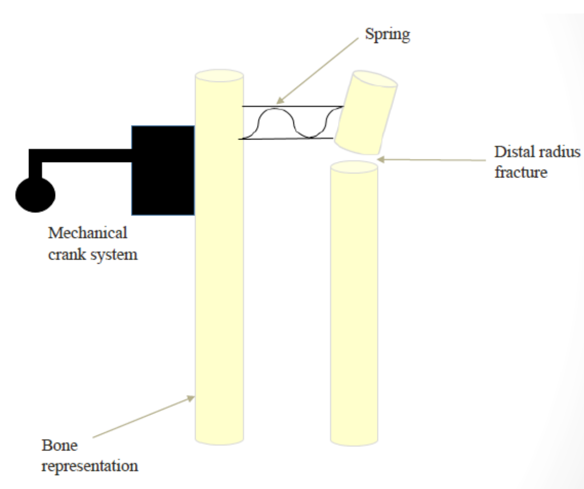

Figure 10: A possible mechanical system to cause radial bone displacement

bone, which would demonstrate various types of forearm fractures. The problem with creating a mechanical system inside the cast is identifying how much pressure is being applied to the system. Therefore, the mechanical system scored lower in manufacturability and usability.

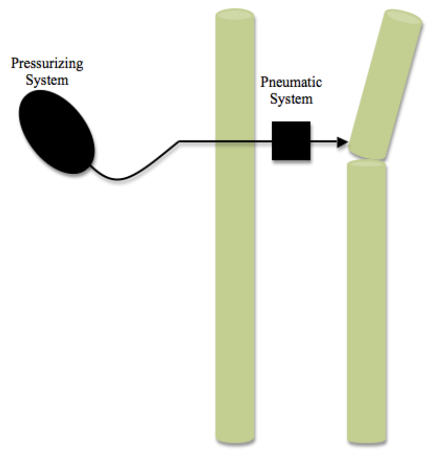

Figure 11: A possible pneumatic system to cause radial bone displacement

Another system that provides a viable option for the radial bone displacement is a pneumatic system. The pneumatic design seen in Figure 11, uses pressure to increase or decrease the amount of bone displacement in the radius. The pump located outside of the cast would be connected by a tube that delivers air pressure to the system inside. Ideally, the system inside the cast would work like a tire pressure gage. As the pressure increases, a fixed rod would increase in length and displace the radial bone. This type of system would allow the user to read exactly how much pressure is being applied to the bone and the displacement could be measured. This would increase ease of use and resistance variability.

Intermediate Design

The intermediate design for the forearm fracture model incorporated multiple components with complex physical and technical interactions in order to be an effective teaching tool. These elements included a bone representation with a fracture creating device, tissue representation, and multiple electronic units interfacing with a software package. Each part had a specific goal that it accomplished while working within parameters presented by the project as well as other parts.

The first design element is the bone and fracture modeling. Two fixed half-inch PVC pipes represented the two bones of the forearm, the radius and the ulna, with the radius cut in the distal portion to simulate a fracture. A variable pneumatic system created separation and resistance to reduce the fracture. This system consisted of an air bladder or piston forcing one portion of the radius out of alignment with the other fixed portion at a pressure and displacement based on the amount of air forced into the system by a pump.

The second element is the forearm tissue representation. Platsil Gel-10 was molded around the simulated fracture into the shape and size of an average pediatric forearm. This material was used from the last project because it is a quality, cost effective simulation of tissue that has the thermal resistance and mechanical properties necessary for an effective model. A second layer of tissue representing skin will be added over the Plastil to cover electronic elements from heat or force damage due to the casting procedure.

A third element in the model will be electronic sensors to provide quantitative measurements of skin surface pressure and bone alignment during the casting process. A custom pressure mapping system will show skin surface pressure of the cast through the use of a sheet containing piezoelectric elements to measure force based on changing resistances in the material due to material displacement. This will cover the entire arm to provide data for the entire model. Bone alignment data will be collected by strain gage potentiometers placed across the fracture to measure fracture displacement and orientation.

The final element of this design will be a software package that collects and records data from electrical elements to display live numerical and visual feedback. This portion will consolidate all data into one efficient, easy to use program. Due to the lack of programming expertise of the team, this portion will be accomplished by an outside source based on system requirements set forth by the design team. At outline of the system requirements is found in Appendix (Software Requirements).

After much consideration, the team decided to change directions with the project. After meeting with Shlomi Laufer who is part of Dr. Carla Pugh's lab, the team decided to use Force Sensitive Resistors (FSRs) to determine the force applied during reduction and casting. Shlomi suggested FSRs because of their low cost, ease of use and available resources for these sensors. Also, the focus was directed toward using a single rod as a representation of bone for ease of fabrication and input from the client. Instead of using PVC pipe like the previous team, the team decided to change directions and use a wooden dowel since it would be easy to manipulate and fabricate in the shop.

Final Design

Modular Resistance System

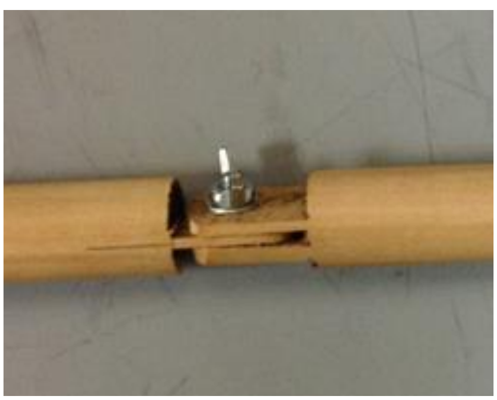

Figure 12: Three tab hinge system created out of wooden dowel

A hinge system was chosen to represent the forearm fracture as seen in Figure 12. The hinge was fabricated using a wooden dowel, a screw, wing nut, and washers. Wood was chosen as the material due to its ease of fabrication. A 7/8 of an inch diameter dowel was chosen because it best fit in the already fabricated Platsil forearm. The wooden dowel was cut down to two components with approximate lengths of four inches and ten inches. The tabs on the ends of the components were created using a band saw. The edges were rounded using a sander, and the holes in the tabs were created using a drill bit that matched the clearance for the screw used to secure the hinge. A screw, washers, and a wing nut were used to secure the two components together and give the axis of rotation for the hinge. A wing nut was used to make it easy to vary friction, or amount of resistance, in the hinge. The amount of force needed to align the hinge components from its angular displacement can be varied by either loosening or tightening the wing nut.

The wooden hinge was primarily used as a proof of concept that a hinge system could adequately represent a forearm fracture that matched the expectations of the client. After the client used the model, he stated that the hinge system was a reasonable representation of a fracture, but it was difficult to vary the resistance in the hinge without taking the model apart. Another limitation of the wooden hinge is the low level of fatigue and wear resistance. A wooden hinge made from a dowel would become worn out sooner than would be acceptable for a commercially viable product and would wear sooner than client expectations.

Future work for the hinge system should include upgrading to a stronger material, such as a form of metal, ideally a compound that is easy to fabricate but has a higher strength compared to wood. A better mechanism for varying the amount of resistance should be developed, or at the very least, the resistance in the hinge must be consistent from trial to trial, so the users of the model get a consistent feel for the amount of force needed to align the hinge.

Tissue Representation

The past BME design team's tissue representation was used for the model delivered at the end of this semester. The past team used Platsil Gel-10 for the muscle tissue layer which is pictured in Figure 13. The Platsil Gel-10 kit comes with two components that are mixed in a 1:1 ratio and poured into a specific mold. In this case, the mold was a female pediatric forearm that was provided by the client. The mold was made of plaster that the team cut it into dorsal and ventral halves and plastered together once filled with Platsil. Before pouring in the Platsil, they coated the mold with Vaseline to make removal of the Platsil form the mold easier. Once the Platsil settled, the plaster pieces that held the mold together were ripped apart in order to remove the Platsil mold.

Figure 13: Platsil get tissue representation

Circuitry/Programming

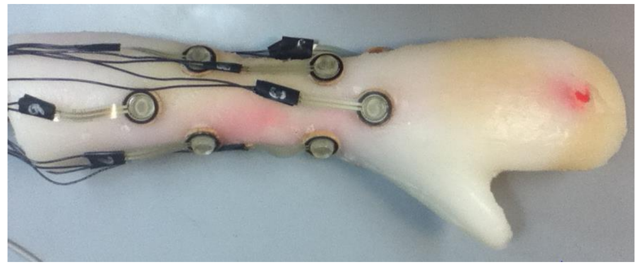

Figure 14: FSRs placed on Platsil model

The measurement of pressure is accomplished using Force Sensitive Resistors (FSRs). FSRs are variable electrical elements that decrease in resistance when a force is applied to them. For the final design, ten Interlink 402 (half inch diameter) Force Sensitive Resistors, seen in Figure 14, were placed at various locations on the outer surface of the Platsil forearm model. The placement of the FSRs on the forearm were placed strategically based on the advice of the client. Sensors were emphasized on the top and bottom of the forearm, as this is where the doctor applies the necessary force. The doctor applies a three-point bending force on the forearm, with a force also being applied in the middle of the forearm. Therefore, sensors were placed distally, proximally, and also near the middle where the fracture occurred. These were connected to a breadboard in series with another resistor (10kOhm), with the source voltage being 5V while the output voltage was measured between the resistors (shown in Figure 15). A voltage divider equation (Equation 1):

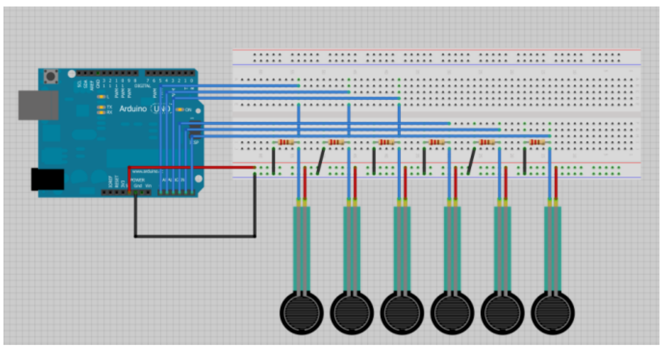

Figure 15: Circuit schematic used

$$V_O / V_I = R_{fsr} / (R_1 + R_{fsr}) \qquad \text{(Equation 1)}$$

was used to determine the resistance of the FSR based on applied values of R1 and Vi, while Vo was measured. This value was compared with the calibration curve (Figure 18) to determine the force being applied.

The output voltage for each resistor was sampled by an Arduino Mega2560 microcontroller. This device was programmed to quickly read the voltage at each analog input, and form them into an array. When an outside source sent an input signal into the microcontroller, this sampling array was sent, cleared, and filled again based on current values. (Code shown in Appendix C)

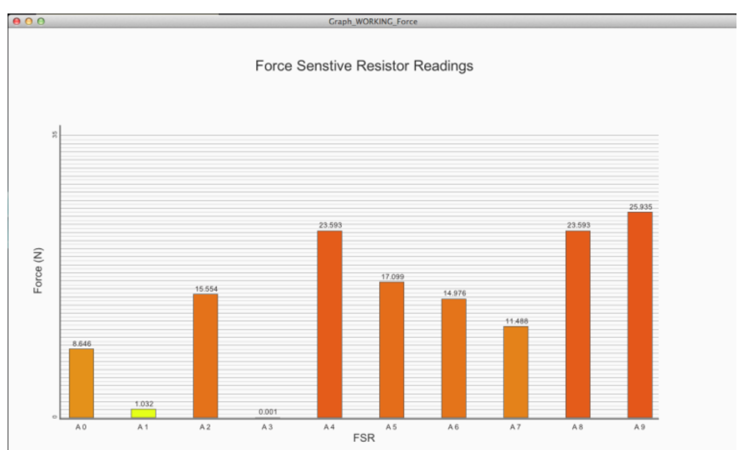

Figure 16: Graph displayed on computer in Processing

The outside source used for this project was a Java extension called Processing. This contained a code to create a live, color-coded graphical representation of the data being gathered from the microcontroller. The array of data being inputted was converted to voltage, which was subsequently converted to Force based on the Force vs. Voltage calibration curve (Figure 18). The graph constantly updated height of the bar graph as well as display values, seen in Figure 16, based on input gathered from the microcontroller. (Code shown in Appendix D).

Calibration

Using the datasheet provided and various weights ranging from 1-2000 g, the FSR sensors were calibrated as seen in Figure 17 and the curve below was created. The graph also displays the equation of the line of best fit as seen in Figure 18. However, since there were not weights over 2000 g available and the poor accuracy of FSR sensors, the graph shows the optimal range of the FSR sensors that were purchased to be between 3 N and 30 N of applied force even though the information explains the sensors should be able to withstand up to 100 N of force. This range is sufficient since the average applied force on each FSR sensor is only about 20 N when Dr. Halanski used the model to correct the fracture.

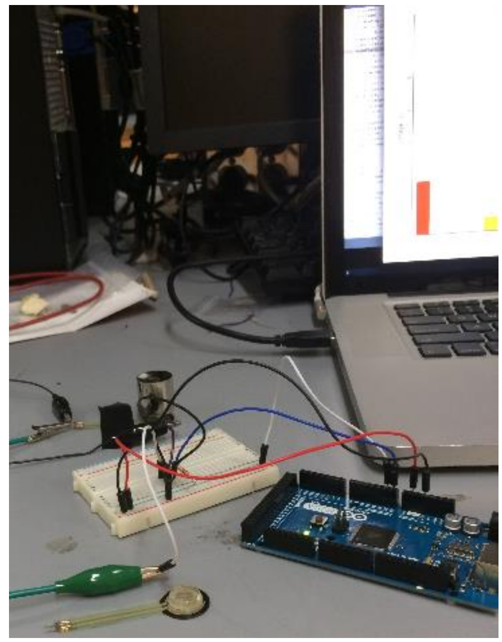

Figure 17: Calibration set up with weights and FSR sensors

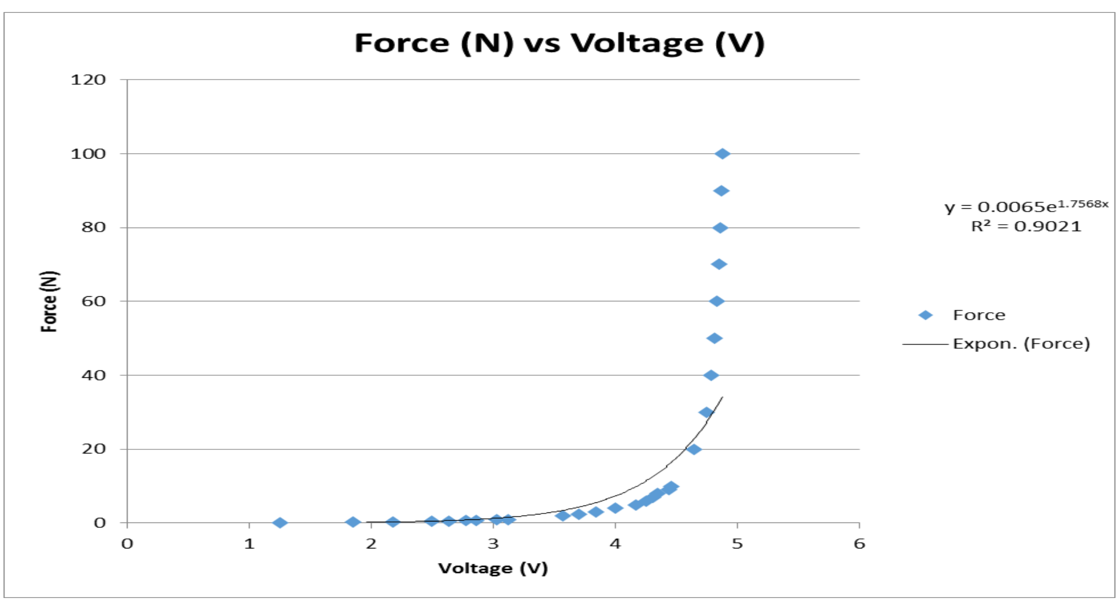

Figure 18: Calibration curve converting voltage to force for FSR sensors

Experimental Testing

Two tests were conducted to verify the accuracy of the sensors and prove the variable resistance capabilities of the fracture. The first consisted of placing a 100-gram weight at different locations around the FSR, as can be seen in Figure 19. The sensor's output voltage was then recorded for each placement. The same locations were then tested with a bumper applied to the FSR, and the output voltage recorded. These results were compared with their corresponding locations with and without the bumper to verify whether the bumper distributed the force more evenly across the sensor. The set of data with the smallest standard deviation is the method that more accurately and consistently distributes the force.

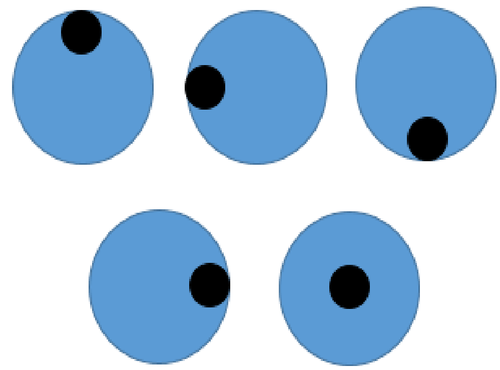

Figure 19: 5 different placements of 100 g point load on face of FSR sensors

Another test was done to verify the variable resistance capabilities of the modular fracture. The fracture was set at different levels of tightness and then the fracture was reduced. The forces necessary to straighten the forearm were recorded. This was done at full tightness and at quarter turn increments with respect to the tightest setting. The data that is obtained can be used to assess the necessary forces to reduce the fracture at varying levels of torque. The average of all the sensors can be calculated to provide an estimate of the force required to straighten the fracture.

Results

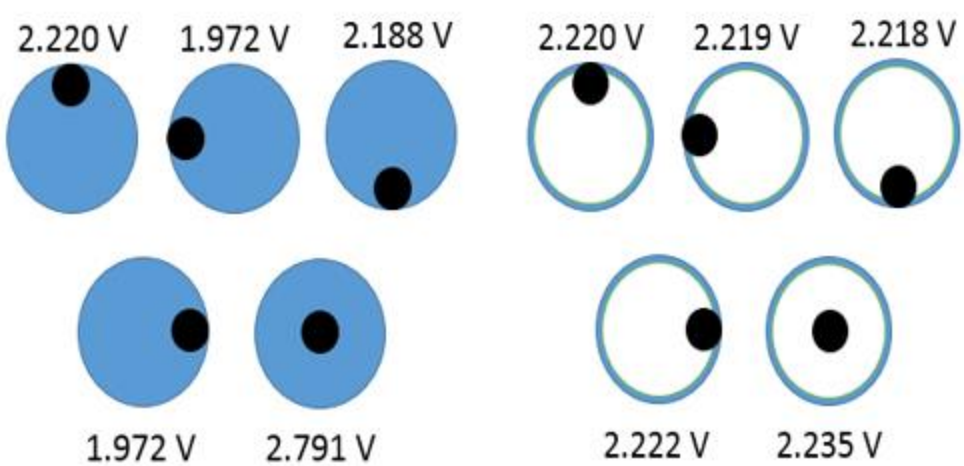

Figure 20: Left picture shows FSR sensors without bumpers and the voltage output. Right picture shows FSR sensors with bumpers and the voltage output.

The results of the testing with and without the bumper applied can be seen above in Figure 20. The test results confirm that applying the bumper more evenly distributes the force across the FSR. This is obviously important when the device is being used, with regards to obtaining the most accurate data over many fractures. The standard deviations of the output voltage without and with the bumpers were 0.335 and 0.00698, respectively. The significantly smaller standard deviation of the FSR with the bumper means that the voltage output is much more consistent throughout the different placements of the load. This proves the idea that applying the bumpers provides a more accurate force distribution with a consistent load applied.

It is clear from the testing that when the fracture model is fully tightened, the force required to reduce the fracture is greatest. It is noted that the data in Table 3 is not perfect. This is due to the different placements of the hands when straightening the fracture. However, after averaging the force applied across each sensor, the data shows the gradual increase in force.

Table 3: Force output at each FSR sensor at varying resistances

# of turns from tight	FSR 1	FSR 2	FSR 3	FSR 4	FSR 5	FSR 6	FSR 7	FSR 8	FSR 9	FSR 10	Average
0	8.646	1.032	15.554	0.001	23.593	17.009	14.976	11.488	23.593	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
0.75	2.546	0.786	1.563	0.0003	13.156	0.001	5.419	6.13	0.163	0.135	2.9899
1.00	0.001	0.303	0.529	1.179	12.629	0.001	2.88	0.052	0.003	0.24	1.7817

Future Work

Multiple aspects of the project must be addressed in the future to continue making progress in completing this design. One of the first things to be done in the spring is to complete baseline data collection from 5-10 experienced orthopedic surgeons to collect average force values for each FSR sensor during casting. This will be used and displayed on the computer screen so that medical school residents will know a range for applied force that they should achieve during application and removal of casts. The team also wants to improve the representation of the skin tissue by perhaps creating a mold of a different material. It is very important to conceal all the wiring from the FSRs and breadboard which may be accomplished by using a wireless device created by another design team this semester. Also, it would be beneficial to change the material of the wooden dowel hinge system to a material such as a metal or polymer which would increase shelf life and decrease wearing from friction. The team would like to embed the sensors in the Platsil in order to create a smooth forearm model. It is also important to consider the ability to vary the resistance of the hinge system without having to dissemble the model. The team would eventually like to develop an advanced system that will display both the constant baseline data and the changing user data and perhaps separation of the sensors based on grouped locations (proximal dorsal, distal dorsal and proximal ventral). Below in Table 4 is the approximate timeline for next semester.

Table 4: Timeline for next semester

Tasks	**January**		**February**				**March**					**April**				**May**	
Week	19	26	2	9	16	23	2	9	16	23	30	6	13	20	27	4	11
Collect baseline data	X																
Add data to graph		X	X														
Modify hinge system			X	X	X	X											
Re-mold tissue model							X	X									
Embed FSRs in tissue								X	X								
Conceal wiring										X	X						
Advanced computer display												X	X	X	X	X	X

Conclusion

The most common pediatric forearm fracture is a distal radius greenstick fracture accounting for 75% of all forearm fractures. Of all pediatric fractures, upper limb fractures account for 84% of the injuries. Currently there are no commercially available forearm fracture models for residents to learn and train with. The previous design team created a sufficient prototype, however, there are many issues including location of fracture, little modular resistance for fracture, inaccurate pressure mapping system, no protective sleeve for hardware and the alignment sensors do not detect potential twisting of the bone during fracture. The design team has created a system which creates resistance for reduction of the fracture, models a distal radius fracture and outputs applied force during casting in a visually appealing and quantitative manner. In the future it will also be important to look into implementing the alignment system, protecting the hardware, creating a method for temperature measurement and creating live data with baseline data also displayed on the bar graph.

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Appendix A

Product Design Specifications

Product Design Specifications for Upper Extremity Fracture Model
Team: Colin Dunn, Lucas Haug, Max Schultz, and Taylor Moehling

Function: To develop a pediatric forearm fracture model that provides temperature, skin surface pressure, and bone alignment feedback for use by medical school residents in order to practice and learn safe, effective casting techniques.

Client Requirements:

- Create distal fracture in model
- Computer interface that is easy to use
- Provide modular resistance for the fracture
- Record pressure and temperature during casting and removal
- Protect hardware from heat and force
- Create a realistic model of the pediatric forearm

Design Requirements:

1. Physical and Operational Characteristics

a. *Performance requirements*: As a teaching aid, the device must be reusable. It must withstand repeated temperature and pressure changes, with pressure and temperature sensors remaining accurate for an extended period of time.

b. *Safety*: The device must withstand changes in temperature up to 70^{o} C and mechanical force (pressure of approximately 150 mmHg) without catastrophic failure that could result in injury.

c. *Accuracy and Reliability*: The device should be accurate within 5% of true pressure and temperature values and should also be precise to create an optimal teaching tool.

d. *Life in Service*: The device will allow for multiple sequential casting procedures in order to give many residents the necessary experience before real time scenarios.

e. *Shelf Life*: The device should last at least 5 years assuming no damage to device during casting.

f. *Operating Environment*: The Platsil, wooden dowel and other materials must withstand pressure and temperature changes associated with the casting process. It should exhibit no reaction to any material used in this process. It must be able to maintain its physical characteristics with repeated use.
g. *Ergonomics*: Must resemble the average size of a child's forearm and allow for variable modular resistance to create different distal fractures of the radius.
h. *Size*: The model arm should be the size of a pediatric forearm.
i. *Weight*: Less than 20 pounds to be easily transported but not crucial to project.
j. *Materials*: The materials must be inert with respect to all materials used in the casting process and show no degradation from these materials or in the range of temperatures and mechanical forces utilized during use. The radius in the forearm will be represented with a wooden dowel and Platsil will be used to symbolize skin.
k. *Aesthetics, Appearance, and Finish*: This device must be representative of a human forearm including a representative radius and skin tissue. The software should display pressure and temperature readings on an easy-to-read screen with color distinctions.

2. Production Characteristics

a. *Quantity*: 1 initially
b. *Target Product Cost*: Under $200

3. Miscellaneous

a. *Standards and Specifications*: N/A
b. *Customer*: Medical Schools and ultimately residents.
c. *Competition*: Past design group's prototype. Simplistic models of extremities exist, but nothing of technical complexity that displays data.

Appendix B

Software Requirements

1. Program will open upon model connection to computer
2. Data from pressure, thermal, and alignment sensors will be displayed in single user interface.
3. User interface will display an image of a forearm (model)
4. Pressure Mapping System
    a. Pressure mapping data will be displayed live on the user interface
    b. Pressure data points will be displayed along the image of the forearm (model)
    c. Pressure data points will be color coded
        i. Pressure too high will be red
        ii. Pressure correct will be green
        iii. Not enough pressure will be grey
    d. An alarm will be activated if pressure is too high
5. Thermal Data
    a. The temperature of inside of cast will be displayed
    b. The temperature of outside of cast will be displayed

   c. There will be an alert system is temperatures are too high
6. Alignment Sensor Data
   a. The degree of fracture will be displayed
   b. There will be an alert system if alignment is incorrect
7. Data logging
   a. All data for each trial will be stored
      i. Pressure data will be stored
      ii. Thermal data will be stored
      iii. Alignment data will be stored
   b. Data at specific points in time can be reviewed in the user interface

Appendix C

Arduino Code

```
//Sending 8 bit reading (256) so analogue
//reading can be sent in 1 byte
int Analogue0 = 0; // first analog sensor
int Analogue1 = 0; // second analog sensor
int Analogue2 = 0; // digital sensor
int Analogue3 = 0; // second analog sensor
int Analogue4 = 0; // second analog sensor
int Analogue5 = 0;// second analog sensor
int Analogue6 = 0;
int Analogue7 = 0;
int Analogue8 = 0;
int Analogue9 = 0;

int inByte = 0; // incoming serial byte

void setup()
{
 // start serial port at 9600 bps:
 Serial.begin(9600);
establishContact(); // send a byte to establish contact until Processing responds
}
void loop()
{
 // if we get a valid byte, read analog ins:
 if (Serial.available() > 0) {
 // get incoming byte:
 inByte = Serial.read();
 // read first analog input, divide by 4 to make the range 0-255:
 Analogue0 = analogRead(0)/4;
```

```
 // delay 10ms to let the ADC recover:
 delay(10);
 // read second analog input, divide by 4 to make the range 0-255:
 Analogue1 = analogRead(1)/4;
 // read switch, multiply by 155 and add 100
 // so that you're sending 100 or 255:
 delay(10);
 Analogue2 = analogRead(2)/4;
 delay(10);
 Analogue3 = analogRead(3)/4;
 delay(10);
 Analogue4 = analogRead(4)/4;
 delay(10);
 Analogue5 = analogRead(5)/4;
 delay(10);
 Analogue6 = analogRead(6)/4;
 delay(10);
 Analogue7 = analogRead(7)/4;
 delay(10);
 Analogue8 = analogRead(8)/4;
 delay(10);
 Analogue9 = analogRead(9)/4;
 delay(10);

// send sensor values:
 Serial.write(Analogue0);
 Serial.write(Analogue1);
 Serial.write(Analogue2);
 Serial.write(Analogue3);
 Serial.write(Analogue4);
 Serial.write(Analogue5);
 Serial.write(Analogue6);
 Serial.write(Analogue7);
 Serial.write(Analogue8);
 Serial.write(Analogue9);
 }
}
void establishContact() {
 while (Serial.available() <= 0) {
 Serial.write('A'); // send a capital A
 delay(300);
 }
}
```

Appendix D

Processing Code

```
String xLabel = "FSR";
String yLabel = "Force (N)";
String Heading = "Force Senstive Resistor Readings";
String URL = "12/03/2013";
float Vcc = 5.0; // the measured voltage of your usb
int NumOfVertDivisions=35; // dark gray
int NumOfVertSubDivisions=70; // light gray
int NumOfBars=10; // you can choose the number of bars, but it can cause issues
 // since you should change what the arduino sends
// if these are changed, background image has problems
// a plain background solves the problem
int ScreenWidth = 1200, ScreenHeight=800;
////////////////////////////////////////////////////////////
// Serial port stuff ////////////////////////
import processing.serial.*;
Serial myPort;
boolean firstContact = false;
int[] serialInArray = new int[10];
int serialCount = 0;
/////////////////////////////////////////////////
int LeftMargin=100;
int RightMArgin=80;
int TextGap=50;
int GraphYposition=160;
float BarPercent = 0.4;
int value;
PFont font;
PImage bg;
int temp;
float yRatio = 0.58;
int BarGap, BarWidth, DivisounsWidth;
int[] bars = new int[NumOfBars];
void setup(){
// bg = loadImage("BG.jpg");
/// NB SETTINGS ////////////////////////////////////////////////////////
 myPort = new Serial(this, Serial.list()[4], 9600);
 ////////////////////////////////////////////////////////////////////////////
DivisounsWidth = (ScreenWidth-LeftMargin-RightMArgin)/(NumOfBars);
 BarWidth = int(BarPercent*float(DivisounsWidth));
```

```
 BarGap = DivisounsWidth - BarWidth;
size(ScreenWidth,ScreenHeight);
 font = createFont("Arial",12);
textAlign(CENTER);
 textFont(font);
}
void draw(){
// background(bg); // My one used a background image, I've
 background(250); // commented it out and put a plain colour
// Headings(); // Displays bar width, Bar gap or any variable.
 Axis();
 Labels();
 PrintBars();
 if (myPort.available()>0){
   int inByte = myPort.read();

if (firstContact == false) {
 if (inByte == 'A') {
 myPort.clear(); // clear the serial port buffer
 firstContact = true; // you've had first contact from the microcontroller
 myPort.write('A'); // ask for more
 }
 }
 else {
 // Add the latest byte from the serial port to array:
 serialInArray[serialCount] = inByte;
 serialCount++;

// If we have 6 bytes:
 if (serialCount > 9 ) {
for (int x=0;x<10;x++){
bars[x] = int (yRatio*(ScreenHeight)*(serialInArray[x]/256.0));
}

// Send a capital A to request new sensor readings:
 myPort.write('A');
 // Reset serialCount:
 serialCount = 0;
 }
 }
}
}
```

```
/////// Display any variables for testing here//////////////
void Headings(){
 fill(0 );
 text("BarWidth",50,TextGap );
 text("BarGap",250,TextGap );
 text("DivisounsWidth",450,TextGap );
 text(BarWidth,100,TextGap );
 text(BarGap,300,TextGap );
 text(DivisounsWidth,520,TextGap );
}
void PrintBars(){
int c=0;
float forceConst = 0.0065;
float eConst = 1.7568;


 for (int i=0;i<NumOfBars;i++){
fill((0xe4+c),(525-bars[i]+c),(0x1a+c));
 stroke(90);
 rect(i*DivisounsWidth+LeftMargin, ScreenHeight-GraphYposition, BarWidth, 13*(-
forceConst*exp(eConst*(float(bars[i])/(yRatio*(ScreenHeight))*Vcc))+.007));
 fill(0x2e,0x2a,0x2a);
 text(forceConst*exp(eConst*(float(bars[i])/(yRatio*(ScreenHeight))*Vcc))-.006,
i*DivisounsWidth+LeftMargin+BarWidth/2, ScreenHeight-
(13*(forceConst*exp(eConst*(float(bars[i])/(yRatio*(ScreenHeight))*Vcc))-.007))-5-GraphYposition );
 text("A", i*DivisounsWidth+LeftMargin+BarWidth/2 -5, ScreenHeight-GraphYposition+20 );
 text(i, i*DivisounsWidth+LeftMargin+BarWidth/2 +5, ScreenHeight-GraphYposition+20 );
 }
}
void Axis(){
strokeWeight(1);
 stroke(220);
 for(float x=0;x<=NumOfVertSubDivisions;x++){
int bars=(ScreenHeight-GraphYposition)-int(yRatio*(ScreenHeight)*(x/NumOfVertSubDivisions));
 line(LeftMargin-15,bars,ScreenWidth-RightMArgin-DivisounsWidth+50,bars);
 }
 strokeWeight(1);
 stroke(180);
 for(float x=0;x<=NumOfVertDivisions;x++){
int bars=(ScreenHeight-GraphYposition)-int(yRatio*(ScreenHeight)*(x/NumOfVertDivisions));
 line(LeftMargin-15,bars,ScreenWidth-RightMArgin-DivisounsWidth+50,bars);
 }
 strokeWeight(2);
 stroke(90);
```

```
 line(LeftMargin-15, ScreenHeight-GraphYposition+2, ScreenWidth-RightMArgin-DivisounsWidth+50,
ScreenHeight-GraphYposition+2);
 line(LeftMargin-15,ScreenHeight-GraphYposition+2,LeftMargin-15,GraphYposition);
 strokeWeight(1);
}
void Labels(){
 textFont(font,18);
 fill(50);
 rotate(radians(-90));
 text(yLabel,-ScreenHeight/2,LeftMargin-45);
 textFont(font,10);
 for(float x=0;x<=NumOfVertDivisions+1;x+=35){
int bars=(ScreenHeight-GraphYposition)-int(yRatio*(ScreenHeight)*(x/NumOfVertDivisions));
 text(round(x),-bars,LeftMargin-20);
 }
textFont(font,18);
 rotate(radians(90));
 text(xLabel,LeftMargin+(ScreenWidth-LeftMargin-RightMArgin-50)/2,ScreenHeight-
GraphYposition+40);
 textFont(font,24);
 fill(50);
 text(Heading,LeftMargin+(ScreenWidth-LeftMargin-RightMArgin-50)/2,70);
 textFont(font);
fill(150);
 text(URL,ScreenWidth-RightMArgin-40,ScreenHeight-15);
 textFont(font);
}
```