PRESSURE SENSING DURING CAST APPLICATION FOR A DISTAL RADIUS FRACTURE

BME 200/300 Design Project Fall 2015

Leader…..Hannah Lider[a]
Communicator…..Rachel Craven[a]
BWIG…..Makayla Kiersten[a]
BSAC…..Breanna Hagerty[a]
BPAG…..Alexandra Hadyka[a]

Client…..Matthew Halanski[b]
Advisor…..John Puccinelli[a]

[a]Department of Biomedical Engineering, University of Wisconsin-Madison, WI 53706
[b]University of Wisconsin School of Medicine and Public Health-Madison, WI 53726

7 October 2015

ABSTRACT

Problem Definition: Casting is becoming a lost art in medicine, yet many children and adults need casts applied. While this appears to be a benign treatment, complications are known to exist in the placement and removal of these devices. Typically medical students and residents learn these techniques by trial and error. Often direct oversight is lacking in the teaching of these techniques. **Design Process:** In this work, a system is designed to monitor the location and magnitude of force applied during cast application to a fracture model arm. Information collected from a sleek pressure sensing sleeve is displayed on a virtual 3D model of the arm. **Conclusions:** Students will be able to make appropriate adjustments according to real-time feedback. This device will assist students in observing how their applied forces affect the molding of a cast.

CONTENTS

1. INTRODUCTION

1.1 Client

Dr. Matthew Halanski specializes in pediatric orthopedic surgery at the University of Wisconsin School of Medicine and Public Health. Among others, his recent research interests include limiting patient morbidity by studying alternatives to invasive procedures. As internal fixation becomes an increasingly popular method of fracture management, Dr. Halanski believes formal instruction is lacking in extremity immobilization.

1.2 Problem Statement

Casting is becoming a lost art in medicine, yet many children and adults needs casts applied. While this appears to be a benign treatment, complications are known to exist in the placement and removal of these devices. Typically medical students and residents learn these techniques by trial and error. Often direct oversight is lacking in the teaching of these techniques. A pre-existing fracture model arm allows students the opportunity to practice cast application, but does not alert the user of improper location or amount of pressure applied. This team will design a device to sense pressure applied in specific areas of concern and give immediate feedback to the user via a visual interface.

1.3 Background

Distal radius fractures are one of the most common types of fractures and are predominantly associated with children and elderly persons. These breaks occur in the wrist approximately 2.54 cm from the distal end of the bone and can be be observed in various ways and levels of severity. In children, distal radius fractures account for 25% of fractures and are usually due to falling onto an extended arm [1]. In elderly patients this fracture accounts for 18% of breaks and is common in those suffering from osteoporosis, a condition which causes bones to become brittle [2]. Distal radius fractures are commonly healed using casts, a noninvasive procedure in which the limb is immobilized. Casting requires realigning the bone fragments in the wrist and wrapping the arm with layers of stockinet, webril, and plaster or fiberglass to provide external stability of the arm for proper healing. Although casting is a basic medical practice, complications can arise during the procedure and care must be taken to assure that the cast is applied properly. Improper cast application can lead to an array of further medical conditions such as abrasions, compartment syndrome, severe skin infections, and malunion. Compartment syndrome is caused by a combination of swelling of damaged tissue and tight casts which lead to built up pressure, a lack of blood flow, and permanent damage to muscles and nerves [6]. Very serious cases of compartment syndrome can lead to amputation of the affected limb [6]. Severe skin infections arise due to skin abrasions from friction between the cast and the arm. Some of these severe infections include necrotizing fasciitis and toxic shock syndrome, both of which can lead to permanent damage and very rarely death [7]. Malunion occurs when the fracture has been improperly set during casting causing it to heal incorrectly and leave a deformity in the bone [8].

1.4 Project Motivation

Because distal radius fractures are common breaks, it is important for medical students to learn proper casting techniques for this frequent treatment. Currently medical students are learning how to cast by observing professionals and trial and error practices. It is important that casts are applied with enough pressure to heal the fracture, but not too much so that the cast becomes too tight leading to pressure sores [3]. Medical students may be unfamiliar with the appropriate amount of pressure to apply when they first begin casting and could benefit greatly from a teaching tool. Ideally this tool would be a pressure sensing sleeve worn over an upper extremity fracture model. The student would be able to practice casting while the sleeve senses the pressure being applied to it. The information collected by the sleeve would be displayed with a 3D sensor map on a computer-aided design (CAD) model of the model arm, giving the student real-time visual feedback. This would allow for adjustments to be made as needed.

2. DESIGN PROCESS

The design can be broken up into two components: pressure sensors and a method of attaching them to the arm. While considering which type of sensors would be the most appropriate for this purpose, the team kept in mind the method of three point fixation used when applying a moulded plaster.

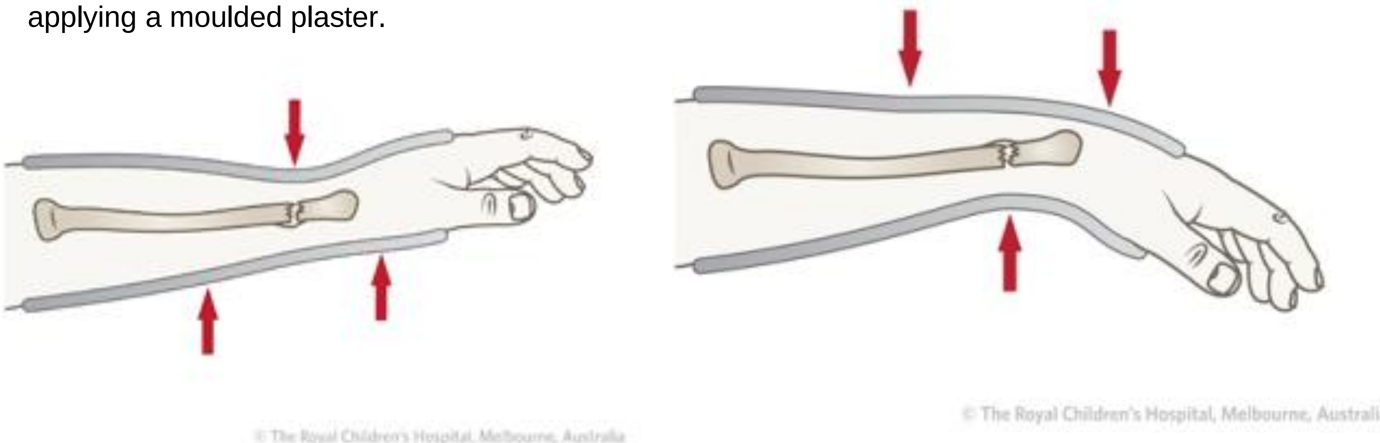

Figure 1. (a) If the distal fragment is angulated volarly, three point molding should cause slight wrist extension. (b) If the distal fragment is angulated dorsally, three point molding should cause slight wrist flexion. Images from www.rch.org.au [1]

The particular Sawbones model on which the device is to be used requires a cast with three point molding with slight wrist flexion. For this reason it is essential that applied force be monitored in these areas. Dr. Halanski described how it would be especially useful if pressure could be monitored throughout the entire surface area of cast application, although not required.

2.1 Pressure Sensing

Three methods of pressure sensing were researched and considered for their applications including: FlexiForce sensors, conductive thread, and Softpot membrane potentiometers. The client stressed the importance of creating a device that is sleek and has limited protrusions. Because of this, the sensors we considered for our sleeve had to be relatively flat and unnoticeable by feel. The first sensor considered was the FlexiForce sensor by TekScan. It is able to accurately read point loads up to 445N and doesn't change resistance when flexed. It comes in lengths varying from approximately 5 cm to 20 cm and has a sensing area of 0.95 cm^2. It is 0.2 mm thick which would cause it to go virtually unnoticed during the casting process [4]. These sensors have been used for force feedback in physical therapy and CPR manikins, both of which have similar applications to the pressure sensing sleeve.

Figure 2: FlexiForce Sensor image from www.tekscan.com[4]

The use of conductive thread to sense pressure was also considered. Conductive thread comes in various resistances and has the capability to carry a current. The thread could be used to sew a circuit directly onto the sleeve which would eliminate wires from the design leading to less protrusions. The biggest drawback of using conductive thread is that it necessitates a mostly, if not completely, custom sleeve making this option less feasible than the others considered.

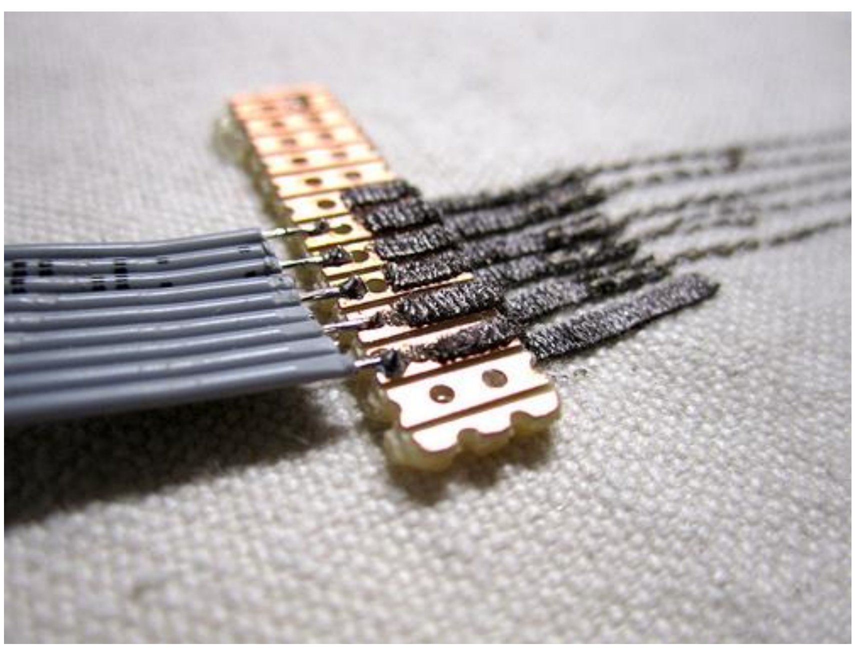

Figure 3. Sewing with top conductive thread to fabric breakouts and soldering wires to perfboard. Image from www.kobakant.at [10]

The third sensor considered is the Softpot membrane potentiometer. This sensor has a large resistance range (100Ω-10000Ω) and sensing area (40.64 cm^2). It has a thickness of .5 mm so it wouldn't interfere with the casting process [5]. The membrane potentiometer is manufactured with an adhesive backing which would allow the sensor to attach easily to the sleeve. This would also inhibit movement of the sensors during the casting procedures.

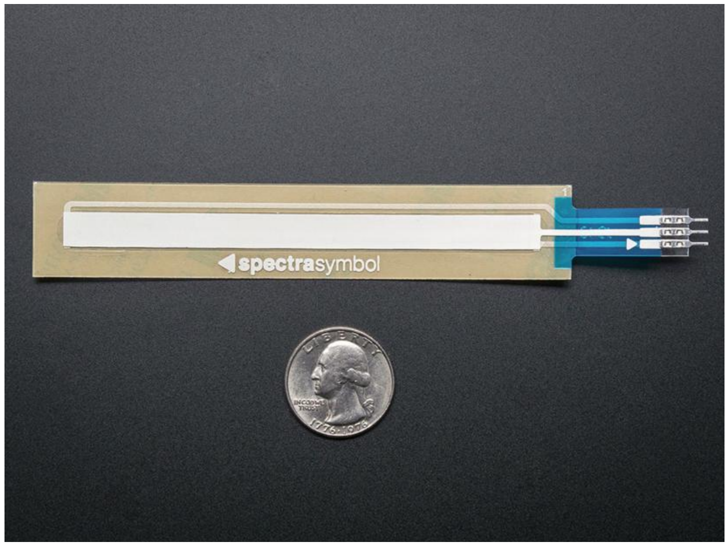

Figure 4. Softpot Membrane Potentiometer with quarter shown for size.
Image from www.adafruit.com [11]

2.2 Methods of Attachment

Method of attachment is also an important design consideration because the sensors need to be applied to the arm but cannot be directly attached to it. Pre-existing, professional compression sleeves and homemade sleeves are the attachment options. Using a professional sleeve would provide more professional pattern and fabrication. This professional stitching would lead to higher quality of the garment. The pre-existing compression sleeve could be stretched over the arm and rolled up or down for removal or application, but this would most likely disturb the sensor. A possible solution would be to cut a seam along the side of the wrist into which Velcro could be sewn. With this additional seam, the sleeve would have a more adjustable fit and be easier to remove from the model arm. A variety of sleeve length are available, but a glove which extends past the elbow would increase the anchorage of the fabric during the setting process.

Figure 5. Existing Edema Compression Glove.
Image from www.pattersonmedical.com [12]

A custom sleeve patterned to the Sawbones model could also be fabricated. Custom fabrication would allow for more material options. This may simplify the waterproofing process depending on the inherent water resistance of the material used. The custom sleeve would be specific to the Sawbones model dimensions. The circumference at the smallest point (wrist) is 19 cm and the circumference at the largest point (bicep) is 37.5 cm. A custom sleeve should have a length of approximately 27 cm to cover the forearm with another 6 cm to secure the fabric below the elbow. As before, the custom design could either be sewn as a whole sleeve or be fitted with Velcro to allow for easier removability. If conductive thread is chosen for the pressure sensing aspect of the design, a custom sleeve would have to be made.

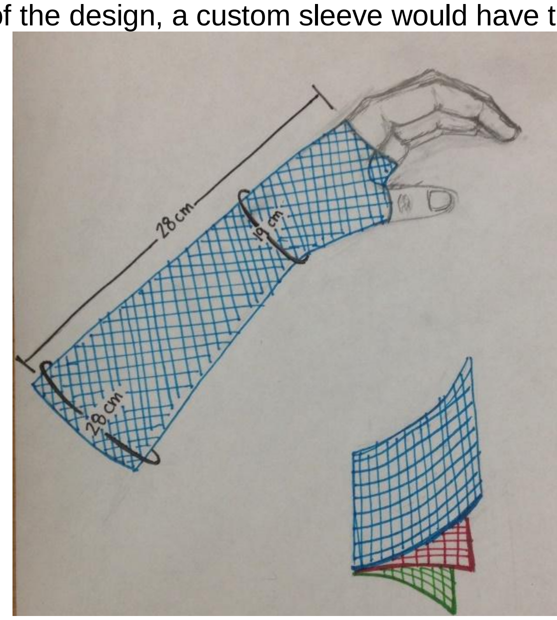

Figure 6. Sketch of Custom Compression Glove

2.3 Evaluation of Preliminary Designs

A major component of the design is its pressure sensing ability. The goal is to obtain change in pressure readings throughout the casting process. These sensors were rated based on the following criteria: feel, feasibility, sensitivity, durability, safety, fit, accuracy, and cost. Feel is the most important aspect because the device must be sleek and protrusions should be kept to the minimal. Casting with the device should be similar in feel to casting on a real patient. Feasibility was another top criteria because only one semester is allowed to create the device and the sensors should be practical and easy to use. Sensitivity relates to the sensor's ability to notice changes in force applied to it. If the sensor doesn't pick up on the pressure applied to it, there will be no feedback. Since the device will be put through the casting process numerous times, it must be durable and able to withstand moisture and repeated compressive forces. Safety is an important aspect of every design; if something isn't safe, it should not be on the market. Accuracy of readings isn't extremely important because the client is more concerned with measuring changes in pressure as opposed to absolute values. Fit is another category that must be considered. The sensors will be fixated to the arm and compressed during casting, so they need to be able to move with the arm and not wrinkle when bent. Cost must also be accounted for but is not a real issue for this project and all of the sensors are relatively inexpensive.

Pressure Sensors	Flexiforce	Conductive Thread	SoftPot Membrane Potentiometer
Feel (25)	(4/5) 20	(3/5) 15	(4/5) 20
Feasibility (20)	(4/5) 16	(3/5) 12	(4/5) 16
Sensitivity (15)	(5/5) 15	(5/5) 15	(4/5) 10
Durability (10)	(4/5) 8	(4/5) 8	(4/5) 8
Safety (10)	(5/5) 10	(5/5) 10	(5/5) 10
Fit (10)	(4/5) 8	(5/5) 10	(3/5) 6
Accuracy (5)	(4/5) 4	(2/5) 2	(3/5) 3
Cost (5)	(3/5) 3	(5/5) 5	(4/5) 4
Total: 100	84/100	77/100	77/100

Table 1: Pressure Sensing Design Matrix

The FlexiForce sensors won out in the top five categories which led to them being our overall winner. The other two options have respectable numbers and tied for second place. The FlexiForce sensors are very thin, giving them minimal feel with high sensitivity.

The method of attaching the sensors is another important design component. As before, it is critical that the device is sleek and doesn't interfere with the casting process. Methods of attachment were assessed based on the following criteria: functionality, bulkiness, removability, feasibility, durability, safety, cost, and aesthetics. Functionality is considered our top criteria because if the sleeve does not provide secure attachment for the sensors then it is useless. The sleeve cannot be bulky because that would interfere with the feel of the arm, and thus the medical students' learning because the teaching model would be tactilely unrealistic. As per the client's request, the sleeve should also be easily removable. Feasibility is again important because we have to be able to construct the device in one semester, and it should be easy to use. As with the sensors, the attachment device will undergo numerous iterations of the casting process and must be durable. Safety must be taken into account but is virtually not an issue because there will be no hazardous materials used. Since the materials we are looking at are quite cheap, cost is not a large concern for any of the designs. Lastly, we want our product to be aesthetically pleasing; however, how well our device functions is more important than how it looks.

Method of attachment	Compression Sleeve	Compression Sleeve - Velcro	Complete Custom Sleeve	Custom Sleeve - Velcro
Functionality (25)	(2/5) 10	(4/5) 20	(3/5) 15	(4/5) 20
Bulkiness (20)	(5/5) 20	(4/5) 16	(4/5) 16	(4/5) 16
Removability (20)	(3/5) 12	(5/5) 20	(3/5)	(5/5) 20
Feasibility (15)	(5/5) 15	(4/5) 12	(2/5) 6	(3/5) 9
Durability (10)	(4/5) 8	(4/5) 8	(3/5) 6	(3/5) 6
Safety (5)	(5/5) 5	(5/5) 5	(5/5) 5	(5/5) 5
Cost (5)	(5/5) 5	(5/5) 5	(4/5) 4	(4/5) 4
Aesthetics (5)	(5/5) 5	(5/5) 5	(4/5) 4	(4/5) 4
Total: 100	80/100	91/100	68/100	84/100

Table 2: Method of Attachment Design Matrix

The compression sleeve attached with Velcro is the clear winner of the four. It would be professionally sewn with strong stitching and professionally patterned to the shape of the hand and wrist. Once fitted with Velcro, the sleeve would be very simple to remove and would fit snug against the arm.

3. FUTURE WORK

3.1 LabVIEW

One of the most emphasized requirements of this device is that it includes a real-time visual display of the magnitude and location applied forces. Using LabVIEW 3D sensor mapping feature, data collected by the pressure sensors can be mapped directly onto a user-defined CAD model. This display will provide the student a precise visual on how acquired data corresponds to specific regions of the arm. The actual data acquisition channels can be assigned and displayed on the LabVIEW front panel. This team will begin with attempting to create a CAD model by imaging the arm using the 3D motion capture system located in the Badger Athletic Performance Center, with the help of Mikel Stiffler.

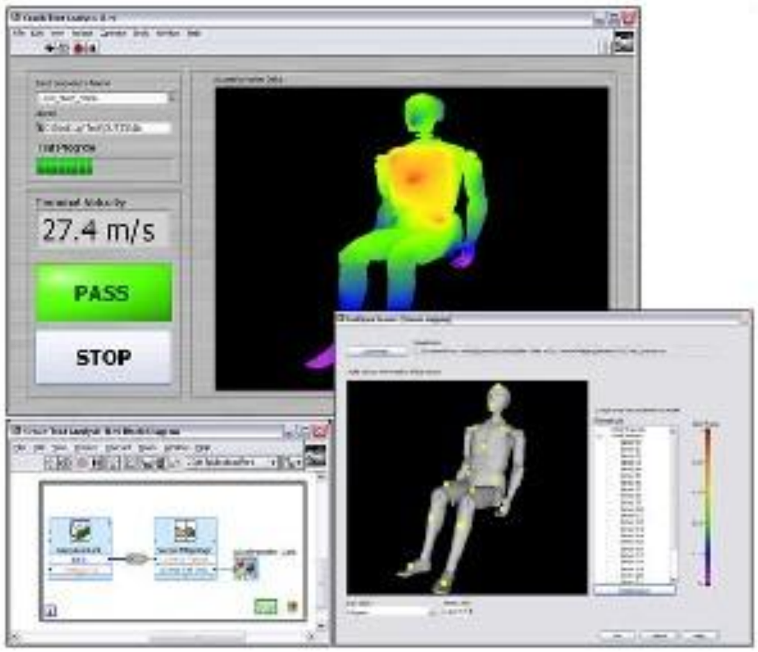

Figure 7. LabVIEW 3D Sensor Mapping Express VI
Image from www.ni.com [13]

3.2 Circuit Design

The pressure sensing device will function as a resistor in a circuit and obstruct the flow of current. To determine the resistance value of our sensing device we'll have to utilize the equation $R_2 = (V_{out} * R1) / (V_{in} – V_{out})$. We'll have a series circuit with a resistor of a known value placed next to the sensor (values to be determined). R_1 is the known resistor value, V_{in} is the voltage being put into the circuit, and V_{out} is the voltage being produced by the circuit and will be measured. From those three values, the resistance of the sensor can be calculated.

4. DISCUSSION & CONCLUSION

This device could change the way medical students learn and administer casts for the betterment of all patients. With the ability to practice many times on a nonhuman model and receive live feedback of applied pressure, casting injuries should drop and casting technique should drastically improve. The client's work is focused in pediatrics, and children are one of the highest at-risk groups for casting complications [7]. Children are considered an at-risk group because of their inability to verbalize exactly what they are feeling when complications arise and the dismissal of their complaints as those of regular discomfort. The purpose of this teaching device is to diminish these complications and achieve an overall improved casting experience for both medical students and their future patients.

5. REFERENCES

1. Nellans, Kate (2012). The Epidemiology of Distal Radius Fracture. Retrieved from http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3345129/
2. AAOS (2013). Distal Radius Fractures (Broken Wrist). Retrieved from http://orthoinfo.aaos.org/topic.cfm?topic=a00412
3. DryCast (2013). Cast Complications. Retrieved from http://www.drycast.com/blogs/blog/8382035-cast-complications
4. Tekscan (2015). Force Sensors. Retrieved from https://www.tekscan.com/product-group/embedded-sensing/force-sensors
5. Spectra Symbol (2015). SoftPot Datasheets. Retrieved from http://www.spectrasymbol.com/potentiometer/softpot/softpot-datasheet
6. C. Benjamin (2014). Compartment Syndrome. Retrieved from https://www.nlm.nih.gov/medlineplus/ency/article/001224.htm
7. Delasobera, Elizabeth (2011). Serious Infectious Complications Related to Extremity Cast/Splint Placement in Children. Retrieved from http://www.medscape.com/viewarticle/746890_2
8. Brown, Jennifer (2014). Cast Care. Retrieved from http://www.emedicinehealth.com/cast_care/page7_em.htm
9. The Royal Children's Hospital Melbourne. Retrieved from http://www.rch.org.au/clinicalguide/guideline_index/fractures/Distal_radius_and_or_ulna_metaphyseal_fractures_Emergency_Department_setting/
10. *How to Get What You Want,* Machine-sewable Hard/Soft Connections. Retrieved from http://www.kobakant.at/DIY/?p=1272
11. Adafruit. Retrieved from http://www.adafruit.com/search?q=softpot&b=1
12. Patterson Medical. Retrieved from http://www.pattersonmedical.com/app.aspx?cmd=getProduct&key=IF_45672
13. National Instruments, *Connect Sensor Data to 3D Models*. Retrieved from http://www.ni.com/white-paper/7335/en/

6. APPENDIX

Preliminary Product Design Specifications September 18, 2015

Function: Casting is becoming a lost art in medicine, yet many children and adults need casts applied. While this appears to be a benign treatment, complications are known to exist in the placement and removal of these devices. Typically medical students and residents learn these techniques by trial and error. Often direct oversight is lacking in the teaching of these techniques. The client would like a supplement to an already existing fracture model arm that can aid medical students in learning how to appropriately apply casts for distal radius fractures. The device will sense pressure applied to specified areas of the arm/hand and give immediate feedback to the use via a visual interface.

Client Requirements:

- Create an easily removable device for a fracture model arm
- Monitor pressure at specified locations
- Visually display applied pressure

Design Requirements

1. Physical and Operational Characteristics
    a. *Performance Requirements:* Pressure sensing device must be sufficiently affixed to the arm such that sensors are not moving during the procedure. Display must then give immediate visual and quantitative feedback of applied pressure to specified areas.
    b. *Safety:* The product must not damage the model arm or the user.
    c. *Accuracy and Reliability:* Not a great amount of sensitivity is necessary on the lower threshold of pressure, but the device should be able to measure when an excessive and potentially dangerous amount of force is being applied (upwards of 700 N).
    d. *Operating Environment:* Device will be used in a medical classroom setting as well as hospitals and will be subjected to a range of pressures.
    e. *Ergonomics*: Should be able to withstand maximum human grip strength forces of up to 700 N and 25 kN/m of torque.
    f. *Size:* The device must cover the model sawbone arm that has a circumference of 19 cm at the smallest point (the wrist) and a circumference of 37.5 cm at the largest point (the bicep). Its length should fall between 25.4 and 30.5 cm.
    g. *Materials:* Device should use materials which will not be damaged by the plaster or fiberglass materials used in the casting process. Materials should be relatively flat to keep a realistic feel. Materials must not damage the arm model with regular use.
    h. *Aesthetics, Appearance, and Finish:* Device should have a smooth feel and appearance with limited protrusions. Display of feedback should be visually descriptive and given on a laptop or tablet.

2. Production Characteristics
    a. *Quantity:* One complete device is necessary for Dr. Halanski’s purposes.
    b. *Target Product Cost:* The total cost of the device should be less than $1000.

3. Miscellaneous

    a. *Customer:* After practicing with this product, medical students should have knowledge of the proper pressure to apply during the casting process.

b. *Patient Related Concerns*: The device is to be used on a teaching model, not an actual patient. However, it must be assured that the device accomplishes given requirements to make sufficient teaching possible.
c. *Competition:* There are currently no pressure sensing devices on the market that assist in the teaching of cast application. Medical students traditionally learn how to apply appropriate amounts of pressure during casting by observing and doing.