Development of an Upper Extremity Fracture Model

Kimberly Maciolek[1] (Team Leader), Gabriel Bautista[1] (BSAC), Kevin Beene[1] (BWIG), Hope Marshall[1] (Communicator)

Client: Dr. Matthew Halanski[2] · Advisor: Dr. Thomas Yen[1]

[1]Department of Biomedical Engineering, University of Wisconsin-Madison

[2]Department of Orthopedics and Rehabilitation, University of Wisconsin School of Medicine & Public Health

1. Abstract

Bone fractures to the distal radius and ulna are one of the most common pediatric ailments. Casting is often preferred as the common treatment method for pediatric forearm fractures, yet residents often learn such techniques through trial and error, leading to complications arising from cast application or removal. Therefore, a pediatric fracture simulator is needed to teach proper techniques of cast application, reduction, immobilization, and cast removal. The fracture simulator must provide immediate feedback to the user and monitor fracture reduction, force applied during three-point molding, and temperature of skin surface. The final design will utilize latex surgical tubing to maintain the angulated position of the forearm fracture and will also include a pressure mapping system, thermistors, and finally flex sensors to indicate proper alignment. Additional design components include an aluminum screen double-layer to protect the sensors, inductive sensors to measure cast saw location relative to skin, and tissue-mimicking materials for skin, soft tissue and bone. Once the client and other medical professionals have tested the final device and all appropriate adjustments have been made, the design will be validated through use by casting experts at the Pediatric Orthopedic Society of North America (POSNA) national meeting.

2. Background/Motivation

Motivation:

- Casting immobilization has become a lost art
- Young physicians learn casting techniques via trial and error
- Increased risk for patients
- 40% of fractures among children involve the forearm
- Teach proper techniques of cast application, reduction, immobilization, and cast removal

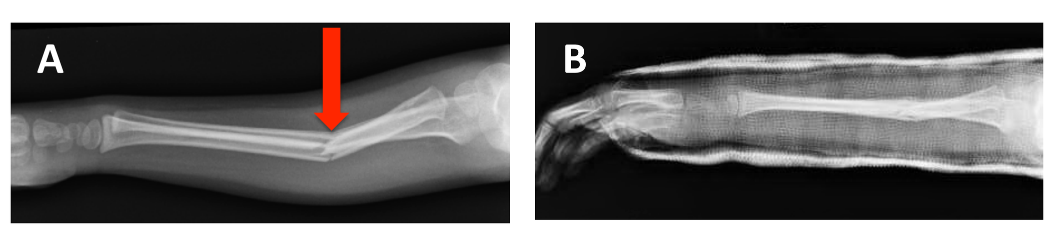


Figure 1: A. X-ray of green stick fracture. B. X-ray of properly reduced green stick fracture [1]

Background:

Casting Process

- Assess the fracture via x-ray
- Determine best treatment option
- Use 3-point molding technique to reduce the fracture
- Maintain pressure and apply casting material, commonly plaster or fiberglass

Complications

- Cast application
  - Temperature of casting materials
  - Soft tissue irritation
  - Loss of fracture reduction if loose
  - Rigid tourniquet if too tight
- Cast removal
  - Cast saw burns

Figure 2: Example of burns and cuts from cast saw [2]

3. Design Specifications

The final simulator should:

•Closely resemble the resistance and feel of a fracture

•Be reusable

•Easy for one person to transport

•18cm from elbow to wrist

•5-6cm in diameter

The simulator should provide immediate feedback to the user:

•Fracture reduction/alignment:

-Translation not more than 2mm

-Rotation not more than 15°

•Display real-time force applied during three point molding

•Display temperature of skin surface and saw blade

4. Design Components

Mechanical Resistance Structure

A.Spring Design

B.Band Design

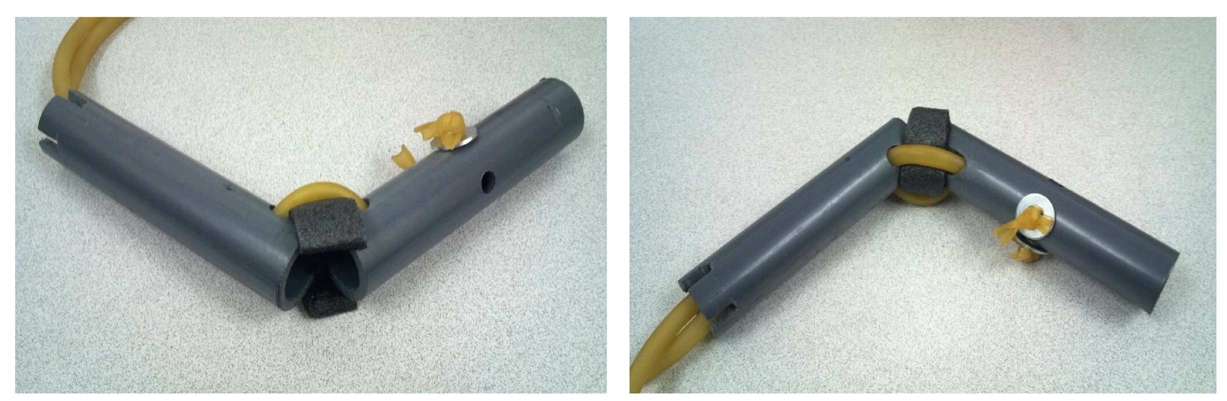
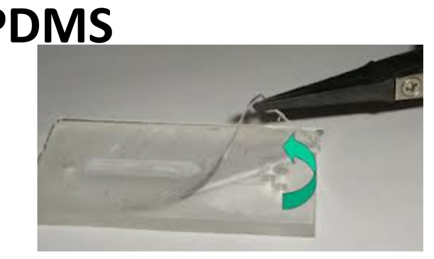


Figure 3: Mechanical Resistance Structure; A. Spring Design, B. Band Design [3]

Tissue Mimicking Material

A.PDMS

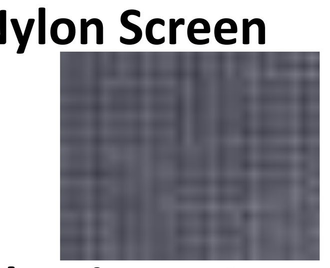


B.PlatSil

Figure 4: Tissue Mimicking Materials. A. PDMS B. Platsil [4]

Protective Layer

A.Nylon Screen



B.Aluminum Screen

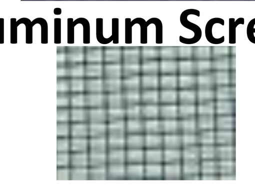
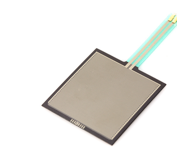


Figure 5: Protective Layer A. Nylon Screen B. Aluminum Screen [5]

Sensors

A.Thermistor

B.Force Sensing Resistor



C.Flex Sensor

Figure 6: Sensors; A. Thermistor, B. Force Sensing Resistior, C. Flex Sensor [6]

User Interface

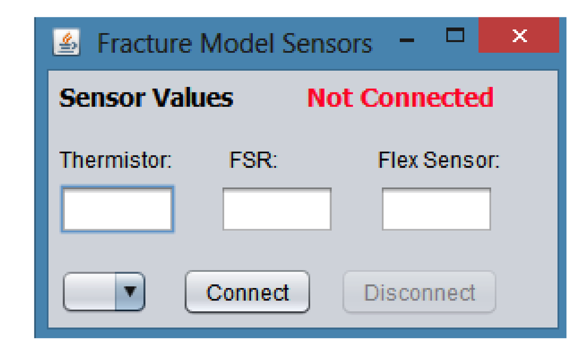


Figure 7: User Interface [7]

5. Testing

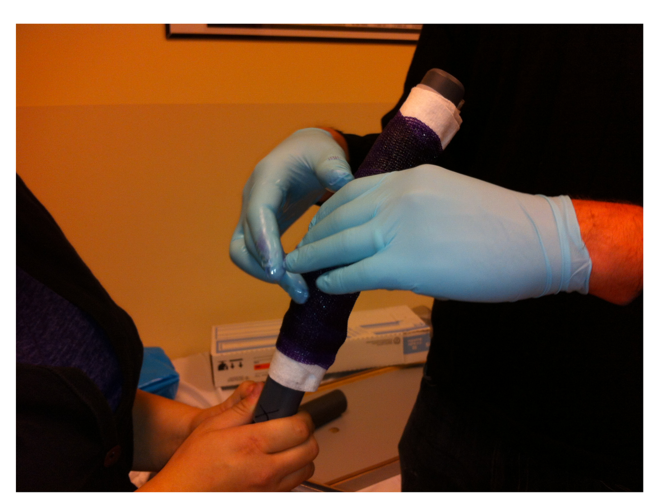
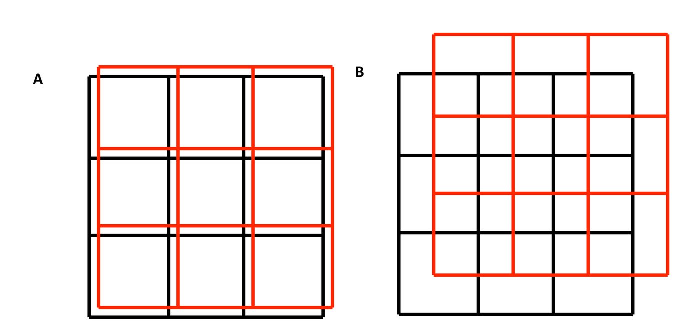


Figure 8: Testing cast application. Picture courtesy of Hope Marshall



A. Overlapped B. Offset

Figure 8: Orientation description of screen positions for protective material testing.

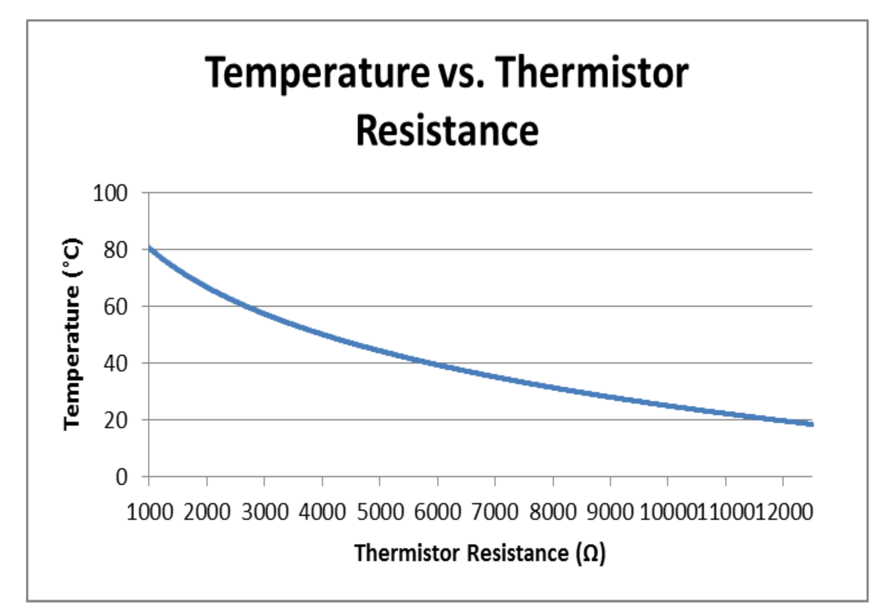


Figure 9: Temperature vs. Thermistor Resistance.

Table 1. Protective Material Testing

Material	Layers	Orientation	Cut PlatSil
Nylon	1	-	Yes
	2	A	Yes
	2	B	Yes
Aluminum	1	-	Yes
	2	A	Yes
	2	B	No

Table 2. Spring Constant Testing. A. Band Design, B. Spring Design

A.

Mas s (kg)	F (N)	x (m)
0	0	0
0.5	4.9 05N	0.0 12
1	9.8 1 N	0.0 33
1.5	14. 72N	0.0 72
1.7	16. 67N	0.0 88

A. $k = -8.0\times10^{-3}$ N/m

B.

Mas s (kg)	F (N)	x (m)
0	0	0
0.5	4.9 05N	0.0 01
1	9.8 1 N	0.0 03
1.5	14. 72N	0.0 05
1.7	16. 67N	0.0 06

B. $k = -4.077\times10^{-4}$ N/m

Steinhart-Hart Equation

$$\frac{1}{T} = A + B\ln(R) + C(\ln(R))^3$$

Steinhart-Hart Coefficients

A = 0.0029319432

B = -0.00118805

C = 0.000006401

Voltage Divider Equation

$$V_{\text{out}} = \frac{R_2}{R_1 + R_2} \cdot V_{\text{in}}$$

Qualitative Comparisons:

•The client was unable to damage the 3:1 ratio of PDMS skin material with the cast saw, but damaged the 5:1 ratio PDMS

•Client preferred the band design for the fracture resistance component over the spring design, as it closely matched the feel of a fracture

6. Future Work

- 3D print final mechanical resistance component, including crank system for modular resistance
- Test temperature conduction of PDMS skin material
- Develop method to remove layers to access mechanical resistance component easily
- Purchase & integrate pressure mapping system
- Update user interface to include all sensors

7. Final Design

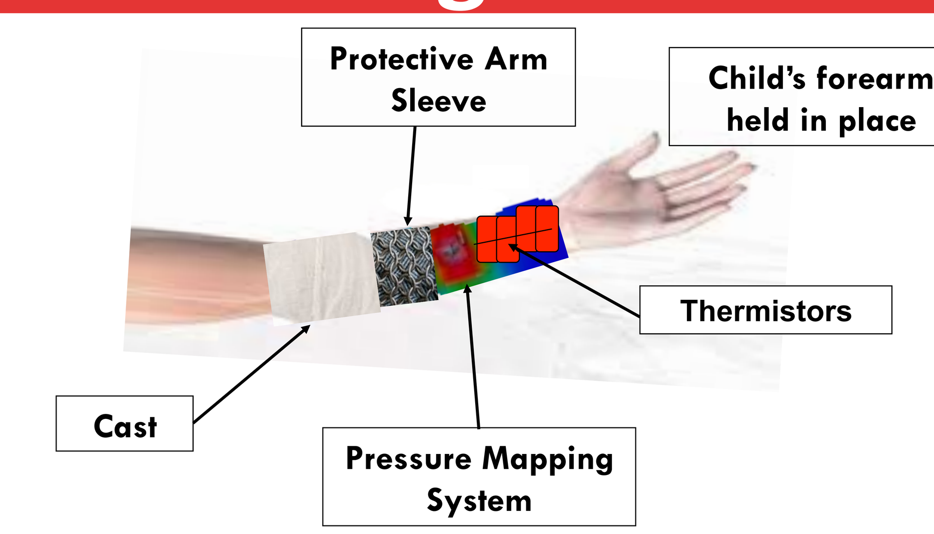


Figure 10: Final Design courtesy of Hope Marshall

8. Cost Analysis

Table 4. Current Budget

Material	Quantity	Cost
Plywood Base	1	$5
PVC Pipes	1	$0
Thermistor	3	$3.24
Force Sensing Resistor	1	$20
Arduino Mega Microcontroller	1	$47.99
Arduino Starter kit	1	$22.50
Protective Sleeve material	2 square ft.	$0.85
PDMS	500 grams	$60
PlatSil Gel-10	2 lbs	$47
USB A-B Cable	1	$4.00
1/4" ID Latex Surgical Tubing	5 ft	$13.50
Prewrap material	1 roll	$5
Flex Sensor	2	$24.90
Miscelaneous Mechanical Components	-	$0
	TOTAL:	$248.98

Table 5. Future Budget Predictions

Additional Materials	Quantity	Cost Estimate
PVC Pipes	1	$20
Thermistors	12	$13.00
Protective Sleeve material	10 square ft.	$5.00
PlatSil Gel-10	10 lbs	$250.00
1/8" ID Latex Surgical Tubing	10 ft	$27.00
Flex Sensors	6	$75.00
Pressure Mapping system	1	$4500
Miscellaneous Mechanical and electrical Components	-	$30
	TOTAL:	$4920.00

*Note: The total cost of the fracture simulator based on future cost analysis is: $5163.98, which is within the budgetary limits.

9. Acknowledgements

Special thanks to: Dr. Matthew Halanski (client), Dr. Thomas Yen (advisor), Dr. John Puccinelli (materials consultant) & W. John Kao (materials consultant)

10.References

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[3] Photos. Dr. Matthew Halanski.

[4] Duke Orthopaedics. Green Stick Frx of Forearm. *Wheeless' Textbook of Orthopaedics.* Online: http://www.wheelessonline.com/ortho/green_stick_frx_of_forearm

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