Development of an Upper Extremity Fracture Model

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1. Abstract

Improper bone alignment during bone fracture reduction or burns from cast removal by physicians can lead to severe and costly complications for the patient, especially in children. A pediatric fracture simulator that provides immediate feedback, in the form of pressure, align-ment, and temperature data, will provide an improved and cost effective training for the physicians. The final design consists of the following components from internal to external order (function described): an artificial PVC bone structure, tensioning system (provide resistance to proper alignment), potentiometer sensors (indicate alignment), custom molded Plat-Sil 10 layer (mimic muscle), pressure mapping system (indicate proper force application), temperature sensors (alter for possible skin burns), Kevlar protective mesh strip (prevent sensors from data), and a custom user interface (display sensor values). Temperature sensors were calibrated for 20°C to 80°C. Alignment sensors were tested at set angles and verified using X-ray during the casting process. The device closely mimics the feel of a real fractured wrist according to our client, a practicing orthopedic surgeon. Currently, there are no competing commercially available devices that allow physicians to train on proper fracture reduction. The fracture simulator gives physicians the opportunity to gain more hands-on experience in properly reducing fractures before ever having to practice on a live patient and without the risk of possible litigation.

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 [1]

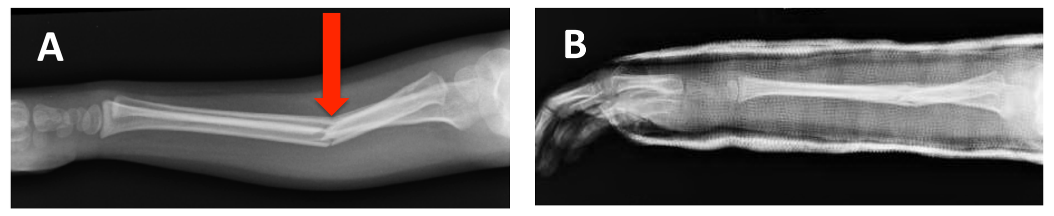

Figure 1: A. X-ray of green stick fracture. B. X-ray of properly reduced green stick fracture [1]

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 [2]


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 2 mm
  - Rotation not more than 15°

• Display real-time force applied during three-point molding

• Display temperature of skin surface

4. Final Design

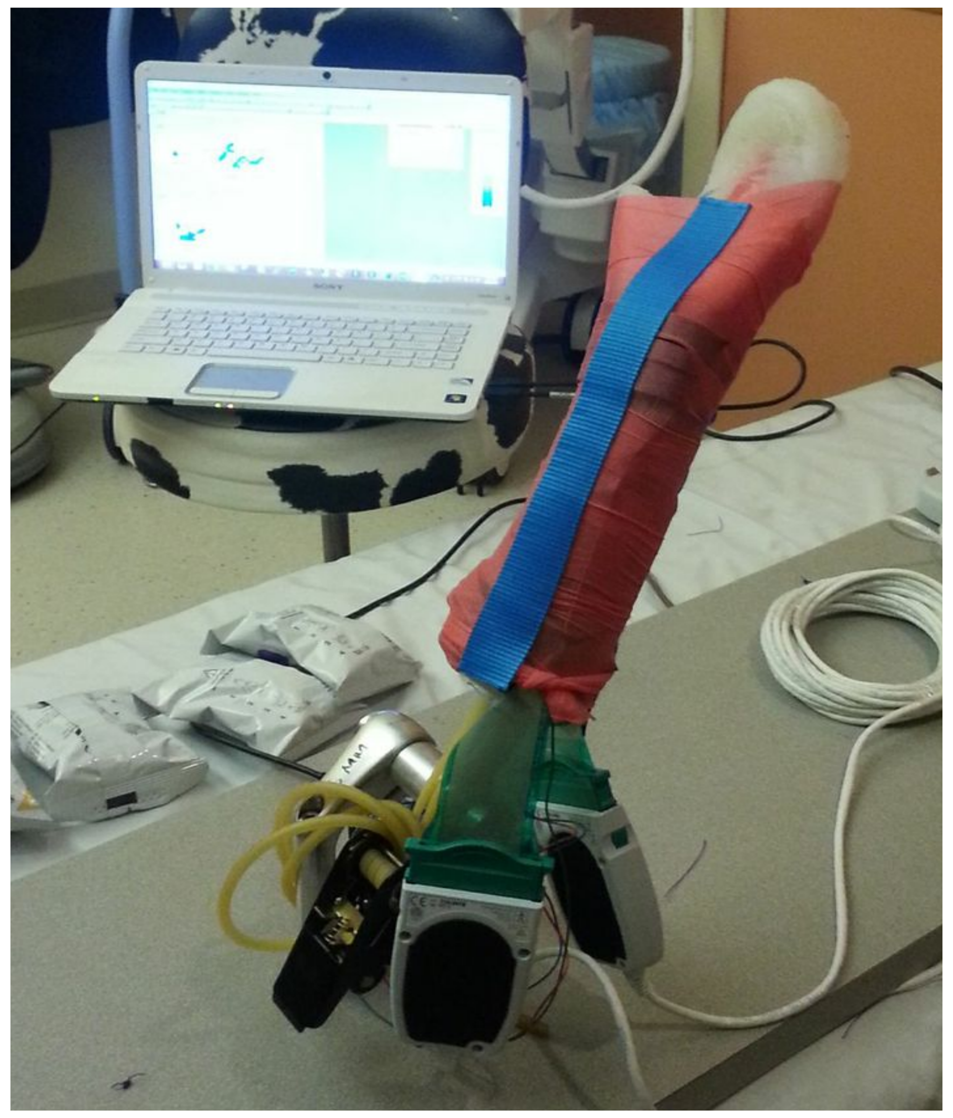
Figure 3: Final Design with all components [3]

Alignment Sensors


Figure 4: Alignment sensors on end caps [3]

User Interface

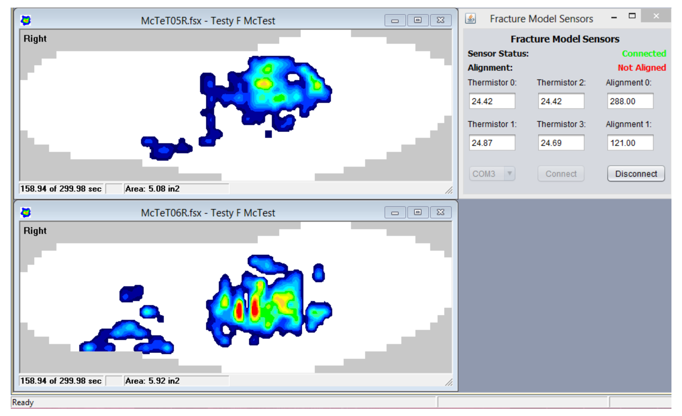
Figure 6: User interface with immediate user feedback [3]

Fracture Mechanical Structure

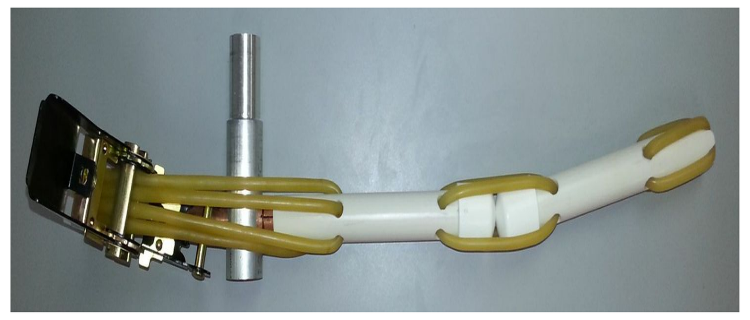
Figure 5: PVC pipes with surgical latex tubing [3]

Pressure Mapping System

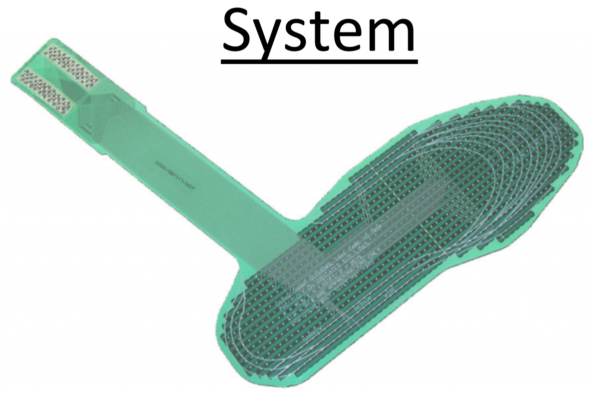
Figure 7: Tekscan pressure mapping system [3]

5. Testing

Qualitative and Baseline Testing


Figure 8: Dr. Halanski performing casting procedure [3]

- Client approved of the final design as it closely mimicked the feel of a fracture
- Suggested placing the fracture more distal
- Client performed casting procedure on simulator; force and alignment data recorded to use as baseline data to provide user feedback indicating successful fracture reduction

X-ray Images

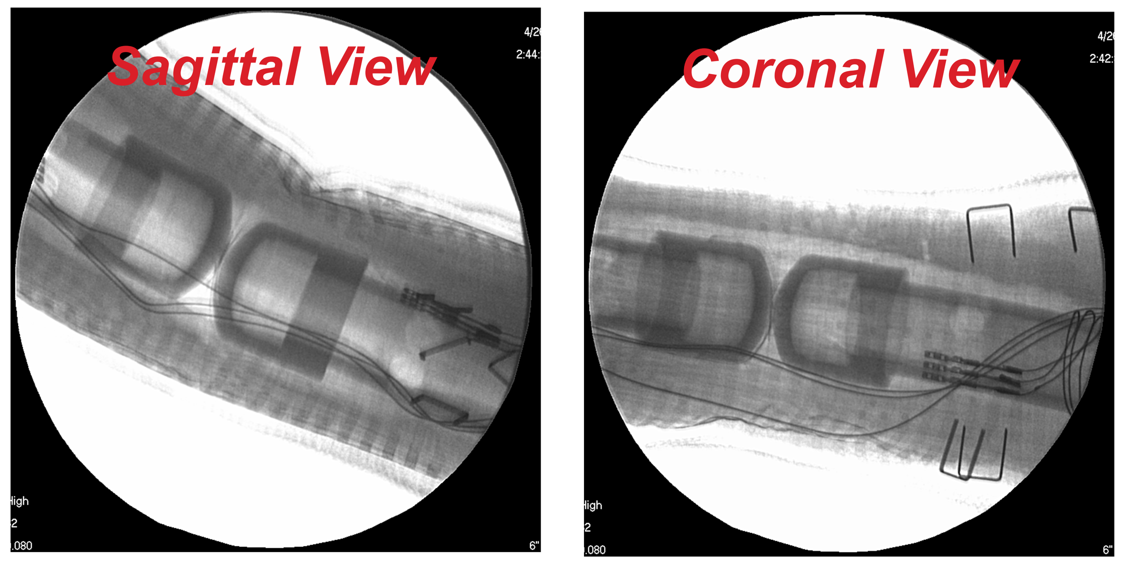

Figure 9: X-ray image of immobilized simulated fracture [3]

Alignment Testing

- Used ImageJ to analyze series of photos of fracture at various angles
- Data used to determine range for successful alignment
- Successful range of 436-586Ω

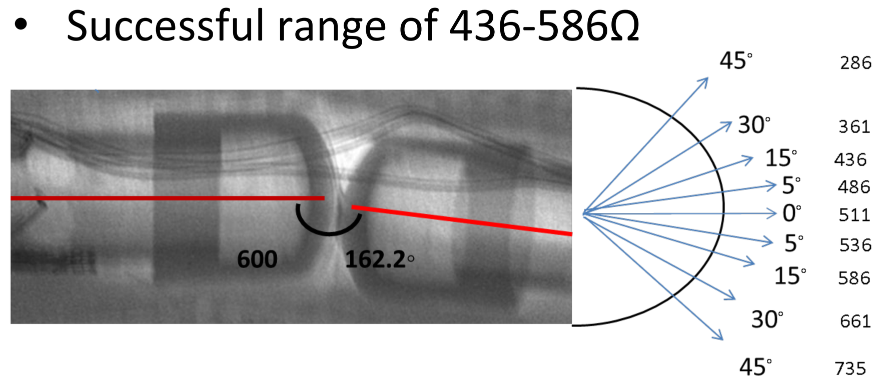

Figure 10: Correlation between potentiometer resistance and fracture angle [3]

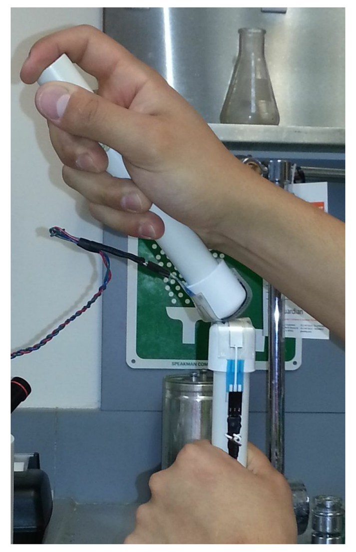
Figure 11: Alignment testing [3]

Thermistor Testing

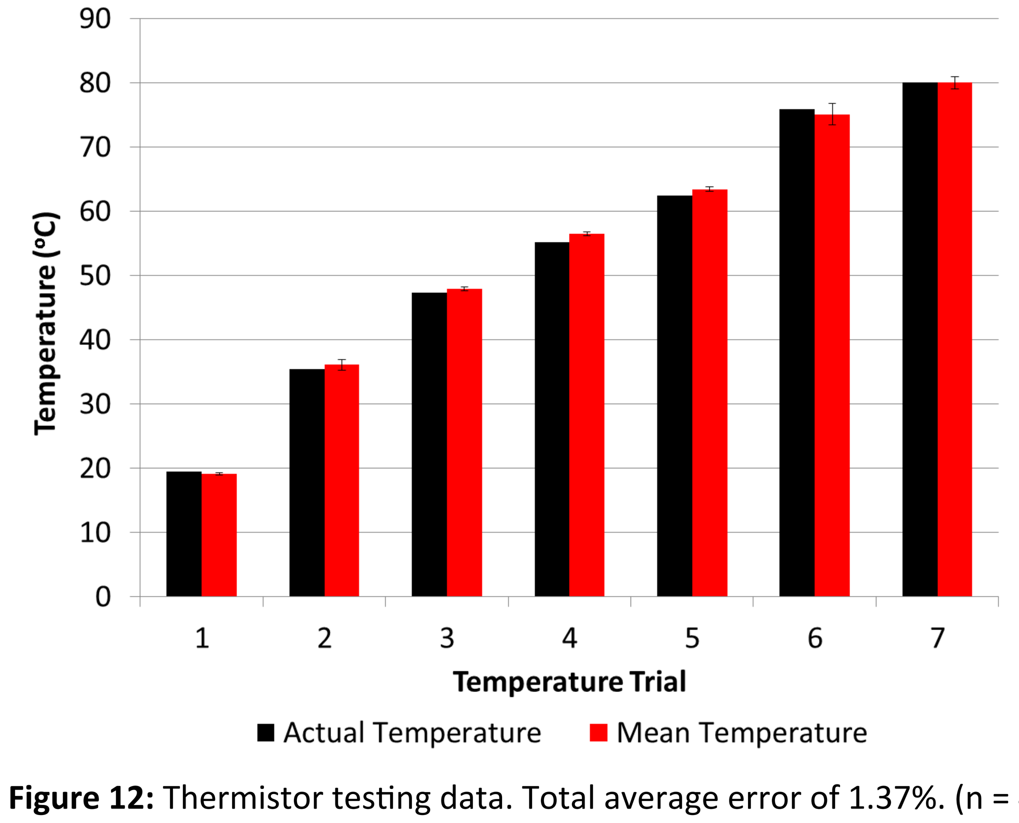

Figure 12: Thermistor testing data. Total average error of 1.37%. (n = 4) [3]

6. Future Work

- Complete baseline testing with additional experts
  - Collect force data from expert orthopedic surgeons
  - Develop force range for successful reduction
- Distinguish translational from rotational alignment
- Complete learning tool evaluation
  - Test with experienced orthopedic surgeons and inexperienced residents
  - Each user is his/her own control
  - Test, practice, retest
  - Evaluate improvement over time
- Customized pressure mapping system
- Modulate resistance of surgical latex tubing
  - Allow for different user experience
  - Consistent resistance between users
- Customized protective sleeve for PlatSil Gel-10 layer

7. Cost Analysis

Material	Quantity	Cost
Pressure Mapping System	1	$9,334
PlatSil Gel-10	6 lbs	$116
Arduino Mega Microcontroller	1	$47.99
Potentiometers	2	$22
Arduino Starter kit	1	$22.50
1/8” ID Latex Surgical Tubing	10 ft	$17.00
Crimps and heat shrink tubing	1	$15
Ratchet tie-downs	1 set	$10.89
Thermistors	16	$11
Arduino project box	1	$10
Proto shield	1	$8
Aluminum screen material	1 roll	$7
Op amps	4	$7.00
Ethernet Jack	1	$7.00
Pre-wrap material	1 roll	$5
Project box	1	$3.49
PVC caps	8	$4
USB A-B Cable	1	$4.00
PVC Pipes	1	$1
Mechanical Components	-	$0
	TOTAL:	$9,652.87

8. Acknowledgements

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9. References

[1] Erik M Hedstrom, Olle Svensson, et al. Epidemiology of fractures in children and adolescents: Increased incidence over the past decade: a population-based study from northern Sweden. *Acta Orthopaedica* 2010; 81 (1): 148.

[2] Halanski M, Noonan KJ. Cast and splint immobilization: complications. *J Am Acad Orthop Surg* 2008 January;16(1):30-40.

[3] Images courtesy of Dr. Matthew Halanski and design team.