Development of a Sensorized Distal Radius Fracture Model for Teaching Casting via Simulated Fluoroscopy

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Background: Proper angle reduction and casting is vital to overall recovery, but medical students and orthopedic residents have no means to receive objective, real-time feedback when learning the casting process. The development of a distal radius fracture training model is described; i.e., the teaching tool allows users to train proper fracture realignment while displaying a target force range and a simulated fluoroscopy display synchronized with the actual angle of reduction.

Methods: A prototype for fracture reduction training and evaluation was developed using a modified Sawbones® distal radius fracture model. The model was retrofitted with a force-sensing linear potentiometer and inertial measurement units that allow for a readout of reduction quality to the user via a graphical user interface. Tests were developed to ensure the force-sensing linear potentiometer could detect a range of 1-100 N, accurate to ± 1 N, and the angular sensors are accurate to ± 2°. Through usability testing and participant evaluation, benchmark values were created for determining casting competency.

Results: N/A

Conclusions: We developed a sensorized distal radius fracture model for teaching and evaluating casting via simulated fluoroscopy.

Clinical Significance: Non-surgical reduction of distal radius fractures have greater than a 23.5% rate of malunion upon final recovery[1]. Training simulators that include real-time objective feedback of performance could improve the proficiency of trainees, reducing malunion rates.

Teaching and training residents in orthopedic surgery is an ever-changing task. With a decrease in the number of hours spent per day working, and an increase in the complexity of many procedures, there is a greater need for efficient ways to train surgical residents. Currently, programs are becoming increasingly interested in the use of simulators to realistically replicate orthopedic procedures. This could facilitate students becoming proficient in the specified task before they assume any risk associated with a real patient.

One of the most common procedures handled by orthotopic surgeons is the reduction of a distal radius fracture (DRF). This is due do the high frequency of DRFs, with one-sixth of all adult and one-third of all pediatric fractures treated in emergency departments occurring on the distal radius[2,3]. Although this is one of the most common fractures treated, reduction and casting of a DRF is frequently done improperly. Findings indicate that non-surgical DRF casting techniques result in a 23.5% rate of malunion[1]. Malunion is considered any misalignment in the fully healed bone that leaves the patient with a recordable loss of functionality on the arm associated with the facture. While the angle of misalignment associated with malunion is highly variable, misalignments greater than 10 to 15 degrees tend to be where malunion symptoms occur[4]. Development of a simulator that can reliably teach surgical residents how to reduce and cast a DRF with less than 10 degrees of misalignment could greatly improve overall outcomes of patients who seek treatment of a DRF.

Several lifelike DRF models currently exist on the market[5,6,7]. Orthopedic residents train using simulators largely obtained from Sawbones®. During training, the fracture in the model is to be reduced as if it were a real fracture. A three-point molding technique is most widely taught for aligning and reducing a fragmented radius before casting[8]. If accessible, fluoroscopy can be used to evaluate reduction alignment after casting is complete[6]. While the Sawbones® model has been well-received by the orthopedic community in terms of its face validity[5,9], current evaluation of the training procedure is subjective[10], often coming from a resident's senior practitioner. This leads to inconsistencies in training, and therefore inconsistencies in casting capabilities, potentially increasing the risk of malunion. Thus, there is growing interest for objective testing of casting competency[11,12].

For any simulation model, lifelikeness and function of fracture replication are important in establishing accurate training techniques and easing the transition from simulation casting to casting in a clinical setting. Accordingly, it is crucial for the data the arm collects to be accurate. Residents will be making corrections to their technique in response to simulator feedback, so inaccurate data could lead to the creation of improper casting techniques, which may increase the frequency of malunion in the clinical setting rather than decrease it.

Study and analysis of successful learning techniques has shown that a key factor in committing anything to memory is an accurate calibration of understanding via immediate feedback[13]. Calibration of understanding is the accuracy of a person's judgement of performance matches his or her actual performance. This method of teaching that seeks to improve calibration has been widely used for centuries in the form of quizzes, spelling bees, or oral feedback. Recent studies have found empirical evidence that improved calibration of understanding correlates to improved achievement in the given field of education[14]. We seek to create a simulator that will replicate the anatomical feel of DRF reduction and casting, while giving accurate real-time feedback to help students accurately calibrate their understanding of the procedure.

In this paper we describe the development of a sensorized distal radius fracture model for teaching casting via simulated fluoroscopy. We detail the assembly of the sensorized prototype and subsequent validation of sensor accuracy. We present our usability testing results and feedback from experienced orthopedic surgeons at UW Hospital. We hypothesize this model will improve proficiency of students in DRF reduction without adding additional time to the training of this procedure.

Materials and Methods

Development of Interactive Distal Radius Fracture Model

An existing distal radius model, manufactured by Sawbones®, was modified to provide additional user feedback. This prototype is capable of accurately collecting data from user reduction. Data was collected through use of two sensors: a force-sensing linear potentiometer (FSLP) and an inertial measurement unit (IMU). Sensor readings were interpreted by a microcontroller and presented to the user via real-time simulated fluoroscopy (Figure 1).

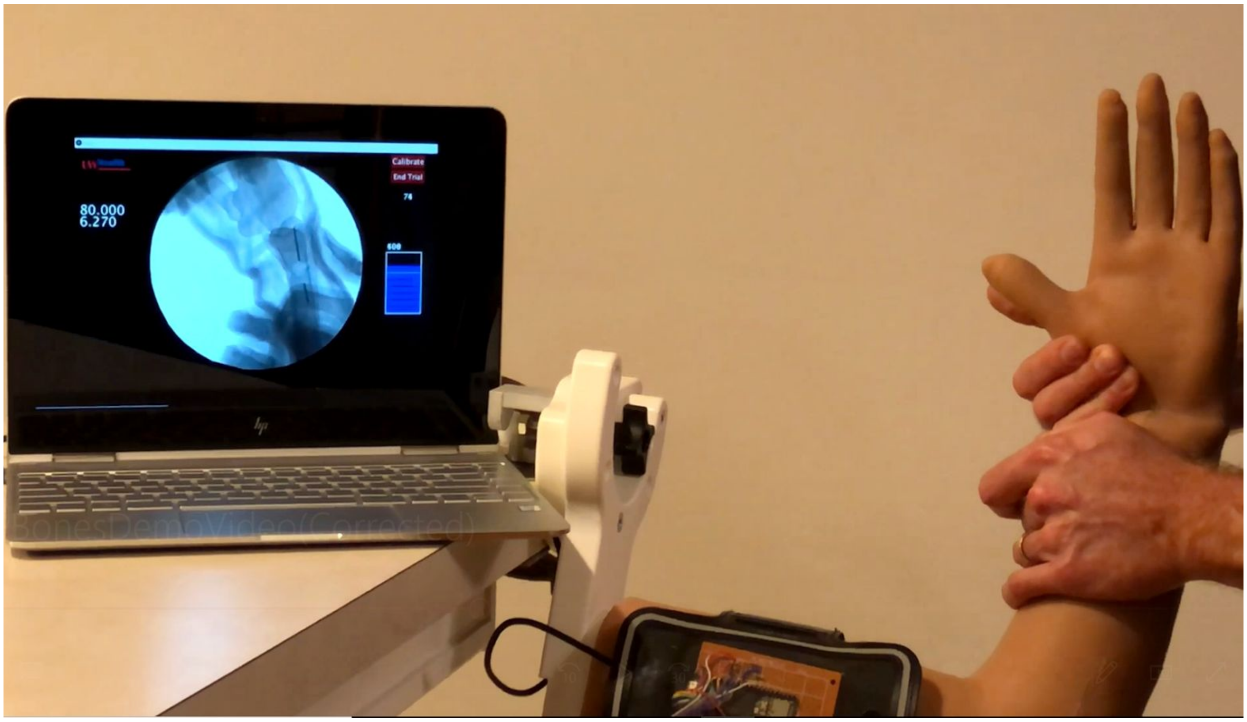


Figure 1. Modified arm being manipulated with the GUI updating live to reflect the changes via a dynamic force indicator (blue bar) and a simulated fluoroscopy feed.

The FSLP is implanted distally to the fracture site on the dorsal side of the Sawbones® DRF model. The positioning of the FSLP is in accordance with feedback received from medical practitioners who interacted with the previously prototyped model at the 2017 International Orthopaedic and Pediatric Symposium (IPOS). The function of the FSLP is to capture amount and localization of force applied; i.e., it captures how much force orthopaedic surgeons and medical students are applying to reduce the fracture at a given site along the FSLP.

The IMU used is an MPU-9250. This IMU is relatively inexpensive and consists of an accelerometer, gyroscope, and magnetometer. The magnetometer component is used to establish the relative position and angle of the fracture site with respect to the the unfractured segment of the radius. The purpose of finding theses two values is to determine the alignment of the fractured radius. This was accomplished through the implantation of a strong neodymium magnet on the distal radius fragment and an IMU on the proximal segment of the radius. Upon IMU calibration, to correlate the magnetic field vector to a 3D (x,y,z) position with known units, the relative position of the distal radius fragment can be acquired. The angle of the distal radius fragment with respect to the proximal segment can be determined as well.

When the calibration between position and magnetic field is complete, the angle of the fracture site can be determined. The magnitude of ***a*** and ***b*** is based on implantation parameters. The magnitude of **c** can be determined from the pythagorean theorem because the endpoint of the vector is known given proper IMU calibrations. As shown in Figure 2, when all three magnitudes are known, it is trivial to calculate the angle associated with **c** given the law of cosines. This angle is used in the live graphical user interface (GUI) and reflected in the simulated fluoroscopy feed to show the image that correlates with the angle measured.

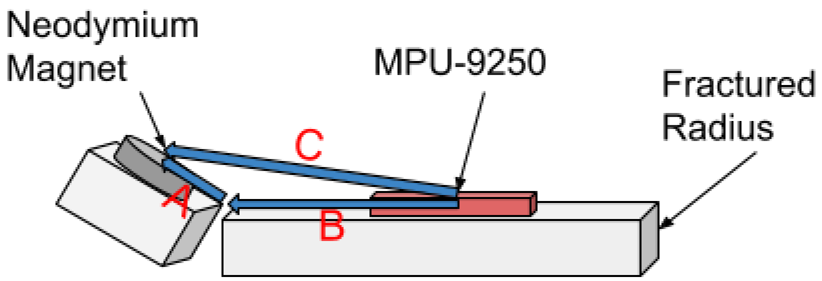


Figure 2. A cartoon depiction of the fractured radius highlights the three vectors necessary for determination of the reduction angle.

The aim for this device is to simulate fluoroscopy and dynamically display force applied in a specific region. Design specifications include integrated angle, position, and force sensors that produce repeatable results over time. Force detection is between 1-100 N with an accuracy of ± 1 N. An angular and positional detection system is incorporated to determine fracture geometries. The angle detection accuracy is ± 2° to enable accurate representation of the simulated fluoroscopy. All sensors were installed internally and circuitry was minimized to a size that does not distract users, which also enhances protection from casting as well as aesthetic appeal. Life in service for the device is guaranteed to 300 cycles of casting. The sensor system is non-palpable, allowing for a more realistic experience. The GUI displays real-time interactive feedback. This includes, but is not limited to, a fluoroscopy display of the simulator and a dynamic force and force location display. Although the allocated budget was $5,000, the entire system costs under $100, not including the Sawbones® DRF model, making it a low-cost, efficacious simulator trainer.

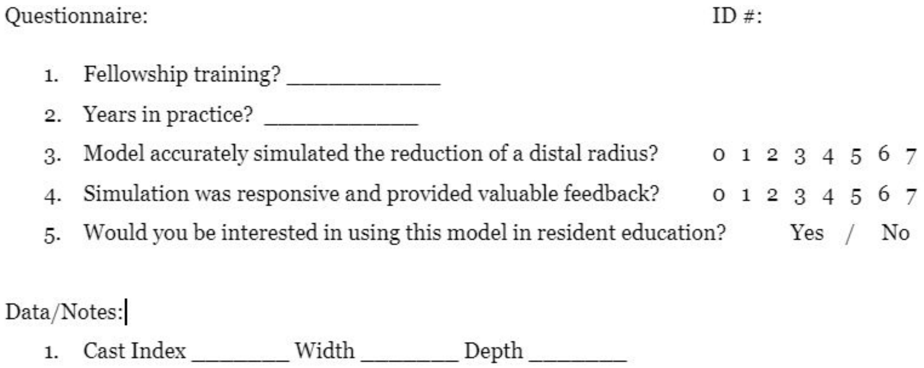
Functional Testing Methods

In order to validate the requirements of the device, testing for functionality will be completed in multiple phases. The first phase will be the easiest to complete as it is only calibration of the FSLP. Many effective methods for calibrating an FSLP have been documented, and all it should involve is creating a correlation curve to applied force, via an MTS machine, and ADC output. The calibration of the linear potentiometer portion of the FSLP will be trivial as well. The change in the resistance of the potentiometer correlates to where force is being applied to the strip. A voltage will be applied to this component and the ADC output will vary with force location. A correlation curve will be created that relates the ADC output to location of force in units of centimeters.

The next phase of testing is validating the functionality of the magnetometer. Two components will be validated: 3D position accuracy and measured angle accuracy. The 3D position accuracy will be calibrated. To do so, a correlation curve will be created for the the three component magnetic vector and a position in 3D space. The goal is to establish a relationship between the distance from the magnet and a measured magnetic field at that point. The accuracy and replicability of this calibration can be validated through multiple iterations of repeated measurements of the same position; the angle determination, as depicted in Figure 2, is a feature made possible from proper calibration. Once this has been validated, the position of "perfect" reduction can be determined by using the system to measure the position of perfect reduction confirmed with fluoroscopy. This can be done multiple times to get a mean of (x,y,z) coordinate points along with standard deviations. This coordinate point will be used as the baseline representing "perfect" reduction when used for competency evaluation testing.

Usability Testing & Feedback

The product evaluation testing is aimed to create benchmark values for determining casting competency. It would be the first data of its kind and valuable for the development of a product for research and commercialization. Participating physicians are provided two rolls of webril, two rolls of fiberglass casting material, and a water basin. Initially, participants are asked to complete a reduction without viewing the GUI. Once they consider the arm reduced, the position is marked, and the participant is instructed to repeat the reduction using the GUI. The two reductions are then graded against the "perfect" reduction to assess casting competency. A questionnaire (Figure 3) is administered to gather usability data.



Questionnaire: ID #:

1. Fellowship training? ____________
2. Years in practice? ____________
3. Model accurately simulated the reduction of a distal radius? 0 1 2 3 4 5 6 7
4. Simulation was responsive and provided valuable feedback? 0 1 2 3 4 5 6 7
5. Would you be interested in using this model in resident education? Yes / No

Data/Notes:

1. Cast Index ________ Width ________ Depth ________

Figure 3. Questionnaire for collecting user feedback from participating orthopedic surgeons.

Results

- Calibration curves generated for each scenario
- Angle accuracy data - may not be pertinent
    - Will claim how reliable our angle reading is with support from data
- Error of each functional testing method
    - Quantitative and qualitative
- Expected grading scale of residents on a scale of 0-100
    - Number generated by how close each (x,y,z) coordinate is to the "perfectly" reduced coordinate; weight of each coordinate will be 33.3%
    - Analyze grades given to a host of participants, ideally with varying experience ranges, but may not be possible to achieve

Discussion

We acknowledge there are innate limitations to our training model. This model is limited to replicating only a left arm fracture on a patient of a single body type, one fracture location, and one initial angle of bone misalignment. The sensors are also arranged to assess the success of the typical three-point molding technique, not other molding techniques. The simulator *probably* also has marked irregularities that arise under a significant shearing force but will function well under moderate shearing force (e.g., less than 50 N).

In addition our usability testing is currently limited to a small, relatively homogeneous sample size from a single event. Further usability testing in various test locations with users of various skill levels would result in a much more robust assessment of the usability of our training model. The actual improvement to clinical results cannot be assessed until the simulator is being broadly used by healthcare systems.

- Review what was accomplished with the design
  - “In this study we designed a training device that replicates the reduction of a DRF while giving real-time, objective feedback to the learner…”
  - Discuss the reliability of our functional testing methods and confidence in our accuracy
  - Discuss the success of testing procedures and feedback from users
- Acknowledge limitations of our design and studies
  - IMU accuracy doesn’t perfectly replicate real fluoroscopy
  - Doesn’t encompass all angle reduction techniques but successfully trains users in one very common technique with a range of pressure points being read from the FSLP

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