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CREATING A FRACTURE REDUCTION AND WIRE NAVIGATION SIMULATOR FOR ORTHOPAEDIC SKILLS TRAINING AND ASSESSMENT

Marcus Tatum
University of Iowa
Iowa City, IA

Steven Long
University of Iowa
Iowa City, IA

Don Anderson
University of Iowa
Iowa City, IA

Geb Thomas
University of Iowa
Iowa City, IA

ABSTRACT

We describe a novel surgical simulator designed to train and assess an orthopaedic residents surgical skill on the tasks of fracture reduction and surgical wire navigation. We use a unique approach of combining accurate surgical models created using patient CT data along with a 3D tracking system that allows for realistic, real-time imaging along with automated performance tracking and benchmarking. Additionally, we have devised a method for tracking the surgical wire associated with the procedure to allow for a complete simulation of reducing and pinning a pediatric elbow fracture.

Keywords: Simulation, surgical training, skill assessment

1. INTRODUCTION

Currently, orthopaedic surgery is taught and learned on live and vulnerable patients. Clearly, this is a serious issue that has prompted medical education boards and institutions to start demanding skills training and a competency-based advancement towards independent practice. However, implementing this goal requires greater access to simulation platforms both for training and assessing surgical skill than are currently available.

This is particularly true with fracture reduction and surgical wire navigation, two fundamental skills in orthopaedic surgery. A surgeon's skill in fracture reduction, the technique of placing broken and displaced bones back to their correct anatomical position, is vital in determining how well a patient heals and recovers from a traumatic injury [1]. A poor fracture reduction can lead to osteoarthritis, malunion, non-union, or gross misalignment [2,3]. Surgical skill in fracture reduction also directly affects soft tissue healing and infection rates, where a skilled surgical performance decreases the likelihood that patients will experience negative outcomes including infection and damage to sensitive adjacent anatomy [4].

Wire navigation is the technique of using a surgical drill to insert long semi-flexible wires (Kirschner wire, or K-wire) into the patient's bony anatomy. K-wires are used for a large array of purposes, including temporarily or definitively fixing a fracture after it has been reduced. Accurately drilling these wires into the correct location is an essential step in providing the strongest construct to hold a reduced fracture in place. Additionally, errant drilling can result in damage to surrounding anatomy, such as nerves and vasculature structures.

Here we present an augmented reality surgical simulator that trains both of these skills in conjunction, on a simulated pediatric elbow fracture of the distal humerus (Figure 1). This is a common fracture for children and is a procedure that many residents will have to perform multiple times during their training. Resident preparedness and competency is vital to ensuring a suitable result and patient safety.

Figure 1: Simulator package including surgical model, surgical drill, and associated laptop.

We combine a physical fracture model in a soft tissue envelope with an electromagnetic tracking system that reads the position of the synthetic bones are surgical tools in real time, allowing for performance recording, scoring, and for virtual fluoroscopy to be generated to guide the surgical procedure.

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2. MATERIALS AND METHODS

We begin with a CT scan of the anatomy that we are simulating, in this case a pediatric elbow. Segmentations are performed on the CT to create surface models of the bones (Figure 2, top). Artificial fractures are then created on the segmentation models, allowing a variety of fractures to be created using the same CT scan. Creating the artificial fractures at this stage also allows for the CT data to be extracted belonging to the artificial fracture fragments for virtual fluoroscopy to later be generated.

After fractures are generated, modifications are made to the surface models to prepare them for use in the simulator, including adding hinge joints at the wrist and elbow, swivel joints between the radius and ulna, and insert locations for tracking sensors to be plugged in (Figure 2, bottom). Surface models from additional CTs are merged with the original CT to create the rest of the arm anatomy not visible in the starting CT, including the proximal and distal portions of the arm.

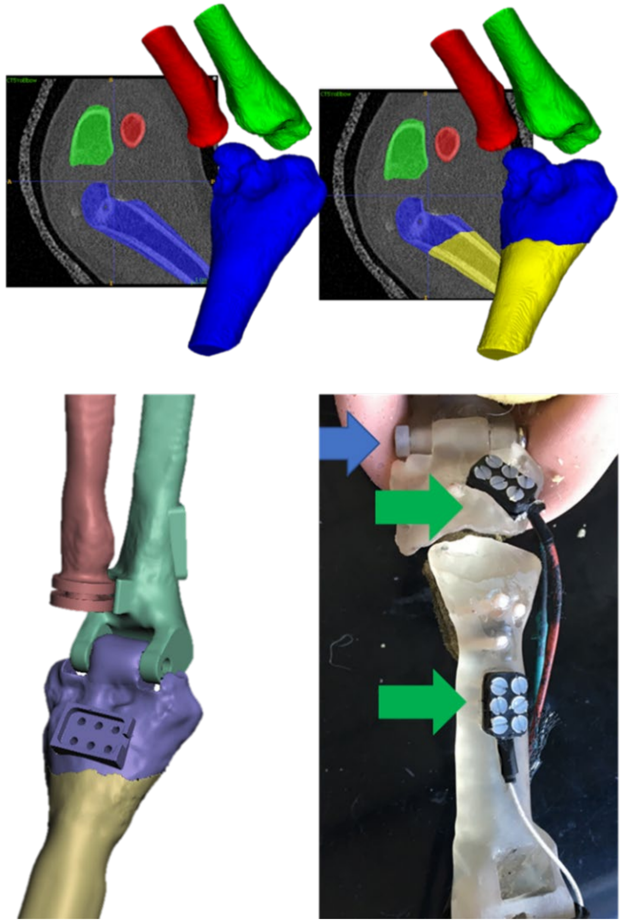

Figure 2: Artificial fracture design process. CT is segmented and artificial fracture is created (top). Surface models are then prepared for simulator use by adding joints and tracking sensor insert locations (bottom). Green arrows point to tracking sensors. Blue arrow shows pin holding elbow joint (bottom right).

A soft tissue sleeve is then extracted and modeled from the combined CT data. The thickness of this sleeve ranges from 5mm thick on the proximal end, to fully filled in at the hand (Figure 3, left). A 3D printed mold is generated for the soft tissue model and low durometer silicone is cast to create the final soft tissue sleeve (Figure 3, middle, right). This sleeve rolls up when changing the fracture pattern or placing a new bone into the simulator, and then is unrolled and clamped in place for a procedure. Closed-cell memory foam is inserted under the sleeve to represent additional soft tissue. The complete surgical model is attached to the simulator via a locking ball and socket joint to allow for manipulation when performing a reduction.

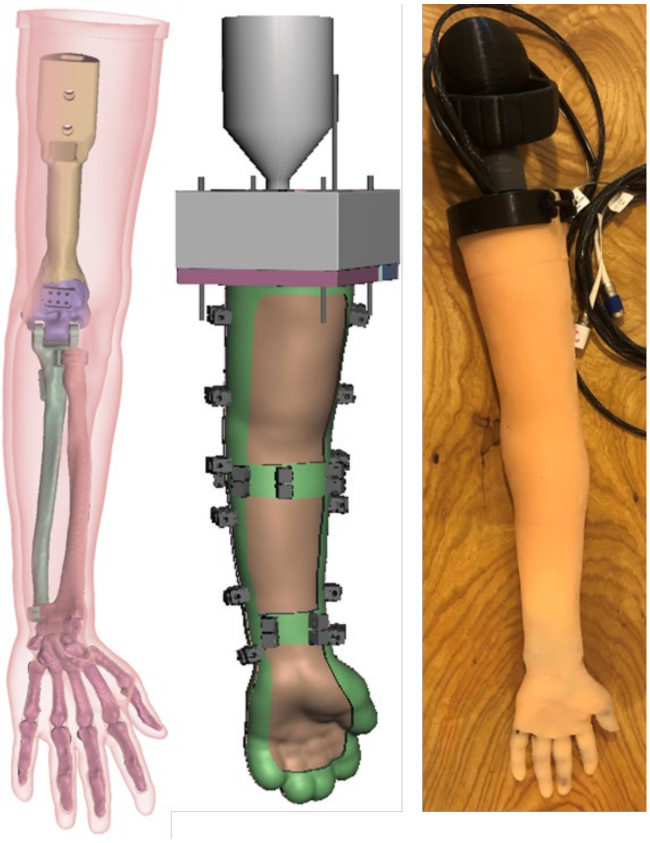

Figure 3: Artificial soft tissue design process from silicone skin design (left) to mold design (middle) to fabricated soft tissue sleeve (right).

The surgical drill used for pinning the simulated fracture is also tracked with the electromagnetic tracking system for analysis and virtual fluoroscopic image generation (Figure 4). This is achieved by using a two-part surgical wire, with one stationary, tracked wire, that is inserted into a second hollow wire, which is drilled into the anatomy. The stationary wire is held from spinning by slotting into a guide on the back of the surgical drill, while the outer wire is spun by the drill to bore into the fracture model. This allows for the outer wire to be placed and left in the bone while a new wire is loaded into the drill for multi-wire constructs.

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Figure 4: Surgical drill tracking. Stationary wire (top) inserts into the hollow wire that can freely rotate when inserted into the surgical drill (bottom).

Because the fracture fragments have associated CT data, we can render accurate artificial fluoroscopic images, or digitally reconstructed radiographs (DRRs), that are updated based on the actual positions of the bone fragments and surgical tools tracked by the tracking system (Figure 5). Additionally, we render a DRR of the surgical wire, also updated based on the real-world position of the surgical wire. Incorporating accurate fluoroscopy into the simulator is crucial because orthopaedic surgeons rely heavily on this imagery to both guide their performance and to check their progress and surgical results.

Figure 5: User interface showing AP and Lateral virtual fluoroscopic views, guiding the user during surgical wire navigation.

A laptop that connects to the simulator provides the user with the artificial fluoroscopic imaging, and records user performance during the simulation procedure. In addition to tracking the user, this also allows for an automated scoring system to be implemented. This scoring analyzes both the fracture reduction and wire navigation aspects of the simulation, including reduction quality, fracture reduction efficiency, wire placement accuracy, wire navigation skill, and fracture stability.

3. RESULTS AND DISCUSSION

This work successfully recreates the surgical procedure of a pediatric elbow fracture reduction and pinning. Preliminary testing shows promise in the validity of the simulation and the useability of the simulator.

Use of this platform allows for direct user comparison by having residents operate on the same fracture pattern, and for users to monitor their improvement as they repeat the procedure. The objective scoring provided in the user feedback allows for residents to highlight areas in need of improvement and deliberately practice on deficient skills until they perform at a competent level.

Earlier designs of this simulation platform have shown their ability to differentiate user skill levels and predict user skill levels based on their performance [5,6]. Similar testing will be conducted on this simulation platform to validate the design and provide a performance database to allow residents to compare themselves to their peers.

4. CONCLUSION

We have created a surgical simulator that incorporates both a physical model that the user can operate on and a state-of-the-art tracking system that can record the user's performance in real time, providing accurate imagery along with automated scoring. Together, this simulator brings us one step closer to implementing a skills based, simulation centric education model, where residents first learn on, and subsequently prove their surgical skills with this simulator prior to operating on live and vulnerable patients.

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