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Three-dimensional Printed Surgical Simulator for Kirschner Wire Placement in Hand Fractures

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Summary: Closed reduction and percutaneous pinning (CRPP) of hand fractures can be a deceptively challenging procedure that requires significant hands-on time to teach and learn. We created a realistic three-dimensional simulator that can be used for teaching junior residents the CRPP. Computer-aided design and computer-aided manufacturing (CAD/CAM) software was used to create a three-dimensional hand model incorporating several common hand fractures: Bennett's fracture, transverse fifth metacarpal neck, and transverse second proximal phalanx. Three-dimensional printing was used to create molds in which the bones and soft tissue were poured. A polyurethane foam was utilized for the bones with iron incorporated to render them radiopaque, whereas silicone of varying viscosities was used for the soft tissues. Five plastic surgery residents and 5 consultants evaluated the model. Individuals then completed an anonymous 12-question survey evaluating the model based on realism, educational utility, and overall usefulness. Survey responses obtained from both residents and consultants were strongly in favor of the simulator. Average realism was graded as 4.48/5 by residents and 4.68/5 by consultants. Average educational utility was graded as 5/5 by residents and 4.95/5 by consultants. Average overall usefulness was graded as 5/5 by both groups. We created an anatomically accurate and realistic simulator for CRPP of hand fractures that was low cost and easily reproducible. Initial feedback was encouraging in regard to realism, educational utility, and overall usefulness. *(Plast Reconstr Surg Glob Open 2018;6:e1706; doi: 10.1097/GOX.0000000000001706; Published online 19 March 2018.)*

INTRODUCTION

Closed reduction and percutaneous pinning (CRPP) of hand fractures can be a deceptively difficult procedure that requires simultaneous spatial coordination and haptic feedback.[1,2] Multiple attempts at CRPP are not benign, occurring even in the hands of experienced surgeons, and may lead to further injury.[1,2]

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Surgical simulators aim to improve operative skills and patients' safety by allowing trainees to recreate tasks modeled after surgical procedures.[3,4] Benefits of surgical simulation include reduced time spent in the operating room teaching basics, maximizing benefit from actual cases, ensuring adequate case volume, skill transfer from the simulator to the operating room, and improved patient outcomes.[5,6]

Presently, there are no commercially available realistic models for simulation of CRPP in hand fractures. Our purpose is to create a realistic three-dimensional model that could be used in teaching junior residents the CRPP for hand fractures and to validate the utility of the model based on feedback from residents and consultants.

MATERIALS AND METHODS

A three-dimensional virtual hand template was created utilizing CAD/CAM software (Z-brush; Pixologic, Los Angeles, CA) based on reference x-rays and average bone length measurements.[7] Common hand fractures distant from each other were incorporated into the model:

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Fig. 1. A fully assembled model is visualized, with the radiopaque bones visible through the dorsum. A thicker consistency silicone is utilized for the base, whereas a less viscous silicone, which is more translucent and allowed greater flexibility, is used on the dorsum.

Bennett's fracture, transverse fifth metacarpal neck fracture, and transverse second proximal phalanx fracture.

Three-dimensional printing was utilized to create silicone molds in the shape of individual hand bones, and for the external skin and soft tissues of the hand. Polyurethane foam (Smooth-On, Macungie, PA) combined with iron powder (Alpha Chemicals, Cape Girardeau, MO) in a 10:1 ratio by weight was used to create the bones. Iron was added to render the bones radiopaque and increase their visibility. After allowing 1 hour to set, the bones were separated and rough edges were trimmed and sanded. A thicker consistency silicone was utilized for the base, whereas a less viscous translucent silicone with greater flexibility was used on the dorsum (Fig. 1). The cost of labor and materials was approximately $50 United States dollars per hand.

Five plastic surgery residents and 5 consultants volunteered to evaluate the model. All individuals were instructed to K-wire all 3 fractures present in the model without fluoroscopic guidance. Individuals then completed an anonymous 12-question survey evaluating the model based on model realism, educational utility, and overall usefulness. Responses were graded on a 5-point Likert scale (5, strongly agree; 4, agree; 3, neutral; 2, disagree; and 1, strongly disagree). Results of responses were averaged together separately for the resident physician and attending physician groups.

RESULTS

We successfully created an anatomically accurate model that afforded mobility at the individual joints of the hand (**Video 1**) (**See video**, **Supplemental Digital Content 1**, which displays the demonstration of the use of the model for CRPP of the fifth metacarpal neck fracture. The model was shown in its native form and also covered with a glove to increase the realism of the model, ***http://links.lww.com/PRSGO/A714***). Fluoroscopy was not utilized during evaluation due to concerns of subjecting participants to radiation. However, our independent testing under fluoroscopy demonstrated excellent visualization of both individual bones and soft tissues (Fig. 2).

Survey responses obtained from both residents and staff were both extremely positive in all domains measured (Table 1). Average realism was graded as 4.48/5 by residents and 4.68/5 by consultants. Average educational utility was graded as 5/5 by residents and 4.95/5 by consultants. Average overall usefulness was graded as 5/5 by both groups.

DISCUSSION

Surgical simulators allow learners the opportunity to become proficient in surgical procedures in a safe and ac-

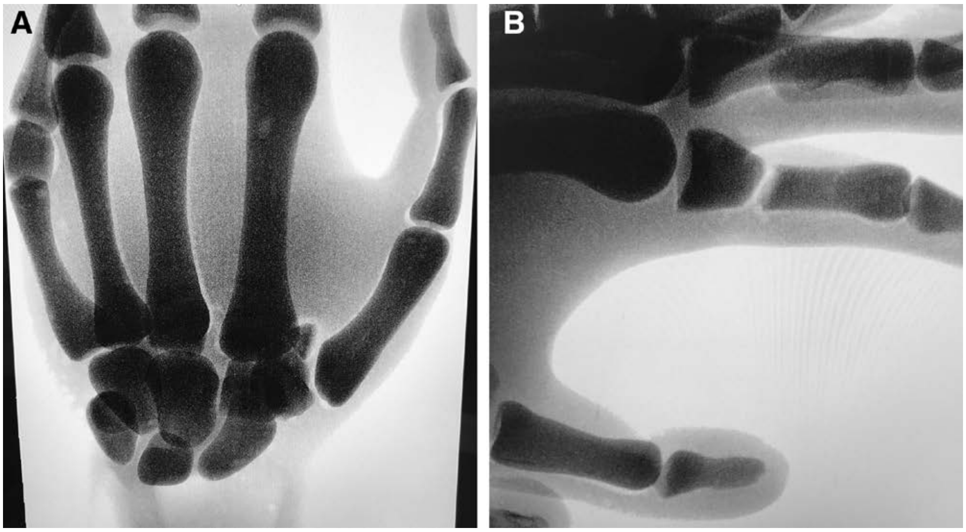


Fig. 2. Fluoroscopy of the model demonstrates excellent visualization of both individual bones and soft tissues. Individual fractures are easily identified. A, demonstrating fifth metacarpal and Bennett's fractures. B, demonstrating a transverse proximal phalanx fracture.

Table 1. Survey Responses Evaluating the Model Based on Model Realism, Educational Utility, and Overall Usefulness

	Resident Physicians (Score Out of 5)*	Attending Physicians (Score Out of 5)*
Model realism		
Model is anatomically accurate	4.6	4.8
Position and orientation of the model are realistic	5	5
Tissue feel is realistic	4	4.4
Feel of bone palpation is realistic	4.6	4.8
Feel of drilling through bone is realistic	4.2	4.4
Average model realism	4.48	4.68
Educational utility		
Useful for teaching anatomy	5	5
Useful for teaching surgical planning	5	5
Useful as an overall training tool	5	5
Useful for improving operative technique	5	4.8
Average educational utility	5	4.95
Overall usefulness		
I would recommend this model to other trainees	5	5
This model should be incorporated into our training curriculum	5	5
Skills learned on this model are transferable to the operating room	5	5
Average overall usefulness	5	5

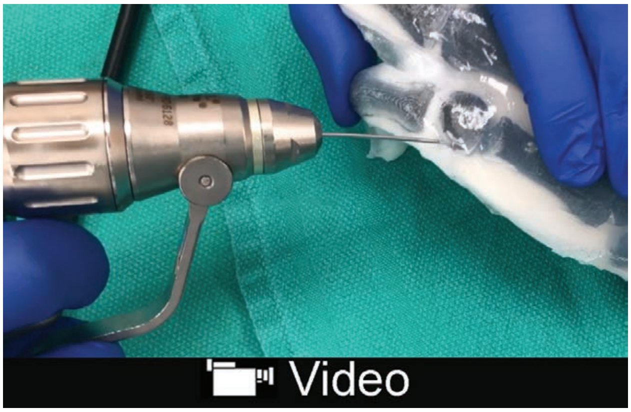
*Responses were graded on a 5-point Likert scale: 5, strongly agree; 4, agree; 3, neutral; 2, disagree; and 1, strongly disagree.

cessible environment.[8] Resident physicians currently obtain experience in procedures through a graduated training model, where they initially begin by assisting in operations and progressively take over further steps.[9] Restrictions on resident work hours have resulted in the increased use of simulators as a way to supplement surgical education.[10] Training residents on a bench simulator allows for transfer of skills to human cadaver models, and likely to the operating room.[11]

Our model incorporates several unique features to optimize realism: anatomically accurate, flexible silicone on the dorsum allowing palpation of bones and joint mobility, radiopaque bones, and realistic feel of bones with drilling. Evaluators graded the model highly in all domains studied: realism, educational utility, and overall usefulness. All individuals felt that even in its current form, the model was a useful training tool and that it should be incorporated into our training curriculum. These high ratings by residents and attendings were encouraging for future development and further testing.

Our model was designed to help junior residents become more comfortable with performing CRPP of common hand fractures. A translucent dorsum was incorporated so that more novice surgeons could easily visualize the location of the bones. A stepwise increase in difficulty can be achieved by placing a surgical glove on the hand, which obstructs the visibility of the bones (**Video 1**). Junior residents first become familiar with the equipment, learning how to use the K-wire driver to place wires. Next they learn to incorporate fluoroscopy, and finally as they become more proficient, they can transfer this knowledge on a real patient.

Limitations of this model include the lack of a joint capsule, collateral ligaments, and a volar oblique ligament in case of the thumb. This limits the realism of fracture



Video Graphic 1. See video, Supplemental Digital Content 1, which demonstrates the use of the model for CRPP of a fifth metacarpal neck fracture. The model is shown in its native form and also covered with a glove to increase the realism of the model, ***http://links.lww.com/PRSGO/A714***.

reduction; however, despite this limitation, participants felt that the model was useful when aimed at training junior residents. It was felt that the usefulness of the model for senior residents was limited, and that they should focus on obtaining experience in the operating room. This model should not be considered as a patient substitute, but rather as an adjunct to help junior residents become more comfortable with CRPP in a safe environment.

Future directions will include testing under fluoroscopic guidance, developing variations with different fracture patterns, and development of more rigorous validations protocols to assess its effectiveness in resident education. Fluoroscopy was not utilized during our evaluations as exposing participants to radiation would require a complicated ethics approval process; we felt it prudent to first test our model to see if it merited further study and development. Ultimately, we hope to demonstrate knowledge transference from skills learned on the model to application in the operating room setting.

CONCLUSIONS

We created an anatomically accurate and realistic simulator for CRPP of hand fractures that is low cost and easily reproducible. Initial feedback is encouraging in regard to realism, educational utility, and overall usefulness. Further validation is required to assess its effectiveness in resident education.

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