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

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 simulator that can be used for teaching junior residents the CRPP.

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:

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.

Michal Brichacek, MD*
Julian Diaz-Abele, MD*
Sarah Shiga, MD, FRCSC†
Christian Petropolis, MD, FRCSC*

From the *Section of Plastic Surgery, Department of Surgery, University of Manitoba, Winnipeg, Manitoba, Canada; and †Division of Plastic Surgery, Department of Surgery, University of Ottawa, Ottawa, Ontario, Canada.

Received for publication January 3, 2018; accepted January 19, 2018.

This manuscript has not been previously published nor is it under consideration elsewhere.

Presented at the 71st Annual Meeting of the Canadian Society of Plastic Surgeons, June 21, 2017, Winnipeg, MB, Canada; Plastic Surgery The Meeting, October 9, 2017, Orlando, FL; and The American Association for Hand Surgery Annual Meeting, January 10–13, 2018, Phoenix, AZ.

Copyright © 2018 The Authors. Published by Wolters Kluwer Health, Inc. on behalf of The American Society of Plastic Surgeons. This is an open-access article distributed under the terms of the Creative Commons Attribution-Non Commercial-No Derivatives License 4.0 (CCBY-NC-ND), where it is permissible to download and share the work provided it is properly cited. The work cannot be changed in any way or used commercially without permission from the journal.

DOI: 10.1097/GOX.0000000000001706

Disclosure: The authors have no financial interest to declare in relation to the content of this article. The Article Processing Charge was paid for by the authors.

Supplemental digital content is available for this article. Clickable URL citations appear in the text.
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-
and progressively take over further steps. Restrictions on res-
model, where they initially begin by assisting in operations through a graduated training on a bench simulator allows for transfer of skills to a real patient.

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.

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. 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. Restrictions on resident work hours have resulted in the increased use of simulators as a way to supplement surgical education. Training residents on a bench simulator allows for transfer of skills to human cadaver models, and likely to the operating room.

Our model incorporates several unique features to optimize realism: anatomically accurate, flexible silicone on the dorsum allowing palpation of bones and joint mobility, radioopaque 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.

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.

CONCLUSIONS

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 transfer from skills learned on the model to application in the operating room setting.

REFERENCES

1. Akinleye SD, Garofolo-Gonzalez G, Culbertson MD, et al. Iatrogenic injuries in percutaneous pinning techniques for fifth metacarpal neck fractures. Hand (N Y). 2018. doi: 10.1177/1558944717731858.
2. Grandizio LC, Speeckaert A, Kozick Z, et al. Anatomic assessment of K-wire trajectory for transverse percutaneous fixation of small finger metacarpal fractures: a cadaveric study. Hand (N Y). 2018;13:86–89.

3. Akhtar K, Sugand K, Sperrin M, et al. Training safer orthopedic surgeons. Construct validation of a virtual-reality simulator for hip fracture surgery. Acta Orthop. 2015;86:616–621.

4. Hsieh TY, Dedhia R, Cervenka B, et al. 3D printing: current use in facial plastic and reconstructive surgery. Curr Opin Otolaryngol Head Neck Surg. 2017;25:291–299.

5. Dawe SR, Pena GN, Windsor JA, et al. Systematic review of skills transfer after surgical simulation-based training. Br J Surg. 2014;101:1063–1076.

6. Schaefer JJ 3rd. Simulators and difficult airway management skills. Paediatr Anaesth. 2004;14:28–37.

7. McFadden D, Bracht MS. Sex and race differences in the relative lengths of metacarpals and metatarsals in human skeletons. Early Hum Dev. 2009;85:117–124.

8. Buckley CE, Kavanagh DO, Traynor O, et al. Is the skillset obtained in surgical simulation transferable to the operating theatre? Am J Surg. 2014;207:146–157.

9. Picarella EA, Simmons JD, Borman KR, et al. “Do one, teach one” the new paradigm in general surgery residency training. J Surg Educ. 2011;68:126–129.

10. Schwab B, Hungness E, Barsness KA, et al. The role of simulation in surgical education. J Laparoendosc Adv Surg Tech A. 2017;27:450–454.

11. Anastakis DJ, Regehr G, Reznick RK, et al. Assessment of technical skills transfer from the bench training model to the human model. Am J Surg. 1999;177:167–170.