Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Elsevier hereby grants permission to make all its COVID-19-related research that is available on the COVID-19 resource centre - including this research content - immediately available in PubMed Central and other publicly funded repositories, such as the WHO COVID database with rights for unrestricted research re-use and analyses in any form or by any means with acknowledgement of the original source. These permissions are granted for free by Elsevier for as long as the COVID-19 resource centre remains active.

A 3-Dimensional-Printed Hand Model for Home-Based Acquisition of Fracture Fixation Skills Without Fluoroscopy

Adnan Prsic, MD,^{*} Michael K. Boyajian, BA,[†] William K. Snapp, MD,[†] Joseph Crozier, BS,[†] and Albert S. Woo, MD[†]

^{*}Division of Plastic and Reconstructive Surgery, Department of Surgery, Yale School of Medicine, New Haven, Connecticut; and [†]Department of Plastic and Reconstructive Surgery, Brown University Alpert Medical School, Lifespan, Providence, Rhode Island

OBJECTIVE: To design a low cost (\$40), realistic and fluoroscopy-free percutaneous Kirschner wire hand fracture fixation training instrument kit for home-based skill acquisition during the COVID-19 pandemic.

DESIGN: A 3D-printed hand was designed from a computed tomography scan of a healthy hand. These data were used to create replaceable hand and wrist bones and reusable silicone molds for a replica of the soft tissue envelope. The model is currently being integrated into the simulation curriculum at 2 integrated plastic surgery residency programs for training in percutaneous wire fixation of hand fractures.

SETTING: Brown University, Warren Alpert Medical School of Brown University. Department of Surgery, Division of Plastic and Reconstructive Surgery. Large academic quaternary referral institution. Yale University, Yale School of Medicine. Department of Surgery, Division of Plastic and Reconstructive Surgery. Large academic quaternary referral institution.

PARTICIPANTS: PGY 1-4 plastic surgery residents preparing to meet ACGME Accreditation for Graduate Medical Education hand surgery specific milestones.

RESULTS: A realistic and durable 3D model with interchangeable bones allows trainees to practice the key motor skills necessary for successful fixation of hand and wrist fractures with K-wires in a home-based setting.

CONCLUSIONS: A low cost, realistic and durable 3D hand model with interchangeable bones allows easy integration into any home-based hand surgery

curriculum. With 3D printers and programming becoming more prevalent and affordable, such models offer a means of low-cost and safe instruction of residents in fracture fixation with no harm to patients. (J Surg Ed 77:1341–1344. © 2020 Association of Program Directors in Surgery. Published by Elsevier Inc. All rights reserved.)

KEY WORDS: Surgical simulation, Simulation model design, Fundamentals of bony fixation, Rapid prototyping, 3D printing

COMPETENCIES: Patient Care, Medical Knowledge

INTRODUCTION

Graduated responsibility is the hallmark of modern-day surgical training. However, with increasing restrictions on work-hours, an increasing percentage of graduating residents lack adequate readiness for the work force.¹ Given the COVID-19 pandemic the number of residents participating in patient care has decreased at our institutions. Hand surgery volume has decreased with only emergent surgeries being performed. Given reduced number of cases and resident participation, alternative means of resident education and progress are essential during this time.

To track progress of clinical skills, the Milestone Project in plastic surgery was established between 2011 and 2014. Specifically, it was created “to define training outcomes and measure progress as a trainee progresses from novice to expert.”² The levels are graded from 1 to 5.

One requirement for the level 3 milestone is the performance of routine procedures, such as the repair of hand fractures. Kirschner wire (K-wire) fixation of bones is a complex procedure, requiring the acquisition of 3D

Funding: This work was supported by Yale School of Medicine Plastic and Reconstructive Surgery research fund.

Correspondence: Inquiries to Adnan Prsic MD, Division of Plastic and Reconstructive Surgery, Department of Surgery, Yale School of Medicine, 330 Cedar Street, New Haven, CT 06510; e-mail: Adnan.prsic@yale.edu

spatial skills as well as utilizing haptic and visual feedback to obtain a successful result. Given such complexities, achieving a level 3 skill level can be a challenge in training programs with a low volume of hand surgery. The opportunity to practice these skills independently and supplement clinical practice can be difficult to come by. It has been demonstrated that practicing prior to surgical interventions “enable[s] the trainee to maximize learning episodes and trainers more likely to delegate surgical training.”³

Given limited simulation tools for hand fracture fixation and the absence of commercially available 3D hands that replicate the tactile feel of bone and soft tissue, we focused on developing an affordable and durable model for resident training. While previous reports have cited costs over \$100 per hand, we have achieved this under \$50 per hand.⁴ With 3D printers becoming more affordable and ubiquitous at academic centers, it is our goal to share our knowledge and increase access to easy production of 3D-printed models for resident training. At the same time, it is our goal to make simulation available at home and outside of the hospital.

MODEL DESIGN

Our 3D-printed hand model consists of 2 distinct parts: a 3D-printed set of bones and a silicone soft tissue envelope. The 3D-printed stereolithographic file is created from a computed tomography scan of a hand. To replicate haptic feedback into the model, the cortical surface and the medullary canal of the bones were made with variable fill patterns of the material, in our case Acrylonitrile Butadiene Styrene (ABS) (Fig. 1).

After printing, the bones are set into an ABS mold and covered with silicone. Transparent silicone is used for beginners and skin-colored silicone for advanced learners (Figs. 2 and 3). Fracture patterns can be created at

FIGURE 1. Shown are 3D-printed bones and a 3D-printed soft tissue mold.

FIGURE 2. Beginner hand model complete with 3D-printed bones and transparent silicone soft tissue.

the time of practice or at time of printing. Bones can be individually printed and easily interchanged for repeat use (Fig. 4). Intrinsic properties of the silicone allow it to be used repeatedly without compromising soft tissue feel and creating damage from K-wires.

Our model is designed with a cost goal of under \$50. We have used materials specifically selected to replicate the tactile feedback of “bone” and “soft tissue envelope.”

FIGURE 3. Advanced skin-colored model (B) removes the handicap of direct visualization. Can be used with fluoroscopy if desired.

FIGURE 4. Replaceable metacarpal bones with digitally designed fracture patterns (left).

TABLE 1. Cost of Material for 1 Hand

Hand Mold*	\$3/Hand
Silicone soft tissue	\$11/hand
Hand and wrist bones	\$25/hand
Total cost	\$39/hand

*Original hand mold has a one-time cost of \$300. It is durable and can withstand 100+ hand production. We have assumed 100 hand production for the purpose of accounting.

Our <\$50 include the materials and manufacturing of a 1-time hand mold, silicone for soft tissue replication and ABS material for bones. Cost breakdown per hand is shown in Table 1. The overhead, not included in the cost of the hand, includes 3D printing space, 3D printing machines and available personnel. Our laboratories at Yale University and Brown University have 3D printers and materials available at no cost to the user.

MODEL BENEFIT

Our 3D-printed hand model allows trainees to practice basic and complex fracture fixation with a multitude of attempts, precise bony anatomy and haptic feedback. The nature of the silicone soft tissue allows the fingers to be naturally flexed and the hand positioning to be manipulated during use. The option to replace bones also gives our model the added benefit of allowing novices and experienced trainees to practice fixation of simple and complex fracture patterns.

The model is the size of an average human hand and is easily portable. Fractures can be fixed with operating room quality K-wire drivers or with a home power drill. Using the power drill reduces overall cost and allows trainees to practice fixation in their own home. Our model does not require fluoroscopy and avoids unnecessary radiation exposure to the trainee. However, if trainees wish to practice incorporating fluoroscopy feedback, the 3D-printed bones are radiopaque.

MODEL LIMITATIONS

Limitations of our model are the availability of a 3D printer, the price of overhead costs associated with purchase and maintenance of the printer, and the time for construction of the silicone mold. stereolithographic files can be easily shared across institutions. The printing time of hand bones can vary based on the quality of 3D printer available. However, once the soft tissue molds have been printed, pouring the silicone and placing the

bones require no specific training. The other limitation is the upfront cost of the 3D printers and materials for the molds. However, in our experience, there are many facilities (including universities and local libraries) that hold workshops and allow community members access to 3D printers for a small fee.

Another limitation is the limited number of attempted fixations of the “bone.” For example, our “bones” can be used to drill up to 6 to 8 different entry points, on meta-carpal head radial and ulnar sides each, before the entry points coalesce into a large hole. We expect novice learners to require more attempts compared to advanced learners, and therefore require varying number of “bones” to complete an exercise. Our individual bones can be manufactured for \$2 and are exchangeable.

CURRICULUM INTEGRATION

With the COVID-19 pandemic we have begun integration of 3D-printed hand fracture fixation into our educational curriculum. Written instructions on fracture fixation have been created for residents in postgraduate years 1 to 4 and focus on visuospatial coordination, tactile feel of bony fixation, and proper use of the K-wire drivers. Zoom sessions have been utilized to facilitate interaction among trainees and provide real-time instruction. Trainees have expressed an extremely positive impact on their visuospatial orientation and tactile feedback with the use of 3D-printed hand for fracture fixation simulation. We will begin a formal program in evaluating improvements in basic fracture fixation skills.

CONCLUSIONS

A concerted effort to prepare plastic surgery residents for practice and enable them to meet all milestones as set forth by the Accreditation for Graduate Medical Education ACGME prior to graduation should be made during the COVID-19 pandemic. We believe that our 3D hand-printed model can assist trainees in the acquisition of tangible fracture fixation skills with the use of a low-cost 3D-printed hand.

REFERENCES

1. Teman NR, Gauger PG, Mullan PB, Tarpley JL, Minter RM. Entrustment of general surgery residents in the operating room: factors contributing to provision of resident autonomy. *J Am Coll Surg*. 2014;219:778–787. Epub 2014/08/28.

2. McGrath MH. The plastic surgery milestone project. *J Grad Med Educ*. 2014;6(1 Suppl 1):222-224. Epub 2014/04/05.
3. Sadideen H, Plonczak A, Saadeddin M, Kneebone R. How educational theory can inform the training and practice of plastic surgeons. *Plast Reconstr Surg Glob Open*. 2018;6:e2042. Epub 2019/01/19.
4. Wu YY, Rajaraman M, Guth J, et al. A high-fidelity tactile hand simulator as a training tool to develop competency in percutaneous pinning in residents. *J Am Acad Orthop Surg Glob Res Rev*. 2018;2:e028. Epub 2018/10/04.