University of Groningen

A 3-Dimensionally Printed, High-Fidelity Ultrasound-Guided Pericardiocentesis Training Model

Baribeau, Yanick; Bortman, Jeffrey; Khamooshian, Arash; Laham, Roger; Mahmood, Faraz; Mahmood, Feroze; Sharkey, Aidan; Steely, Andrea; Matyal, Robina

Published in:
Journal of cardiothoracic and vascular anesthesia

DOI:
10.1053/j.jvca.2019.08.051

IMPORTANT NOTE: You are advised to consult the publisher's version (publisher's PDF) if you wish to cite from it. Please check the document version below.

Document Version
Publisher's PDF, also known as Version of record

Publication date:
2020

Link to publication in University of Groningen/UMCG research database

Citation for published version (APA):
Baribeau, Y., Bortman, J., Khamooshian, A., Laham, R., Mahmood, F., Mahmood, F., Sharkey, A., Steely, A., & Matyal, R. (2020). A 3-Dimensionally Printed, High-Fidelity Ultrasound-Guided Pericardiocentesis Training Model. *Journal of cardiothoracic and vascular anesthesia*, *34*(1), 245-247. https://doi.org/10.1053/j.jvca.2019.08.051

Copyright
Other than for strictly personal use, it is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), unless the work is under an open content license (like Creative Commons).

The publication may also be distributed here under the terms of Article 25fa of the Dutch Copyright Act, indicated by the “Taverne” license. More information can be found on the University of Groningen website: https://www.rug.nl/library/open-access/self-archiving-pure/taverne-amendment.

Take-down policy
If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

Downloaded from the University of Groningen/UMCG research database (Pure): http://www.rug.nl/research/portal. For technical reasons the number of authors shown on this cover page is limited to 10 maximum.

Journal of Cardiothoracic and Vascular Anesthesia 34 (2020) 245–247

Contents lists available at ScienceDirect

Journal of Cardiothoracic and Vascular Anesthesia

journal homepage: www.jcvaonline.com

Emerging Technology

A 3-Dimensionally Printed, High-Fidelity Ultrasound-Guided Pericardiocentesis Training Model

Yanick Baribeau, BS[*], Jeffrey Bortman, BS[*],
Arash Khamooshian, MD[†,‡], Roger Laham, MD[*],
Faraz Mahmood, MD[*], Feroze Mahmood, MD[*,1],
Aidan Sharkey, MD[*], Andrea Steely, MD[§], Robina Matyal, MD[*]

[*] *Department of Anesthesia, Critical Care and Pain Medicine, Beth Israel Deaconess Medical Center, Harvard Medical School, Boston, MA*
[†] *Beth Israel Deaconess Medical Center, Boston, MA*
[‡] *University Medical Center Groningen, University of Groningen, Groningen, The Netherlands*
[§] *Division of Cardiac Surgery, Department of Cardiac Surgery, Beth Israel Deaconess Medical Center, Harvard Medical School, Boston, MA*

Key Words: pericardiocentesis; training model; 3D printing; high-fidelity

PERICARDIOCENTESIS generally is performed emergently on hemodynamically unstable patients.[1] The clinical context and nature of the procedure limit training opportunities for cardiologists-in-training. Even though high-fidelity haptic training simulators are commercially available for pericardiocentesis, they are expensive, have a limited life span, and are devoid of clinical variability.[2] Because of their limited availability, these phantom models are not used routinely for pericardiocentesis task training. In this respect, availability of a low-cost, high-fidelity task training phantom model for pericardiocentesis can improve training for this important clinical procedure by expanding its clinical use.

Using 3-dimensional (3D) printing, near-realistic and low-cost haptic training models for various invasive procedures have been developed.[3] With 3D printing becoming affordable, anatomic models now can be created to mimic normal and disease states.[4] In addition to being risk free with no consequences of failure, these models offer trainees the opportunity to practice pericardiocentesis without the time pressure of an emergency situation. Using rapid prototyping, multiple anatomic variations can be created for a comprehensive training model. Therefore, using commercially available materials and components, the authors of the present report sought to develop a realistic pericardiocentesis model for training with 3D printing technology. Using progressive technology in the form of 3D printing coupled with foundational ultrasound interpretation, the model ties together dynamic elements of 3D printing and ultrasound imaging to serve as a novel, efficient method of procedural education. Furthermore, to promote the usage of ultrasound and to familiarize users with the standard in imaging for pericardiocentesis, the model was created to be echogenic.

Materials and Methods

The pericardiocentesis model was created with commercially available components that were configured in the perioperative echocardiography laboratory at the authors' medical center. The phantom model consisted of the following components:

- A life-size mannequin torso (OnlyMannequins, East Orange, NJ).

---

[1] *Address reprint requests to* Feroze Mahmood, MD, Department of Anesthesia, Critical Care and Pain Medicine, Beth Israel Deaconess Medical Center, 1 Deaconess Road, Boston, MA, 02215.
E-mail address: fmahmood@bidmc.harvard.edu (F. Mahmood).

https://doi.org/10.1053/j.jvca.2019.08.051

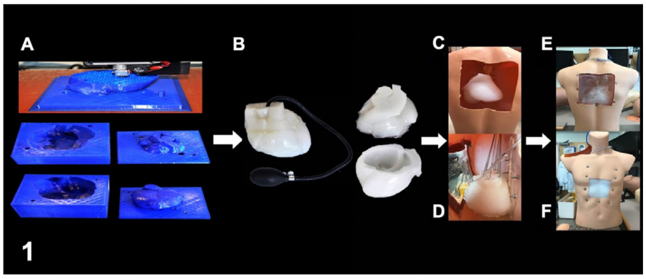

Fig 1. (A) The Lulzbot 3D printer was used to print 4 components that together created the entirety of a mold to scale of an anatomical heart. (B) The silicone was placed into the mold and cured. Once removed, 2 slices were fastened together to create the complete heart. A sphygmomanometer could be used to generate pulsatility. (C) The heart surrounded by the pericardium, which was created by combining 2 sheets of silicone. (D) A side view of the heart suspended in the mannequin model via an S-hook. (E) A posterior view of the suspended heart, visible through the acrylic sheet. (F) An anterior view of the mannequin model fit with bolts to secure the silicone piece, which allows for needle entry for effusion.

- A commercially available model of a sternum with cartilage (3B Scientific, Tucker, GA).
- A square anterior piece of the mannequin centered on the xiphoid process was removed to reveal a silicone window beneath for users to perform the procedure (Fig 1, F). The silicone piece was secured to the anterior wall of the mannequin using bolts to allow for adequate palpation of the sternum. On the posterior surface of the mannequin, an acrylic sheet was secured using bolts to allow for visualization of the procedure (Fig 1, E).
- A mold of the heart consisting of anatomically correct chambers was 3D printed using a Lulzbot 3D Printer (Aleph Objects, Inc, Loveland, CO) (Fig 1, A). A premade, to-scale 3D file of a heart was imported into Blender (Blender Foundation, Amsterdam, The Netherlands), which is a 3D modeling program. The heart then was inserted into a 3D cube, and a Boolean function was performed to leave a negative space inside the cube. Silicone then was poured into the resulting components. When cured, 2 halves of the heart remained, and small amounts of silicone were applied between the halves to create a sealed product (Fig 1, B).
- To create the pericardium, 2 identical Frisbees were filled with silicone to create thin, circular pieces. These were wrapped around the heart and sutured together. Silicone then was painted over the sutures between the pericardial halves to create a water-tight pericardium, and the heart was suspended into the chest cavity using an S-hook and stitched cradle (Fig 1, C and D).
- The tube leading into the heart was filled with red liquid, and the tube leading into the pericardium was filled with blue liquid. When a needle was inserted through the anterior portion of the mannequin, the color of liquid withdrawn signified the location of the user's needle. A blue return signified proper needle placement in the pericardium, a red return signified needle placement into the heart, and a clear return signified that the heart and pericardium were missed altogether (Fig 2, B and C). A cardiac transthoracic echocardiography probe was used in the subcostal position to acquire the 4-chamber subcostal view and identify pericardial effusion (Fig 2, D).
- The model took approximately 1 week to construct, and the materials cost approximately $204.77. The development first began with generation and 3D printing of the heart molds and ended with suturing the apex of the silicon heart to the lateral sides of the mannequin model. The entirety of the purchasing process is outlined in Table 1.
- To test the fidelity of the model, a group of cardiology fellows were asked to train on the model and provide feedback through an anonymous survey administered after the training (Fig 2, A). Ultimately, attending physicians will test the model and grade its fidelity based on their comparison with the real-life procedure.

Results

Introducing the model to cardiology fellows yielded promising results when asked about the fidelity and echogenicity of

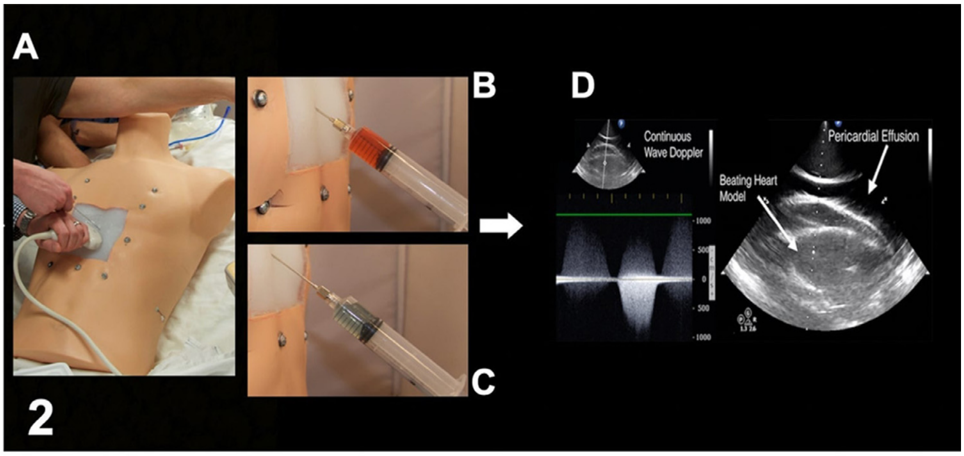

Fig 2. (A) A cardiology fellow training on the model using transthoracic echocardiography in conjunction with the pericardiocentesis kit. (B) A red fluid return signifies incorrect needle placement in the heart. (C) A blue fluid return signifies correct needle placement in the pericardium. (D) A cardiac transthoracic echocardiography probe was used in the subcostal position to acquire the 4-chamber subcostal view to identify pericardial effusion.

Table 1
Materials for Assembly

Name	Description	Price
Software		
Blender	3D modeling suite	Free
Hardware and Materials		
Lulzbot Taz 5 3D Printer (Aleph Objects, Inc, Loveland, CO)	Heart mold fabrication	$2200.00
3.00 mm diameter high-impact polystyrene dissolvable filament	Material for 3D printed heart mold	$0.048/g
Ecoflex 00-30 silicone Smooth-On (Macungie, PA, USA)	Heart and pericardium material	$91.50
Mannequin shell (OnlyMannequins, East Orange, NJ)	Model body	$35.00
Ethilon 2-0 sutures (New Brunswick, NJ, USA),	Joining the pericardium and suspending the heart in the model	$9.66
0.9% sodium chloride intravenous solution bags (Baxter, Deerfield, IL)	Filling the heart and pericardium with fluid	$17.98
Food coloring (Wilton, Naperville, IL)	Coloring the heart and pericardial fluid	$2.99
Clear acrylic glass sheet	Viewing window in the back	$10.99
Coarse, zinc-plated steel, round-head combination machine screw (4-pack)	Fastening the clear acrylic glass sheet to the posterior of the model	$1.18 ea.
Sternum model (3B Scientific, Tucker, GA)	Replicating an anatomical sternum with cartilage and landmark for palpation pre-needle entry	$29.00
White oversized S-hooks (3 pack) (Arrow, Minneapolis, MN, USA)	Suspension of the heart model by its superior sutures	$5.29

the model. The authors developed a 5-day perioperative transthoracic echocardiography training curriculum that included a 30-minute lecture on ultrasound-guided placement for pericardiocentesis before practice with the model. The fellows were assessed on their ability to place the needle into the pericardium accurately as per their lecture-based learning. Four fellows practiced with the trainer and were given a brief questionnaire of 6 questions with answer choices on a rating scale of 1 to 5, with 1 being the lowest and 5 being the highest score. When asked whether use of the model was an effective teaching method and whether the residents felt more accustomed to performing the procedure, answers were 3.75 ± 1.5 and 3.5 ± 1, respectively. The realism in palpation for the xiphoid process received a score of 3.5 ± 1.3 and effectiveness of echo-guidance of 3.25 ± 1.5. The depth of the pericardium and corresponding needle entry into the pericardium were graded 3.5 ± 1.3 and 3.25 ± 1.5, respectively.

Discussion

At present, there is a limited number of affordable, high-fidelity pericardiocentesis training simulators for training. The high cost and limited life span preclude routine use of phantom models for hands-on training.[5] Herein, the authors have demonstrated the feasibility of developing a custom-made pericardiocentesis training phantom model that overcomes these limitations. It is a low-cost phantom model with components that are commercially available and can be replenished easily without significant technical expertise. The present report demonstrates that, with using local resources, it is possible to manufacture high-fidelity training phantom models for invasive procedures. With no risk to the patient or consequences of failure, a life-saving procedure can be learned and mastered with this phantom model.

Current improvement in 3D printing technology in the speed and quality of materials facilitates efficiency in production and promotes a shorter time frame necessary for building models.[6] Moreover, the ultrasonic views of the model proved realistic. Practicing physicians also appreciated the palpability of the xiphoid process to promote orientation for needle insertion. Trainees performed multiple pericardiocentesis procedures without any significant wear or tear of the phantom model. Even though an initial investment of the purchase of a desktop 3D printer, materials, and mannequin is required, the total cost ranges from $2,000 to $3,000. However, by using this technology, multiple phantom models can be created as task trainers for invasive procedures.

This model has demonstrated the possibility of constructing a low-cost, high-fidelity pericardiocentesis training model that can be used to as a task trainer to develop competence. The development of the model is a reasonable and tangible task that takes less than 1 week to complete and proves practical and effective for deliberate practice. This model served its purpose in a pilot study to determine its educational potential, and in the future, the model will be implemented into a longitudinal study of training cardiology residents in order to test and promote preclinical procedural competency.

Declaration of Competing Interest

There are no conflicts of interest to report.

References

1 Balmain S, Hawkins NM, MacDonald MR, et al. Pericardiocentesis practice in the United Kingdom. Int J Clin Pract 2008;62:1515–9.
2 Daly R, Planas JH, Edens MA. Adapting gel wax into an ultrasound-guided pericardiocentesis model at low cost. West J Emerg Med 2017;18:114–6.
3 Maisch B, Seferović PM, Ristić AD, et al. Guidelines on the diagnosis and management of pericardial diseases executive summary; the Task Force on the Diagnosis and Management of Pericardial Diseases of the European Society of Cardiology. Eur Heart J 2004;25:587–610.
4 Bortman J, Baribeau Y, Jeganathan J, et al. Improving clinical proficiency using a 3-dimensionally printed and patient-specific thoracic spine model as a haptic task trainer. Reg Anesth Pain Med 2018;43:819–24.
5 Sullivan A, Khait L, Favot M. A novel low-cost ultrasound-guided pericardiocentesis simulation model: Demonstration of feasibility. J Ultrasound Med 2018;37:493–500.
6 Mashari A, Montealegre-Gallegos M, Knio Z, et al. Making three-dimensional echocardiography more tangible: A workflow for three-dimensional printing with echocardiographic data. Echo Res Pract 2016;3:R57–64.