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Techniques and Procedures

A COST-EFFECTIVE, RAPIDLY CONSTRUCTED SIMULATION MODEL FOR ULTRASOUND-GUIDED PERICARDIOCENTESIS PROCEDURAL TRAINING

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☐ Abstract—Background: Emergent ultrasound-guided pericardiocentesis (USGP) is an uncommonly performed procedure by emergency physicians (EPs). USGP simulation models have previously been developed to increase procedural proficiency, but these models are limited for routine implementation secondary to high-cost, lengthy time to construct, and lack of durability. The objective of this study was to develop an USGP simulation model that is cost-effective, easily and rapidly constructed, and has procedure-specific fidelity. Discussion: We have developed a novel tofu simulation model for USGP training. The model cost per unit was $1.81 and the average construction time was 2.5 ± 0.3 min. The model can withstand upward of 100 needle punctures. Our model provides USGP procedure–specific aspiration of a simulated pericardial effusion. Conclusions: The tofu USGP model provides a cost-effective and rapidly constructible simulation tool that could be readily integrated in EP procedural training. © 2018 Elsevier Inc. All rights reserved.

☐ Keywords—ultrasound; pericardiocentesis; simulation; medical education; emergency medicine; cardiology; critical care

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INTRODUCTION

Simulation models have been increasingly incorporated into emergency medicine (EM) education in recent years. Structured and rigorous procedural training in EM is imperative, and recommendations have been proposed for the improvement of simulation-based training (1,2). Simulation provides a comfortable, low-stress, ideal environment for learning emergent, life-saving high-risk procedures. As simulation strategies become more integrated into the curriculum of EM residency programs, there is a need for the development of low-cost, durable, and high-fidelity, procedure-specific simulation models.

Pericardiocentesis is an emergent intervention for pericardial tamponade, a life-threatening condition (3). Compared to the traditional "blind" approach, ultrasound-guided pericardiocentesis (USGP) has emerged as the preferred technique due to higher success rates and fewer complications (3–9).

Pericardiocentesis is a low-frequency, high-risk procedure that some EM trainees may have limited exposure to. Commercially available pericardiocentesis models have been developed to address this proficiency gap; however, these models are expensive, with costs in the thousands of U.S. dollars (10,11). Cadaveric models have been developed for pericardiocentesis training, however, they have several disadvantages, including the

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cost and availability of cadavers (12,13). Previous studies have described "homemade" USGP simulation models that offer a lower-cost alternative to commercial models (14–18). Only one other USGP model has successfully merged both low-cost and construction time within minutes (18). The objective of this paper was to develop a novel tofu USGP simulation model that is cost-effective, easily and rapidly constructed, and with favorable needle puncture durability for EP procedural training.

Materials for Creation of the USGP Model

1. One container of non-silken extra-firm tofu (minimum dimensions of ~10 cm × 8 cm × 4 cm)—we used Nasoya® Extra Firm TofuPlus (Ayer, MA), 12 oz, $1.79
2. Glad® Press'n Seal plastic wrap, 0.45 square feet required per model, $0.02
3. Ladle, $0.49 (plastic) or $5.80 (stainless steel)
4. Ice-cream scooper, $2.62 (plastic) or $7.60 (stainless steel)
5. Water source
6. Large plastic basin or sink

Method for Creation of the USGP Model

Step 1: The core of an extra-firm tofu block is first hollowed out with a ladle (Figures 1B, 1C).

Step 2: The tofu block can be hollowed further as needed with an ice-cream scooper to shape the desired contour of simulated parietal pericardium (Figure 1D).

Step 3: The tofu core plug can then be refined with an ice-cream scooper or steak knife to shape the desired contour of simulated endocardium, myocardium, and visceral pericardium (Figure 1E).

Step 4: The modified core plug is then placed back into the hollowed tofu block, with reassembly occurring under water in a sink or plastic basin to avoid the accumulation of trapped air bubbles (Figure 1F).

Step 5: The tofu block and plug reassembled unit is then gently inverted under water into the plastic tofu container (Figures 1G, 1H).

Step 6: The tofu container is covered with Glad Press'n Seal plastic wrap to provide a protective covering (Figure 1I). The plastic wrap simulates needle puncture through skin.

Step 7: The completed model can be used for USGP simulation (Figure 2).

The entire stepwise construction of the model is demonstrated in Videos 1 and 2.

RESULTS

The tofu USGP model was designed to simulate procedure-specific anatomy of relevant cardiac structures, including parietal and visceral pericardium, pericardial effusion, endocardium, myocardium, and an intracardiac chamber (Figure 2). The model facilitates procedural instruction of USGP with the paramount aim of achieving a successful aspiration of "pericardial fluid" (Figure 2). Our model was introduced to EM residents during several USGP procedural workshops and it was deemed as highly satisfactory in mimicking a pericardial effusion, suitable for developing learners' dexterity and accuracy of needle placement, and adequate as a training tool for increasing competency in USGP.

The model ease of use and practicality were evaluated by cost, construction time, and durability. The model cost, excluding the costs of commonly available household utensils, was $1.81 per unit. The total cost per unit, if all materials required purchase, would be $4.92 (plastic utensils) or $15.21 (metal utensils). There were no differences in model construction between the usage of either plastic or metal utensils. The mean construction time was 2.5 ± 0.3 min (opening of the tofu container to completion of Steps 1–6 as described above), based on the assembly of fifteen independent models by a single operator (E.J.K.). There was no significant learning curve in terms of time to complete model construction. The model has a durability of approximately 25 needle punctures before minor decay in ultrasound image quality develops within a single image plane, based on the use of 10 independent models by a single operator (E.J.K.) (Figure 3). The model can withstand at least 100 total needle punctures without compromising structural integrity (Figure 3). Our model was piloted during three separate 1-day USGP procedural simulation workshops for EM residents and demonstrated similar durability characteristics with individual models withstanding 3–5 needle punctures each for 25–30 participants. The model was stored at room temperature for the duration of each 1-day procedural workshop. The model was not assessed for its longer-term durability or storage requirements beyond a single-session use.

DISCUSSION

Simulation models have been developed to facilitate USGP procedural training, but these are limited as educational tools due to potential significant costs, extensive time for construction, or lack of needle puncture durability (10–18). Our objective was to develop a novel USGP model that addresses all of these shortcomings.

Figure 1. Tofu ultrasound-guided pericardiocentesis (USGP) model construction. (A) Construction materials; (B, C) hollow out a core plug of extra-firm tofu with a ladle; (D) further hollow tofu block as desired to shape of parietal pericardium; (D) refine shape of core plug as desired to shape of endocardium/myocardium and visceral pericardium; (F, G, H) reassemble tofu block with modified core plug and invert into plastic container under water; (I) cover container with Glad Press'n Seal plastic wrap; (J) Completed model; and (K, L) performing USGP simulation.

Previous studies have applied tofu-based simulation models into training sessions for ultrasound-guided regional anesthesia (19–21). These studies described the utility of tofu models in developing needle dexterity for procedural guidance. Tofu-based models are ideal for ultrasound-guided task trainers in that tofu is easy to handle, inexpensive, and readily available. Furthermore, tofu models offer a more hygienic and ethical alternative to other simulation models in which animal products are used. These factors are advantages of using a tofu-based

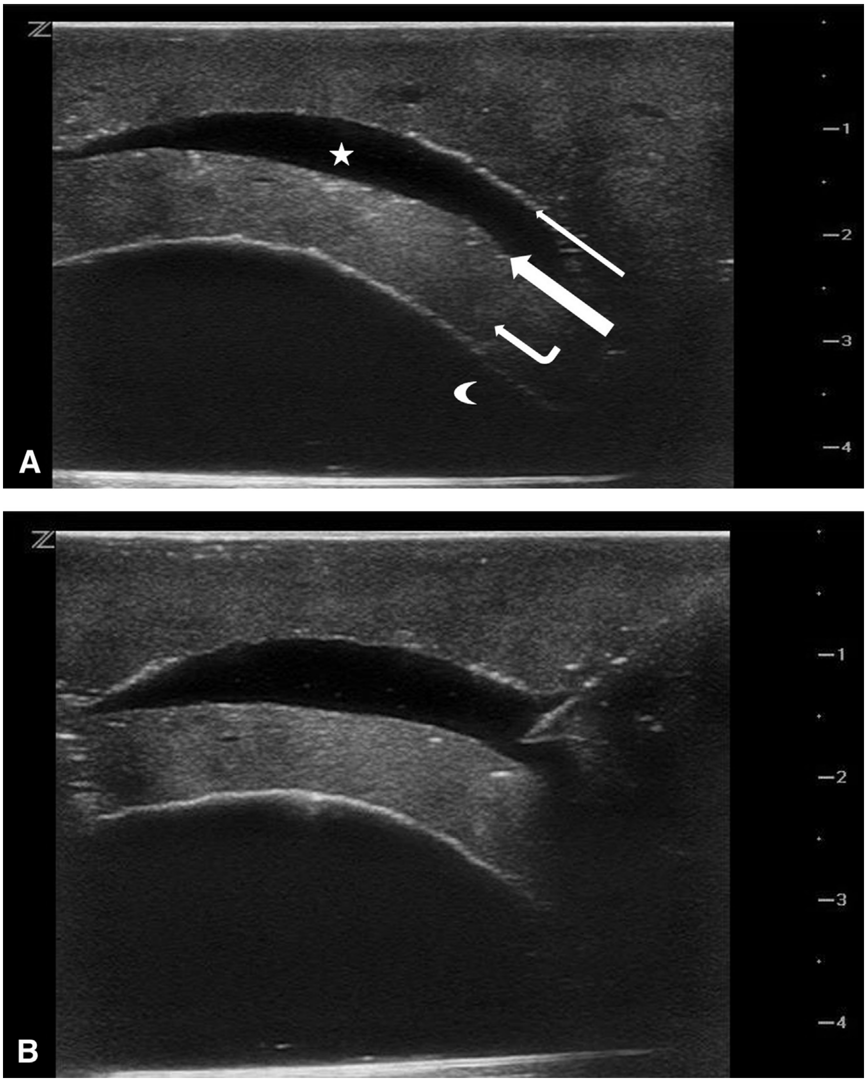

Figure 2. Ultrasound images of tofu ultrasound-guided pericardiocentesis (USGP) model with procedural demonstration. (A) Ultrasound image of the model with parietal pericardium (thin straight white arrow), pericardial effusion (white star), visceral pericardium (thick straight white arrow), endocardium/myocardium (bent white arrow), and intracardiac chamber (white crescent). (B) Ultrasound image of needle visualization while aspirating pericardial fluid with an 18-gauge spinal needle attached to a 30-mL syringe. Both images were acquired with a linear L14-5w transducer.

USGP model that can be simply constructed on-demand for training of EM providers during a shift or implemented into educational workshops.

The tofu USGP model offers distinct advantages when compared to other simulation models in the terms of achieving both low cost (∼$2 excluding common household utensils) and rapid construction time (∼2.5 min). A gelatin-based USGP model costs about $20 and requires several hours to construct (14). Similarly, a gel wax-based USGP model costs about $70 and requires 2 h of construction time (15). A recently described gel wax-based USGP model integrated into an artificial thorax requires about 4 h of actual construction time (16–20 h of total construction time) and costs < $200 (17). A USGP balloon-in-balloon water bath model has also been developed, with a cost per unit of about $10 and a construction time of < 5 min (18). The two previous studies that described a cadaver USGP model did not report construction times (12,13). In our experience, a modified non-thoracotomy approach to creating a cadaver USGP model can be achieved in < 30 min. To our knowledge, our simulation model is the least expensive and offers the shortest construction time of published simulation models for USGP procedural training.

The tofu model demonstrated favorable needle puncture durability when compared to previously reported USGP models. The model routinely withstood upwards of ∼100 total needle punctures, based on our

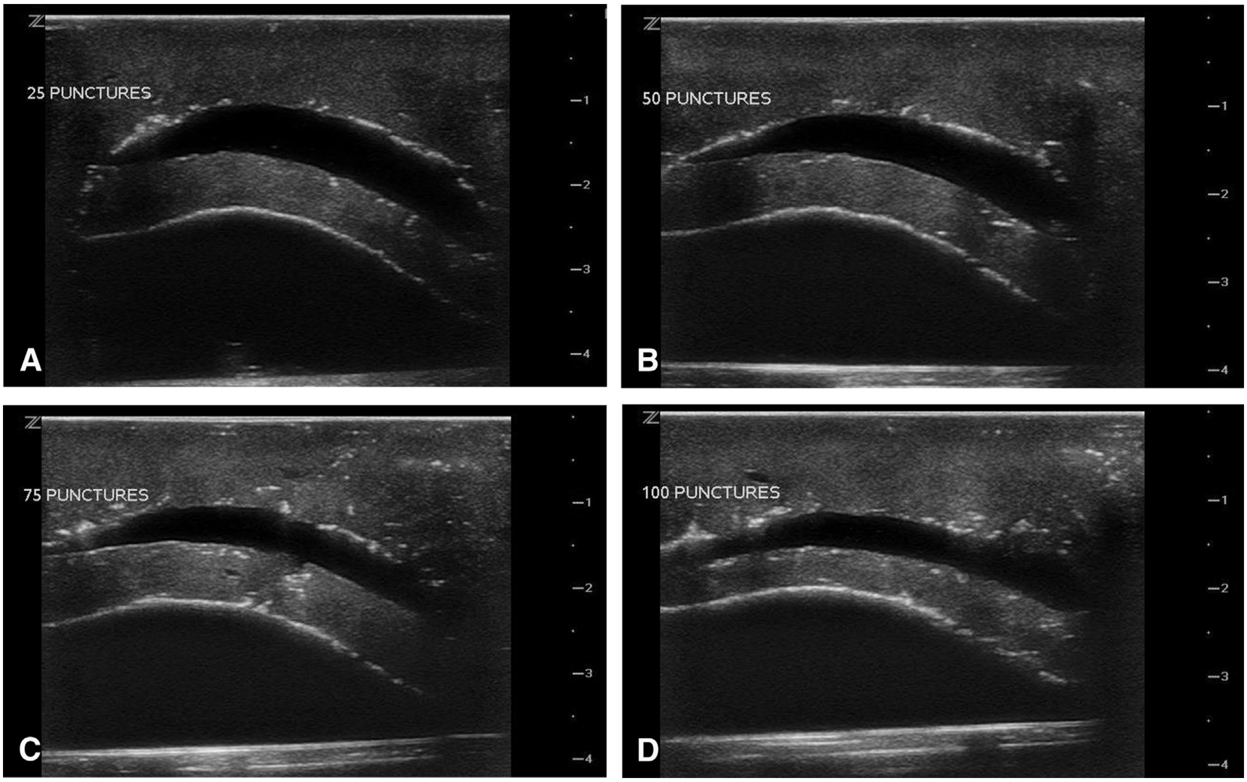

Figure 3. Ultrasound images of tofu ultrasound-guided pericardiocentesis (USGP) model demonstrating model durability. Representative images after (A) 25 needle punctures, (B) 50 needle punctures, (C) 75 needle punctures, and (D) 100 needle punctures. Needle punctures performed consecutively with an 18-gauge spinal needle. All images acquired with a linear L14-5w transducer.

observations of at least five independent models used during USGP procedural training sessions. This is an improvement in needle puncture durability with the tofu model when compared to the gelatin- or gel wax-based models, which can withstand ~40–60 total needle punctures (14,15). Notably, the only other previously described low-cost, rapidly constructed USGP model can only withstand an average of four needle punctures before model degradation (18). Our novel tofu model achieves the combination of low-cost, rapid construction, and needle puncture durability that other USGP task trainers have been unable to offer.

Limitations

A general limitation of phantom simulation models includes the lack of anatomic landmarks and restrictive storage requirements. Consistent with the limitations noted in previously designed do-it-yourself USGP models, our model is unable to simulate cardiac movement and does not provide external anatomic landmarks for procedural guidance. Additionally, tofu is a perishable material and therefore the model is not intended for long-term storage or repeated usage over multiple instructional sessions. Further studies are needed to determine the comparative effectiveness of the tofu model versus other task trainers in training EM sonographers to perform USGP.

CONCLUSIONS

The tofu USGP simulation model is both a cost-effective and rapidly constructed alternative for USGP procedural training. This simulation model could be easily adapted into the procedural curriculum of EM, cardiology, and critical care training programs.

SUPPLEMENTARY DATA

Supplementary data related to this article can be found at https://doi.org/10.1016/j.jemermed.2018.09.010.

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