A Low-Cost, Reusable, Ballistic Gelatin Ultrasound Phantom for Simulation of Glenohumeral Intraarticular Injections

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ABSTRACT

Background: Deliberate practice of invasive procedures on simulation phantoms has been recommended to teach trainees. For many departments, these task trainers can be prohibitively expensive. Sometimes, phantoms for specialized procedures are not commercially available at all. There are currently are no commercially available simulation phantoms for the purpose of ultrasound (US)-guided glenohumeral joint injection.

Objectives: The objective was to create a low-cost, reusable, homemade simulation phantom for US-guided glenohumeral joint injection using easily obtainable materials as well as to determine whether use of such a homemade model by novice learners is associated with increased self-reported comfort level and knowledge of the procedure.

Methods: Fourth-year emergency medicine–bound medical students and PGY-1 residents were asked to participate in a hands-on 30-minute training session for US-guided glenohumeral joint injection using a homemade simulation phantom. Participants were assessed by pre- and postintervention survey of self-reported comfort levels with the procedure. Outcomes were measured on modified global rating scale (GRS; minimum = 1, maximum = 7). The primary outcome was learner comfort with US-guided glenohumeral joint injection. Secondary outcomes were comfort level in obtaining adequate US image and identifying landmarks of the glenohumeral joint as well as likelihood to perform US-guided injection of the glenohumeral joint in a clinical setting.

Results: In the primary outcome, mean GRS scores in 13 participants for comfort with the procedure increased from 2.7 to 5.0 ($p < 0.01$) after intervention. Mean GRS for knowledge of anatomy increased from 2.8 to 5.4 ($p < 0.01$) and mean GRS for comfort in image acquisition increased from 2.8 to 5.3 ($p < 0.01$). Mean GRS for likelihood to perform the procedure trended toward increase from 4.6 to 5.5 ($p = 0.25$).

Conclusions: Use of a homemade, low-cost, ballistic gelatin US phantom for simulation of glenohumeral intraarticular injection was associated with increased learner comfort with the procedure.

NEED FOR INNOVATION

Deliberate practice of invasive procedures on simulation phantoms has been recommended to teach trainees. For many departments, task trainers can be prohibitively expensive. Sometimes, phantoms for specialized procedures are not commercially available at all. There currently are no commercially available simulation phantoms for the purpose of ultrasound (US)-guided glenohumeral joint injection.

BACKGROUND

Increasingly, US is being used as an adjunct for procedural guidance to improve accuracy and efficacy and to

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decrease complications of procedures.[1] Procedure simulation has been shown to improve outcomes by allowing for repetition in a safe environment.[2–6]

There are commercially available US phantoms available for specific procedural applications. However, they are often prohibitively expensive. Cost of an internal jugular central venous access phantom begins at $1,506.96 USD from the popular Blue Phantom series. Advanced models for regional anesthesia can approach $5,000.00 USD.[7,8] In this case, there were no commercial models available for our desired purpose. On surveying the literature, we were able to find one attempt at creating a similar model.[9] The authors used gelatin to create a model to allow for acromiohumeral distance measurement. Their method, however, was technically difficult and required equipment such as 3D printing and plastic vacuum-forming machines that are not available to the novice.

Many instructors have taken it upon themselves to develop homemade simulation models. Various methods have been described, from using food-grade gelatin,[10] to agar,[11] to SPAM brand potted meat.[12] Each has downsides in that they often degrade under use, require constant refrigeration, or allow for mold growth upon storage. The use of military-grade "ballistic gelatin" has also been described for this purpose.[13,14] Ballistic gelatin has unique physical properties similar to human tissue and appears to have favorable sonographic properties. This commercially available product has the advantages of being inexpensive, easily accessible, stable at room temperature, mold- and bacteria-resistant, and reusable.

The purpose of this study was to evaluate the benefits of deliberate simulation practice on trainee comfort in performing US-guided glenohumeral joint injection and show that a low-cost homemade model is sufficient for achieving this goal.

DEVELOPMENT PROCESS

We set out to develop a phantom for US-guided intraarticular glenohumeral injections in an anterior shoulder dislocation with associated hemarthrosis. We used 3 pounds of commercially available 10% ballistics gelatin ($13.98/lb, Clear Ballistics),[15] a PVC model of shoulder joint ($26.95, eBay), Gypsona plaster bandages ($3.44ea, VivoMed),[16] a Foley catheter ($4.84 FirstOptionMedical),[17] a disposable cake tin, a 20-mL syringe, two hemostats, cyanoacrylate Super Glue, aluminum foil, and red food coloring. These materials were chosen as they are in most cases easily accessible to health care providers. The approximate cost of materials for one model is $85.00.

To create this model, the shoulder model was disarticulated at the glenohumeral joint. The humerus was then superglued in approximate anatomic location of an anterior dislocation (Figure 1A). The Foley catheter tubing was prepared by cutting off a portion of collection tubing. The cut edge of the tubing was clamped with two hemostats (Figure 1B) and heated over an open flame to seal. The tubing was then superglued to the glenoid fossa to simulate the location of a hemarthrosis, and the remainder of tubing run along the anterior portion of the bone model, making sure to leave enough length for the tubing to be externalized outside the gelatin portion of the model (Figure 1C). To create the mold, Plaster of Paris bandages were molded to the shape of the anterior aspect of a shoulder in the bottom of a foil cake pan (Figure 1D).

The gelatin was cut into 1-inch cubes (Figure 2A) and heated in an electric slow cooker for approximately 2 hours, until the gelatin had become a uniform liquid. The gelatin was not allowed to exceed a temperature of 260° F (Figure 2B). Then, one-third of the gelatin was poured into the mold. The mold was placed in a refrigerator at 35°F for 1 hour or until solid. At this point, the shoulder model was placed on top of the solidified gelatin (Figure 2C), and the remaining two-thirds of liquid gelatin was poured on top, submerging the entire model. The mold was again refrigerated for 1 hour. The gelatin was then removed from the mold (Figure 2D). Using a 20-mL syringe, the tubing was filled with colored water. This process of creating the model takes approximately 5 to 6 hours.

Ultrasound investigation of the model with high-frequency linear probe revealed easily identifiable landmarks including glenoid fossa and fluid-filled hemarthrosis (Figure 3). Learners were able to use the model to perform US-guided needle aspiration of simulated hemarthrosis and injection of saline into the simulated joint capsule. The model was able to sustain approximately 30 needle punctures without degrading the image or showing signs of wear.

IMPLEMENTATION PHASE

The study was submitted to the institution's institutional review board and received exempt status for nonhuman subjects research. Participants were recruited by e-mail and verbally consented for optional

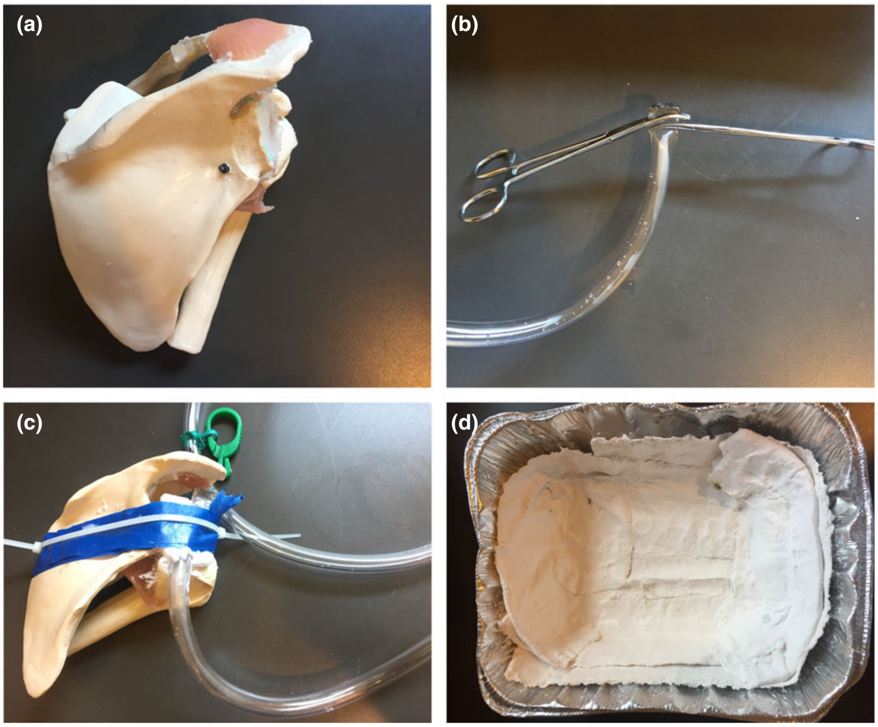

Figure 1. Creation of shoulder model: (**A**) Disarticulation of shoulder model; (**B**) clamping of cut end of Foley tubing prior to heating; (**C**) gluing of tubing to glenoid fossa; (**D**) Plaster of Paris bandages used to create mold in bottom of foil pan

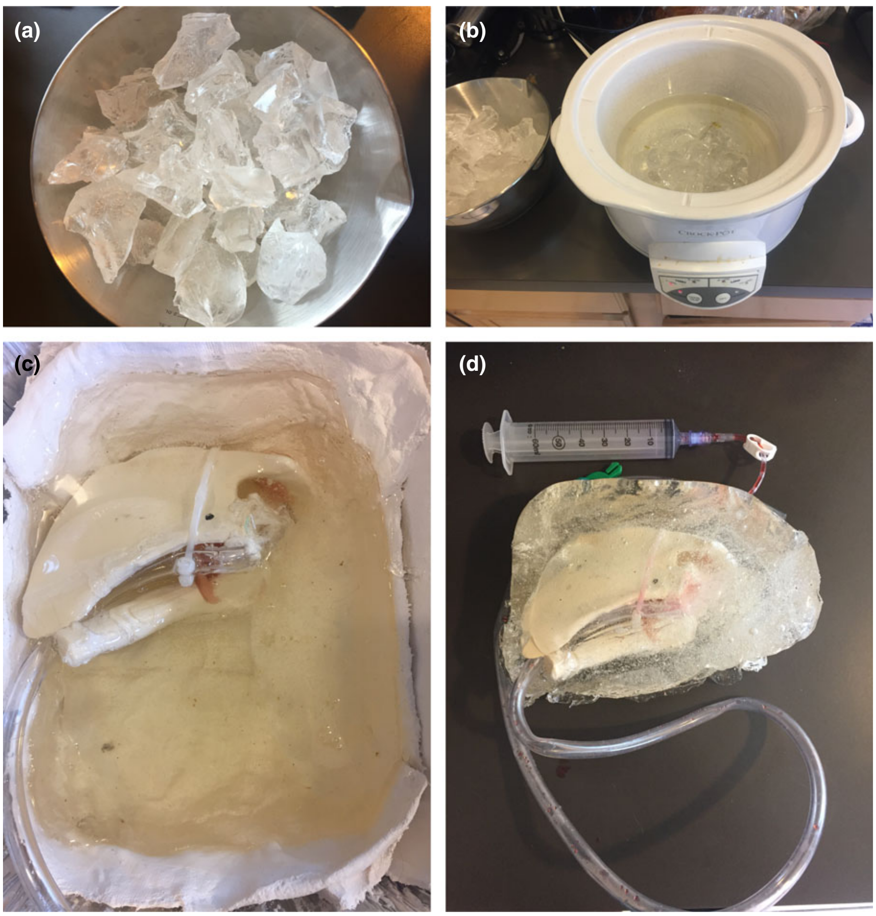

Figure 2. Preparation of gelatin: (**A**) Gelatin cut into 1-inch cubes; (**B**) gelatin melting in slow cooker; (**C**) shoulder model placed on top of mold with one-third of mixture solidified; (**D**) completed model removed from mold.

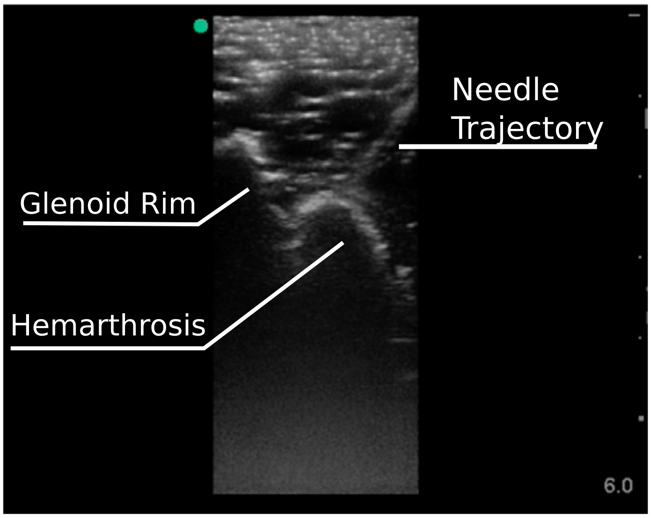

Figure 3. Ultrasound appearance of simulated glenohumeral joint upon interrogation with linear probe. Identified with labels are location of glenoid rim, location of hemarthrosis, and trajectory of needle during attempted injection.

participation in the research study. The study was attended by five PGY-1 emergency medicine residents and eight MS4 students for a total of 13 subjects. The participants attended a 30-minute hands-on didactic session focused on teaching US anatomy at the glenohumeral joint and one-on-one instruction using the simulation model to perform glenohumeral joint injection.

OUTCOMES

All participants completed a pre- and posttest survey. Our primary outcome was comfort level with US-guided needle injection of the glenohumeral joint. Secondary outcomes included comfort level obtaining adequate US image of the glenohumeral joint, comfort identifying anatomical landmarks on US image of the glenohumeral joint, and likelihood to perform US-guided injection of the glenohumeral joint in a clinical setting. These were rated on a previously validated 7-point modified global rating scale (GRS) ranging from "not at all" to "very" with value of 4 assigned as neutral.[18,19] Data were analyzed using dependent t-tests via SPSS software.

Thirteen participants completed the pretest survey, intervention, and posttest survey. None of the participants reported having performed US-guided glenohumeral joint intervention prior to the study. Mean GRS for comfort level with US-guided injection at the glenohumeral joint increased following the simulation intervention from 2.7 to 5.0 ($p < 0.01$, 95% confidence interval [CI] = 1.151–3.310; $t(12) = 4.502$). Mean GRS for comfort in identifying anatomic landmarks on US increased from 2.8 to 5.4 ($p < 0.01$; 95% CI = 1.853–3.377; $t(12) = 7.479$) and mean GRS for comfort in image acquisition increased from 2.8 to 5.3 ($p < 0.01$; 95% CI = 1.857–3.219; $t(12) = 8.124$). Mean GRS for likelihood to perform the procedure trended toward increase from 4.6 to 5.5 ($p = 0.25$). The learners also rated the realism of the model favorably compared with previously used commercial task trainers with a mean value of 5.25 ($n = 13$).

REFLECTIVE DISCUSSION

We have developed a high-fidelity, specialized US phantom for the purpose of simulating intraarticular glenohumeral joint injection. Despite the many benefits of this model, there are some limitations. First, although the material is durable and needle tracks are resealable with surface heating with a hair dryer, after repeated punctures the model will contain large needle-track scars, necessitating recreation of the model. Cost of the ballistic gelatin, while low overall, is higher than that of food-grade gelatin products. Also, we were unable to simulate certain soft tissue structures such as fat, muscle, and tendon, which could be of importance in certain applications.

Our results show that after participating in a single 30-minute instructional session, participants reported increased comfort in performing US-guided injection at the glenohumeral joint. They also reported increased comfort in secondary outcomes of image acquisition and identification of anatomical landmarks on US. We found that our learners had positive feedback regarding the realism of the simulation model, rating the homemade model similar in realism compared to commercially available task trainers for US-guided procedures. This is also supported by prior literature.[20]

In performing this study, we were able to identify some limitations. First, as the study was voluntary, we had a small sample size and heterogeneous sample in using both fourth-year medical students and PGY-1 emergency medicine residents for data collection. Similarly, there is the possibility of some selection bias, although this effect should be minimized by surveying the same group before and after intervention. Although the participants had never performed this intervention in the past, they had baseline experience with US, limiting the generalizability of this study. We aimed at assessing comfort and did not assess for procedural competency or knowledge retention of participants.

We feel that our ballistics gelatin model shows promise for use in high-fidelity US simulation. It allows for a safe method for learners to hone procedural skills prior to application to a live patient. Our model illustrates that use of ballistics gelatin in US simulation models will allow instructors to develop cost-effective models for a variety of applications. Although prior studies have shown improvement in procedural competence in other procedures with similar commercially available trainers, further research is needed to determine if use of this and similar homemade trainers will have the same results.

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