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Versatile, Reusable, and Inexpensive Ultrasound Phantom Procedural Trainers

Dustin S. Morrow, MD, RDMS, Julia A. Cupp, MD, Joshua S. Broder, MD

We have constructed simple and inexpensive models for ultrasound-guided procedural training using synthetic ballistic gelatin. These models are durable, leak resistant, and able to be shaped to fit a variety of simulation scenarios to teach procedures. They provide realistic tactile and sonographic training for our learners in a safe, idealized setting.

Key Words—medical education; procedural training; ultrasound; ultrasound phantom

Physicians are required to become skilled in a variety of procedural competencies, ranging from critical care interventions (central venous cannulation) to diagnostic testing (lumbar punctures) to therapeutic interventions (abscess drainage). Simulation is superseding the traditional see-one, do-one, teach-one apprenticeship model as a more efficacious teaching strategy.^{1–6} Procedure simulation has been shown to accelerate intern competency past that of their more clinically experienced peers,^{2,3} with higher success rates compared to the traditional bedside apprenticeship model.⁴ Simulation-trained proceduralists have improved adherence to sterile technique and decreased complication rates.^{1,5} With the presumed advantages of simulation training (eg, trainee and patient comfort, opportunities for troubleshooting, and repetition) and now with these demonstrations of success, simulation is becoming standardized into residency curricula.⁶

Commercial ultrasound (US) phantoms have been designed to produce high-fidelity simulation, but with each phantom specifically tailored to one procedure and a high cost per phantom, collecting an adequate variety and quantity⁷ of commercial phantoms can easily exceed a budget. Models currently available and reported in the literature include the Blue Phantom series: lumbar puncture and spinal epidural training model (\$3799),⁸ abscess drainage training model (\$999),⁹ and central line training model (\$3199)^{1,4,6}; and alternatively, the Kyoto lumbar trainer (\$2150).²

The high cost of US simulation phantoms has led teachers to explore alternatives, including cadavers and homemade alternatives¹⁰ using culinary gelatin^{11–15} or animal products.^{16–19} Each method accepts several disadvantages of the proposed materials in exchange for its much lower cost: the phantoms require careful storage, break down with multiple uses, and degrade and mold over short periods.

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Address correspondence to Dustin S. Morrow, MD, RDMS, 5212 Penrith Dr, Apt J, Durham, NC 27713 USA.

E-mail: dustinmorrowmd@gmail.com

Abbreviations
US, ultrasound

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Furthermore, although homemade gelatins have become popular because of their sonographic properties and ability to incorporate examples of pathologic conditions, they require special recipes with specific mixing ratios²⁰ to achieve an appropriate consistency and melt at room temperatures and with typical handling.¹⁵

In contrast, we describe a simpler and cleaner production method using commercially available synthetic ballistic gelatin.²¹ Ballistic gelatin was originally developed as a human tissue simulant for firearm testing.²² In recent times, it has been optimized from gelatin-in-water recipes to synthetic versions and popularized by television shows such as *MythBusters* (Discovery Channel). Given its properties that approximate human tissue density and feel, we explored its capacity for US imaging and found it to be an excellent simulant: it provides an interface through which needles and their targets, such as vessels or abscess pockets, can be visualized sonographically, and it is self-sealing after needle cannulation. Synthetic gelatin is stable at room temperature, is recyclable, and can be remolded multiple times without loss of quality. Models created with synthetic gelatin have the convenience and cleanliness of commercial phantoms at the cost of homemade phantoms.

Materials and Methods

We used a 4.5-lb block of synthetic gel obtained from Clear Ballistics²¹ (\$36.66) to create the 3 US phantoms described, using approximately 1.5 lb of gel per phantom (Appendix). The gel was molded to the various models by melting it in a covered heating container such as a 3-qt saucepan on a low setting on a range and then pouring the liquefied gel into a molding container, allowing it to cool at room temperature to solidify. Depending on the density of the US target and its desired depth in the final product, the target was added to the molding container before or halfway through the pouring process. With some creativity to design and incorporate the appropriate US target, this general process using this synthetic material can simulate any US-guided procedure through soft tissue. We specifically describe US targets and methods for US phantoms for central venous catheter insertion, lumbar puncture, and abscess drainage.

To create the phantom for central venous catheter insertion, we used latex tubing (8-mm internal diameter; latex-tubing.com²³) to simulate the target blood vessel. The tubing was filled with water by tying a knot in one end, attaching a water-filled 60-mL catheter tip syringe to the free end, aspirating air, allowing the vacuum to pull the water into the tube, and then clamping the free end of the water-filled

tube with a hemostat to prevent leakage. The tube was secured to the bottom of the molding container with tape so that it would not lose its place when the melted gel was poured over it. The final product allows the trainee to complete all of the steps of central venous catheter insertion, from identification of the “vessel” with US to incision, dilation, and threading of the catheter. These final steps are usually omitted with the commercial trainers and some homemade models, as they irreparably damage the models, preventing their use for further practice. For reuse of the synthetic gelatin central venous catheter model, after removal of the central venous catheter, the syringe was reattached to the tubing to check for leakage. If water leaked through the dilated track, the track could be repaired by aspirating the water from the tubing, patting the surface of the gel dry, and then applying a hair dryer for 30 to 60 seconds to remelt the area of the track. Once the area had cooled and resolidified, the water was reintroduced into the tubing via the syringe. Despite this quick repair procedure, a sonographically visible scar from the dilation tract did remain; however, it did not prevent reuse of the model. To remove these scars, the model must be broken down and the gel fully remelted and repoured.

To create the phantom for lumbar puncture, we purchased a lumbar spine anatomic model (\$19.99; Anatomical Chart Company²⁴) and placed liquid-filled latex tubing in the spinal canal to simulate the cerebrospinal fluid-filled dural sac. The tubing was knotted at the inferior end, filled via a syringe, clamped with a hemostat, and otherwise manipulated in fashion similar to that for the central venous catheter phantom. The lumbar spine and tubing assembly was placed in the molding container, spinous processes down, and the melted gel was poured over it to at least the level of the spinal canal and transverse processes; the vertebral bodies were left partially uncovered to decrease the amount of gel required. The vertebral bodies were taped to the sides of the molding container to keep the model balanced on the spinous processes while the gel was poured and solidified. A second layer was molded by pouring the melted gel into an empty molding container to a depth of 3 to 4 cm; the depth and resulting thickness of this layer can be adjusted to the desired difficulty and body habitus of the simulated patient's back. The 2 layers were allowed to cool at room temperature and fully solidify; then the second layer was placed over the spinous process side of the initial layer. The 2 layers self-annealed with minimal pressure and time. The spinous processes could be palpated through the second layer for landmark-guided lumbar puncture; with a thicker second layer, palpation

became more difficult, and US was used to identify osseous boundaries. With successful lumbar puncture, there was a loss of resistance into the tubing, and when the stylet was removed, fluid drained out of the spinal needle. The model withstood multiple punctures without leaking.

To create the phantom for abscess drainage, we filled a balloon with 10 to 20 mL of water and left it in a freezer to solidify. The gel was poured in the molding container in 2 layers: a 5-cm base layer was poured into the empty molding container and allowed to solidify while the remaining melted gel was kept liquid in the heating container on a warm range setting. Then the frozen balloon was placed on top of the base layer, and the remaining gel was poured over it until 2 to 3 cm of gel was covering the balloon. On US imaging, the abscess pocket appeared as a hypoechoic fluid-filled structure, which could be aspirated with a needle under US guidance. Multiple needle aspirations did leave air in the pocket; the air was removed, and the pocket was refilled with a needle and syringe. Unlike all other commercial phantoms, the abscess can be incised with a scalpel, and the pocket can be dilated with a hemostat just as in clinical practice; the gel can be repaired by pulling off a small piece of gel the size of the incision from the periphery of the gel, placing it over the wound, and applying heat with a hair dryer until the section melts (becomes reflective and glassy). After cooling for 5 minutes, the section will be solid, and the pocket can be refilled by using US and a needle and syringe.

As described, each of the 3 phantoms is composed of clear gel such that the target is visible to the naked eye. An opacifying dye is available,²¹ which can be added to the melted gel to increase the difficulty level of the model, depending on the needs of the learner. Clear gel allows new learners to understand how 2-dimensional US correlates with 3-dimensional space; the learner, when having difficulty grasping the spatial orientation of the needle and intended target on the screen, can look directly at the phantom and see the objects embedded within, which facilitates real-time feedback from instructors in showing learners how to troubleshoot. For advanced users, opacifying dye can be added to obscure the target's actual spatial location and force the user to solely rely on US guidance. Opaque layers of ballistic gelatin of varying thickness can be constructed separately (as described for the lumbar puncture model) and will temporarily and reversibly anneal to the surface of a transparent model without additional heat or adhesives, allowing the difficulty of a model to be adjusted for learners of varying levels.

Discussion

With reusable synthetic ballistic gelatin and easily obtained medical and household supplies, we have created a variety of phantoms that can withstand multiple punctures, allow for US needle guidance, as well as further expand the capabilities of previously described homemade and commercially available models. We have optimized the substantial limitations of previously described models in terms of cost, cleanliness, durability, leaking, and reusability.^{20,25} We have used all 3 phantoms with large groups of emergency medicine residents and medical students with positive feedback regarding the experience. We have found them to provide a cost-effective, practical method of demonstrating and supervising important clinical procedural skills.

These models allow students to make mistakes and complete entire procedures, as tracks, cuts, and holes are easy to repair by reapplying heat. The synthetic gel is amenable to remolding the models again and again for multiple uses. This factor is of particular appeal in central venous cannulation training: most commercial models recommend against performing the second half of the procedure, including incision and dilation, as the control of remaking and repairing the models belongs to the manufacturer and not the end user. Our abscess model, similarly, allows incision and drainage in addition to the needle aspiration method to which the commercial models are limited. With this material, we have found that our increased control over the molds and what we create and recreate with them has far fewer limitations than single-purpose products. Without the fear of financial loss with expensive models, these models allow the learner to practice skills from first steps to completion.

Recent advances in simulation research have suggested having simulation as an intervention for entire residency classes early in residency,^{2,3,6,26} with a low resident-to-phantom ratio⁷ and an appropriate variety of procedures taught. In addition to the 3 specific procedures described above, these materials and strategies can be applied to other US and procedural targets to fully stock a program's simulation needs. We have designed phantoms for US-guided peripheral venous access²⁷ and are currently using the synthetic gelatin to develop cleaner and more durable ocular phantoms with previously described methods for designing pathologic conditions.²⁸ We have found thoracic and abdominal molds, a heart mold, and a thoracic skeleton to enable the creation of chest tube, pericardiocentesis, subclavian, and paracentesis phantoms.

We found the greatest limitation to these models to be the time required to make them, which is substantially greater than simply ordering a commercially available model. The cost of the synthetic gelatin is higher than that of homemade gelatin. As with the homemade gelatin, there is risk from exposure to the heating element, which can be mitigated with proper handling and personal protective equipment. Sonographically, although this tissue allows for needle visualization and identification of vessels and abscess pockets, needle approaches will leave small, sonographically apparent scars. These can be minimized by reheating with a hair dryer to resurface the gel, or they can simply be ignored, as the needle can be clearly distinguished from these artifacts, and the scars do not leak. Additionally, culinary gelatin and commercial phantoms require less gain to appear isoechoic with human tissue than do our phantoms, which appear hypoechoic on grayscale US images (see side-by-side comparison in Figure 7). However, as these are procedural trainers, and the primary goal is target acquisition and needle finding, this hypoechoic appearance of our simulated soft tissues did not affect the utility of the models to achieve those goals.

The synthetic gel has been specifically designed to mimic human tissue, and our residents have found the models to provide high fidelity in replicating the US images and tactile feel of each procedure. The fidelity of the procedural model has been shown to be vital to successful simulation, as low-fidelity simulation has produced negative results.²⁹ Although so far we have only collected qualitative feedback, future goals include testing these models against other simulation models and the traditional apprenticeship teaching model.

Given the easy handling, low cost, reusability, and multiple uses for synthetic ballistic gelatin and its tactile and sonographic similarities to both commercially available simulation products and human tissue itself, this material has become an invaluable tool for a multitude of applications. With this material and these production strategies, we have been able to teach a large number of learners a variety of techniques in a safe and controlled environment before assisting them in performing these procedures on our patients.

Appendix

General Guidelines for Gel Preparation

Materials

1. 10% ballistic gelatin (Clear Ballistics, LLC, Fort Smith, AR; \$36.66/4.5 lb [2.04 kg], 144 cubic inches [2359 mL])
2. Opacifying agent, if desired: gel dye (Clear Ballistics; \$9/120 mL; will need \approx 30 mL for each application)
3. Molding container: 7 × 4-inch glass baking dish (for setting the mold)
4. Heating element in a well-ventilated setting:
 - Can use any typical kitchen range with a low setting (we used a Waring SB30 1300-W portable single-burner range [Waring Products, McConnellsburg, PA] set at 1 of 5)
 - Alternative heating method: oven set at 200°F (93°C) and an oven-safe molding container
5. Other heating equipment:
 - Heating container: 3-qt (2800-mL) saucepan or pot with lid (for heating the gel)
 - Culinary temperature gauge
 - Personal protective equipment (gloves, apron, and eye protection)
 - Hair dryer and towel (for reuse)

Procedures

1. Measure the appropriate amount of gel by breaking pieces off the gel block and placing them in the molding container until it is filled to the desired level (Figure 1).
2. Transfer the broken gelatin pieces to the heating container; cover the container with the lid.
3. Heat the gel pieces on a low heat setting: use the thermometer to ensure the gel temperature does not exceed 260°F (126.6°C). We used level 1 of 5 on our Waring range, and it took 20 minutes for our gel to melt completely. The gel does not require stirring or other intervention during the melting process.
4. Once the gel is liquefied, stir in the gel dye, if opacification is desired (Figure 2).
5. Pouring the mold: This process depends on how the US target can be secured in the molding container and the desired final location of the target in the gel block, which determines the depth of the simulated procedure. For the central line trainer, the tubing was secured in the molding container, and all of the gel was poured over it at once; for the abscess and lumbar puncture trainers, the mold was poured in layers, as described in those subsections.

- Allow your phantom to cool and solidify, and then it can be removed from the molding container. The surfaces should separate with minimal pressure, and then the final product can be lifted out of the container.

Alternative Heating Method

If the US target is heat stable and can be secured at its desired location in the molding container, then the molding container can be filled with the target and the gel pieces and then placed in a conventional oven at 200°F (93°C) until the gel is melted. It is then cooled at room temperature to solidify. This process negates the need for a separate heating container and the pouring steps but allows less flexibility for placement of the target.

Central Venous Catheter

Additional Materials

- 60-mL catheter tip syringe
- Water (with red or blue food coloring added, if desired)
- Hemostat
- Tape
- Latex tubing: available at a local hardware store or online (latex-tubing.com); sizes range from internal diameters of 1.5 to 8 mm; prices range from \$0.50 to \$0.89 per foot

Procedures

- Cut the tubing to the appropriate length (this step depends on the size of the molding container, as described in step 2), and tie a knot at one end, leaving the other end open (Figure 3).
- Place the latex tubing in its desired orientation with the ends draped over the sides of the glass and the middle

Figure 1. Molding container filled with broken gel pieces.



Figure 2. Liquefied gel.



Figure 3. Simple knot tying the free end of the latex tubing.



Figure 4. Taped tubing and hemostat attached.





Figure 5. Finished central line phantom (opacifying agent added to clear gel).

- running across the bottom of the molding container; secure it by taping each end to the sides of the glass (above the intended gel fill level, so that the tape can be removed later). If taped securely with the tubing snugly running across the bottom of the container, the tubing will not float with pouring of the gel; this step is convenient, but not critical, as explained in step 4 (Figure 4).
3. Fill the tubing with water: Fill the catheter tip syringe with water, and attach it to the free end of the tubing; draw back on the syringe to pull air out of the tubing, and then release the syringe to fill the tubing with the water. Once the tubing is filled, clamp the free end with the hemostat.
 4. Melt the ballistic gel and pour a layer of approximately 3 to 4 cm over the top of the tubing (Figure 5).
 5. Depending on how the tubing has been secured in the molding container, it may float upward (and become too superficial) as the gel fills the container. If the tubing starts to rise with pouring of the gel, stop, and allow the poured gel to cool and solidify around the tubing.
 6. Keep the remaining melted gel warm on a warm setting on the burner or in the oven until the initial layer has solidified.
 7. After the initial layer has cooled, pour the rest of the melted gel over it; the initial layer should keep the tubing secure.

Using the Phantom

Use the vascular probe to identify the water-filled tubing as the simulated patient's vein. Cannulate the vessel, and proceed with the usual steps of central line placement:

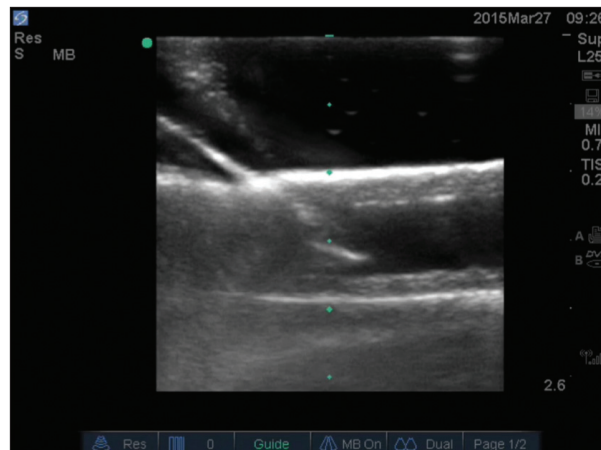


Figure 6. Needle shown cannulating the vessel with a superior scalpel and dilation track scar superficial to the needle (our model).

these include a superficial incision or “skin nick” and the use of a dilator to create a track to accommodate a central venous catheter, steps that are usually discouraged in commercially available models, as they diminish the reusability of the model.

Reusing the Phantom

Remove the catheter. Image the tubing with US to observe for any air that may have been introduced. Clear the air from the tubing by aspirating and refilling the tubing, as in step 3 above.

There may be some leaking from the surface where the dilation was performed. Leaks can be fixed by drying and heating: Empty the tubing by aspirating with the syringe, and pat the surface of the phantom dry. Apply a hair dryer to the wound for 30 to 60 seconds or until the superficial layer becomes reflective and molten in appearance. Allow it to set for 5 minutes to resolidify, at which time the model should not leak when refilled with water. This process can be repeated several times per phantom.

There will be a sonographically visible scar left from the dilation track. Prior tracks will not interfere with sonographic visualization of the needle on repeated cannulations (Figure 6). These tracks will remain until the ballistic gel is melted entirely and repoured. Once a simulation session is complete, these phantoms can be broken into gel pieces and remolded many times.

See comparison versus a commercial phantom (Figure 7).

Cost: \$13 per phantom; time investment (including the general gel preparation): 30 minutes.

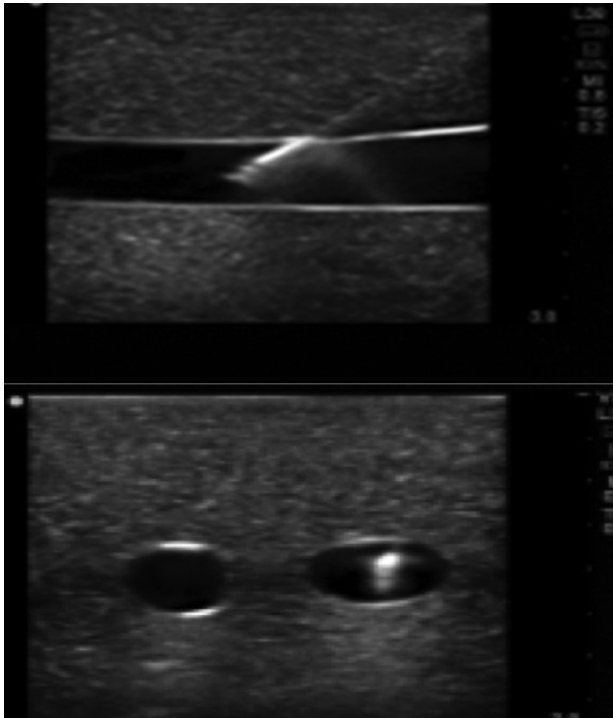
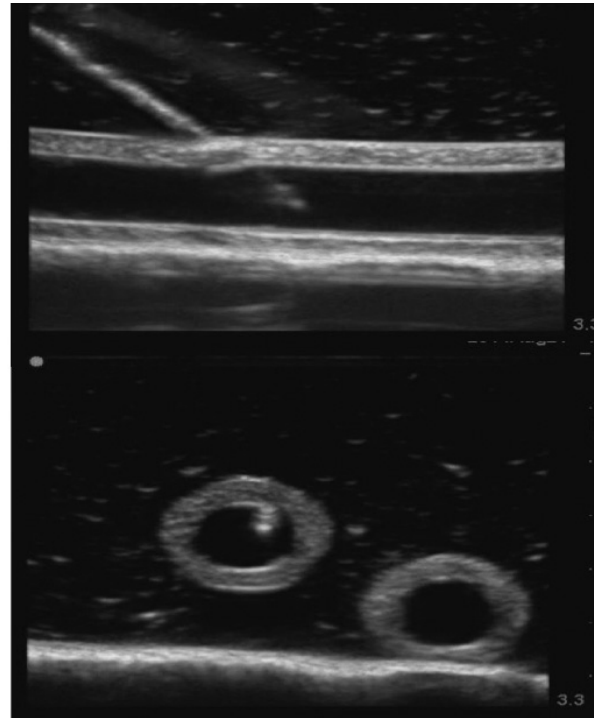


Figure 7. Commercial phantom (left) and our synthetic gel phantom (right).



Lumbar Puncture

Additional Materials

1. 4-part lumbar spine anatomy model (\$19.99; Anatomical Chart Company via amazon.com²⁴; if the model comes with spinal cord and roots included, they must be removed to make room for the tubing)
2. 10 inches of latex tubing, water-filled syringe, and hemostat, as under central venous catheter materials
3. Tape

Procedures

1. Tie one end of the latex tubing into a knot (Figure 3).
2. Place the latex tubing through the spinal canal on the anatomic model, oriented with the knotted end inferior and free end superior (Figure 8).
3. Fill the tubing as performed with the central venous catheter model: Attach the syringe filled with water to the free end of the tubing, aspirate air out of the latex tubing, and allow the vacuum to refill the tube with water. Then clamp the free end with the hemostat.
4. Secure the lumbar spine in the molding container with the spinous processes down. Keep the spine balanced on the spinous processes by taping across the vertebral bodies to the sides of the container (Figure 9).



Figure 8. Latex tubing inside the spinal canal (spine model from Anatomical Chart Company).

Figure 9. Taped spinal model with the posterior spinous process facing downward.



- Allow the clamped free end of the tubing to hang over the side of the container.
5. Melt the gel.
 6. Pour enough gel into the molding container to cover the spinal model up to at least the transverse processes and spinal canal. Note that the vertebral bodies do not have to be fully covered, as they are not involved in the procedure, and not fully covering them decreases the amount of gel required. Keep the remaining liquefied gel in the heating container on the heating element on a warm setting to keep it in liquid form.
 7. Allow the initial layer, encompassing the lumbar spine model, to cool; then remove the layer from the molding container. Set the initial layer aside (Figure 10).
 8. Pour the second layer of molten ballistic gel into the empty molding container. This layer will simulate the subcutaneous tissue; its thickness depends on the desired difficulty and body habitus of the simulated patient's back. For further difficulty, gel dye can be added to this layer for opacification.

Figure 10. First layer of gel cooled.

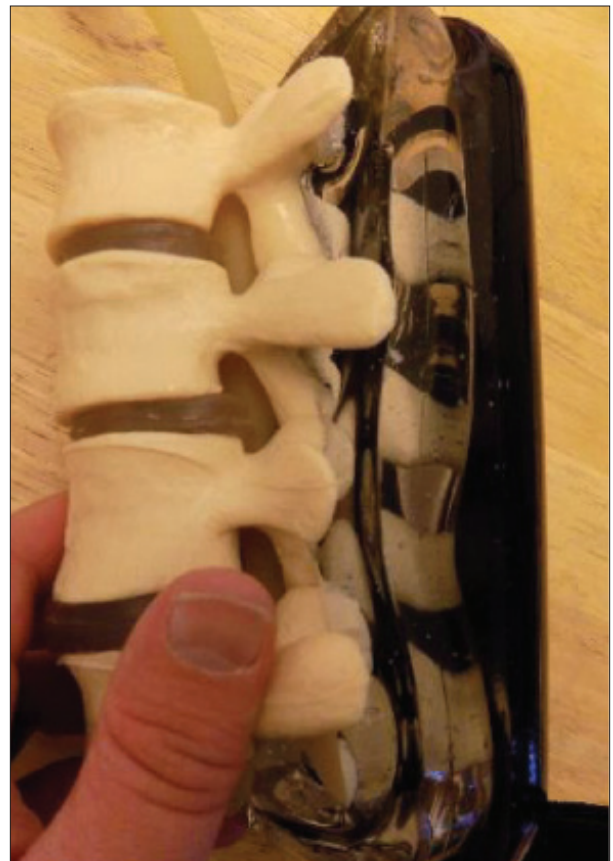


9. Allow the second layer to cool (Figure 11). Then remove it from the molding container, and place it over the initial layer so that it adds a layer of thickness to the side with the spinous processes. The 2 layers will self-anneal with minimal pressure and time (Figure 12).

Figure 11. Second layer made to desired thickness to simulate human tissue; opacifying dye has been added to this layer.



Figure 12. Finished product, with the second tissue layer pressed onto the spine model. No additional adhesive or heating is required.



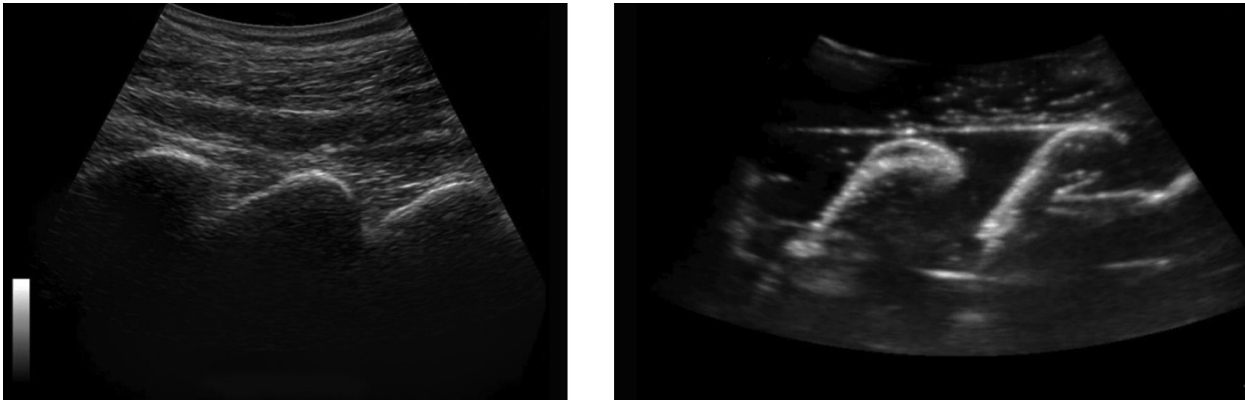


Figure 13. Human spinal US anatomy of the posterior process (left) and our phantom (right).

Using the Phantom

Landmarks for spinous processes can be palpated. Osseous findings on US look similar to commercial phantoms and human anatomy (Figure 13); the second “subcutaneous tissue” layer can be made thicker to simulate more-difficult patients, making palpation more difficult and US more crucial to assist in assessing the midline. With successful lumbar puncture, there is a loss of resistance into the tubing, and fluid will drain out of the spinal needle; if faster drainage is desired, mild pressure can be applied to the free end of the tubing manually or with the syringe. The model does not leak after multiple punctures, and as with all of these models, the gel can be broken apart and melted repeatedly.

Cost: \$33.71; time investment: 1 to 2 hours.

Abscess Model

Additional Materials

1. Latex balloons (25 count for \$1)
2. Water (with food coloring added, if desired)

Procedures

1. Add 10 to 20 mL of water to the balloon, and tie the balloon; avoid leaving air bubbles in the balloon (Figure 14).
2. Place the balloons in the freezer until the contents are frozen solid
3. Melt the gel, and pour a 5-cm layer on the bottom of the molding container; allow it to cool for 20 to 30 minutes until solidified. Keep the remaining melted gel in the heating container on a warm setting.
4. Place the frozen balloon on the first layer of ballistic gel, and then pour the remaining melted gel over it until 2 to 3 cm of gel covers the balloons. Allow to cool and solidify (Figure 15).



Figure 14. Balloons filled with water and tied at the ends.

Figure 15. Completed abscess model after the second layer of opacified gel has been applied and cooled.



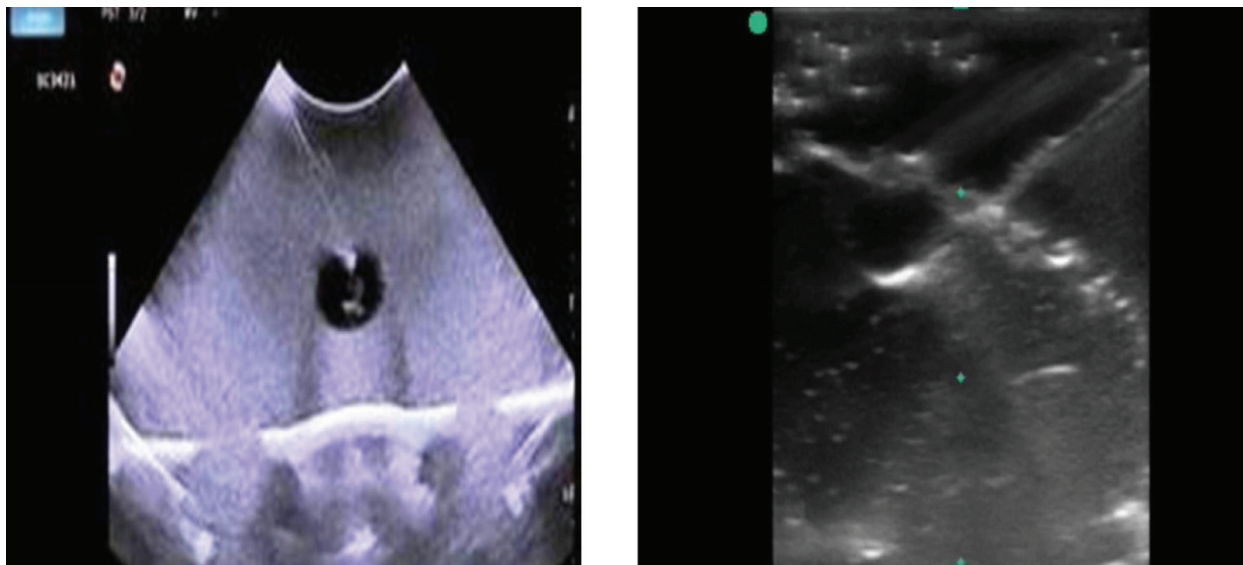


Figure 16. Side-by-side comparison of a commercial phantom (left) and a synthetic gel phantom (right).

Using the Phantom

Apply a high-frequency standard probe to the phantom: the abscess pocket will appear to be a hypoechoic fluid-filled structure, which can be aspirated under needle guidance. Multiple needle aspirations may leave air in the pocket: the air can be removed and the pocket refilled with a needle and syringe. Unlike all other commercial phantoms, the abscess can be incised with a scalpel, and the pocket can be dilated with a hemostat, just as in real clinical practice. The gel can be repaired by pulling off a small piece of gel the size of the incision from the periphery of the gel, placing it over the simulated wound, and applying heat with a hair dryer until the section melts (becomes reflective and glassy). After cooling for 5 minutes, the section will be solid, and the pocket can be refilled by using US and a needle and syringe.

A side-by-side comparison with a commercial phantom is 839 shown in Figure 16.

Total cost: \$13.72; time investment: 10 minutes active work, 1 to 2 hours to include melting/freezing/cooling.

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