A Novel Technique for Teaching Challenging Ultrasound-Guided Breast Procedures to Radiology Residents

Joseph Sutcliffe, MD, Rulon L. Hardman, MD, Nella Carol Dornbluth, MD, Ken A. Kist, MD

Ultrasound-guided breast interventions (core biopsies, needle-wire localizations, and fine-needle cyst aspirations) are common procedures performed by radiologists. Residents must gain competency in these interventions during training. Phantoms and simulations have been advocated for teaching interventions, and various systems are available for standard breast interventions. However, simulations for difficult/high-risk interventions are not readily available. We describe an inexpensive method for simulating difficult ultrasound-guided breast procedures, including masses over breast implants, deep masses along the chest wall, and lymph nodes adjacent to axillary vessels.

Key Words—breast; education; radiologic phantoms; sonography

Ultrasound (US)-guided percutaneous breast interventions are well-accepted techniques for safely performing minimally invasive breast biopsies, cyst aspirations, and needle-wire localizations. Radiology residents should acquire basic mastery of US-guided breast interventions before completing radiology residencies because general radiologists are often expected to perform image-guided breast procedures in a variety of practice settings. There is increasing emphasis on the use of simulation training in graduate medical education across multiple specialties, with a goal of increasing patient safety in the training environment.[1,2] The use of a turkey breast or gel breast phantom for simulation training of freehand US-guided breast procedures is a well-accepted technique and is used by many residency training programs. Ultrasound-guided core biopsy of simulated breast masses (eg, imbedded olives) or US-guided fine-needle aspiration of simulated breast cysts (eg, tied-off water-filled plastic glove fingers) are the simulation techniques most commonly described.[3–10] At our institution, we have intermittently used both gel and turkey models for years, but note that these models are limited for training residents in techniques for more challenging breast lesions. We consider deep lesions overlying the chest wall and lesions overlying breast implants as technically challenging lesions for core biopsy, fine-needle aspiration, or wire localization. Ultrasound-guided axillary lymph node core biopsy is also a technically challenging procedure, which has become common in our practice to assist with preoperative staging. Our anecdotal experience is that mammography faculty often personally perform US-guided breast interventions for lesions positioned in these locations rather than allowing the resident to

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Address correspondence to Rulon L. Hardman, MD, Department of Radiology, University of Texas Health Science Center, 7703 Floyd Curl Dr, San Antonio, TX 78229 USA.

E-mail: hardmanr@livemail.uthscsa.edu

Abbreviations
US, ultrasound

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perform the procedure, in an effort to minimize risks of complications.

In general, US-guided breast interventions and axillary core biopsies are safe procedures with the common complications of bleeding, infection, pain, and nondiagnostic samples.[11] On the basis of the literature, complications of iatrogenic pneumothorax, saline implant rupture, and axillary vascular injury are relatively rare with US-guided breast and axillary interventions.[11–20] Even if rare, however, we suspect that the fear of these complications often influences the behavior of the attending radiologist toward limiting the hands-on experience of the resident in more challenging US-guided breast intervention cases.

As a result, we believe that radiology residents often graduate having learned how to perform US-guided breast procedures on "easy" breast lesions but with limited experience and expertise with breast lesions that are in more difficult locations. To address this training opportunity, we developed inexpensive gel breast phantom models that simulate lesions that are positioned in such a way that iatrogenic pneumothorax, saline implant rupture, and axillary vessel injury are potential complications that must be avoided. We describe our process of creating breast phantoms that simulate: deep breast masses and cysts overlying simulated lung and pleura, deep breast masses and cysts overlying simulated breast implants, and enlarged axillary lymph nodes overlying simulated axillary arteries and veins. We describe radiology resident simulation training of US-guided core biopsies, US-guided fine-needle cyst aspirations, and US-guided needle-wire localizations using these models. We also measured the subjective change in confidence levels of our residents before and after the simulation training.

Materials and Methods

Institutional Review Board approval was sought for this study, and the study was deemed exempt. Procedures were performed in accordance with the ethical standards set forth in the 1964 Declaration of Helsinki. Various breast phantoms were tested and developed by the investigator. The most cost-effective and best-performing phantom was made from inexpensive Knox gelatin (Associated Brands, Medina, NY). Breast phantoms made from Knox gelatin have been described previously.[4,7] Slightly firmer and more resilient gel phantoms were created by using a "homemade ballistics gel" technique described in several nonacademic ballistics-oriented resources.[21,22] The resulting gel was firm, relatively resilient to repeated needle insertions, and kept for several weeks in a refrigerator.

Phantom Design

Knox gelatin is slowly dissolved and stirred in very hot tap water in a concentrated formulation. We have found that the best consistency of the final gel is obtained by mixing 12 of the ¼-oz packets of Knox gelatin into 1 qt of water. The gelatin powder must be poured and mixed very slowly into the water to allow it to completely dissolve and avoid the formation of air bubbles. The solution is then refrigerated for 3 to 4 hours, which allows the gel to "bloom." The gel is then melted slowly in a double boiler, without allowing the gel to boil. We then added a mixture of blue and red food coloring to the solution to create a brown opaque effect. The melted gel solution is next poured into small mixing bowls that simulate medium sized-breasts. After the gel is poured into the molds and refrigerated, it begins to thicken in 10 to 15 minutes. Simulated lesions must be prepared and ready to place in the gel before placing the gel in the refrigerator. Small-pitted olives with pimentos (large masses), capers (small masses), and tied-off water-filled fingers of standard examination gloves (cysts) are placed gently into the shallow side of the gel just as it begins to thicken. The gel should have the consistency of a very thick fluid when placing the lesions to allow them to stay precisely where placed. For each phantom, the lesions are placed relatively shallowly into the gel. After refrigeration, when the phantom is taken out of the mold and turned over, the lesions are then in the deeper portion of the breast.

A saline implant phantom is created using a standard examination glove filled with water, the fingers tied and cut off, creating a water-filled latex bag, which simulates the size and shape of a saline implant. This bag is pushed into the gel, after the gel becomes relatively thick but not firm, and positioned directly over the lesions. The "implant" is pushed slightly into the gel to form its own concavity, and the mold is then refrigerated for 12 hours. The end result is a breast phantom simulating deep breast lesions directly overlying a saline implant.

An axillary node phantom is made by pouring melted gel into a small square plastic container, and several small olives are placed into the gel as it begins to thicken. Two glove fingers are filled with water and tied and cut off so that they remain elongated and tubelike in shape. The glove fingers are then placed into the gel on top of the olives and pushed slightly into the thickening gel to form shallow concavities, and the mold is refrigerated for 12 hours. This process results in a phantom that simulates enlarged axillary nodes overlying axillary vessels.

For deep masses and cysts overlying the chest wall using olives and capers, cysts are placed shallowly into the gel as it begins to thicken creating a phantom with deep breast lesions. To simulate lung and pleura, air is blown into a quart-sized resealable zippered bag, inflating it to approximately 75% and then closing the zippered seal. The inflated bag is then placed into a quart-sized resealable square plastic container, which helps hold the phantom lung in place and provides phantom stability. The gel phantom is then placed on top of the resealable bag, which creates a simulated breast with deep breast lesions over a simulated lung and pleura.

The entire process to create all 3 phantoms requires approximately 2 hours of labor (excluding the refrigerating time). The phantoms last for several weeks in a refrigerator, at which point they begin to degrade. These phantoms allow for multiple simulations during a resident rotation if needed. Needle tracks do tend to persist in the phantom after multiple trials. Microwaving the phantom at low energy for a few seconds reseals the gel and removes the prior needle tracks. New phantoms are made before each subsequent rotation (see Table 1 for recipe).

Simulation Laboratory Design

At the beginning of each resident rotation, a traditional US-guided simulation laboratory is set up in one of the breast US rooms, and an assortment of breast intervention instruments are available. Our simulation includes a 14-gauge automated spring-loaded core biopsy device (Bard Medical, Covington, GA) through an 11-gauge trocar, needle-wire localization (10-cm Homer needle-wire combination), and cyst aspiration with a 5-mL syringe and 18-gauge spinal needle. Our institution uses Philips US machines (Philips Healthcare, Best, the Netherlands). A linear high-resolution L17-5 probe is used in these simulations. Each resident, regardless of program year, is individually trained and assessed in the simulation laboratory. The phantoms are placed on the biopsy table at a similar height and position as a real breast procedure. Ultrasound guidance is used on a real-time basis, providing immediate image feedback during the simulated procedures. Each resident is individually trained in the freehand technique of US-guided core biopsy of a deep

Table 1. Phantom Recipe

Materials

Knox gelatin	Hot water	Olives or capers
Plastic gloves	Food coloring	Plastic containers or bowls
Quart-size square container	Quart-size resealable bag	Biopsy equipment

Knox gelatin preparation

1. Dissolve 12 ¼-oz Knox gelatin packets in 1 qt of very hot tap water.
2. Mix slowly to completely dissolve the powder and prevent air bubbles.
3. Refrigerate for 3–4 h, allowing the gel to "bloom."
4. Remelt in a double broiler, without allowing the gel to boil.
5. We mix in red and blue food coloring to give the gel a brown opaque appearance.
6. Pour melted gel into small bowls to simulate breast contour.
7. Refrigerate for 10–15 min.
8. Olives or capers in gel will simulate "masses."
9. Fill glove fingers with water and tie off at 1–2 cm to make small "cysts."
10. Fill glove fingers with water and tie off at the base of the fingers to simulate "vessels."
11. Use the "hand" of the glove with tied-off/cut-off fingers to simulate an implant.

Mass on implant

1. Place "masses" and "cysts" superficially in the gel (when the phantom is removed, it is flipped over and the mass will be deep).
2. Multiple masses and cysts are placed in each phantom.
3. Place simulated implant (water-filled glove) on top of masses/cysts in gel while gel is firming, creating a concavity in the gel.
4. Refrigerate for 12 h.

Axillary lymph node by vessel

1. Pour gel into square mold.
2. Place masses and cysts in mold.
3. Place 2 long glove fingers superficially into the mold to simulate vessels.
4. Refrigerate for 12 h.

Mass along chest wall

1. Pour gel into a bowl to simulate breast contour.
2. Place masses and cysts shallow in the mold.
3. Refrigerate for 12 h.
4. Inflate resealable zippered bag to 75% and close zipper.
5. Place bag in a small square container for stability and use to simulate the lung and pleura.
6. Invert the gel mold and place on the plastic bag.

Preparation time: 2–3 h; total preparation time: 15–16 h breast mass overlying the simulated chest wall without causing a pneumothorax, wire localization of a deep breast mass without causing pneumothorax, and fine-needle aspiration of a deep breast cyst without causing pneumothorax (Figures 1 and 2). Each resident is then trained to perform the same procedures over the simulated saline implant without causing a saline implant rupture (Figures 3 and 4). Each resident is finally taught how to core biopsy enlarged axillary nodes without causing injury to an axillary vessel (Figures 5 and 6). Training focuses on teaching the appropriate choice of needle entry point, accurate needle alignment with the US transducer (parallel angle to the chest wall or shallowest possible angle of the needle approach to the lesion to avoid intrusion into adjacent sensitive structures), and assessment of the needle throw length in relation to the angle and distance from sensitive structures.

After each simulated intervention, the teaching staff and resident checked the integrity of the resealable bag lung, the simulated saline implant, and the simulated axillary vessels to determine whether pneumothorax, implant rupture, or vessel injury was successfully averted. A leak in any of these structures indicated a simulated iatrogenic injury. Those devices could then be quickly and inexpensively replaced, and the training could resume. To reinforce the concept of safe versus unsafe angles of approach, after successfully completing the simulation, residents were then often asked to purposely angle the needle too steeply to cause pneumothorax, rupture a saline implant, or rupture an axillary vessel. This process helped reinforce the concept of a parallel or shallow angle of approach.

Before the simulation, each resident is given a questionnaire with a 1 to 10 Likert-type scale to subjectively assess the resident's confidence in performing each procedure (Figure 7). After the simulation exercise, each resident repeats the questionnaire. The supervising staff member or fellow also objectively assesses each resident's safety and competency in performing these procedures and provides immediate feedback and corrective training until each resident achieves competency for each procedure. Our experience is that residents require varying amounts of training time to achieve competency.

Results

A total of 20 residents have participated in the simulation training at our single institution and have completed pre- and post-training questionnaires. Overall, confidence levels substantially increased for all residents who participated in the training. Comparison of the pre- and post-training evaluation scores are shown in Figure 8. Examples of the phantoms are shown in Figures 1–6.

Figure 1. Simulation gel breast phantom setup to teach avoidance of pneumothorax when performing biopsy of a deep breast mass adjacent to the chest wall. **A**, Homemade gel breast phantom (undersurface) containing deep simulation cysts and masses. **B**, Air-filled 1-qt resealable bag in a 1-qt resealable open container. **C**, Phantom placed directly on top of the air-filled resealable bag, which simulates breast overlying an air-filled chest wall/lung/pleura.

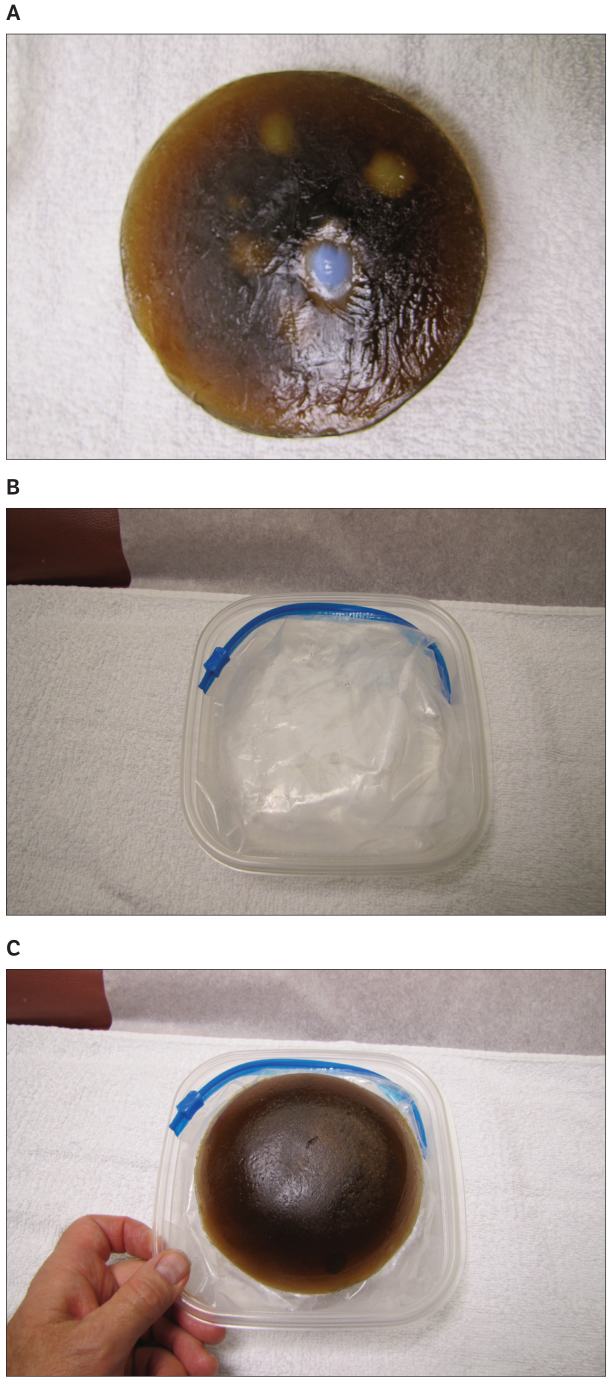
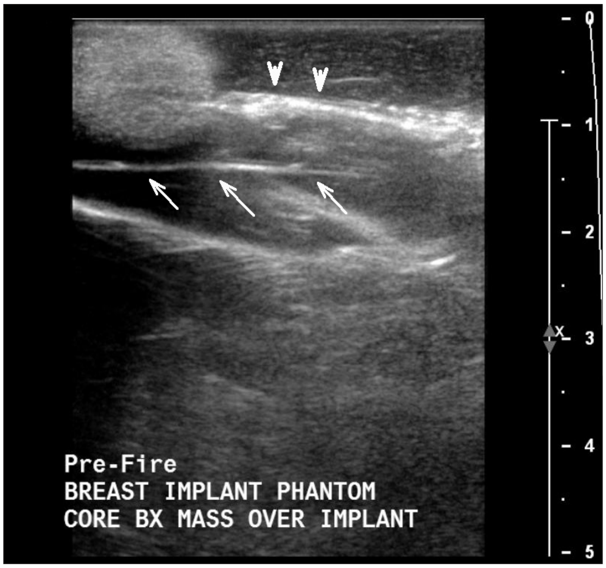


Figure 2. Simulation of US-guided core needle biopsy with insertion of an 11-gauge trocar to target a deep breast mass overlying the chest wall and simulated lung. **A**, Inserting the trocar with US guidance into the gel phantom. **B**, Sonogram of the trocar tip (arrowheads) approaching the deep mass (olive) at a shallow angle, which will avoid puncturing the simulated pleura, shown as an echogenic line (arrows) generated by the underlying air-filled resealable bag. **C**, Removing the phantom and checking the integrity of the resealable bag after biopsy to prove no puncture: eg, no simulated pneumothorax.

A

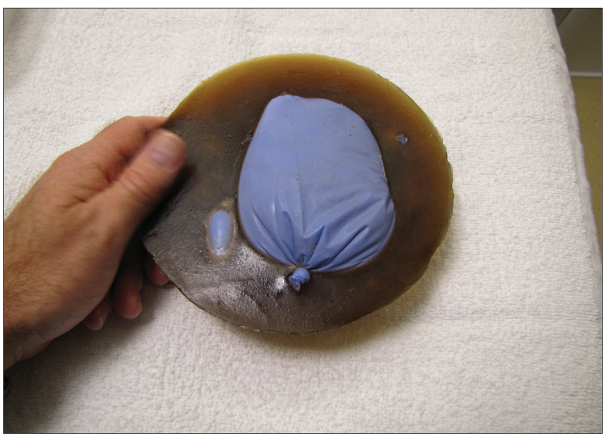
B



C

Figure 3. Simulation of US-guided biopsy of a breast mass overlying a saline implant. **A**, Homemade breast gel phantom with concavity into which a water-filled glove is placed. Simulation cysts and masses overlie the simulation implant deep in the gel phantom. **B**, Inserting an 11-gauge trocar into the breast implant phantom using US guidance.

A



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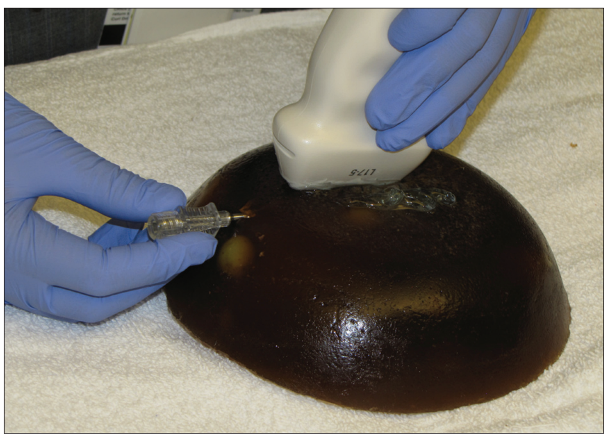
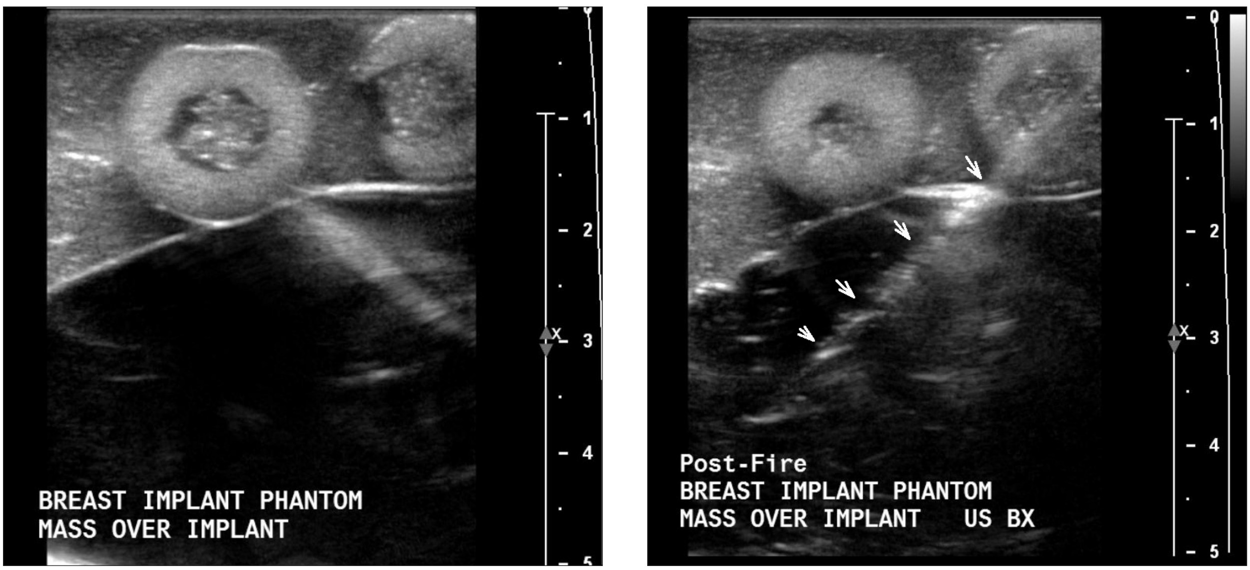


Discussion

Simulation training is a core technique in many industries in which customer safety is of prime importance. The aviation industry, for example, requires extensive simulation training of its pilots and other crew members before working in the live flight environment. Medicine, as a profession, has been criticized for being slow to adopt simulation training and for continuing to favor the traditional training method of "see one, do one, teach one" on live patients. To address this deficiency, the Accreditation Council for Graduate Medical Education has strongly encouraged the increased use of simulation training in graduate medical education in an effort to enhance safety, predictability, and respect for patients.[1]

Ultrasound-guided breast procedures have become the standard of care for providing tissue diagnoses or interventions of breast lesions that are sonographically visible. US-guided breast procedures are among the most commonly performed minimally invasive procedures in radiology practices. Despite this fact, many radiology residents graduate residencies with little or no hands-on experience with US-guided breast procedures. A 2003 survey of radiology residents by Bassett et al[23] found that 14% "rarely" and 17% "never" performed US-guided breast procedures as part of their residency training, yet many of these same residents will be expected to perform US-guided breast procedures as part of their general practice duties in their initial practice setting. Many practices do not have the luxury of having fellowship-trained or dedicated breast

A B



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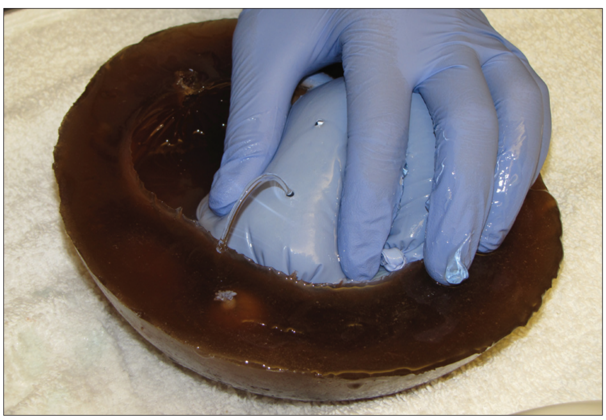

Figure 4. Simulation of iatrogenic rupture of a saline breast implant due to an improper biopsy technique. **A**, Sonogram of 2 deep breast masses (olives), which abut a simulation saline implant. **B**, The operator uses too steep an angle of approach of the biopsy needle, which is clearly shown penetrating into the implant (arrows) after firing. **C**, Immediately after the simulated biopsy, the integrity of the simulation implant is visually tested. Water is shown leaking out of the puncture site.

imagers to exclusively perform US-guided breast procedures, and these practices expect all staff members to perform US-guided breast procedures. This policy unfortunately creates a scenario of newly graduated radiologists learning to do US-guided breast procedures by the seat of their pants in their first practice setting, creating an unsafe environment for patients and unnecessary stress for the radiologist. Fortunately, most radiology residents in the survey by Bassett et al[23] did indicate that they had received hands-on training in US-guided breast procedures. It is our anecdotal experience that teaching staff almost always allow residents to perform US-guided breast procedures under supervision on cases when lesions are positioned in "safe" locations in the breast; however, staff often perform the procedures themselves, asking the resident to observe, when breast lesions are positioned in more challenging

Figure 5. Simulation of enlarged deep axillary lymph nodes overlying an axillary artery and vein. **A**, Homemade gel axillary phantom (undersurface) showing 2 water-filled tied off glove fingers simulating an axillary artery and vein. **B**, Sonogram of the axillary phantom showing 2 deep enlarged axillary nodes (olives) overlying and abutting the simulated axillary artery and vein. This phantom specifically exaggerates the size of the vessels and proximity of the nodes to the vessels to increase the safety challenges of the simulated US-guided core biopsy.

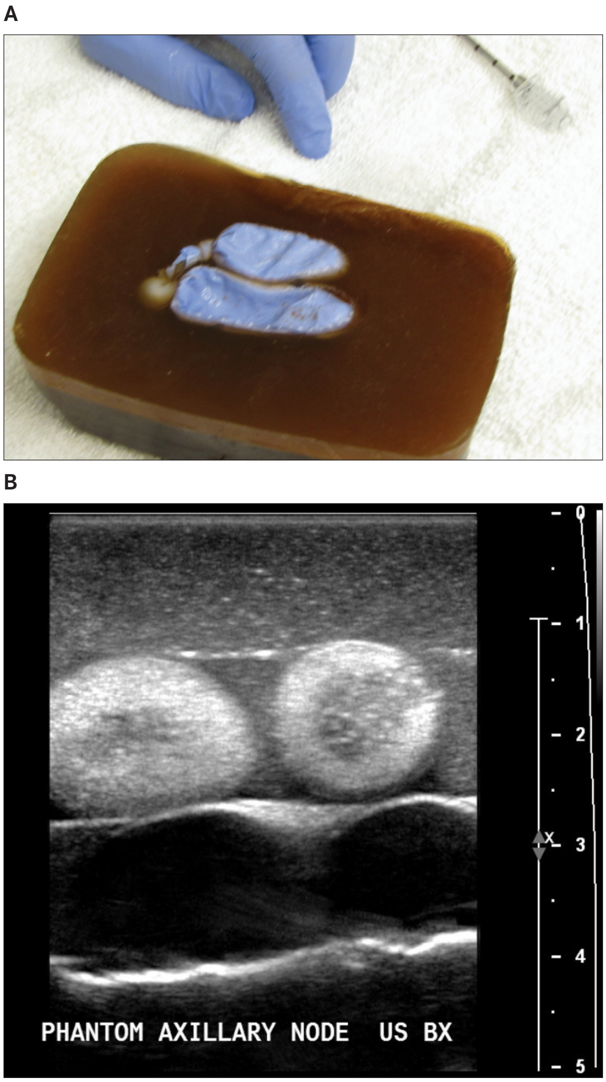

Figure 6. Simulation of US-guided core biopsy of enlarged deep axillary nodes. **A**, Sonogram showing shallow angle of approach of the biopsy needle (arrows) to the simulated enlarged axillary node, which will avoid injury of the simulated axillary vessels. **B**, The operator tests integrity of the simulated axillary vessels after biopsy to check for puncture.

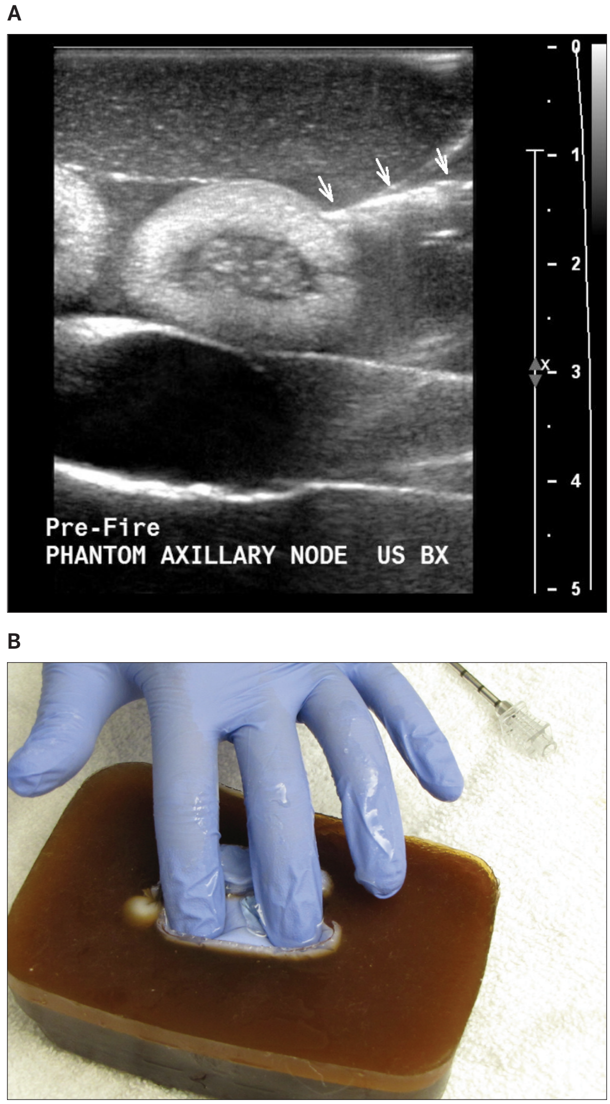

Figure 7. Participant questionnaire.

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Post-Training Self Assessment

Breast Ultrasound Guided Interventions

Phantom Simulation Training for Radiology Residents

This questionnaire is part of a research protocol entitled: How to Teach Challenging Ultrasound-Guided Breast Procedures to Radiology Residents for less than Ten Bucks - Protocol ID: 12-03-4108 The purpose of this study is to assess the effectiveness of breast gel phantoms in simulating challenging ultrasound guided breast procedures. We would specifically like to assess your subjective confidence levels of performing several challenging breast procedures before and after your simulation training on the breast phantoms. Your participation is entirely voluntary. Your responses will be anonymous and will not be used towards your performance evaluation on the mammography rotation.

Resident Number: _____ (anonymous survey) Date of training:_______________

On a 1 to 10 scale (1 equals no confidence ; 10 equals great confidence), please rate your post-training confidence level in performing the following ultrasound guided breast procedures without causing pneumothorax, implant rupture or vessel injury.

(1 to 10 scale)

Biopsy of a deep breast mass and avoiding pneumothorax

1. US guided core biopsy of large mass abutting chest wall _______
2. US guided aspiration of deep breast cyst abutting chest wall _______
3. US guided wire localization of deep mass abutting chest wall _______
4. US guided core biopsy of deep small mass abutting chest wall _______

Biopsy of deep breast mass overlying a breast implant- avoiding implant rupture

1. US guided core biopsy of large mass abutting implant _______
2. US guided aspiration of cyst abutting implant _______
3. US guided wire localization of mass abutting implant _______
4. US guided core biopsy of smaller mass abutting implant _______

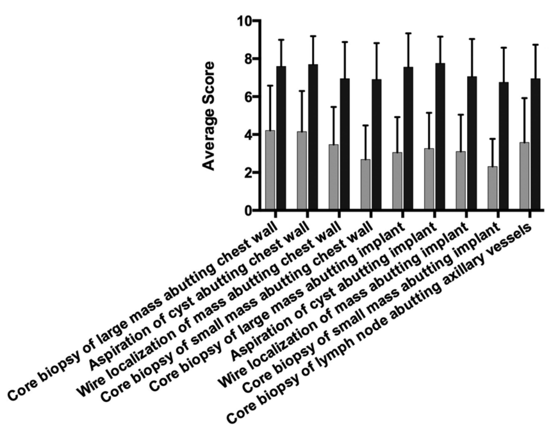
Deep axillary node biopsy over axillary vessels – avoiding vessel injury

1. US guided core biopsy of enlarged axillary node abutting axillary vessels _______

locations. Although this practice is ideal for patient safety, it is suboptimal for resident training. We have attempted to address this training opportunity by creating phantom models, which simulate more challenging breast lesions.

We believe that our models improve on the established models by simulating deep breast lesions where iatrogenic pneumothorax, implant rupture, or axillary vascular injury can be simulated and avoided. We also prefer the gel substrate for the phantom because it seems to be more durable than the previously described gel models and more malleable, longer lasting, and more sanitary than a turkey breast model. A minor drawback of this technique is that the breast phantoms are more time intensive to make than purchasing phantoms or turkey breasts (requiring ≈2 hours of preparation and ≈14 hours including refrigeration time). Such a time investment requires a monthly commitment by the staff and residents to perform the simulation training. The training requires 1 to 2 hours of dedicated staff and resident time. In addition, one of the diagnostic US rooms is also taken out of use while the training occurs. Residents can be given the recipe and ingredient list and make their own phantoms. The phantoms can also be reused over the space of a month. We have noticed that the needle tracks leave air in the phantom, which obscures US visualization after multiple procedures. These tracks can be "healed" by microwaving the phantom for about 3 minutes and then recooling. We think the benefit gained from the training substantially outweighs the time costs.

Figure 8. Survey results from the residents (n = 20) who participated in the US-guided breast gel phantom simulation exercise for challenging breast lesions. Left bars, pre-training; right bars, post-training.



Ultimately, we demonstrated with a small group of residents that their subjective confidence levels for performing challenging US-guided breast procedures substantially increased with the use of phantom simulation training. The training was well received and was generally an enjoyable exercise for the residents and staff. After the training, we observed that our residents felt more confident and were more eager to volunteer to perform US-guided procedures as a result of the training. As staff, we noted that we were also more confident in allowing our residents to perform more hands-on US-guided breast procedures for lesions that were more technically challenging.

This study certainly had substantial limitations. It was not designed as a randomized controlled evaluation of a novel training technique. Our sample size of residents was very small, and the format of subjective assessment of confidence levels was not intended to accurately assess actual pre- and post-training competency. We did not correlate rates of US-guided breast procedure complications before and after the training, as they are exceedingly rare in our practice. However, we are confident that our method has improved our resident training experience and resident confidence in performing US-guided breast interventions and will translate into improved competency of staff radiologists in their initial practice settings.

In conclusion, US-guided breast procedures are basic skills in which graduating radiology residents should have competency. Simulation training on breast phantoms is an excellent way to learn these skills before advancing to performing procedures on patients. Our unique breast phantom models allow residents to hone their skills on breast/axillary lesions that are located in more challenging positions: overlying the chest wall, overlying an implant, and overlying an axillary vessel. To the best of our knowledge, this report is the first description of breast phantom models that collectively simulate these more challenging situations. These phantoms are inexpensive, but the creation of the phantoms and the simulation laboratory are slightly time intensive. It is our hope that other training programs will use and improve on these techniques.

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