A Tissue Phantom Model for Training Residents in Ultrasound-guided Liver Biopsy

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Rationale and Objectives: The apprenticeship model for training of percutaneous liver biopsy has limitations, and costs of commercially available simulation models can be prohibitive. We created an inexpensive tissue phantom for liver biopsy simulation and evaluated the utility of this model for training radiology residents.

Materials and Methods: A bovine–porcine tissue phantom was devised as a simulation model and consisted of bovine liver with a porcine rib layer and inserted pimento olives simulating target lesions. Training sessions (a 20-minute didactic lecture and a 90-minute practice session) were offered to all residents in a diagnostic radiology residency. Effect of training was assessed by questionnaire before and after training. Level of knowledge of topics covered in the didactic session, confidence in technical skills, and anxiety level were evaluated on a five-point scale (1, poor to 5, excellent).

Results: Thirty-five of 38 residents received training on the models (~$40). Mean reported value score for training was 4.88/5. Improvement was greatest for knowledge of technique (2.3–4.1/5, $P < .001$) and knowledge of postprocedure care (2.2–4.1/5, $P < .001$). Technical confidence increased (2.4–3.8/5, $P < .001$) and anxiety related to performing liver biopsy improved (2.7–3.7/5, $P < .001$). Residents with no prior experience in liver biopsy ($n = 21$) had significantly greater increases in all categories than residents with prior experience ($n = 14$), except for knowledge about obtaining informed consent and anxiety levels.

Conclusions: Utilization of an inexpensively created bovine/porcine liver biopsy simulation model was well perceived by radiology residents and can be used as an educational tool during residency.

Key Words: Liver biopsy; resident education; ultrasound; simulation training.

Ultrasound guidance for procedures is a skill used in many radiology subspecialty areas, such as body imaging, interventional radiology, mammography, and musculoskeletal radiology. Proficiency with ultrasound-guided (US-guided) procedures should be a part of a radiology residency core curriculum.

Percutaneous liver biopsy is a commonly performed procedure for staging of diffuse liver disease and diagnosis of hepatic lesions; however, it does carry the risk of hemorrhage, biliary leak, injury to adjacent structures, and even death (1–3). Ultrasound guidance for nontargeted liver biopsy can significantly decrease complication rate from 2.1% for blinded liver biopsy to 0.53% for those with ultrasound guidance (4). Learning to perform liver biopsies under ultrasound guidance also provides a solid foundation for percutaneous interventions on other solid organs and is a necessary step before performing targeted liver biopsies.

Resident training in both percutaneous liver biopsy and US-guided procedures, however, is variable between various institutions and even within a residency cohort (5). Reduced resident work hours, increasing diagnostic imaging volume, increased utilization of physician extenders, and increasing fellowship opportunities in body and interventional radiology may limit residents' experience with percutaneous procedures. Further drawbacks of a purely apprenticeship model include inconsistency of instruction and inability to familiarize oneself with equipment and technique prior to a patient encounter.

Simulation training has been shown to improve procedural competency, allowing residents to become familiar with equipment and to learn safe and effective technique in a standardized setting (6–9). However, there are few commercially available phantoms suitable for percutaneous biopsy, and their costs can be prohibitive.

Therefore, we sought to create an inexpensive tissue-based simulation model for practicing percutaneous US-guided liver biopsy and to evaluate the utility of this model in a standardized training curriculum for radiology residents.

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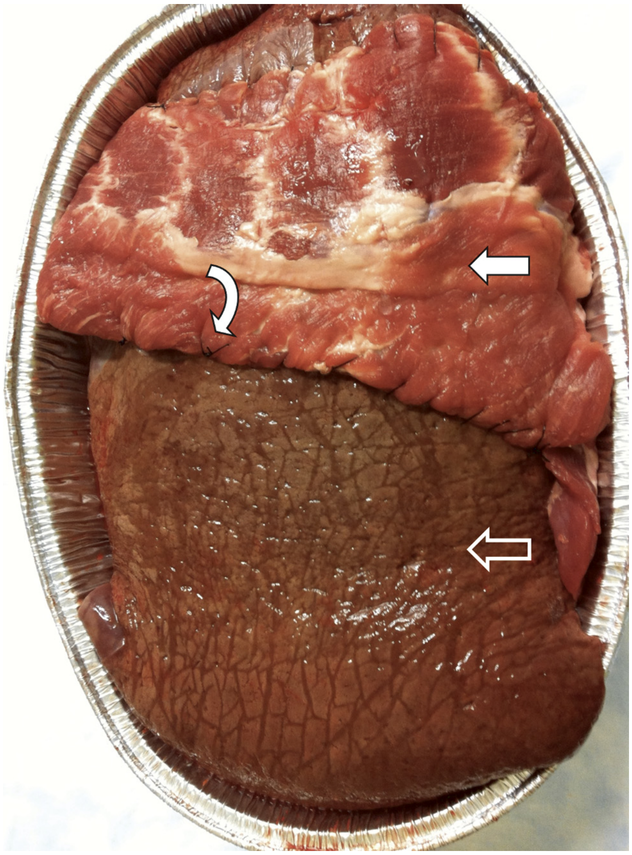

Figure 1. Bovine–porcine tissue phantom. Porcine rib layer simulating the chest wall and allowing for practice targeting the liver between ribs (*white arrow*), whole or halved cow liver (*open arrow*), sutures to keep the porcine rib/chest wall layer in place (*curved arrow*).

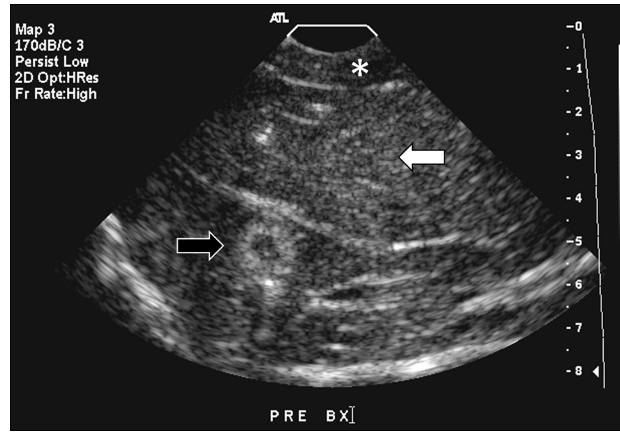

Figure 2. Ultrasound images of the model. Excellent visualization of the porcine chest wall (*), hepatic parenchyma (*white arrow*) and pimento olive target lesions (*black arrow*) was obtained.

METHODS

Study Design

This study was performed with institutional review board (IRB) exemption. The study group included all radiology residents ($n = 38$) in all 4 years of training at an academic medical center. A prospective study was performed in which all residents were offered participation in a liver biopsy training session. The teaching session included a 20-minute didactic lecture followed by a 90-minute practical teaching session. Participants completed surveys before receiving training and after training. At the beginning of the didactic session, per IRB exemption requirements, participants were informed about the voluntary nature of this session and anonymity of survey results.

Creation of a Bovine–Porcine Tissue Phantom

The tissue phantom consisted of bovine liver (whole or halved) with an overlying porcine rib layer sutured to its surface to simulate the challenges of rib shadowing and the intercostal approach (Fig 1). Inserted pimento olives resulted in a target appearance on ultrasound, simulating focal hepatic lesions (Fig 2). All materials were readily available at a local supermarket on being specifically requested and the total cost of each model was ∼$40. A total of four models were created, two for each training session. The models were prepared as follows: the bovine livers were thawed and rinsed with tap water, the liver was sectioned into halves (after initial sessions demonstrated sufficiency with 1/2 liver volume), small incisions were made along the ventral surface of the liver and pimento olives were inserted into the liver parenchyma, a porcine rib layer was then placed over the dorsal surface of the liver, and the edges were sutured using 0 silk. Preparation was straightforward and took ∼45 minutes per model. The model was wrapped in a biohazard bag to contain fluids and allow removal of ultrasound gel between biopsy procedures. Models used over a 2-day period were stored overnight in an ice bath. The models can last up to 3–4 days, potentially longer if frozen.

Selection of Participants

Liver biopsy training sessions were offered to all radiology residents ($n = 38$) in all 4 years of training at an academic medical center.

Training Sessions

Each session consisted of a 20-minute didactic lecture (Table 1) given by an abdominal imaging fellow, followed by a 90-minute hands-on practice session. The trainees completed a pretraining survey to assess their prior experience and subjective degree of knowledge and confidence on a number of variables related to the performance of US-guided liver biopsy (Appendix 1).

The 90-minute hands-on sessions were held in a conference room setting. During each session, two small groups of 3–5 residents were trained, with each group supervised by an abdominal interventionalist (XX, with 2 years of experience, XX, with 6 years of experience). Equipment used

TABLE 1. Didactic Topics

Didactic lecture content (20 minutes)
- Indications for nontargeted and targeted biopsy
- Target selection
- Coagulation parameters
- Informed consent and specific risks of liver biopsy
- Considerations for pain control and/or conscious sedation
- Collaboration with nursing and pathology colleagues
- Technique: equipment setup, preliminary imaging and selection of an entry site, preprocedure time out, sterile technique, local anesthesia, breathing instructions, needle deployment, and sample handling
- Postprocedure care

was similar to that used during clinical US-guided liver biopsies during the study period, including HDI 5000 ultrasound machines (ATL/Philips, Botell, WA), S4-1 probes with a needle guide, sterile probe covers with disposable needle guides (CIVCO, Kalona, IA), 21-ga spinal needles for anesthesia, and 18-ga automated biopsy needles (Bard, Tempe, AZ).

Following the session, each trainee completed a posttraining survey (Appendix 2). The pre- and post-surveys were paired to allow comparison between pre- and post-training results on a per-trainee basis. Anonymity was preserved by collecting the paired surveys in a collection box and without evaluation of the surveys until all residents had completed the training.

RESULTS

Over the course of five separate sessions, 35 of 38 residents completed the training. Each resident performed 2–5 nontargeted or targeted liver biopsies on the tissue phantom with personal supervision and immediate feedback from the abdominal interventionalist. Sonographic appearance of the bovine liver subjectively resembled the echogenicity and structure of human liver (Fig 3). The use of a plastic biohazard bag to contain the model, with applied ultrasound gel, did not interfere with the sonographic visualization of the model. Several of the residents stayed for additional time after completion of the formal training session to practice "free-hand" technique. One resident sustained a needle stick while handling the biopsy equipment and model, which was managed conservatively by immediate and extensive washing of the area.

Survey Results

Paired pre- and post-training survey results were analyzed on SAS software. All residents indicated that the training session was valuable, with a mean reported score for the session of 4.88 of maximum possible score of 5. The Wilcoxon signed rank test was used to compare pre- and post-training ranking. There was a statistically significant increase in knowledge in all areas surveyed (Table 2). There was also a statistically significant increase in technical confidence and decrease in anxiety related to performing liver biopsy. Improvement was greatest for knowledge of technique (increase from 2.3 to 4.1 on a five-point scale) and knowledge of postprocedure care (increase from 2.2 to 4.1 on a five-point scale). Residents with no prior experience in liver biopsy ($n = 21$) had significantly greater increases in all categories surveyed when compared to residents with any single prior liver biopsy experience ($n = 14$), except for knowledge about obtaining informed consent and anxiety levels.

Comments were provided by residents in the free text portion of the survey. Particular aspects listed as beneficial included the practical and concise nature of the session. Residents requested additional teaching sessions for other image-guided procedures such as US-guided and computed tomography–guided percutaneous drainage.

DISCUSSION

We describe a low-cost tool for simulation of real-time US-guided liver biopsy and a standardized training curriculum for residents. The module was well received by radiology residents and subjectively rated to increase their knowledge, technical skills, and comfort level regarding liver biopsy. Residents particularly appreciated the hands-on nature of the module, supporting the concept that experiential learning supersedes didactic teaching. Residents with less experience showed a greater increase in measured outcomes, suggesting that this type of training would be more beneficial earlier in residency.

Simulation training is gaining momentum, fueled by limitations in resident work hours, concerns about patient safety, and Accreditation Council for Graduate Medical Education emphasis on proficiency-based assessment methods. Simulation has been widely used for procedural training, such as for laparoscopic surgery, colonoscopy, central venous lines, and intubation but is less widely reported within the field of radiology. Most models, including extremely sophisticated virtual reality environments such as Stanford University's Comprehensive Anesthesia Simulation Environment (which includes a technologically advanced mannequin and a real operating room), have been developed and used by anesthesiologists and surgeons (5). Development of these models was fueled by a high level of interest and financial commitment by these specialties.

Radiology has been a late adopter, mostly reporting simulation within the subspecialty areas of vascular interventional radiology (10) and mammography. Stereotactic breast biopsy simulation has been reported using breast phantoms composed of turkey breast, eggplant, or pastry and instilled with barium, salt, calcium powder, and so forth to simulate microcalcifications (11–13). These studies did not report a specific training curriculum. A study by Mendiratta-Lala et al. (14) described a Web-based and interactive training

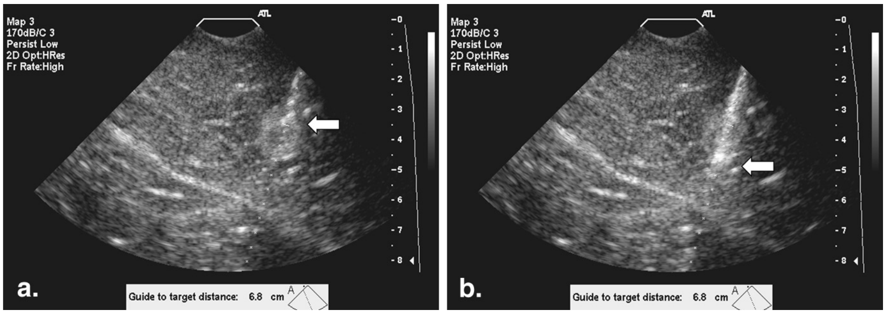

Figure 3. Ultrasound images of a target lesion before **(a)** and after biopsy **(b)** showing the needle positioned superficial to the lesion (→) and with the needle tip through the lesion (→).

TABLE 2. Survey Results

Survey Query	Mean Preintervention Rating (Scale 1–5)	Mean Postintervention Rating (Scale 1–5)	Wilcoxon Signed Rank Test, *P* Value
Indications	2.7	4.2	<.001
Informed consent	3.4	4.4	<.001
Target selection	2.3	4.0	<.001
Coagulation parameters	2.7	4.4	<.001
Local anesthesia	2.7	4.4	<.001
Technique	2.3	4.1	<.001
Postprocedure instructions	2.2	4.1	<.001
Technical confidence	2.4	3.8	<.001
Anxiety	2.7	3.7	<.001

module for US-guided biopsy; however, their training used a nonspecific blue phantom made of synthetic material, which does not simulate the appearance or texture of any specific organ or human tissue.

In fact, the few available synthetic phantoms that replicate human tissue are usually not designed to sustain percutaneous biopsy, which disrupts the synthetic layers, thereby limiting shelf life and the number of biopsies possible before visualization diminishes. Furthermore, their costs can be prohibitive. To our knowledge, the only commercially available US-guided liver biopsy phantom is the "Triple Modality 3D Abdominal Phantom" (CIRS, Norfolk, VA), which simulates the native liver setting and adjacent organs (kidney, aorta, and ribs). However, the cost of this model at the time of publication was $2633, and the phantom contains six lesions, each of which can only be biopsied 3–5 times, preferably by a small needle (≤22 ga) (15).

An ideal phantom should be of low cost, easily available, and of similar consistency to the target organ. Based on our experimental and others' experience (16), we created a tissue phantom comprised of bovine liver and porcine rib layer, which was of low cost ($40/model), locally available, and simple to prepare. This model is a part-task trainer (reproducing a limited portion of reality), with high "face validity", that is, strong replication of human liver conditions (17). The porcine rib layer provides accurate simulation of the body wall and the acoustic barriers provided by the ribs, often a challenge for residents to navigate. The bovine liver has strong acoustic, structural, and tactile ("haptic") resemblance to human liver and maintains integrity during repetitive sample over multiple biopsy sessions and days, with minimal visualization of prior needle tracks (each model was biopsied approximately 16–25 times). The inserted pimento olives visually replicate target lesions, which allows for more nuanced target practice.

Although noninvasive sonographic and magnetic resonance techniques are in use for assessment of liver fibrosis and hepatic steatosis (18), percutaneous nontargeted liver biopsy will likely long remain a clinically relevant diagnostic tool for a wide range of pathologies, as well as important prognostic indicator of disease severity (2). For focal hepatic lesions, even when the diagnosis is predictable (such as metastases), histologic confirmation and analysis can provide added information for oncologic treatment.

The study has several limitations. First, although offering high face validity, the phantom does not replicate respiratory motion, which can be a major challenge when learning how to perform US-guided liver biopsies. Likewise, the "content validity" (degree to which the simulation reproduces all facets of a real-world experience) is limited without the use of standardized patients who can reflect the realistic aspects of obtaining informed consent and responding to patient anxiety, concerns, and reactions during the procedure. "Concurrent validity" (degree to which the simulation correlates with trainees' subsequent real-world performance) is also an important metric that was not measured in the present study. Future studies are needed to establish the efficacy of this type of simulation in ultimately reducing adverse outcomes and costs related to liver biopsy.

Second, proficiency during the simulation module was not measured objectively, rather the same limited apprenticeship model was applied to measure the residents' skills. Task analysis to evaluate individual technical skills, as well as metrics for objective structured observation, is currently being developed (7,19,20). An intensive and near-realistic model devised by Kneebone et al. (21,22) incorporates standardized patients with inanimate models, with direct supervision and external review by videotapes. This model allows trainees to practice communication as well as procedural skills, with multiple sources of feedback.

Even more advanced options are being developed, such as virtual reality and computer-enhanced mannequins (7,8). Both of these exciting innovations (routinely used in the military and aviation fields) would, in our case, adequately simulate respiration and physiologic response to liver biopsy, however neither are likely available or affordable in the near future. Until these do become available, we feel that our tissue model provides a low-cost and effective option for training residents.

Third, our study did not assess long-term retention of knowledge following intervention. A study by Gaies et al. (23) showed improved performance of pediatrics residents immediately following a structured curriculum for procedural skills, however no differences between the intervention and control groups at 7 months, with both groups demonstrating declining skills. This study raises the important issue of interval retraining. The inexpensive nature of the phantom model described here could facilitate multiple retraining sessions.

Conclusions

A bovine–porcine tissue phantom model can be easily and inexpensively created for simulation training with excellent replication of the sonographic appearance of hepatic parenchyma and focal hepatic lesions. US-guided liver biopsy simulation training using a short didactic lecture and small group hands-on sessions is a helpful educational tool during radiology residency.

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APPENDIX 1. Preintervention Survey

Item Number	Query	Response				
1	In what year of training are you?	PGY 2	PGY 3	PGY 4	PGY 5	
2	How many ultrasound guided core biopsies of any abdominal organ have you performed?	None	1–5	>5–10	>10–20	>20
3	How many liver biopsies have you performed?	None	1–5	>5–10	>10–20	>20
4	How knowledgeable do you consider yourself regarding the following components of the procedure? (Rank from 1–5, 1 = no knowledge, 5 = extremely knowledgeable)					
	Indications for liver biopsy	1	2	3	4	5
	Informed consent	1	2	3	4	5
	Feasibility of lesions/approach	1	2	3	4	5
	Coagulation parameters	1	2	3	4	5
	Local anesthesia and pain control	1	2	3	4	5
	Technique	1	2	3	4	5
	Postprocedure instructions	1	2	3	4	5
5	How confident are you in your technical skills? (Rank from 1–5: 1 = lack confidence, 5 = extremely confident)	1	2	3	4	5
6	How do you estimate your anxiety level prior to performing this procedure on a patient? (Rank from 1–5: 1 = extremely anxious, 5 = not anxious)	1	2	3	4	5

PGY, postgraduate year.

APPENDIX 2. Postintervention Survey

Item Number	Query	Response				
1	How many liver biopsies did you perform on the phantom during the simulation?	None	1–2	3–4	5–6	≥7
2	How knowledgeable do you consider yourself regarding the following components of the procedure? (Rank from 1–5, 1 = no knowledge, 5 = extremely knowledgeable)					
	Indications for liver biopsy	1	2	3	4	5
	Informed consent	1	2	3	4	5
	Feasibility of lesions/approach	1	2	3	4	5
	Coagulation parameters	1	2	3	4	5
	Local anesthesia and pain control	1	2	3	4	5
	Technique	1	2	3	4	5
	Postprocedure instructions	1	2	3	4	5
3	How confident are you in your technical skills? (Rank from 1–5: 1 = lack confidence, 5 = extremely confident)	1	2	3	4	5
4	How do you estimate your anxiety level prior to performing this procedure on a patient? (Rank from 1–5: 1 = extremely anxious, 5 = not anxious)	1	2	3	4	5
5	How helpful did you find the simulation training? (Rank from 1–2: 1 = not helpful, 5 = extremely helpful)	1	2	3	4	5
6	Any comments/suggestions?					