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Ultrasound in Emergency Medicine

A HOMEMADE, HIGH-FIDELITY ULTRASOUND MODEL FOR SIMULATING PNEUMONIA WITH PARAPNEUMONIC EFFUSION AND EMPYEMA

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☐ **Abstract—Background: Point-of-care ultrasonography (POCUS) is increasingly used for both diagnostic and guided procedures. Increasingly, POCUS has been used for identification of pneumonia and to assist in the differentiation of pleural effusions, as well as to guide thoracentesis. As such, there is a need for training with ideally high-fidelity lung ultrasound phantoms to ensure ultrasound proficiency and procedural competency. Unfortunately, most commercial ultrasound phantoms remain expensive and may have limited fidelity. Objective: Our aim was to create and describe a homemade, high-fidelity ultrasound phantom model for demonstrating pneumonia with pleural effusions for teaching purposes. Discussion: An ultrasound phantom was constructed using a water-filled latex glove with a sliver of meat in it, covered over by a palm-sized piece of meat (skin and ribs are optional to increase ultrasonographic details and realism). This would appear like parapneumonic effusions with organized pneumonia under ultrasound examination. Creamer (or talc) can be added to the water in the glove to simulate empyema. The model can also be used to teach simple effusions and for ultrasound-guided thoracentesis and in clinical decision making. Conclusions: Easily prepared, homemade high-fidelity ultrasound phantom models for instructions on identification of pleural effusions and ultrasound-guided pleural tap of parapneumonic effusion were made.** © 2018 Elsevier Inc. All rights reserved.

Streaming video: Five brief real-time video clips that accompany this article are available in streaming video at www.journals.elsevierhealth.com/periodicals/jem. Click on Video Clips 1–5.

☐ **Keywords—ultrasound; animal model; teaching; pneumonia with pleural effusion; empyema**

INTRODUCTION

Point-of-care ultrasound is increasingly used in emergency departments. Ultrasound proficiency training of the residents has thus become a vital part of the emergency curriculum (1). It has been shown to be an efficient and cost-effective clinical tool to assess patients who present with respiratory distress to the emergency department (2). Ultrasound has been found to be a comprehensive imaging modality and can distinguish between various lung conditions, such as large pleural effusion, lung masses, massive consolidation, and extensive pulmonary edema, all of which can present as "white-out lung" on the chest radiograph (2). Empyema is a complex collection of pus in the thoracic cavity and early diagnosis is of paramount importance to prevent morbidity and mortality. Lung ultrasound is largely dependent on the presence of various sonological artifacts (3–5). Proficient use of point-of-care lung ultrasound may be challenging for ultrasound novices in the pediatric emergency department. This emphasizes the need for familiarization and skill training, which, in turn, would ideally require cost-effective ultrasound simulation models.

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Exposure to a wide range of abnormal and normal ultrasound images of lung and pleural pathologies has been shown to accelerate the learning curve of the novice ultrasound learner (6,7). Traditionally, this has been done with the help of retrospectively captured still images and video analysis of recorded images. The use of real-time phantoms has been shown to augment the understanding of ultrasound technique, images, and pathological conditions (6). Regular simulation training in lung ultrasound has been shown to reduce the time to acquire competence and enhance performance among the learners (6).

There is an increasing demand to create better and inexpensive simulation models to educate the trainees (8). Utilization of simulation models for ultrasound training of health care providers has shown to improve patient safety during procedures and diagnostic accuracy at the bedside (9,10). Access to these commercial training models may be significantly restricted by their costs. Commercially available lung phantoms are targeted to demonstrate limited pathologies.

Ideal homemade ultrasound phantoms should be easy to prepare, economical, and should resemble the human tissue on ultrasonography (6). Optimally, these models should be highly portable and compact to facilitate training needs and potential space constraints. Another important consideration in the creation of ultrasound phantoms using "meat models" is their integrity ability to last for at least 6–8 h at room temperature.

The aim of this paper was to describe an inexpensive, readily available, and highly compact homemade lung phantom that can provide high-fidelity simulated appearance of pleural effusion, including parapneumonic effusion and empyema and be used for training emergency physicians to perform ultrasound-guided needle thoracentesis.

MATERIALS AND METHODS

The various types of materials used to develop the phantom and their roles in the lung phantom are listed in Table 1 and Figure 1.

Phantom Preparation

Preparation of the chest wall. Use a piece of palm-sized, boneless, raw chicken breast meat (fresh or thawed). Alternatively, to increase the fidelity of the homemade lung phantoms, a piece of similarly sized pork ribs (fresh or thawed) was used. This would provide a higher-fidelity chest wall phantom, which would allow the imaging of the chest wall, intercostal muscles, and ribs. To decontaminate the meat, thoroughly soak it in a container with 10 mL of household bleach diluted in 1 L of tap water for 5–10 s. Place the chicken breast or pork ribs on top of the prepared fluid-filled latex glove with the sliver of meat in it.

Table 1. Role of Individual Material Used to Develop Phantom Lung Model

Materials	Anatomical Correlation
Powder-free, disposable latex glove	Pleural cavity
Water	Transudative pleural effusion
Creamer/talc	Internal echogenicity in pleural effusion to resemble empyema
Chicken breast (boneless, fresh/thawed) Size: palm-sized	Human chest wall (without ribs)
Pork chest wall with intact skin, muscles, and ribs Size: palm-sized	Human chest wall (with ribs)
Sliver of chicken breast meat or pork meat (boneless, fresh/thawed) Size: half a finger length	Consolidated lung Occasionally, blood vessels in the meat can simulate air bronchograms
Intravenous cannula and syringe	For ultrasound-guided thoracentesis
Plastic tray/disposable kidney dish	To hold the phantom and collect leaking fluids
Water-resistant sheet/cover	For keeping station hygiene

Preparation of the consolidated lung model. A sliver of raw, boneless meat (from chicken breast or pork meat) (around half a finger's length) is cut off from the chest wall model. This is used for simulating lung consolidation. The blood vessels within the meat can sometimes be visualized on ultrasound and resemble "air bronchograms" especially when visualized longitudinally. Add the meat into the glove before filling it with water. Prepare the appropriate fluid as necessary. Align the sliver of meat in a suitable position under optimal exposure so

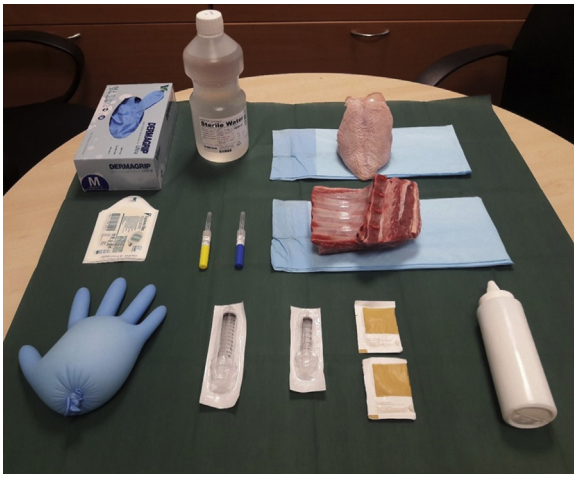

Figure 1. Materials used to create high-fidelity phantoms for pediatric pneumonia with parapneumonic effusions and empyema.

that consolidated lung part of the phantom can be clearly visualized within the scan field.

Preparation of the pleural cavity model. Fill the disposable powder-free latex glove with water and tie off at the end to create the pleural cavity phantom for transudative pleural effusion. The simulated "diseased" pleural lining is simulated by the latex glove (see Figure 2 and Video 1). It is important to ensure that there are minimal bubbles at the chest wall to pleural cavity model interface. This can be improved by trapping any existing bubbles in the finger ends of the gloves. To simulate an exudate (empyema) under ultrasound, add one to two sachets of creamer (or talc) to create internal echogenicity in the fluid to simulate empyema in the simulated pleural cavity (latex glove). Place the pleural cavity model in a container (plastic tray or disposable kidney dish) for stabilization. Agitation of the glove can simulate respiratory movements and for the empyema model (with talc) a "snowstorm" appearance (see Video 2).

Universal precautions. Wear disposable gloves and plastic aprons to prevent contamination of the scrubs during the practice sessions. Place the phantom created in disposable plastic trays to prevent contamination of the demonstration surface. Place the disposable trays with phantoms on water-resistant blue sheets to prevent the contamination of the surface due to dripping from the phantom. It is advisable to cover the ultrasound probe with a sheath or a Tegaderm (3M, St. Paul, MN) transparent film to protect the probe.

Preparing the ultrasound machine for image capture. Use high-frequency linear array transducer ultrasound probe 13–6 MHz for image capturing. Cover the probe surface with Tegaderm (3M) transparent film to prevent contamination of the probe.

Gently agitate the glove filled with sterile water mixed with talc or creamer to give the resemblance of Brownian movement of the fibrin particles within the empyema fluid, which can resemble a "snowstorm" appearance. Please refer to Video 2.

Fidelity of the homemade lung ultrasound model. A short ultrasound clip of a ventilated young infant with empyema is shown for comparison. See Video 3.

Ultrasound-guided needle thoracentesis practice. The ultrasound model can be used five to six times per model to practice needle thoracentesis. Please refer to the Videos 4 and 5. The glove model would usually tolerate repeated attempts. This can be prolonged with a Tegaderm (3M) transparent film after two to three attempts.

Once the glove has deflated significantly, clear the tray/dish and replace it with a newly prepared glove model. The chest wall model should be replaced once there is an unpleasant smell. However, they generally last 5–6 h if presoaked in diluted bleach. Containers for sharp disposables and biohazard bags should be readily available for safety and hygiene.

Applications of the Phantom Model

These models have been used in regular ultrasound simulation training and in pediatric ultrasound training courses conducted in various parts of South-East Asia by the authors. These high-fidelity phantoms were used to reinforce ultrasound image interpretation of pleural effusions and facilitate pattern recognition. Training in psychomotor skills needed for needle thoracentesis under ultrasound guidance could also be done with these phantoms. They were also used in interactive clinical scenarios to facilitate the trainees' clinical decision-making process by facilitating the integration of relevant ultrasound findings in the appropriate clinical context. For example, the decision-making process for the trainee to perform, or not, an ultrasound-guided needle thoracentesis when a simulated empyema is noted on ultrasound.

Point-of-care lung ultrasound can rapidly differentiate non-specific, radiopaque appearance of lung fields on chest radiographs into consolidation, pleural effusions, empyema, atelectasis, elevated hemi-diaphragm, and lung masses (11). Numerous studies have demonstrated superior diagnostic accuracy of ultrasound compared to chest radiography for detection of pleural effusions (12,13). Lung ultrasound can detect as little as 5 mL pleural fluid and ultrasound is 100% sensitive for effusions > 100 mL (14,15). Point-of-care ultrasound has the additional benefit of characterizing underlying lung parenchyma (16). Parapneumonic effusions, which are transudative, appear as completely anechoic collections on the ultrasound scan (2). The underlying diseased lung tissue can often be seen free-floating in the effusion at the base of the lung. Empyema appears on ultrasound scan as heterogeneous areas of internal echoes within anechoic areas. In advanced stages, internal septations or loculations can be seen on the ultrasound scan due to fibrin deposition (13). While there are commercial ultrasound phantoms for lung and pleural pathologies, these remain extremely expensive and are usually beyond the means of many emergency departments in peripheral hospitals and low-middle income countries (17). Ironically, physicians with resource limitations in these areas may have a greater need for point-of-care ultrasonography due to limited formal diagnostic imaging resources readily available to them.

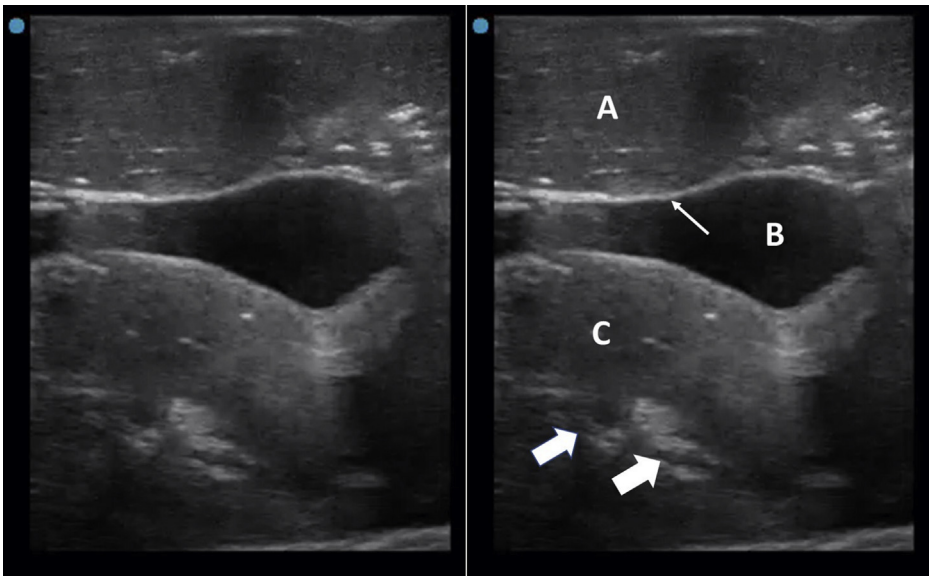

Figure 2. Lung phantom for transudate pleural effusion. (A) Simulated chest wall (chicken breast). (B) Transudate pleural effusion (water). (C) Simulated consolidated/collapsed lung (chicken meat). Small arrow: simulated diseased pleura (glove); large arrows: simulated air bronchograms.

Our ultrasound phantoms were demonstrated to successfully simulate the appearance of pleural effusion with a consolidated lung (Video 3). The disposable glove filled with water gave the hypoechoic sonographic appearance resembling transudate-like pleural effusion (Figure 2 and Video 1). The addition of talc produced echogenic debris, which gave an empyema-like appearance (Figure 3 and Video 2). Agitation of the model would also simulate a "snowstorm" appearance, as noted in the Video 2. A sliver of chicken or pork meat added to the water-filled glove gave the appearance of consolidated lung (Figures 2 and 3). Blood vessels in the sliver of meat can simulate air-bronchograms (Figures 2 and 3). The optional use of pork ribs with intact skin and subcutaneous tissue provides a high-fidelity human chest wall model (Figure 3). While this is more expensive, the ribs would give a higher level of ultrasound fidelity and could facilitate the local anesthesia infiltration training with the ribs as landmarks before thoracentesis.

The simulation techniques can be used to assess the sonological procedural proficiency of the trainees during training before these are performed on real patients. The lung phantom can be used to understand ultrasound image generation, image optimization, image interpretation, and device operation. The authors were consistently able to reproduce the lung phantom model and acquire high-fidelity simulated ultrasound imaging for training. There were no notable changes in the ultrasound signals when the model was left at room temperature for up to 6 h. The phantom was also easy to transport between different teaching stations. Future research should focus on the clinical effectiveness of point-of-care ultrasound in the routine management of pleural effusions and how new technologies may expand its clinical utility (11). It would be important to prospectively validate if the training using these models could be translatable; with improved competency of the trainees to identify and make appropriate clinical decisions in the management of real patients with parapneumonic effusions and empyema.

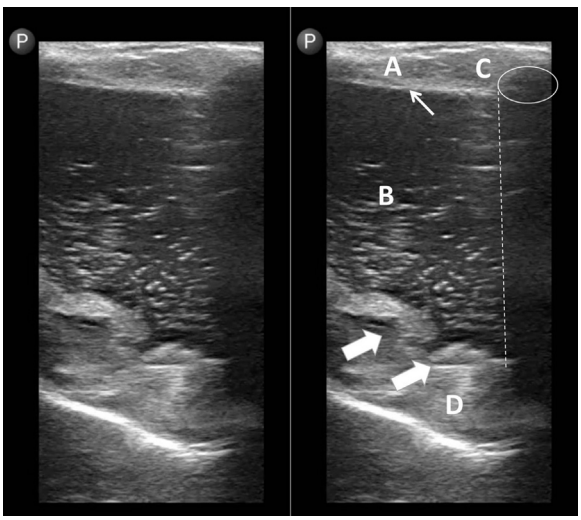

Figure 3. Lung phantom for empyema. (A) Simulated chest wall (pork meat with ribs). (B) Empyema (talc/creamer in water). (C) Rib with posterior acoustic shadowing. (D) Simulated consolidated/collapsed lung (meat). Small arrow: simulated diseased pleura (glove); large arrows: simulated air bronchograms.

The major limitations of the phantom were the unwanted odor because of the use of biological materials, and need for infection control precautions after the use of the phantom. These can be minimized by pretreatment with diluted bleach and ensuring that there are sufficient replacement models.

CONCLUSIONS

We described a high-fidelity, homemade simulation phantom that simulated pediatric pneumonia with a pleural effusion that can mimic parapneumonic effusions and empyema on ultrasound. It can also be used for training ultrasound-guided needle thoracentesis. We believe that the lung ultrasound simulation model described in this paper is cost-effective, has high fidelity, and is easily reproducible. We propose that this ultrasound phantom be considered as an alternative to the commercially available models for training.

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SUPPLEMENTARY DATA

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