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ORIGINAL ARTICLE

Development of cost-effective ultrasound phantoms for image artifact training: A study on learning outcomes and inter-rater agreement

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ABSTRACT

Introduction: Ultrasound phantoms are useful teaching tools for demonstrating image artifacts. However, commercial phantoms are often costly, limiting their accessibility for education. This study aimed to design and evaluated low-cost homemade ultrasound phantoms for demonstrating image artifacts in medical training. **Methodology**: Four homemade phantoms were constructed using gelatine and corn flour. Different materials were used to replicate ultrasound artifacts: a stone for acoustic posterior shadowing, a water-filled glove for acoustic posterior enhancement, a glass mirror with a water-filled glove for the mirror artifact, and a PVC-insulated cable for the comet tail artifact. The phantoms were scanned, and images were analysed by four sonographers to assess their reliability in visualizing artifacts. A group of students later scanned the phantoms to compare learning outcomes between theory-only and hands-on learning. **Results**: Mann-Whitney U test indicated that commercial phantoms had a significantly higher price (6.50) than the price of homemade phantoms (2.50), U = 16.000, p = 0.02. The Fleiss' Kappa test showed a moderate agreement among four sonographers, k = 0.71 (p = < 0.001). The Mann-Whitney U test found no significant difference in marks scored by both groups, although the theory with hands-on learning group achieved higher scores (20.78) compared to the theory learning group (17.32), U = 139.000, p = 0.34. **Conclusion**: Homemade phantoms can serve as a cost-effective alternative to commercial phantoms for visualizing image artifacts in learning applications, demonstrating substantial agreement among sonographers. Thus, these phantoms offer an effective tool to enhance students' performance through hands-on practice.

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1. INTRODUCTION

Diagnostic ultrasound is a convenient, non-invasive imaging modality. It is heavily reliant on the user, and diagnoses are made based on the operator's real-time image interpretation [1]. Physicians and sonographers who perform ultrasound examinations must have a strong understanding of the fundamentals of diagnostic ultrasound. The implementation of minimum requirements for qualified ultrasound practitioners is crucial to ensuring competence in three components: image acquisition, image interpretation, and clinical integration of findings into patient management decision-making.

Physicians should be conversant with the physical explanations of the artifacts and apply this understanding to enhance the diagnostic efficacy of their interpretations as well as the scan's image quality [2]. The fundamentals of comprehending the artifacts in conventional ultrasonography and Doppler methods are needed to highlight the potential impact of these artifacts on diagnostic accuracy. The radiologist should be able to identify artifacts when they appear to prevent misunderstanding. Ultrasound imaging artifacts can arise from patient-related factors, equipment limitations, or operator technique. Therefore, recognizing artifacts is essential, as they can serve as markers of tissue composition. Artifacts are common in ultrasound imaging [3]. While some artifacts may interfere with image interpretation accuracy, others can aid in diagnosis. Identifying and correcting ultrasound artifacts improves image quality and ensures optimal patient care. Therefore, understanding artifacts, their characteristics, and their causes are crucial, placing a significant responsibility on both sonographers and interpreting physicians.

While many ultrasound artifacts are detrimental, some are diagnostically useful and aid interpretation. For example, acoustic posterior shadowing is often seen in breast masses [4], acoustic posterior enhancement commonly occurs in cystic lesions [5], mirror artifacts may be observed when heterotopic pregnancy is suspected [6], and comet tail artifacts can indicate cholesterol crystals in gallbladder adenomyomatosis [7].

A circular letter outlines three key training components: a didactic program, clinical experience, and hands-on procedural experience [8]. Research has shown that using simulation to teach fundamental skills can enhance learners' confidence before they practice on actual patients. This teaching approach has led to the adoption of phantoms as learning tools in ultrasound training.

Simulation-based ultrasound training increases student skill competency in an array of prior studies, and the skill translated well to actual clinical practice [9]. Ultrasound phantoms serve as valuable tools for learning and practicing; thus, it can be used as a fundamental instrument to improve understanding of ultrasound image artifacts. With a properly engineered phantom, its role can be improved specifically to demonstrate ultrasound artifacts that usually appear in diagnostic medical ultrasound images.

Ultrasound phantom designs can be either commercially manufactured or handmade. Example of ultrasound phantoms that have been manufactured commercially such as Blue Phantom [10]. However, manufactured ultrasound phantoms are costly [11]. A commercial ultrasound phantom costs approximately USD400, and when it comes to replicating more types of conditions, homemade phantoms may be ideal [12]. This research aims to develop a gelatine-based ultrasound phantom that stimulates artifacts commonly caused by certain pathologies using materials that mimic disease characteristics.

2. METHODOLOGY

Four ultrasound phantoms were constructed using gelatin mixed with corn flour. Each phantom contained a specific material designed to produce an ultrasound artifact. The artifacts produced were as follows: acoustic posterior shadowing from a stone, acoustic posterior enhancement from a water-filled glove, a comet tail artifact from a PVC-insulated cable, and a mirror artifact from the combination of a water-filled glove and a glass mirror.

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The process of making phantoms was adapted from The British Journal of Radiology [12]. The ingredients for the phantom mixture included 200 grams of corn flour, 40 grams of gelatine powder, 1000 ml of tap water, and food coloring. The corn flour was gradually mixed with room-temperature water in a saucepan to create the base of the artifact phantoms. The mixture must be stirred continuously to avoid clumping. Once the mixture turned into a milky liquid, 15 drops of food coloring were added into the mixture. Next, the mixture was heated on a stove. The mixture must be stirred during the heating process until it was thickened and began to bubble. The temperature was monitored with a kitchen digital thermometer to ensure it stayed between 144-162°F (62-72°C). The gelatine was then added into the mixture. An electric hand mixer was used to mix the gelatine thoroughly until the mixture reached a panna cotta-like consistency. The gelatin-cornstarch mixture was poured into four separate plastic containers to form the first layer, approximately 2 cm in height, and left to cool. Once the first layer had fully set, an artifact material was placed on top. The second layer of the gelatin-cornstarch mixture was poured over the artifact material, covering it by about 2 cm. This process was repeated for each container, ensuring that each contained a different artifact material. The containers were then placed in the refrigerator and allowed to set for at least 12 hours to ensure the mixture solidifies properly.

The cost of each phantom was recorded and compared with the purchasing prices of four commercial ultrasound phantoms: Kyoto Kagaku Fast-Acute Abdomen Phantom, FAST-ER FAN, with Sonography for Trauma, Kyoto Kagaku DPediatric FAST-Acute Abdomen Phantom, Kyoto Kagaku Ultrasound Exam 'ABDFAN' With Pathologies, and Anatomy Lab Lab Abdominal Ultrasound Phantom.

The phantoms were scanned and the acquired artifact images were captured in cini mode. The recorded artifact images were distributed to four sonographers, each with a minimum of five years' experience, to evaluate inter-rater agreement (Figure 1). The participating sonographers were affiliated with teaching hospitals, a private institution, and included one international practitioner.

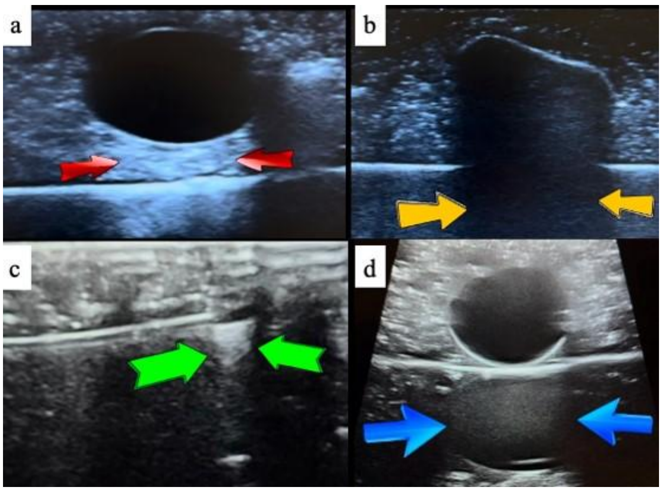

Fig. 1. (a) Ultrasound image artifacts of scanned homemade phantoms with acoustic posterior enhancement artifact (red arrow), (b) acoustic posterior shadowing artifact (yellow arrow), (c) comet tail artifact (green arrow), and (d) mirror artifact (blue arrow)

Source: Nur Aqila Razali & Sook Sam Leong 2026

Next, homemade ultrasound phantoms were used as hands-on scanning material for Medical Imaging undergraduate students. Their inclusion criteria were as follows: full-time students who registered for the subject of Ultrasound Physics and Instrumentation. The exclusion criteria applied to students who were repeating the Ultrasound Physics and Instrumentation course or had prior working experience in ultrasonography. A total of 37 students were recruited and assigned to two groups: a control group, which received theory-based instruction, and a study group, which received a combination of theory and hands-on practice. Following the learning sessions, all students underwent testing to assess the learning outcomes.

All data were analysed using SPSS statistical software (version 29, SPSS Inc, IBM). The Mann-Whitney U test was used to compare the price between homemade ultrasound phantoms and commercial ultrasound phantoms. The reliability of inter-rater agreement between four sonographers over four image artifacts ultrasound phantoms were analysed using Fleiss Kappa test. The difference in performance between theory-learning students and learning combined theory with hands-on practice students was evaluated using the Mann-Whitney U test.

3. RESULTS

The total cost per mixture to create the base structure of four phantoms artifact amounting to RM 3.19. To manufacture phantoms that produce image artifacts, specific materials were employed to construct the artifacts. Some materials were purchased from online stores while others were sourced locally. The cost to produce each artifact phantom is as follows: acoustic posterior shadowing artifact phantom – RM 0.94, acoustic posterior enhancement artifact phantom – RM 1.18, mirror artifact phantom – RM7.39, and comet tail artifact phantom – RM 1.12.

The cost of each homemade image artifact ultrasound phantom was compared to that of the commercial ultrasound phantoms (Table 1). The Mann-Whitney U test indicated that the costs for commercial phantoms (RM 6.50) were significantly higher than those for homemade phantoms (RM 2.50), $U = 16.000$, $p = 0.02$.

Table 1. Price list of homemade phantom versus commercial phantoms

Homemade Phantom	Price (*RM*)	Commercial Phantom	Price (*RM*)
Phantom 1 Acoustic Posterior Enhancement Artifact	4.37	Kyoto Kagaku Fast-Acute Abdomen Phantom, FAST-ER FAN, with Sonography for Trauma	64591.36
Phantom 2 Mirror Artifact	7.39	Kyoto Kagaku DPediatric FAST-Acute Abdomen Phantom	39200.27
Phantom 3 Acoustic Posterior Shadowing Artifact	0.94	Kyoto Kagaku Ultrasound Exam 'ABDFAN' with Pathologies	40091.19
Phantom 4 Comet Tail Artifact	1.12	Anatomy Lab Lab Abdominal Ultrasound Phantom	12918.27

Source: Nur Aqila Razali & Sook Sam Leong 2026

All phantoms were scanned, and the scanned images were sent to four sonographers for an inter-rater reliability test. The results from the sonographers were classified as 1 (true) and 0 (false). All sonographers answered incorrectly for the comet tail artifact, and the Fleiss Kappa test showed substantial agreement, $k = 0.71$ ($p < 0.001$).

A total of 37 students' test marks were collected (control group = 19 students; study group = 18 students) (Figure 2). The Mann-Whitney U test indicated that the study group scored higher marks (mean = 20.78) than the control group (mean = 17.32). However, there was no significant difference in students' comprehension of ultrasound image artifacts between theory-based learning and theory with hands-on learning, $U = 139.000$, $p = 0.30$.

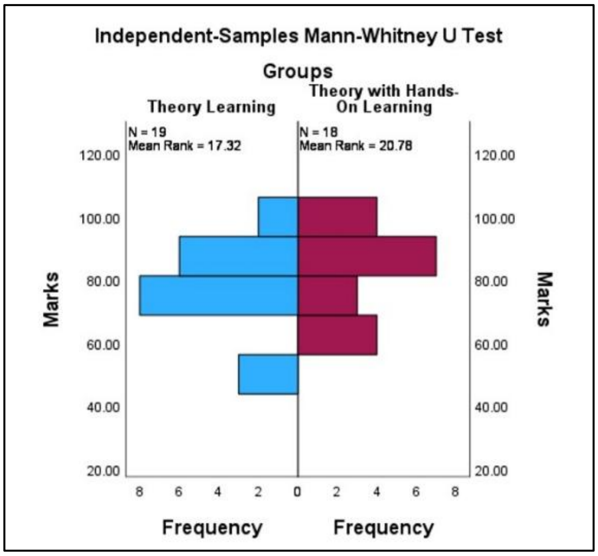

Fig. 2. Students' performance between theory learning and theory learning with hands-on learning group

Source: Nur Aqila Razali & Sook Sam Leong 2026

4. DISCUSSION

Ultrasound imaging is a common diagnostic modality that produces images of internal organs and tissues by using high-frequency sound waves. Compared to other imaging modalities, ultrasound images appear to be safe, non-invasive, and cost-effective. Ultrasound, like all medical imaging, is susceptible to image artifacts, which can lead to misinterpretation but can also aid in diagnosis and treatment planning [13]. Ultrasound phantoms are invaluable tools in medical practice, providing a realistic and safe environment for healthcare professionals to enhance their skills in image acquisition, interpretation, and procedure skills [14]. There are various types of ultrasound phantoms available on the market, but most commercial phantoms are expensive [14].

This study demonstrates a significant difference in the total production costs of homemade phantoms compared to the market price of commercial phantoms with foreign bodies. The cost difference may be attributed to the materials used to make the base of the phantoms and the types of materials used as foreign bodies. Commercial phantoms are generally made from hydrogel polymer or elastomer rubber [12]. However, they are costly, about USD 400, which makes them prohibitive for many training facilities and students. Furthermore, after frequent use, they may deteriorate [12]. The texture of commercial phantoms is often very hard, which can limit their ability to provide accurate tactile feedback to users [12]. In contrast,

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when gelatine is combined with corn flour, it produces ultrasound echogenicity comparable to that of soft tissue [12].

Previous studies have used various materials to create the homemade phantom, but most of the studies suggest gelatine-based phantoms. A study compared several simple and low-cost phantoms for ultrasound-guided fine needle aspiration biopsy training using different materials such as ballistic gel, gelatine, chicken breast, extra firm tofu, canned cooked pork, and commercial phantoms [15]. The study found that gelatine phantoms performed on par with, or even superior to, commercial phantoms in terms of performance and educational value. The study highlighted several advantages of using gelatine: low cost, ease of construction, excellent echogenicity comparable to human tissue, and good haptic quality. Furthermore, the opacity of gelatine phantoms can be adjusted to suit the trainee's preferences.

Another study investigated how well different non-commercial phantoms replicate the haptic and echogenic characteristics of ultrasound-guided peripheral intravenous implantation in actual patients [16]. Additional objectives included describing the phantom's cost, simplicity of development, and reusability. This study showed that despite being reusable, the high expense of commercial-grade ultrasound phantoms may make it difficult to plan simulation training. Additionally, a study by Turkish Journal of Emergency Medicine compared homemade and commercial phantoms [17]. Their homemade phantom model, projected to cost between USD 6 and USD 8, was significantly more affordable than the commercially available phantom, which ranged in cost from USD 1000 to USD 1200.

While previous studies have used homemade ultrasound phantoms for learning and training purposes, none have focused on creating homemade image artifact phantoms. Some materials used in this study were easy to find locally and were obtained for free, such as stone and water. Stone, for example, closely resembles calculi with an anechoic appearance, which produces an acoustic shadowing artifact [18]. Meanwhile, a water-filled glove simulates a cyst, creating a hyperechoic appearance and producing an acoustic enhancement artifact [2]. Other materials used in this study can be purchased inexpensively from department stores or online shops. For instance, gloves filled with water function as balloons to create an acoustic enhancement artifact. A separate water-filled glove, when combined with a mirror, acts as a single reflector to produce a mirror artifact [7]. Besides that, a polyvinyl chloride (PVC) cable has an acoustical interface to visualize comet tail artifact [2].

It is crucial to ensure that the homemade phantom is reliable, accurately producing artifacts that closely represent the actual ultrasound images to maintain its effectiveness as a training tool. A substantial agreement was achieved after all sonographers agreed that the mirror artifact phantom and acoustic posterior shadowing artifact phantom could visualize the designated artifacts. In contrast, all sonographers agreed that the comet tail artifact phantom could not display the image artifact. They labeled the comet tail artifact as a reverberation artifact and ring-down artifact.

Reverberation artifacts are produced when the ultrasound beam contacts two highly reflective interfaces in tandem. The comet tail artifact is a subtype of reverberation artifact, produced when highly reflective interfaces are so close together that it is impossible to distinguish individual echoes. Although the comet tail artifact is based on the same reverberation principles, its appearance manifests as a tapering echogenic triangle or cone located distal to a parallel structure that reflects strongly [7]. Ring-down artifacts are similar to reverberation artifacts and may resemble comet tail artifacts; however, the process is different [7]. The ring-down artifact is caused by a tiny pocket of fluid trapped between surrounding air bubbles [19]. Therefore, in this present study, all 4 sonographers labeled the comet tail artifact phantom as both a reverberation artifact and a ring-down artifact, as their appearances are likely similar. According to Oglat et. al., artifacts in diagnostic ultrasound are frequent [20]. The underlying physical characteristics of the beam and its echoes often cause this error in image display, which is unavoidable. It is important to recognize this undesirable artifact, as it may help support tissue structure identification and aid in diagnosis. The ability to identify and address potentially problematic artifacts are crucial for improving scan image quality and providing the best possible treatment for patients.

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This study also found that while both hands-on and theoretical training improved students' knowledge of topographic anatomy, those who participated in hands-on ultrasound training demonstrated faster interpretation of ultrasound images without a loss in accuracy. This suggests that hands-on training may facilitate pattern recognition and improve the speed of recall in clinical settings. Engaging directly with ultrasound equipment allows students to develop essential psychomotor skills and gain confidence in image acquisition and interpretation. Furthermore, research by Recker et al., highlighted that key practical training elements, including early hands-on sessions and exposure to various equipment, substantially improved learning outcomes [21]. This hands-on experience enables learners to bridge the gap between theoretical knowledge and clinical application, fostering a deeper understanding of ultrasound principles and techniques.

Another study investigated the effectiveness of a brief teaching scenario in a phantom-based learning model for students to achieve ultrasound-guided vascular access [22]. Eleven medical students with no experience performed ultrasound-guided vascular cannulation. Afterward, the students performed the same procedure again after learning theory and practical lessons. The findings showed statistically significant improvements for every comparison measured between the first-hand and second hands-on training sessions. In the current study, students who received theory learning with hands-on practice scored higher during the test compared to those who received only theory learning. However, both groups showed an insignificant impact of practical experience on the phantom model itself. One possible justification for this could be that lecture notes were shared with students in advance, thereby enhancing the results of the theory-based students.

5. CONCLUSION

There are several limitations in this study. First, the inter-rater agreement test was based on images produced by a novice operator, and the image quality may have contributed to potential misinterpretation. For future work, we suggest that sonographers produce the images in cini loop to better appreciate the artifact’s appearance. The second limitation concerns the sample size when comparing the performance of students in theory-based learning versus theory with hands-on learning. The small differences in overall marks between the two groups make it difficult to detect significant differences in students’ performance. In future studies, we recommend using larger sample sizes to improve the reliability of the results. Despite these limitations, this study has demonstrated that ultrasound phantoms for image artifacts can be produced at a lower cost with substantial agreement between sonographers. Thus, homemade ultrasound phantoms are ideal for learning purposes, providing an effective tool to enhance students' performance through hands-on practice.

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7. GENERERATIVE A.I DISCLOSURE STATEMENT

AI use is limited to language refinement and authors retain full responsibility for content.

8. CONFLICT OF INTEREST

Authors declare none.

9. AUTHORS' CONTRIBUTIONS

Conception and design: Sook Sam Leong

Subject recruitment: Sook Sam Leong, Nur Aqila Razali

Acquisition of data: Nur Aqila Razali

Analysis and interpretation: Nur Aqila Razali

Drafting the manuscript: Nur Aqila Razali

Review the manuscript: Sook Sam Leong

10. ETHICS STATEMENT

Ethical approval for this study was obtained from the Faculty of Health Sciences Research Ethics Committee (FERC), Universiti Teknologi MARA (UiTM). Approval number FERC/FSK/MR/2024/00022. Written informed consent was obtained from all participants prior to their participation in the study.

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