Shooting With Sound

Optimizing an Affordable Ballistic Gelatin Recipe in a Graded Ultrasound Phantom Education Program

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Objectives—The goal of this study was to investigate the durability and longevity of gelatin formulas for the production of staged ultrasound phantoms for education.

Methods—Gelatin phantoms were prepared from Knox gelatin (Kraft Foods, Northfield, IL) and a standard 10%-by-mass ordinance gelatin solution. Phantoms were durability tested by compressing to a 2-cm depth until cracking was visible. Additionally, 16 containers with varying combinations of phenol, container type, and storage location were tested for longevity against desiccation and molding. Once formulation was determined, 4 stages of phantoms from novice to clinically relevant were poured, and clinicians with ultrasound training ranked them on a 7-point Likert scale based on task difficulty, phantom suitability, and fidelity.

Results— On durability testing, the ballistic gelatin outperformed the Knox gelatin by more than 200 compressions. On longevity testing, gelatin with a 0.5% phenol concentration stored with a lid and refrigeration lasted longest, whereas containers without a lid had desiccation within 1 month, and those without phenol became moldy within 6 weeks. Ballistic gelatin was more expensive when buying in small quantities but was 7.4% less expensive when buying in bulk. The staged phantoms were deemed suitable for training, but clinicians did not consistently rank the phantoms in the intended order of 1 to 4 (44%).

Conclusions—Refrigerated and sealed ballistic gelatin with phenol was a cost-effective method for creating in-house staged ultrasound phantoms suitable for large-scale ultrasound educational training needs. Clinician ranking of phantoms may be influenced by current training methods that favor biological tissue scanning as easier.

Key Words— ballistic gelatin; Knox gelatin; medical education; phantom; ultrasound education

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The creation of highly functional, durable, and low-cost ultrasound phantoms is an important part in the development of any ultrasound training program. Although ultimately falling short of the reference standard of using standardized patients for training purposes, gelatin-based phantoms are excellent substitutes in the early stages of ultrasound education. These phantoms can allow the early learner an opportunity to master the basic principles of sonography and knobology before moving on to, or in conjunction with, standardized patients or clinical situations. The Association of American Medical Colleges called 2013 "The Year of Ultrasound,"[1] and as ultrasound organizations begin to promote the incorporation of ultrasound education in medical school curricula, it becomes increasingly important for medical education programs to identify economical ways to bring about this goal.

Physics and knobology are the first topics in ultrasound training. Commercial phantoms are expensive options when teaching large groups or when financial resources are limited. The technical difficulties of ultrasound training are associated with learning the complex relationships between the 3-dimensional structures being scanned and their 2-dimensional representation on screen. Another difficulty is gaining competency in distinguishing actual structures from the regular and confounding effects of artifacts.

The study was divided into 2 distinct parts. This first part involved assessment of the longevity and durability of gelatin formulations. The second part involved production of staged ultrasound phantoms for basic scanning and physics and knobology training.

The first part of the study compared the durability and cost of 2 readily available options: Knox gelatin (Kraft Foods, Northfield, IL) and ballistic gelatin. Additionally, this study investigated various preparation methods, seeking to enhance the longevity of the gelatin-based phantoms. The second part was to use the ideal preparation method to create a 4-part series of graded ultrasound phantoms that could be used to help early learners with 2 specific goals. The first goal was to reproduce clinically relevant ultrasound artifacts with suitable fidelity and scalability. The second goal was to produce a stepwise progression to the phantoms that would advance the skills of the learner toward clinical needs. The overall purpose of this study was to help educational programs overcome some of the costs and hurdles associated with large-scale implementation of ultrasound training programs by providing methods of producing cost-effective and optimized formulations for in-house training phantoms to meet their educational goals.

Materials and Methods

The first part of this experiment evaluated the durability and cost of a gelatin phantom made of Knox or ballistic gelatin and 4 variables to maximize the longevity of the gelatin-based phantom. The second part of the experiment evaluated the suitability and reproducibility of a 4-stage program in ultrasound training by creating multiple phantoms of increasing levels of difficulty and evaluating their usefulness for ultrasound education.

Materials needed:

1. Vyse professional-grade ballistic gelatin (Vyse Gelatin Co, Schiller Park, IL)
2. Knox gelatin
3. 6-qt storage containers (4)
4. 16-oz plastic cups (16)
5. Electric kettle
6. Electric drill with paint-mixing attachment

Four test phantoms (2 Knox and 2 ballistic), each weighing 2000 g, were prepared by using a 10%-by-mass gelatin solution (Appendix). Each batch was poured into a 6-quart container and allowed to set in a refrigerator at 4°C overnight. Each phantom was compressed with either a curvilinear or linear ultrasound transducer to a depth of 2 cm, as measured by the on-screen depth gauge until cracking was visible in the gelatin (Figure 1). Both transducers were used to ensure that differences in probe shape were accounted for in determining the strength of the phantom. Pricing information was obtained from Amazon[2] and Gelatin Innovations.[3]

The longevity portion of the experiment evaluated 16 ballistic gelatin samples, prepared with the same 10%-by-mass gelatin solution, and measured their longevity by modifying 3 different environmental variables: container type (lid or no lid), storage location (refrigerated or room temperature), and the addition of phenol as a preservative in varying final concentrations (0.0%, 0.5%, 1.0%, and 2.0%), as shown in Table 1. Samples without phenol served as controls for the different environmental variables.

Longevity data end points were determined when damage to the gelatin appeared, such as desiccation (Figure 1) or mold growth. If samples showed signs of condensation or bubble formation, the day it appeared was noted, but the sample remained under observation until visible molding or desiccation occurred. Once mold was noted, samples were sealed for health reasons, and these were deemed "unsuitable for teaching purposes," and no further monitoring was conducted. Samples were observed for 8 weeks.

In part 2 of the study, four 6-quart containers were then filled with ballistic gelatin. Various objects composed of plastic, rubber, glass, and metal were embedded into the gelatin phantoms. Objects with familiar shapes (sharks, snakes, frogs, metal washers, marbles, bullets, and some superhero characters) were placed within the gelatin as shrapnel that could be found in human bodies. Items were selected on the basis of their identifiable shapes, their differential densities and echogenicity, as well as the artifacts and educational fun that they brought to the learning environment (Figure 2). To identify and create the desired artifacts, various objects were prescanned in a water bath to select the ones that reproduced the desired educational objective. The positioning and angle of the scan could also affect the artifact's appearance, so maps of the phantom were not created until the objects were set in the gelatin and scanned to ensure proper placement.

Phantoms with 4 stepwise levels of difficulty were created. Level 1 phantoms had mapped-out artifacts and objects (Figure 3). Level 2 phantoms had unmapped artifacts and objects. Level 3 phantoms were unmapped and had objects hidden in fluid-filled balloons. Level 4 phantoms were shrapnel embedded in biological organ tissues such as kidney and liver and obscured from view by coloring the gelatin. Eighteen ultrasound-trained clinical team members were asked to identify the intended artifacts in each phantom and rank them on a 7-point Likert scale based on task difficulty, phantom suitability, and fidelity.

Results

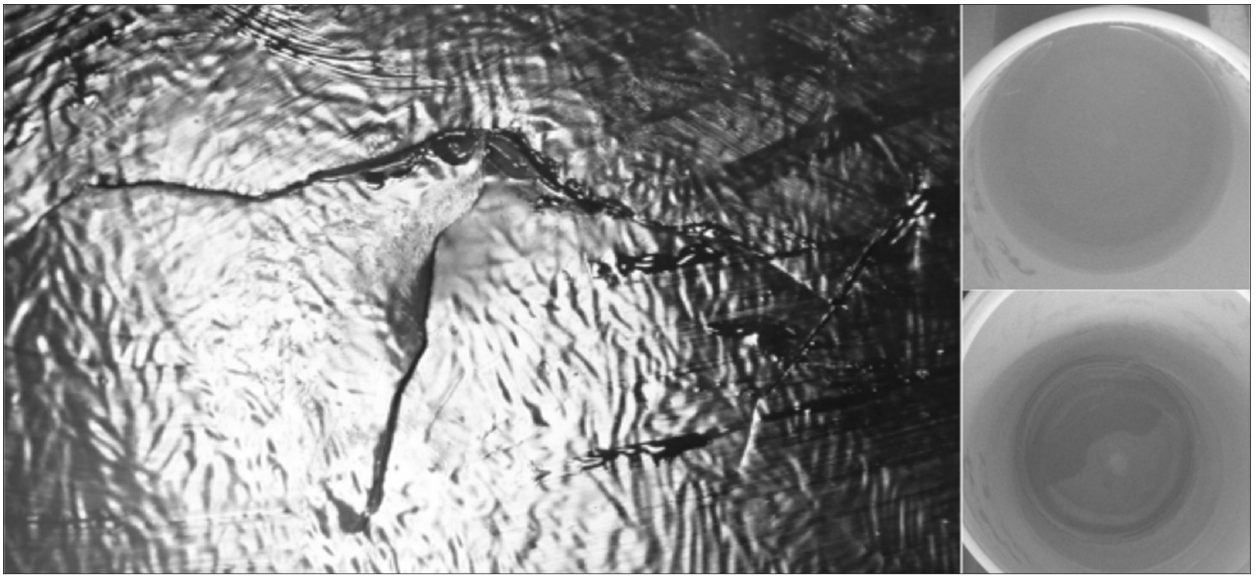
During durability testing, compression of the ballistic gelatin was sustained over the measured maximum of 500 compressions of 2 cm with either a linear or curvilinear ultrasound transducer without failure. Knox gelatin, on the other hand, sustained only 209 and 383 compressions of 2 cm as measured on ultrasound imaging with linear and curvilinear transducers, respectively, before substantial cracking diminished the ultrasound image quality.

The increased durability of the ballistic gelatin came at the expense of a higher cost per batch ($5.24 versus $4.07) when obtaining 10 lb of ballistic gelatin versus 2 lbs of Knox gelatin. The ballistic gelatin cost per batch decreased to $3.77 when buying a 50-lb container. Therefore, the ballistic gelatin was 22.3% more expensive per batch when buying in small quantities (10 lb of dry gelatin powder). However, when buying ballistic gelatin in bulk (50 lb of dry gelatin powder), the cost per batch was 7.4% lower than that of the Knox gelatin.

During longevity testing, the 16 ballistic gelatin samples without a lid had desiccation within 1 month to the point of being unusable for training. None of the lidded samples had desiccation in the 8-week period of observation. The 4 samples that did not contain any phenol showed mold growth by 10 and 41 days with no refrigeration and with refrigeration, respectively. All containers without phenol became moldy within 12 days to 6 weeks, whereas only 1 of 12 samples with any phenol (no lid and no refrigeration) became moldy, as shown in Table 2.

The second part of the study assessed the ability to build a set of staged phantoms, focusing on the development of basic scanning skills, knobology, and artifact recognition. In terms of artifact recognition, it was possible to select both familiar objects and objects that reliably created and reproduced the desired artifacts, such as posterior acoustic shadowing, ring-down, and posterior acoustic enhancement (Figure 4).

Figure 1. Cracking of the phantom after repetitive 2-cm transducer compressions (left), normal ballistic gelatin sample (top right), and desiccated ballistic gelatin sample (bottom right).



In the water bath prescanning, it was seen that rubber created heterogeneously echoic signals, whereas water-filled balloons created posterior acoustic enhancement similar to cysts. Objects made of hard plastic had hyperechoic leading edges and created posterior acoustic shadows that required multiple scan angles. Metal created posterior acoustic shadowing, reverberation, and refraction artifacts and could produce ring-down artifacts depending on the type of metal used. Glass marbles produced posterior acoustic shadowing and better ring-down artifacts or comet tail–like artifacts. Formica boards set at angles could produce mirroring artifacts and ghosting. The selection of reliable materials and objects also made it possible to reproduce multiple phantoms at the same level, such that the learning objectives could be scaled to larger groups. The addition of these objects into the phantoms did not affect the integrity or longevity of the gelatin mixture.

When the 18 ultrasound-trained clinical team members were asked to rank the suitability of the phantoms, they approved of their suitability with an average Likert ranking of 5.9 of 7, with 7 being very suitable. The clinicians were also able to identify the intended artifact simulation in most of the phantoms, although they did have some difficulty in identifying some that had more than 1 artifact. The intention of the study was to ensure that major artifacts were recognizable, and this factor was difficult to tabulate as a data point, since multiple artifacts are often identifiable depending on scanning conditions, technique, and machine settings.

During the difficulty-ranking component of the study, the clinicians ranked the level 1 phantom (mapped and visible objects) as the easiest 100% of the time. Level 2 phantoms (unmapped and visible objects) were ranked as second most difficult, at 67% of the time, and the placement of level 3 and 4 phantoms (unmapped and not visible, being hidden in balloons or biological tissues) was split more

Table 1. Ballistic Gelatin Samples for Longevity

Group	Sample	Phenol Concentration, %	Lid	Refrigeration
1	1[a]	0.0	–	–
	2	0.5	–	–
	3	1.0	–	–
	4	2.0	–	–
2	5[a]	0.0	+	–
	6	0.5	+	–
	7	1.0	+	–
	8	2.0	+	–
3	9[a]	0.0	–	+
	10	0.5	–	+
	11	1.0	–	+
	12	2.0	–	+
4	13[a]	0.0	+	+
	14	0.5	+	+
	15	1.0	+	+
	16	2.0	+	+

– indicates lid or refrigeration was absent; and +, lid or refrigeration was present.
[a]Control sample.

Figure 2. Examples of embedded objects visualized under ultrasound imaging with different echogenicity. Clockwise from top left: metal washer, plastic camel, rubber snake, and plastic superhero figurine.

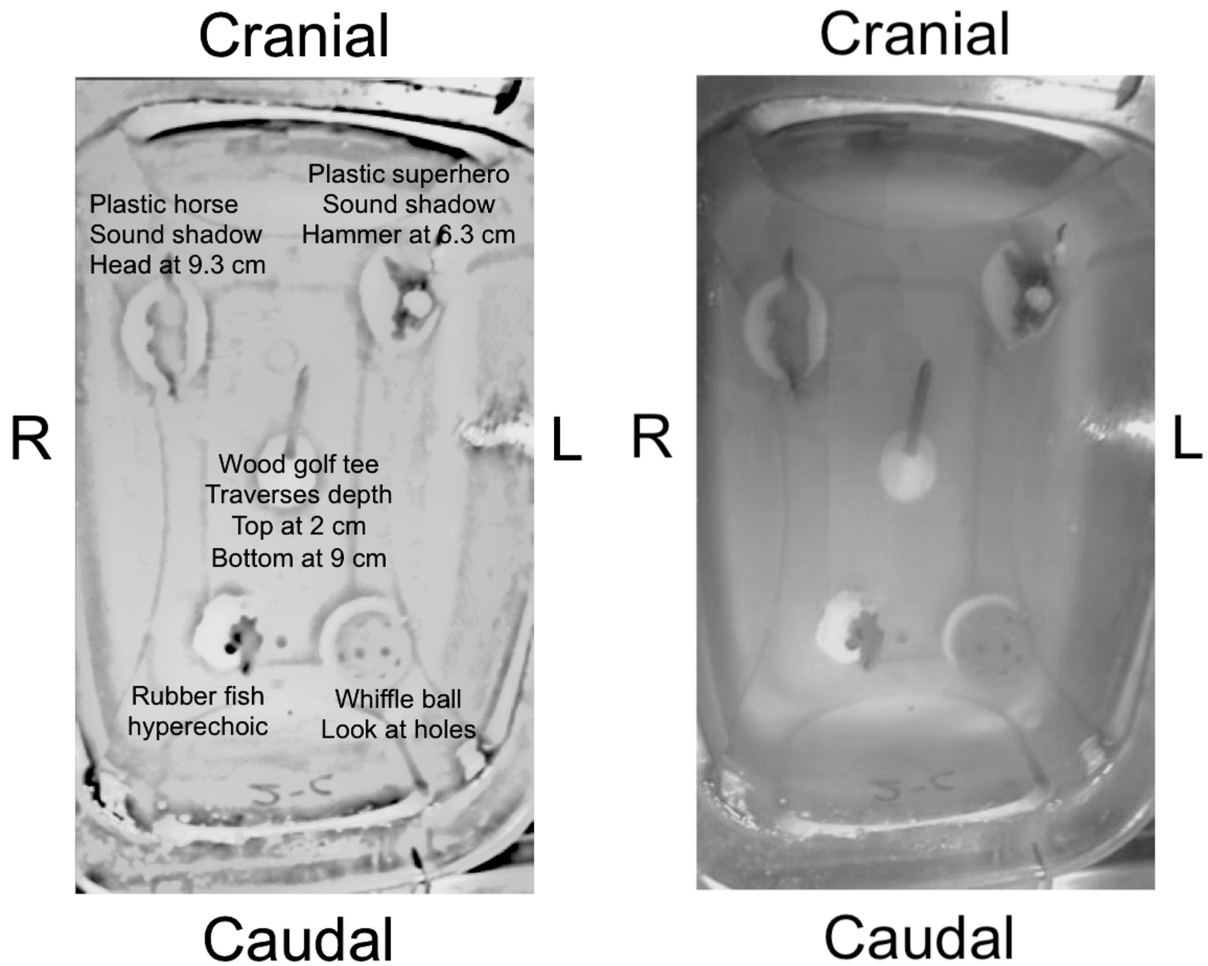
evenly, with level 3 in third place (56%), and level 4, as most difficult (50%). The intended ranking difficulty of the phantoms as 1-2-3-4 was selected by 44% of the clinicians, as shown in Table 3. The second most common ranking was 1-2-4-3, which was selected by 22% of the clinicians.

Discussion

Ultrasound imaging provides an inexpensive, noninvasive, real-time method for imaging a patient's anatomy and provides the physician with an expedient tool to use in such diverse medical settings as the emergency department and a rural geographical region. A study done at Wayne State University[4] pointed out that, as residency programs adopt ultrasound training programs, it becomes imperative for undergraduate medical programs to create or incorporate an ultrasound module or component into the undergraduate medical curriculum.

Both Knox gelatin and ballistic gelatin are adequate analogues in the development of introductory ultrasound phantoms. The decreased cost of homemade phantoms (approximately $10 per phantom, including the container) makes them a better value proposition for introductory ultrasound programs when compared to commercially available gelatin phantoms, which start at around $400 each.[5] Additionally, there is little noticeable difference in the echogenic properties of homemade and commercial phantoms (Figure 5). Homemade phantoms offer an advantage over commercial phantoms in their adaptability to being able to meet specific training or educational needs of individual programs, which may make either Knox or

Figure 3. Example of a level 1 phantom map (left) showing substantial artifacts and depth locations of various embedded objects. The translucent phantom (right) allows visualization of objects to be scanned. L indicates left; and R, right.



ballistic gelatin a better choice for many educational institutions. Both are suitable for staged phantoms, but ballistic gelatin has measurable advantages for the undergraduate medical education setting based on durability, cost, longevity, and scalability.

The increased availability of Knox gelatin in grocery stores makes it a more attractive option for programs considering a 1-time event or small-scale experimentation with gelatin phantoms. However, for larger programs that will be making several phantoms for many students over the course of a longer period, the increased durability and lower cost of the ballistic gelatin in higher quantities is the superior choice when creating gelatin phantoms for introductory ultrasound education.

Outside the criteria measured in this study, other factors affect the strength and longevity of the gelatin. First, water must be boiled, and a powered mixer must be used to ensure proper dissolution of the gelatin powder. Next, the addition of a defoamer reduces the formation of bubbles on the gelatin surface, providing a smooth contact for ultrasound training. Finally, all objects added to the forms must be suitably sterilized first to help prevent formation of mold in the middle of the gelatin.

Although damaged gelatin phantoms can be reheated and repoured, the time necessary for this process and the substantial decrease in image quality were enough to outweigh the cost of simply creating a new phantom. In cases in which the damage was minimal and did not involve mold, a thin new layer of gelatin could be added to restore the phantom's surface. Most of the damage in long-term use came from eventual mold development within the phantom, and using this gelatin again was counterproductive. However, individual programs may find utility in reheating simply cracked gelatin to save on the creation process. It may also be possible to gently reheat the gelatin surface with a heat gun.

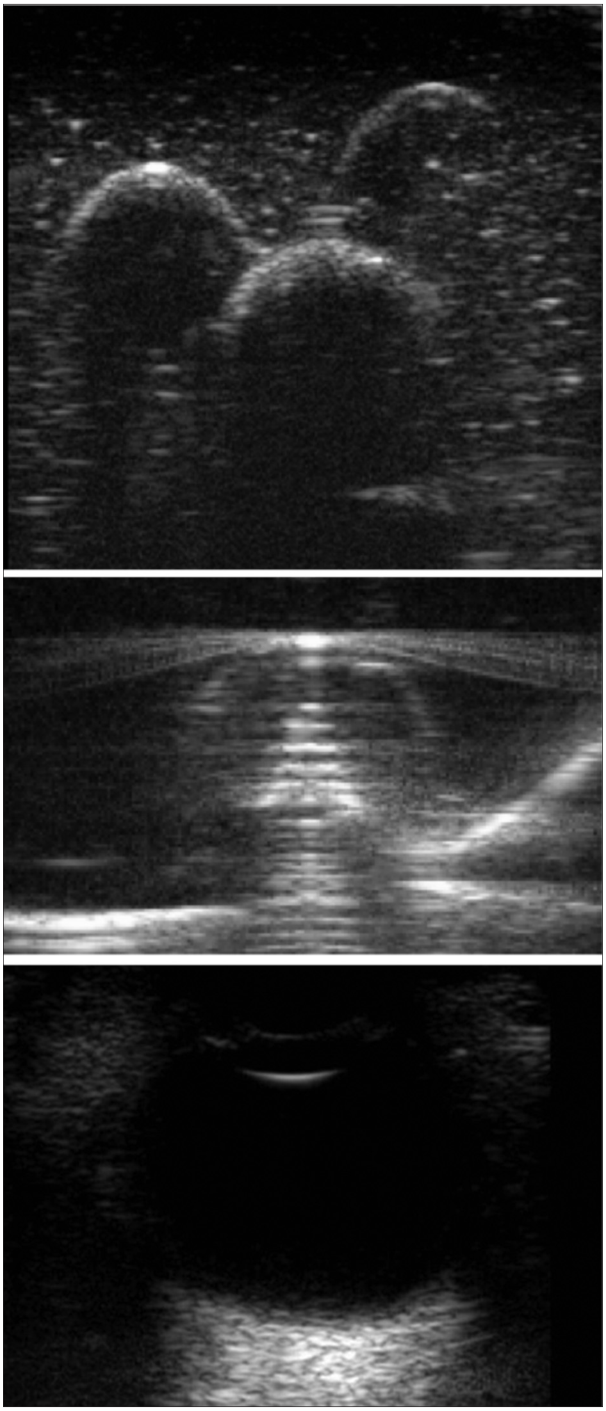
The longevity results indicate that covering the gelatin forms prevented desiccation, and refrigeration retarded the growth of mold. The appearance of bubbles was not predictable and does not seem to be related to any of the variables examined in this study. Although all covered samples accumulated condensation, the condensation did not harm the samples and could be easily wiped away. Mold grew on the surface of all forms without phenol, and all concentrations of phenol seemed to protect the forms from mold equally. Therefore, based on the results of this study, the

Table 2. Ballistic Gelatin Longevity Results

		Day Damage Appeared			
Group	**Sample, Phenol Concentration, %**	**Desiccation Day**	**Mold Day**	**Bubble Day**	**Condensation Day**
Group 1					
(–L, –R)	1, 0.0	NA	10	NA	NA
	2, 0.5	24	NA	NA	NA
	3, 1.0	NA	10	NA	NA
	4, 2.0	24	NA	10	NA
Group 2					
(+L, –R)	5, 0.0	NA	10	5	NA
	6, 0.5	–	–	12	24
	7, 1.0	–	–	–	24
	8, 2.0	–	–	13	24
Group 3					
(–L, +R)	9, 0.0	NA	41	33	NA
	10, 0.5	14	NA	NA	NA
	11, 1.0	39	41	NA	NA
	12, 2.0	20	NA	NA	NA
Group 4					
(+L, +R)	13, 0.0	NA	39	33	5
	14, 0.5	–	–	–	5
	15, 1.0	–	–	–	5
	16, 2.0	–	–	–	5

–L or –R indicates sample had no lid or was stored at room temperature; +L or +R, sample had a lid or was stored in the refrigerator; NA, samples reached an end point and were no longer monitored for other damage; and –, samples never showed that type of damage during the 8-week observation period.

Figure 4. Various clinically important artifacts that can be created in a ballistic gelatin phantom. Top to bottom: posterior acoustic shadowing, ring-down, and posterior acoustic enhancement.



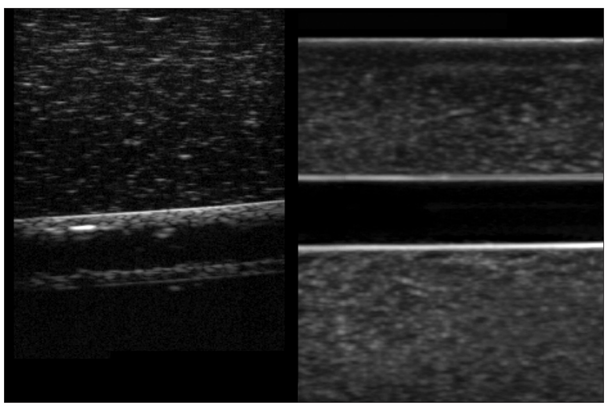
optimal recipe for the ballistic gelatin phantom had a phenol concentration of 0.5%, was lidded, and was refrigerated at 4°C. Clearly, phenol is a chemical with not-unimportant health considerations, but mold also raises concerns for spore dispersion and inhalation risks that we think may be outweighed by a low level of stabilized phenol. Future studies are continuing to explore options that minimize both factors.

The addition of both inorganic and cadaveric tissues to the phantom to simulate realistic clinical scenarios is a great opportunity to create specific stepwise teaching goals that move the learner from novel to clinically relevant. Most objects create multiple artifacts, and the artifacts sometimes vary on the basis of positioning, depth, and the consistency of the gelatin surrounding them, which is why each phantom required a map. By using recognizable objects in the early levels of gelatin phantoms, learners can focus on the knobology of ultrasound imaging without needing to devote mental capacity to image interpretation. This process facilitated the acquisition of good scanning habits as the learner progressed through the levels from the more simplistic objects to the more complicated.

Table 3. Clinician Ranking of the Difficulty of the Graded Phantoms From Least to Most Difficult (n = 18)

Ranking Order	Clinicians, %
1-2-3-4	44
1-2-4-3	22
1-3-4-2	17
1-3-2-4	6
1-4-3-2	11

Figure 5. Comparison of a ballistic gelatin phantom with a simulated vessel (left) to a commercial Blue Phantom branched 2-vessel ultrasound training block model (right).[6]



However, in this study, the lack of consensus in ordering the difficulty of the phantoms raises some interesting possibilities. One possibility may be that the type of training someone receives affects perceptions of what is difficult and what is not difficult. Because all of our evaluators were clinicians who were not trained as part of an undergraduate ultrasound curriculum but were trained in the clinical setting, they may have had a bias on ease based on the premise that the more clinical situation was less novel. The primary difference between the level 3 and 4 phantoms was simply the fact that objects were hidden in balloons in one, whereas they were hidden in biological tissues in the other. It was anticipated that the students in the undergraduate program would be familiar with balloons as simulators for cystic structures due to prior exposure at levels 1 and 2 but would be unfamiliar with biological tissues. The prior training of the clinicians may have affected the scoring of the level 4 phantoms as less difficult than the level 3 phantoms due to familiarity with the organ in which the objects were embedded.

The goal for level 4 phantoms was not to identify the specific organ or its key sonographic features but rather to add an additional layer of complexity to the objects already seen in earlier levels. Embedding these objects in organs within the gelatin phantom again challenges the novice learner to identify that object, its depth, and associated artifacts produced. In future studies among novice learners, the ordering of the phantoms may be more in line with the study's anticipated results because of the learners' exposure during undergraduate medical education programs that have integrated ultrasound into their curriculum.

The idea that ballistic gelatin was originally created as a biological tissue analogue with similar density lends itself very well to its use in ultrasound education without the immediate cost or need for standardized patients. The low cost and relative longevity of in-house phantoms can provide many different and repeatable educational opportunities for early ultrasound learners to grasp the basic concepts in ways specifically designed for their needs and skill levels. The ballistic gelatin forms provide the anatomy instructor with an inexpensive laboratory device for students to acquire rudimentary ultrasound skills before the use of commercial phantoms or standardized patients, without fear of further budgetary or equipment concerns in addition to those already imposed by an ultrasound curriculum.

Appendix: Ballistic Gelatin Preparation—Standard 10% Solution

1. Determine amount of gelatin desired:
   a. First layer typically around 1 to 1.5 kg;
   b. Second layer typically 2 to 4 kg.
2. Weigh out 10% of desired final weight in dry gelatin (eg, for 2 kg of solution, 200 g of gelatin and 1800 g of water).
3. Bring full amount of water to boil; pour into mixing bucket; and add 4 or 5 drops of defoamer per kilogram of water.
4. Mix water using an electric mixer (we used a paint mixer attachment on a power drill) and slowly shake dry gelatin into water while mixing.
5. Continue to mix for about 1 minute or until all visible clumps are dissolved.
6. Optional—add food coloring until desired level of opacity is reached.
7. Optional—add phenol (≈5 mL per 1000 g of gelatin solution) as a preservative after gelatin solution has cooled to less than 40°C.
8. Pour into phantom container and place in refrigerator.
9. After a minimum of 2 hours in the refrigerator, gelatin will be set enough to place plastic toys or other objects to image.
10. Prepare second layer of gelatin same as above, but wait after preparation to allow solution to cool (should be cool enough to touch) before pouring over first layer.
11. Place in refrigerator overnight.

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