Integration of a Low-Cost Introductory Ultrasound Curriculum Into Existing Procedural Skills Education for Preclinical Medical Students

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We evaluated integration of an introductory ultrasound curriculum into our existing mandatory procedural skills program for preclinical medical students. Phantoms consisting of olives, pimento olives, and grapes embedded in opaque gelatin were developed. Four classes encouraged progressive refinement of phantom-scanning and object identification skills. Students improved their ability to identify hidden objects, although each object type achieved a statistically significant improvement in correct identification at different time points. The total phantom cost per student was $0.76. Our results suggest that short repeated experiences scanning simple, low-cost ultrasound phantoms confer basic ultrasound skills.

Key Words—medical education; medical student; procedural skills; ultrasound education

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Owing to the proven benefits of physician-performed point-of-care ultrasound examinations, including improved patient safety, satisfaction, and efficiency of care, it is unsurprising that ultrasound imaging is a skill shared by more than 20 medical specialties.[1–3] As the demand for practicing physicians competent in diagnostic and procedural ultrasound imaging rises, the burden of providing a strong educational foundation in ultrasound falls to medical schools and residency programs.[3–5]

As highlighted by the Association of American Medical Colleges in 2008, although there currently is no national agreement on the content and evaluation of preclerkship procedural skills curricula, it most certainly is the responsibility of the preclerkship curriculum to prepare students for an optimal learning experience as clerks and beyond.[6] Despite a consensus on the value of ultrasound, the timing and degree to which ultrasound use should be taught to medical students has not been universally accepted.[7] We believe that simulation-based procedural skill laboratories are excellent opportunities to introduce basic concepts of ultrasound. Several authors have demonstrated that early exposure to ultrasound leads to improved understanding of the interplay between anatomy and physiology, improved physical examination skills, and enhanced overall basic science knowledge.[1,2,4,8,9] Additionally, early ultrasound exposure coupled with a longitudinal learning experience has been shown to optimize skill development and retention, as well as foster an interest in advanced ultrasound training.[10,11]

As medical schools look to offer structured universal ultrasound education to their students, several obstacles seem to persist. Administrators have cited crowded curricular schedules as their number one perceived barrier.[2] A lack of sufficient qualified instructors required to scale up training for an entire medical school class and financial concerns have also been raised as issues.[12,13]

To address these gaps, we evaluated the integration of a low-cost introductory ultrasound curriculum into the existing procedural skills program at the Stony Brook University School of Medicine. After developing inexpensive gelatin-based ultrasound phantoms from common food items, we taught and evaluated the development of basic ultrasound scanning techniques in preclinical medical students. Our curriculum was designed to be efficient in the use of student and faculty time by minimizing required ultrasound equipment and using inexpensive, easy-to-prepare phantoms.

Materials and Methods

Design

We conducted a retrospective analysis of anonymous student assessments and surveys collected as part of an evaluation of our ultrasound curriculum and effectiveness of our homemade gelatin-based phantoms. The Stony Brook University Institutional Review Board reviewed this study and determined that it did not meet the definition of human subject testing. As such, Institutional Review Board approval was not required.

Settings and Participants

At the Stony Brook University School of Medicine, medical students participate in a mandatory procedural skills program comprising of four 2-hour-long practical skill classes, spaced through 12 months of the preclinical curriculum (Figure 1). For these classes, the 140 medical students were divided into 3 random groups to facilitate small-group learning and decrease needed faculty and equipment. Each class was repeated 3 times to accommodate the full School of Medicine class. Instructional consistency was ensured by having the same ultrasound educators present for each session of the class. At each ultrasound skill station, students received approximately 5 minutes of individualized learning with an instructor, facilitated by a dedicated ultrasound machine and phantom. Students were also encouraged to observe the performance and instruction of classmates, allowing for additional passive learning of image recognition.

All students in the graduating class of 2018 were involved in this study, as it evaluated a new component of their required procedural skills curriculum (n = 140). However, not all students participated in each session because of excused absences, resulting in variable sample sizes across the sessions (first class, n = 106; second class, n = 125; third class, n = 126; and fourth class, n = 121). Data were collected without any identifying information; therefore, we were unable to link data from each class or from the student surveys to an individual student. Thus, the data were analyzed as independent samples rather than paired samples. Percent scores were used to standardize reporting across groups to make values comparable.

Equipment

Four ultrasound machines (M7; Mindray North America, Mahwah, NJ) were available during each class. Linear 7.5-MHz ultrasound transducers (7L4s; Mindray North America) were used during the practice and assessment scans.

Figure 1. Timeline of ultrasound procedural skills education. First class: scan large gelatin phantom, and then tally types of hidden objects. Second class: learn in-plane and out-of-plane concepts by using ultrasound to find and puncture hidden objects in the muffin phantom, and then scan and tally types of hidden objects in the gelatin phantom. Third class: appreciate variable vessel compressibility in the vascular phantom, and then scan the gelatin phantom with 6 objects, identifying the type of object and location on a grid. Fourth class: scan the phantom with an unknown number of objects, identifying the type of object and location on a grid.

Month of Medical School											
1	2	3	4	5	6	7	8	9	10	11	12
								1st Class	2nd Class		
13	14	15	16	17	18	19	20	21	22	23	24
		3rd Class	4th Class								

Ultrasound Phantoms

Several trials of gelatin density (P. Seidman, unpublished data, 2013) determined that 2.5 cups of water, 2 envelopes of unflavored gelatin (Knox; Kraft Foods, Northfield, IL), 2 boxes of black cherry gelatin (Jell-O; Kraft Foods), and 2 boxes of berry blue gelatin (Jell-O) constituted the optimal ratio that allowed for a phantom medium that was firm enough to withstand ultrasound transducer and mimic tissue density and opaque enough to prevent students from visually identifying objects hidden within the phantom.

Large gelatin phantoms were constructed with disposable 28-oz plastic containers. Various ratios of grapes, pitted olives, and pimento olives were hidden within the phantoms (Figure 2), which were used for training and as the standard assessment format during the 4 classes. Muffin phantoms were constructed with disposable muffin trays, with each muffin cup containing a pitted olive, a pimento olive, and a grape. Vascular phantoms were developed with gelatin and generic wound drains to mimic the relative compressibility of arteries and veins.

Figure 2. Large gelatin phantom containing grapes, olives, and pimento olives before and after the gelatin medium was added.

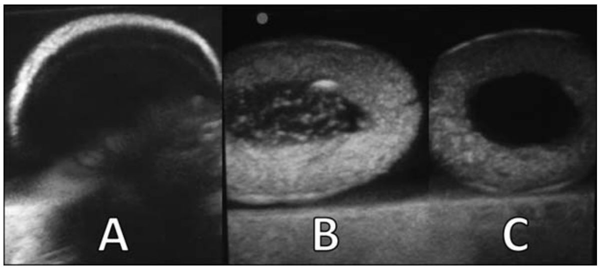
Curriculum

Before the start of their mandatory procedural skills sessions, students were provided with a link to a 5-minute video created by 2 of the authors (N.T. and M.T.), introducing the fundamentals of ultrasound, including basic physics and simple ultrasound scanning techniques.[14] Progressive refinement of phantom-scanning and object identification skills was encouraged during the 4 ultrasound classes by varying the objectives of the timed assessment scans performed at the end of each class.

During their first class, students were taught basic scanning techniques using a large gelatin phantom with a total of 6 hidden pitted olives, pimento olives, and grapes. At least 1 of each type of object was contained in each phantom. Students learned how to identify the sonographic appearance of each of the 3 objects through observation, correction by instructors and repetition (Figure 3). At the end of the class, students were given 90 seconds to scan a new unknown large gelatin phantom and tally the number of pitted olives, pimento olives, and grapes present. Additionally, students completed a survey about their prior experience and satisfaction with the class (Table 1). In addition to the ultrasound station, students also rotated through stations involving informed consent, procedural timeout, sterile glove sizing, and donning of sterile gowns.

During the second class, students were given an individual muffin phantom and a 22-gauge spinal needle. They were instructed on in-plane and out-of-plane

Figure 3. Ultrasound images of a grape (**A**), pimento olive (**B**), and pitted olive (**C**).



concepts of ultrasound-facilitated needle guidance as they used these techniques to identify and then puncture the hidden objects using the spinal needle. At the end of the class, students were given 90 seconds to scan an unknown large gelatin phantom and again tally the number of pitted olives, pimento olives, and grapes present. In addition to the ultrasound station, students also rotated through stations involving Foley catheter placement (male and female), endotracheal intubation, and nasogastric and orogastric tube insertion.

During the third class, students scanned phantoms containing simulated arteries and veins and learned to differentiate them via ultrasound by considering their relative compressibility. At the end of the class, students were given 90 seconds to scan an unknown large gelatin phantom containing a total of 6 pitted olives, pimento olives, and grapes. For this assessment, they were required to both identify and indicate the location of each of the 6 objects on a grid. After the class, students completed a second survey about their skill session experience (Table 1). In addition to the ultrasound station, students also rotated through stations involving peripheral intravenous cannulation and intravascular and intramuscular injections.

During the fourth and final class, students were given 90 seconds to scan a large gelatin phantom containing an unknown number of hidden pitted olives, pimento olives, and grapes, with at least 1 of each object type present, and were tasked with identifying the objects and indicating their location on a grid. In addition to the ultrasound station, students also rotated through stations involving knee aspirations, lumbar punctures, and arterial blood gas sampling.

Data Analysis

Quantitative survey data were analyzed with descriptive statistics. Data are presented as mean and standard deviation unless otherwise indicated. χ^2 testing was performed on categorical survey and scan data, with $P < .05$ for significance. All statistical analysis was performed with SPSS Statistics Standard GradPack 22 (IBM Corporation, Armonk, NY).

Results

Student Surveys

On the student survey from the first class, 77.5% of students indicated that they had used ultrasound before the procedural skills class (Table 1). On a scale of 1 to 10, with a score of 10 as "very useful," students highly rated the precourse introductory video, time spent in the first class, and vascular phantom.

After several ultrasound classes, there was a statistically significant improvement in students' self-reported

Table 1. Results of Student Surveys

Question	Survey After 1st Class	Survey After 3rd Class	Comments
On a scale of 1–10, what was the usefulness of the precourse video? (10 = very useful)	7.8 ± 2.5		
Before this class, had you used ultrasound?	Yes: 78 No: 22		
On a scale of 1–10, how useful was the time spent in the ultrasound procedural skills lab? (10 = very useful)	8.3 ± 1.5		
On a scale of 1–10, how useful was the time spent using the vascular phantom? (10 = very useful)		8.7 ± 1.6	
I understand what in plane and out of plane means.	Yes: 65 No: 35	Yes: 82 No: 18	$\chi^2 = 8.334$ $P = .004$
Could you identify a grape?	Yes: 98 No: 2	Yes: 98 No: 2	
Could you identify a pitted olive?	Yes: 95 No: 5	Yes: 90 No: 10	
Could you identify a pimento olive?	Yes: 96 No: 4	Yes: 84 No: 16	$\chi^2 = 8.667$ $P = .003$
Is a basic understanding of ultrasound important?	Yes: 97 No: 3	Yes: 100 No: 0	
Was 90 s enough time to complete the timed scan?	Yes: 72 No: 28	Yes: 96 No: 4	$\chi^2 = 26.327$ $P < .001$

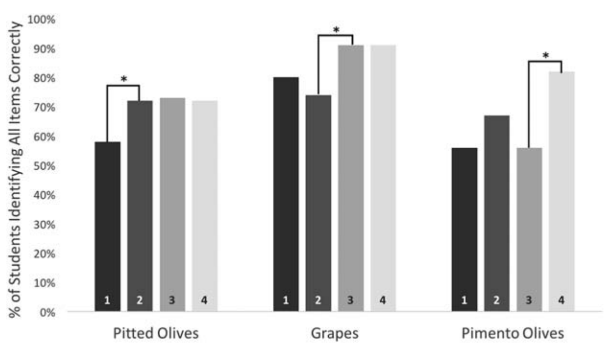
Surveys were collected after the first and third ultrasound classes. Data are presented as mean ± SD and percent where applicable.

understanding of in-plane and out-of-plane concepts, as well as in their opinion that 90 seconds was sufficient time to complete the large gelatin phantom assessment scan. There was a statistically significant decline in their perceived ability to correctly identify a pimento olive with ultrasound. There was no significant improvement in their self-reported ability to recognize a grape or pitted olive with ultrasound. Additionally, there was no significant improvement in their opinion on the importance of an ultrasound education, likely owing to the very high agreement rates on both surveys.

Timed Large Gelatin Phantom Assessment Scans

After 2 ultrasound classes, students had a statistically significant increase in the ability to correctly identify pitted olives. After 3 classes, students had a statistically significant improvement in identifying grapes. After 4 classes, students had a statistically significant improvement in identification of pimento olives. (Figure 4 and Table 2).

Figure 4. Timed large gelatin phantom assessment scan results. Values at the bottom of the columns indicate from which class the data were collected. *Statistically significant change from the previous time point ($P < .05$).



Cost

The cost per student (n = 120) for phantom supplies for the entire curriculum was $0.76.

Discussion

We designed and evaluated the addition of an ultrasound laboratory station using low-cost homemade gelatin-based ultrasound phantoms into our existing procedural skills educational curriculum for preclinical medical students. The primary finding of this retrospective analysis of student survey and student assessment results was that short, simple, repeated experiences performing ultrasound scans can lead to a statistically significant improvement in preclinical medical students' ability to find and correctly identify objects using ultrasound. During each class, students used ultrasound to identify grapes, pitted olives, and pimento olives. Interestingly, each object reached a statistically significant improvement in identification at different time points. We suspect that from the first to second class, students were able to locate pitted olives with greater ease, owing to their thick walls, which sharply contrasted with the surrounding gelatin media, therefore leading to a statistically significant improvement in identification. From the second to third class, there was a significant increase in the ability to find and recognize grapes. This finding might be attributed to their thin, crescent appearance on ultrasound imaging. We postulate that finding the grapes required an improved scanning technique, as once located, its resemblance is completely unlike the other 2 objects. Finally, from the third to fourth class, students improved their ability to both locate and successfully identify the pimento olives. Students seemed to have the most difficulty differentiating between a pitted olive and a pimento olive, suggesting that repeated experiences are necessary for successful differentiation between structures with similar or

Table 2. Results of the Large Gelatin Phantom Assessment Scans From the 4 Ultrasound Procedural Skills Classes

Group	1st Class (n = 106)	2nd Class (n = 125)	3rd Class (n = 126)	4th Class (n = 121)	Comments
Students who correctly identified all grapes, %	80	74	91[a]	91	[a]Improvement from prior class ($\chi^2 = 11.218$; $P = .001$)
Students who correctly identified all pitted olives, %	58	72[a]	73	72	[a]Improvement from prior class ($\chi^2 = 4.652$; $P = .031$)
Students who correctly identified all pimento olives, %	56	67	56	82[a]	[a]Improvement from prior class ($\chi^2 = 17.153$; $P < .001$)

shared ultrasound characteristics. Interestingly, from the first to third class, students had a decrease in their self-assessed ability to recognize a pimento olive, perhaps suggesting that as students became more proficient in their skill, they were less likely to overestimate their competency.[15] It could be argued that this change represents improved self-awareness, a mark of professional development.

Grapes, pitted olives, and pimento olives were selected because of their ability to be punctured by a needle and for their sonographic similarities to a gallstone, vascular thrombosis, or lymph node and an unobstructed vessel or abscess, respectively. In addition, their low cost and universal availability make them easy to incorporate into any ultrasound education phantom. The clinical relevance within the simulation not only addressed adult learning theory but also highlighted the importance of deliberate practice when developing a skill requiring psychomotor competence to render an appropriate diagnosis or perform a safe intervention.

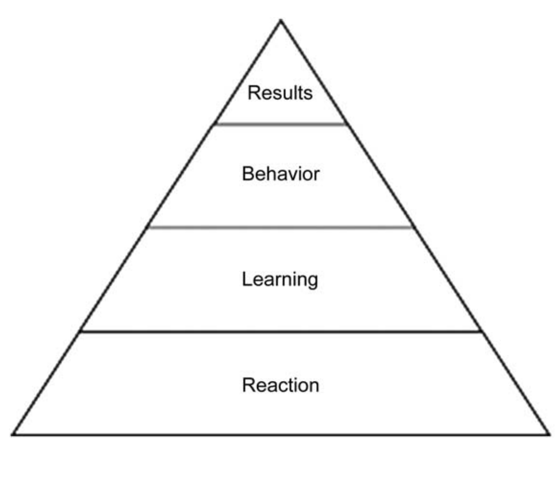
We believe that the significant increase in agreement that 90 seconds was enough time to perform the assessment scan from the first to the third class, coupled with the improvement in overall object identification, further supports the use of deliberate practice in a simulation-based skill laboratory to foster skill efficiency.[16] Furthermore, by reviewing data collected from an identical first exposure to ultrasound and large gelatin phantom assessment scan in the graduating class before the current one, we determined that prior ultrasound experience has no notable association with the score achieved on the first phantom assessment scan.[17] Students who participated in this study indicated that most of their prior experience with ultrasound occurred during their anatomy class on cadavers; however, the educational format for this historical training was not clarified. This finding suggests that prior educational exposure, in the absence of structured deliberate practice in a controlled environment, does not always facilitate learning.

In keeping with the Kirkpatrick 4-stage model of evaluation (Figure 5),[18,19] we found students to have a high opinion of the value of the precourse material, as well as their time spent at the ultrasound procedural skill station. In addition to the objectively demonstrated improvement in their scanning skills and identification of hidden objects, students reported a significant increase in their understanding of in-plane and out-of-plane concepts. Their ability to show significant improvement in locating and identifying hidden objects, despite increasingly complex assessment scans, is likely indicative of their application of improving knowledge and skills, thus reaching Kirkpatrick level 3. It should be noted that the 4 classes were unevenly dispersed across 12 months, in accordance with the existing procedural skills curricular timeline; there was 1 month between the first and second classes, 4 months (summer break) between the second and third classes, and a final month between the third and fourth classes. Although there were intermittent drops in correct identification of objects during the 4 classes, there was an overall positive improvement in identification despite the variable time between classes and increasingly difficult assessments.

Finally, we believe that we were successful in developing a curriculum that was cost-effective, mindful of students' limited time, and frugal in required faculty and equipment resources. During the classes, each student received approximately 5 minutes of individualized instruction. All 4 classes used 90-second assessment scans, during which each student was evaluated and supervised by an expert faculty member. Although each class was run 3 times to accommodate a total of approximately 120 students, only 4 ultrasound machines and 3 or 4 faculty members were required for the 24 hours of instruction time required to offer the full curriculum to all students. Furthermore, the cost of phantom supplies for the entire 4-class experience was found to be $0.76 per student.

The most important limitation to this study was that the experience of only a single cohort was assessed.

Figure 5. The Kirkpatrick pyramid, a model for educators to objectively evaluate training programs.



Furthermore, as this curriculum was integrated into a preexisting procedural skills program with the time and resources already allotted, we collected anonymous data to use as part of curriculum assessment; thus, it was not possible to track individual student performance. Finally, no true "human" scans were used, only gelatin phantoms, although it was thought that this approach would allow the students to focus instead on proper scanning and needling techniques.

As physician use of ultrasound has become ubiquitous across medicine, there is a need for a time- and resource-savvy introductory ultrasound curriculum for preclinical medical students. We have designed, implemented, and evaluated a procedural skill laboratory station using homemade ultrasound phantoms, which was incorporated into our existing longitudinal procedural skills educational curriculum. In doing so, we found that repeated experiences scanning simple, low-cost gelatin-based ultrasound phantoms aids in the development and assessment of basic ultrasound skills.

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