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TAKE NOTICE: TECHNOLOGY

Development of a Homemade Spinal Model for Simulation to Teach Ultrasound Guidance for Lumbar Puncture

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Abstract

Background: Spinal procedures such as lumbar punctures (LPs), epidurals, and spinal blocks are essential components to clinical practice but are challenging to teach, learn, or practice on real patients due to patient safety and comfort limiting the number of attempts. Resident physicians traditionally learn these spinal procedural skills through observation of a more senior physician before attempting the procedure. Simulation using models can improve providers' competency without introducing an added risk to patients. A difficulty encountered with access to simulation training for such procedures is the limited availability of simulators. While there are several high-quality, commercially available models that mimic the anatomy of lumbar spine, the cost of these models often limits the access to students and practitioners. The other challenge is access to simulators with versatility that can be used for palpation as well as ultrasound (US)-guided procedures. A simulator that can combine practice of both palpation and US-guided modalities would be efficacious in reducing cost to the teaching institutions. We attempted to overcome the access barrier to spinal models by developing an alternative that provides a good simulator for both palpation and US-guided LP while keeping the cost low. Our model can be easily manufactured by not only clinicians but also medical students.

Methods: A literature review was conducted to assess the available research and information on the production and use of simulators for practicing LPs and other spinal procedures. Publications queried described the production of models and utilizing the information compiled we devised and fabricated a model.

Results: A lumbar spine model was developed using computed tomography spine data of an average-sized male patient without lumbar spine pathology. The model was created using medical imaging processing software and printed on 3D printer using nylon plastic. This model was then utilized by residents, advanced practice providers, and medical students for palpation and US-guided LP simulation training.

Conclusions: An inexpensive reusable non-commercial LP simulator can be an effective method for teaching invasive procedures like LPs, especially if it can be used both for palpation and US-guided procedures. The method outlined here can be easily reproduced in a relatively short amount of time. We recognize one limitation in the widespread dissemination of this technique being access to a 3D printer and digital designs for printing. Future studies will be necessary to determine the efficacy of the homemade LP simulator in teaching neurointensivist in training.

Keywords: Lumbar puncture, Ultrasonography, Education, Simulation training, Phantoms, Imaging, Point-of-care systems, Models, Anatomic

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Introduction

Spinal procedures such as lumbar punctures (LPs) are essential components to clinical practice but are challenging to teach, learn, or practice on real patients due to patient safety and comfort limiting the number of attempts. Simulators can be of extreme help in these high-risk/high-stake procedures. Resident physicians traditionally learn LP skills through observation of a more senior physician before attempting the procedure on their own on patients. This observational learning does not ensure competency in procedural skills [1]. An LP simulator allows students, residents, and attending physicians to practice their technique in an environment that simulates human anatomy without subjecting a patient to undue discomfort. Residents who completed a 3-h session of simulation-based learning performed significantly better on a skill assessment for LPs than residents who were traditionally trained [2]. Simulation using models can improve providers' competency in such invasive procedures without introducing an added risk to patients.

Availability of simulators due to cost of acquisition and maintenance may be a factor in limiting frequent and easy access to simulation training. Recent data show 53% of medical schools using LP simulator(s) in practice during student clerkships; an increase from 44% in 2012 [3, 4]. We polled neurology clerkship directors using available electronic mailing lists with eighteen respondents. Of those, seventeen stated that at least one simulator was available at their institution for use. At our institution, there are currently five commercial-grade LP simulators available for training. While there are several high-quality, commercially available models that mimic the anatomy of lumbar spine, the cost of these models is not insignificant. One LP and spinal epidural model (Blue Phantom™, CAE Healthcare, Inc., Sarasota, Florida, USA) costs around $4000, with replacement tissue of the lumbar region costing $1610 [5]. Another commercially available simulator (M43B Lumbar Puncture Simulator II™, Kyoto Kagaku Company, LTD, Kyoto, Japan) costs $2150 and can only have 30 punctures performed per vertebral space before it needs to be replaced [6]. There is emerging interest in crafting non-commercial simulators for training of various spinal interventions [7–12]. These non-commercial models are relatively inexpensive compared to available commercial products, costing between $25 and $680 to manufacture, and can be easily remanufactured or repaired.

Intensivists have long utilized ultrasound (US) as a visual guidance tool in various procedures. US guidance can provide better success and prevent repetitive attempts in high-risk patients, e.g., patients with scoliosis, obesity, limited spine mobility, or a high risk of bleeding [13]. Training in this technique is gaining popularity, since it improves the success of a LP without the added risk of radiation associated with fluoroscopy and the convenience of around the clock bedside availability. Mastery of US-guided LP requires learning the distinct skill of using an US machine and learning to interpret landmarks. Simulators used to teach US guidance require an appropriate gel-based medium to reproduce the US appearance of tissue [14] that may lack the capability to reproduce the palpation quality of soft tissue [10]. A versatile simulator that can combine training of both palpation and US-guided modalities would be efficacious in reducing the cost to teaching institutions and by improving access. Currently, there are eight mannequin-based simulators available commercially that allow practice of lumbar spinal procedures and four are US compatible [15].

While the use of simulators can improve skills by allowing multiple repetitions, one underutilized indication is to practice the same procedure with difficult anatomy, where the success of an LP is diminished due to an inability to accurately identify landmarks. US guidance has improved the success rate for LPs in patients with difficult anatomy by allowing identification of landmarks, reducing the number of needed attempts, and decreasing complication rates [16]. This benefit is most evident in patients with indistinguishable surface anatomic landmarks, i.e., obese or post-spinal surgery, or altered spinal anatomy, i.e., scoliosis or elderly [17]. Currently, only three commercial simulators have the ability, with an additional cost of purchasing the wanted spine model, to simulate obese and geriatric patients, and none have the capability to simulate spine pathologies [15]. Customizable spine models through 3D printing increase proficiency in trainees when a patient-specific model is utilized as a trainer [18], but the potential benefit in difficult patient anatomy has yet to be investigated.

We present our experience with making an inexpensive, versatile LP model that allows for palpation and US-guided LP, as well as customization to simulate difficult anatomy using 3D printing technology with detailed instructions to allow reproducibility by other centers. This model has proven to be durable, inexpensive to create and maintain, easy to repair, and easy to transport across air travel.

Methods

A literature review was conducted to assess the available research on the production and use of simulators for practicing LPs. The PubMed search includes the terms "ultrasound," "training model," "lumbar puncture," "spinal tap," "epidural," "phantom." This search yielded sixteen articles with four articles containing detailed instructions on simulator production [11, 12, 19, 20]. These publications described the production of models using mediums

of gelatin, silicon, and agar, with psyllium fiber as opacifying agents. Utilizing the information and challenges compiled from review, we devised and fabricated a model using ballistic gel (Clear Ballistics, Greenville, SC) and a 3D-printed spine.

A spinal model was created from the lumbosacral spine computed tomography (CT) scan of an average size male cadaver without lumbar spine pathology. A digital design was created using Mimics software (Materialise, Leuven, Belgium) and exported as an ".stl" file. The digital design was created by using the automatic bone thresholding setting within the software. This thresholding highlighted cortical bone on each slice of the CT. A 3D digital design was automatically constructed in the software using their construction algorithms that integrate voxel height measurements. Additional supports were added between the mid-point of the vertebral body endplates, so they maintained their relative orientation in the model without adding the spinal ligaments. The inclusion of plastic ligaments would have occluded the spinal canal.

Our digital design was prepared for printing using the CubePro (3D Systems, Rock Hill, SC) software and printed on a CubePro Duo 3D printer using nylon. To maintain the anatomy, structural supports were manually added following bone segmentation. These supports were cylinders placed in the intervertebral disk space to keep the posterior aspect of the spinal column clear for practicing LP techniques. We have tested both nylon and acrylonitrile butadiene styrene plastic and both materials have maintained their shape following immersion in hot ballistic gel; however, the biomechanical properties of the model were not assessed. These materials are standard filaments that can be used with this printer model. The model's external shell thickness mirrored the vertebral body cortical thickness. The percent infill of the cancellous bone was set to a layer resolution of "200 um," print strength of "strong," and print pattern of "cross" in the printer interface (CubePro, 3D systems, Rock Hill, SC).

Latex tubing (9 mm) connected to a fluid reservoir (500 ml normal saline bag) was inserted into the spinal canal of the printed model to simulate the cerebrospinal fluid (CSF) reservoir and lamina propria (Fig. 1). A repurposed ballistic gel block was utilized as the medium to house the printed model, simulating soft tissue. The block was heated at 132 °C (270 °F) over a 2–4 h period until all the bubbles had disappeared. The nylon plastic spinal model was positioned into the gel and left to set. This process resulted in a rectangular shaped, transparent ballistic block with a nylon spinal model suspended inside (Fig. 2) with a hollow latex tube extending out from each side. A homemade wooden frame was created to house the model in a lateral decubitus position. The resulting model was covered in duct tape to conceal anatomic structures of the spinal model yielding palpable anatomy but still visible by US (Fig. 3). Another model was created and left free of tape to allow for direct visualization during practice.

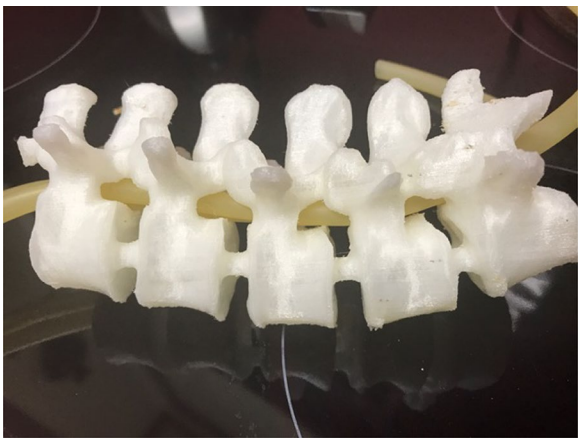

Fig. 1 Spinal model with latex tubing and CSF reservoir

These models were then utilized by residents, fellows, advanced practice providers, and medical students for palpation and US-guided LP simulation training. Training involved a half-day session led by neurology faculty and residents. Various case scenarios were presented to the trainees who were then asked to perform supervised LPs on the models. Feedback was collected after using the model using a survey modified from previous works [2, 6, 21, 22].

A heat gun was used to melt the gel after multiple attempts rendering the surface smooth and allowing the model to be recycled without much effort. To remanufacture the model, the gel from around the spine can be removed by hand easily. The gel is melted following the above instructions and the model can be reconstructed from the same components. To date, we have not needed to remanufacture the model due to ease of repair.

Results

Our LP models proved to be inexpensive, customizable, and versatile simulators that allowed for palpation and US-guided LPs and the capability to simulate difficult anatomy. In addition, they have turned out to be inexpensive to maintain and repair while being durable over innumerable practice attempts without compromising the experience over 1.5 years.

The production costs for the model totaled $25–30 for materials excluding the price of the 3D printer, which was available and being used regularly in our institute for other indications. The preparation time included printing of the lumbar spine model (30–60 min), heating of the gel medium in a portable oven (2–4 h, with intermittent checking only), assembly of the model in the molten

Fig. 2 LP simulator after placement of spinal model and setting overnight

Fig. 3 Completed LP model before and after concealment. Latex tubing inserted within the spine model at the site of spinal canal was connected to a fluid reservoir (500 ml normal saline bag) to simulate the cerebrospinal fluid (CSF) reservoir. The height of the reservoirs can be adjusted to simulate different opening pressure. The "give" of the latex tubing simulates the "give" experiences in real-life LPs

ballistic gel (10 min), overnight cooling and setting (10–12 h), preparation of the wooden frame (1 h), and mounting and preparation for use and display (10 min). Two LP simulator models were created in parallel through this process.

The US images produced by insonating this model with a 5–15 MHz linear probe were very similar and reflective of the bony landmarks used to practice US guidance for LPs (Fig. 4).

The completed LP simulator was then utilized for free by various advanced practice providers, fellows, and residents for US-guided and palpation LP training in various workshops, as well as on an ad hoc basis (Fig. 5). Post-training feedback was obtained from some of the trainees during scheduled LP laboratories (Fig. 6). A majority of respondents agreed that our simulator was easy to use, felt and looked realistic during palpation and US, and would be useful in the teaching and assessment of LPs. Comments for improvement included the request for additional models (i.e., pediatric) for future workshops, and to improve the wooden holders to increase stability during palpation. The results of the survey are presented in Table 1.

Discussion

A non-commercial inexpensive, reusable, versatile LP simulator can be an effective method for teaching invasive procedures like LPs. The method outlined here, using a portable oven, a 3D printed spinal column, latex tubing, and a ballistic gel block mounted on a wooden frame, can be easily fabricated in a short amount of time by clinicians or medical students and provides an incremental improvement on previously described models. It introduces the possibility of producing a large number of models at a reasonable inexpensive cost to create and maintain. Utilizing 3D printing technology also allows for various models to be created representing difficult anatomy for specific pathologies, body habitus, or age and gender groups, as required.

Many publications have used materials like gelatin and silicone in making simulators. Our use of ballistic gel in making an LP phantom has the advantage of increased durability and a more realistic palpation experience, when compared to gelatin, while retaining echogenicity. Silicone can match the durability and palpation fidelity but is generally impenetrable to clinical US and has a tendency to break down with repeated use. Other drawbacks of gelatin include the need to be refrigerated and a limited shelf life. Ballistic gel is available commercially at reasonable costs from many online sources [23–26].

Custom non-commercial phantoms can be a great resource for training programs, like medical schools, residency programs, and physician assistant and nurse practitioner training programs, to expand access to a greater number of models that are durable over time and easy to repair. This would facilitate the practice of procedural skills to improve competency and provider confidence. An added benefit of a non-commercial model is that commercial models are typically fabricated from rubber and have the potential to grow mold due to water exposure when simulating CSF, in which case the parts must be replaced at a reasonable cost. Non-commercial simulators using ballistic gel also have a significant advantage in model durability as they can be repaired by using a heat gun to melt the gel around the needle tracks or

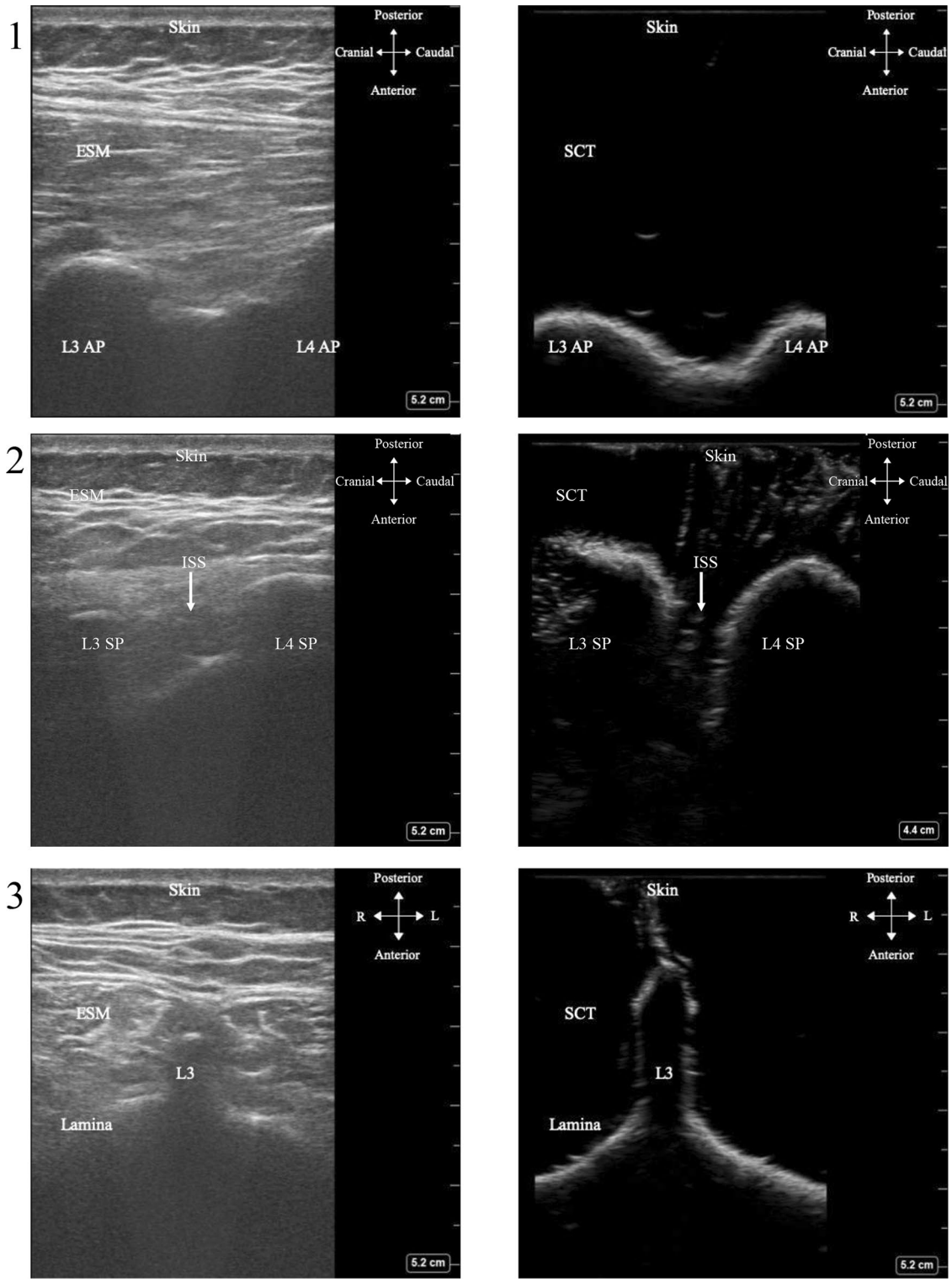

Fig. 4 Parasagittal (1), sagittal (2), and transverse (3) b-mode ultrasound images of adult spine in healthy adult female (left) compared to simulator (right); *AP* articulating process, *ESM* Erector Spinae muscles, *ISS* interspinous space, *SCT* subcutaneous tissue, *SP* spinous process

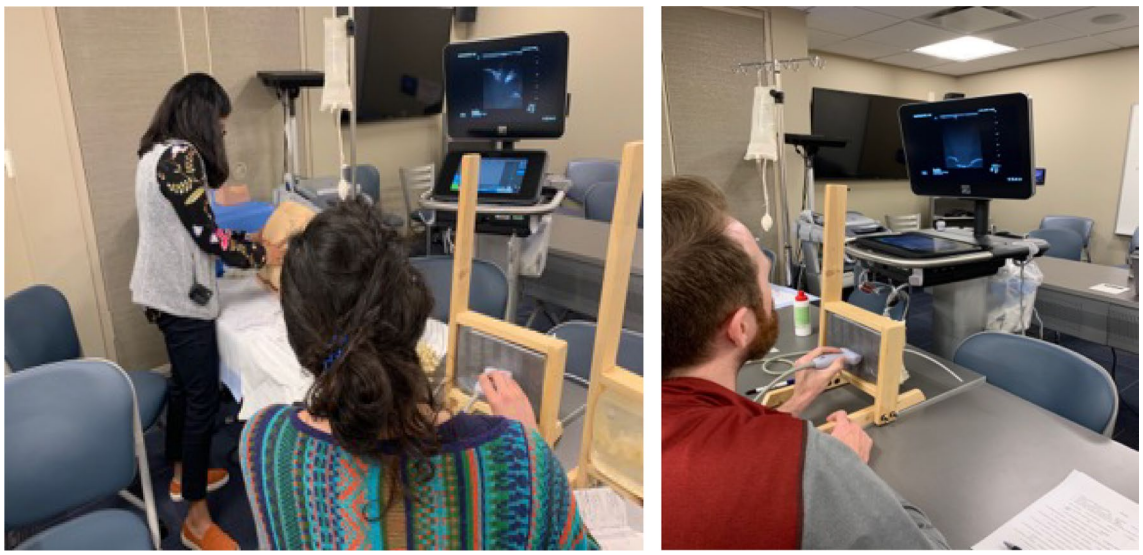

Fig. 5 Simulators in use during workshop

recycled by using the same gel and creating a new model from the same components without added cost.

Many current LP simulators do not have US capabilities. Our simulator proved to be suitable for training in two modalities eliminating the need for multiple distinct trainers and further decreasing the costs for this simulator for our institution.

We recognize one limitation in the widespread dissemination of this technique may be familiarity with 3D printing technology, access to 3D printers, or the availability of anatomically correct digital designs for 3D printing. This is changing with readily accessible sources online [27–29] to familiarize with 3D printing. Many 3D printers are now available for home use ($300) [30] or accessible through biomedical engineering departments for research and clinical use in many medical centers. Several programs like Mimics (Materialise, Leuven, Belgium), 3D Slicer, and InVesalius can produce a 3D digital design from a DICOM image set. Commercial software, like the one used in this paper, can carry a cost of at least $7000, depending on included features in the software package, as well as an annual fee of $900 for maintenance and updates [31]. To avoid this cost, we have used similar open-source software like Slic3r and Cura (Ultimaker, Geldermalsen, The Netherlands) to print other generic anatomical models [32–34]. We were fortunate to be able to work with a collaborator that could provide the software at no extra cost to our non-commercial model fabrication free and open-source collections of digital anatomical designs are currently available and include detailed models of most human body parts [27, 32–36].

We also explored an innovative resource for future 3D printed models. We collaborated with a local biomedical engineering faculty who fabricates 3D printed spines for her research project. There may be an inherent error in the segmentation and printing of models that renders a given printed model imperfect for an advanced research project, like one being done by our collaborator. All such rejected samples were given to us for use in making more simulators, thus providing a recurrent source of unusable models. This error is inconsequential for our purposes because our application is for a general model of the spine for practicing LP.

Conclusions

Future studies are necessary to determine the efficacy of the non-commercial LP simulator in comparison with commercial models or traditional teaching techniques. The learner experience in our settings seems to be reasonably high due to the relative access and number of attempts provided by a low-cost reusable simulator that can be used both for palpation and US-guided LP. In an ideal setting, training programs that can afford commercial stimulators for procedural training should have access to multiple, multipurpose simulators that showcase several patient pathologies with the capability for procedural modification, such as US guidance. For programs or educators where financial stewardship does

Subject Number: ____

Pretest

1. What is your level of training?
   Student Resident APP Attending Other _____
2. How many LPs have you observed? _____
3. How many LPs have you performed? _____
4. What is your confidence that you can successfully perform an LP?

1 Very anxious 2 Some anxiety 3 Neutral 4 Confident 5 Very Confident

5. Have you ever used an LP simulator before?
   Yes No

Posttest

1. Is the homemade simulator easy to use?

1 Completely Disagree 2 Slightly Disagree 3 Neutral 4 Slightly Agree 5 Completely Agree

2. Does palpation of the bone in the homemade simulator feel realistic?

1 Completely Disagree 2 Slightly Disagree 3 Neutral 4 Slightly Agree 5 Completely Agree

3. Does the homemade simulator look realistic under ultrasound?

1 Completely Disagree 2 Slightly Disagree 3 Neutral 4 Slightly Agree 5 Completely Agree

4. Is the simulator useful for assessment of LP competency?

1 Completely Disagree 2 Slightly Disagree 3 Neutral 4 Slightly Agree 5 Completely Agree

5. Would practicing with the homemade simulator improve your confidence in performing LPs?

1 Completely Disagree 2 Slightly Disagree 3 Neutral 4 Slightly Agree 5 Completely Agree

6. Comments / suggestions for improvements
   _____
   _____
7. What did you like about this simulator?
   _____
   _____
8. What did you not like about this simulator?
   _____
   _____

Fig. 6 Survey given during workshops. A total of nine people attended the workshop and nine returned completed surveys

Table 1 Summary of results from survey

Respondent	Pretest					Posttest				
	Q1	Q2	Q3	Q4	Q5	Q1	Q2	Q3	Q4	Q5
1	APP	5	< 30	2	1	5	4	5	4	5
2	Fellow	20	< 30	3	0	5	5	5	5	5
3	Fellow	20	> 30	5	1	5	5	5	4	5
4	Resident	20	< 30	4	1	5	4	3	5	4
5	Resident	10	< 30	2	1	5	5	5	5	5
6	Resident	10	< 30	4	1	5	5	5	5	5
7	Resident	2	< 30	1	0	5	4	5	5	4
8	APP	6	< 30	1	0	5	5	5	5	5
9	Resident	2	< 30	2	0	4	4	4	4	5
	Average	10.56		2.67	5.00	4.89	4.56	4.67	4.67	4.78

APP advanced practice provider

not allow such access or only allows limited access, non-commercial simulators using inexpensive resources and innovative collaboration can help provide a useful and invaluable educational resource.

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Author contributions
All authors listed were responsible for contributions to conception of the project and implementation of the model, drafting the article or revising it critically, and approved the final manuscript to be published.

Source of support
There was no support for this work.

Conflicts of Interest
The authors declare that they have no conflicts of interest.

Ethical approval/informed consent
During the course of this work, there was strict adherence to ethical guidelines. Informed consent was obtain from all survey respondants following insitutional guidelines.

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