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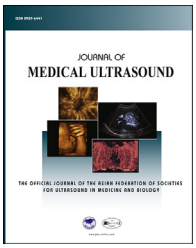

ORIGINAL ARTICLE

Validation of a Low-cost Optic Nerve Sheath Ultrasound Phantom: An Educational Tool

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Abstract *Objective:* To validate an ocular phantom as a realistic educational tool utilizing *in vivo* and phantom optic nerve sheath (ONS) images obtained by ultrasound.
Methods: This prospective study enrolled 51 resident physicians from the Denver Health Residency in Emergency Medicine (EM) and 10 ultrasound fellowship-trained EM attending physicians. Participants performed optic nerve sheath diameter (ONSD) measurements on five *in vivo* and five phantom ocular ultrasound images and rated the realism of each image on a 5-point Likert scale. Chi-square analysis was performed to evaluate the subjective "realness" of *in vivo* and phantom images.
Results: Sixty-one participants performed ONSD measurements. Mean Likert scale values were 3.43 (95% confidence interval: 3.31–3.55) for *in vivo* images and 3.41 (95% confidence interval: 3.28–3.54) for phantom images. There was no statistical difference in subjective "realness" between *in vivo* and phantom ONSD ultrasound images among EM residents. Ultrasound fellowship-trained EM attending physicians aptly differentiated between *in vivo* ($p < 0.01$) and phantom ($p < 0.01$) images, as compared with EM residents.
Conclusion: Our ocular phantom simulates *in vivo* posterior ocular anatomy. EM resident physicians found the phantom indistinguishable from *in vivo* images. Our ONS model provides an inexpensive and realistic educational tool to teach bedside ONSD sonography.

Conflicts of interest: The authors do not have any potential financial or nonfinancial conflicts of interest.

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Introduction

Ocular ultrasound is a very useful tool in the emergency department to diagnose a wide array of ocular and orbital pathology including vitreous hemorrhage, foreign body, and retinal detachment [1]. Ocular ultrasound of the optic nerve sheath diameter (ONSD) has been proposed as a useful screening tool for elevated intracranial pressure [2]. However, in order for emergency medicine (EM) physicians to safely use sonographic measurements of ONSD as a screening tool for elevated intracranial pressure, providers must first learn the technique in order to accurately and reliably measure the ONSD.

Simulation for ultrasound training is a useful tool in EM physician education [3]. Although performing ocular ultrasound on patient models is relatively safe, phantom models are convenient, easily accessible, and allow for prolonged scan time without endangering injury to the retina of patient models. Prior ocular models have focused on simulating vitreous hemorrhage, retinal detachment, and globe rupture [4]. *In vivo* tissue-based bovine and rabbit cadaveric eyes for ocular ultrasound may be cost-limiting. However, a low-cost realistic training tool that is indistinguishable from human anatomy to teach EM physicians to measure ONSD has not yet been developed or validated.

We developed a low cost, easily made phantom model that may assist with training and improve the quality of sonographic measurements of the ONSD. This study aims to: (1) provide a step-by-step description of producing a sonographic phantom of the posterior chamber of the eye; and (2) validate the model as a realistic educational tool utilizing *in vivo* and phantom ONS images obtained by ultrasound.

Materials and methods

Study design

This was a cross sectional study that recruited resident and ultrasound fellowship-trained EM physicians to evaluate still-frame sonograms of five separate ocular ultrasound phantom, and five separate adult eyes that included the retrobulbar optic nerve. This study received Colorado Multiple Institutional Review Board approval (protocol number 13-2134).

Participants

Ten ultrasound fellowship-trained EM physicians and 51 resident EM physicians in postgraduate years (PGY) 1—4 from a single residency were recruited for the study. The ultrasound fellowship-trained EM physicians included in this study completed residency and fellowship at four different institutions and had ultrasound experience ranging from recent EM graduates to >15 years postfellowship. Resident EM physicians had varying degrees of prior ultrasound training ranging from none to 2—3 weeks of general EM-related ultrasound training as part of their medical school or residency curriculum. Any resident or ultrasound fellowship-trained EM physician who was either directly involved with the project or who had previously seen any of the still-frame sonogram images were excluded. All physicians were enrolled using a convenience sample of available and willing volunteers. Informed consent was obtained from all subjects.

Phantom development

The ONS phantom is constructed utilizing the following: a 40-mm diameter ping-pong ball, assorted sizing of clear vinyl tubing, superglue or waterproof sealant, a drill with assorted bits, unflavored gelatin, sugar-free psyllium powder (e.g., Metamucil Sugar Free Dietary Fiber Supplment, Procter & Gamble, Cincinnati, USA), 18 gauge needle, 30 mL syringe, 473.176 mL plastic cups (e.g., Solo Plastic Party Cup, Dart Container Corporation, Mason, USA), and water (Figure 1A). To make the ONS portion of the model, a hole was drilled in the bottom of the disposable cup that matched the outer diameter of the clear vinyl tubing approximating the desired ONSD (for sizing, note that the outer diameter tends to correspond with sonographic ONSD). A section of tubing 7 cm long was cut. All but 2 mm of the tubing was inserted through the bottom of the cup and stabilized in a vertically plumb orientation in the middle of cup using a stylet (e.g., drill bit fixed with tape to brim of cup; Figure 2A). The tubing protruding from the bottom of the cup should be tight-fitting to ensure a tight seal, and its shallow profile allowed the cup to sit flush on the countertop (Figure 2B). This ONS portion was set aside.

The gelatinous matrix used to suspend our phantom eye and ONS was formed using a procedure described by Kendall and Faragher [5] by combining water, unflavored gelatin, and sugar-free Metamucil. Briefly, 250 mL water was boiled, then three packets of gelatin were gradually whisked over a medium heat until the gelatin was completely dissolved. Next, one tablespoon of Metamucil was added and whisked until it completely dissolved. With a spoon, the remaining bubbles were skimmed off. If clumps were present, a sieve was used to remove them. Lastly, this mixture was poured into the plastic cup with the ONS portion of the model. The cup was filled flush to the level of the upper vinyl tubing and placed in the refrigerator for 1—2 hours or until firm. Once the gelatin congealed, the stylet was removed.

To make the eye portion of the model, two small puncture holes 2 mm apart were made on the ping-pong ball with a straight needle and syringe. One hole was used to fill the ball with water until all the remaining air was displaced through the other hole. A small amount of waterproof sealant (e.g., Gorilla Super Glue, Gorilla Glue Company, Cincinnatti, USA; Loctite Stik'n Seal outdoor adhesive, Henkel, Rocky Hill, USA, etc.) was applied over the holes and allowed to cure.

To connect the ONS and eye portions of the model, a small portion of super glue adhesive was applied to the exposed cross section of tubing in the cup with the ONS and congealed gelatin. The cup was placed in the refrigerator and the ping-pong ball was carefully positioned atop the vinyl tubing (Figure 2C). This can be challenging when smaller diameter vinyl tubing is used, therefore, a clean, perfectly horizontal cut of tubing is key. A second batch of the gelatin—Metamucil mixture was made. The second

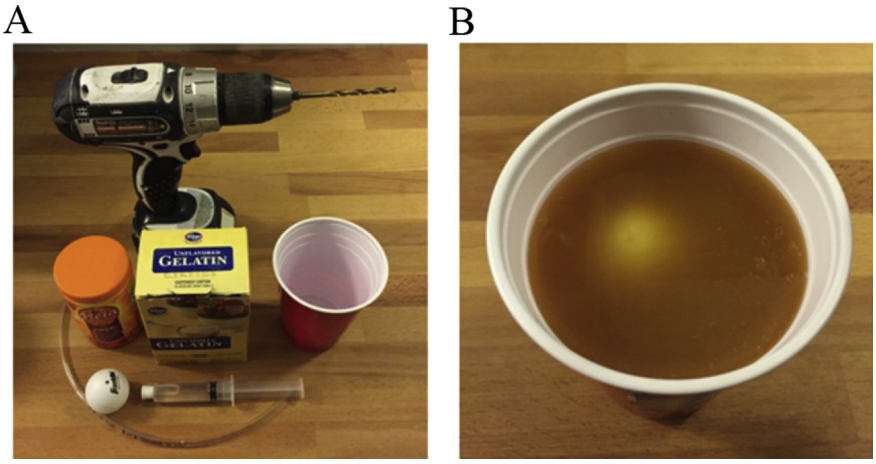

Figure 1 (A) Equipment required for phantom construction; (B) final ONS phantom. ONS = optic nerve sheath.

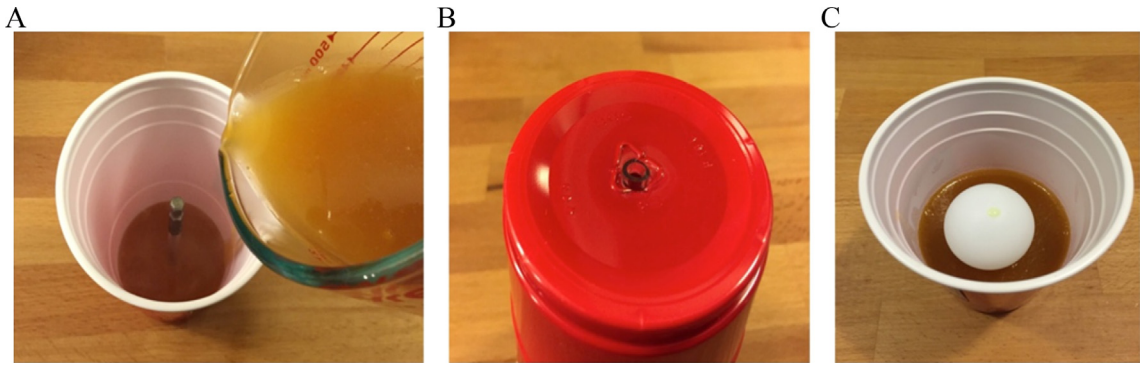

Figure 2 (A) Pouring in gelatinous matrix with vinyl tubing and stylet in place; (B) protrusion of 2 mm of vinyl tubing from bottom of cup; (C) ping pong ball fixed atop vinyl tubing.

layer of gelatin was gently poured on top of the previously congealed layer until the gelatin completely submerged the ping-pong ball. Care was taken to ensure that the ping-pong ball did not fall off the tubing. The phantom was left in the refrigerator until firm, at which point it was ready for use (Figure 1B). For optimal imaging of this ONSD, low gain settings will minimize reverberation artifact produced from the circular walls of the ping-pong ball. Construction of this model required ~30 minutes, with an additional 30 minutes needed for congealing time. The cost of each model was <$5 USD. Ultrasound phantom models should be refrigerated when not in use to promote longevity.

Phantom images

The still-frame sonograms of adult eyes included in this study were selected from a database of ocular ultrasounds acquired by ultrasound fellowship-trained EM physicians from emergency department patients at Denver Health Medical Center. Both the adult eye and ultrasound phantom images were obtained from a GE LOGIQ P6 (General Electric Company, Fairfield, USA) machine. We used a high frequency probe 10 MHz on the small parts preset, tissue harmonics. Low gain settings were used on the phantom models to minimize reverberation artifact. For *in vivo* eyes, the probe was placed in the horizontal axial plane in the center of the visual axis over a closed eyelid with the focus set to the middle of the globe. The images selected were obtained while using still-frame B-mode sonograms of adult eyes that included at least 3–4 cm of the retrobulbar optic nerve, and were chosen from among our database based on good image quality and to provide a range of normal and abnormal ONSD. The images had been securely stored without patient identifiers. Images were specifically chosen to represent a range of diameters >5 mm and <5 mm. Images were cropped to only include the posterior half of the model retina because the current model did not simulate anterior chamber structures.

Data collection and processing

EM physicians were presented with 10 static images of posterior ocular ultrasound including the ONS, and were blinded to whether images were obtained from *in vivo* or phantom sonography. Participants first measured the ONSD (data not presented), and then were asked to rate the reality of each image on a scale of 1–5, with 5 being the most likely to be an ultrasound of an *in vivo* optic nerve sheath. Participants rated the subjective "realness" of the image using a 5-point Likert scale (5: very much; 4: somewhat; 3: undecided; 2: not really; 1: not at all). Data entry was verified by spot checking the data every 10th entry.

Outcome measure

Our primary outcome was subjective "realness" of phantom ONSD images in comparison to *in vivo* images as rated by EM physicians.

Primary data analysis

Descriptive statistics for each ultrasound image were calculated. Chi-square analysis was performed to evaluate the subjective "realness" of *in vivo* and phantom images. Descriptive statistics and bivariate analyses using Wilcoxon rank-sum test were performed by eye group (*in vivo* vs. phantom) and categorized by expertise (ultrasound fellowship-trained versus resident physicians).

Results

Sixty-one EM physicians were enrolled and evaluated ONSD images between November 2014 and January 2015. The 10 ultrasound fellowship-trained physicians practice at multiple private and academic hospitals across the United States. Fifty-one out of 67 PGY 1—4 resident EM physicians from Denver Health Residency in EM were included in the study. Among the EM resident physicians included in the study, 16 were PGY 1, 12 were PGY 2, 14 were PGY 3, and nine were PGY 4 residents. Mean Likert scale values were 3.43 [95% confidence interval [CI]: 3.31—3.55) for *in vivo* images and 3.41 (95% CI: 3.28—3.54) for phantom images ($p = 0.83$) among all participants (Figure 3). Mean Likert scale values for *in vivo* images among ultrasound fellowship-trained and resident physicians were 4.08 (95% CI: 3.79—4.37) and 3.30 (95% CI: 3.17—3.43), respectively ($p < 0.001$). Mean Likert scale values for phantom images among ultrasound fellowship-trained and resident physicians were 2.72 (95% CI: 2.39—3.05) and 3.55 (95% CI: 3.41—3.68), respectively ($p < 0.001$).

Discussion

Simulation-based training is becoming widely incorporated into residency training programs in an effort to provide learners with experience in rare or critical scenarios and procedures. Sonographic phantoms can provide the substrate for training in lieu of rare or costly cadaver tissues. Prior research has shown real-world clinical performance improvement based on simulation-based training utilizing ultrasound phantoms to place central venous catheters [6,7].

Phantoms must have acceptable tissue-mimicking properties. As used in this study, gelatinous matrix made from low-cost, readily available products provide realistic simulation of periorbital soft tissues. The plastic ping-pong ball is hyperechoic, and exaggerates the fluid-tissue interface of the eye. Water infused into the ping-pong ball approximates the hypoechoic humours of the eye, whereas (hollow) vinyl tubing produces a crisp sonographic signal to adjacent gelatinous matrix similar to that of *in vivo* ONS (Figure 4). Together, these features make our model a close approximation of posterior ocular anatomy, and provide the substrate to teach the ONS technique. Additionally, although not presented here the authors have successfully introduced objects into the phantom (e.g., monofilaments) that mimic orbital foreign bodies and retinal/vitreous detachments. Further refinements to this model could easily be made to broaden its utility (e.g., engineer anterior anatomy, etc.).

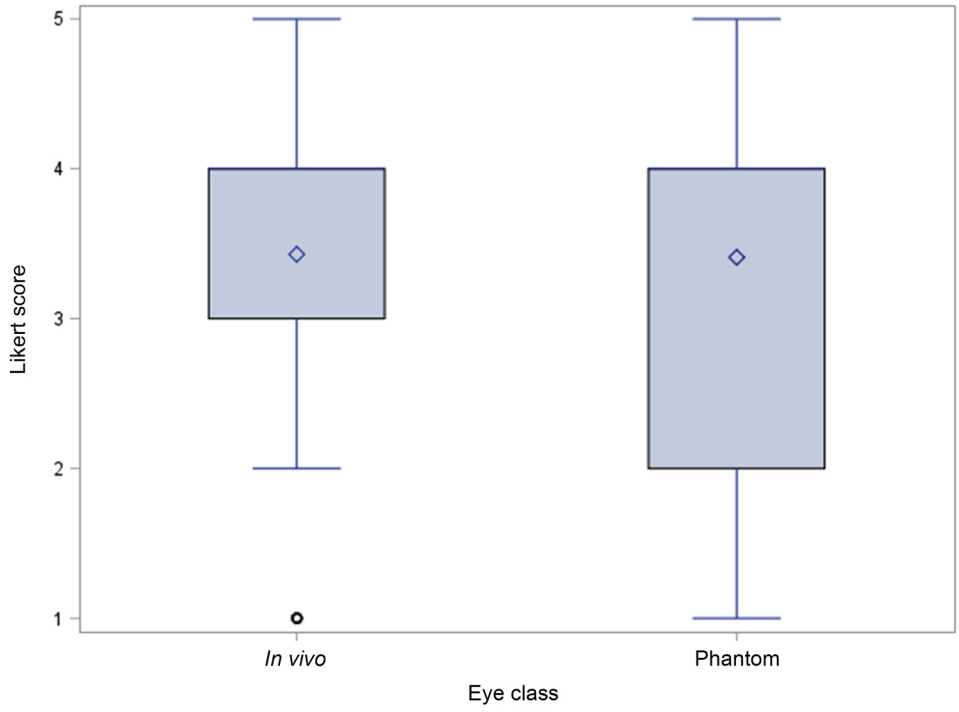

Figure 3 Box and whisker plot of Likert scale by type of eye. Distribution of Likert scores by eye class (Left, *In vivo*; Right, phantom) from all physicians ($n = 61$).

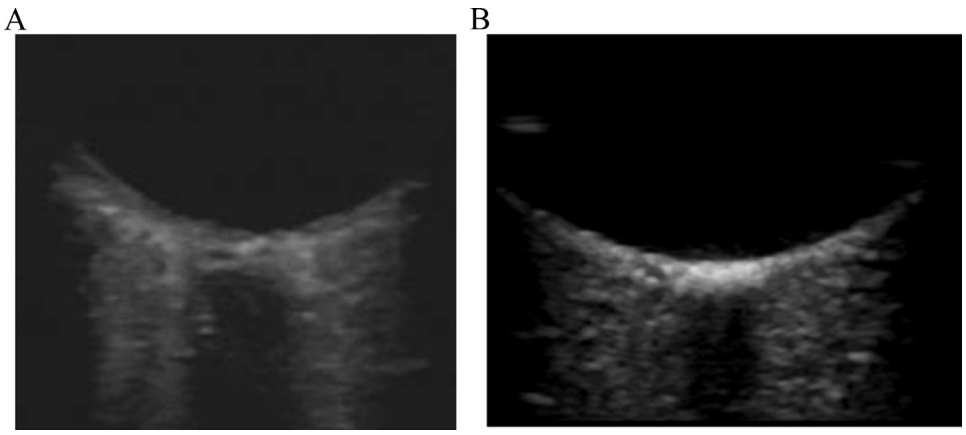

Figure 4 (A) Ocular ultrasound of posterior chamber and ONS of *in vivo*; (B) phantom model. ONS = optic nerve sheath.

Simulating ocular anatomy is fundamental to the utility of phantoms designed to teach ONSD measurement. Other phantoms have been developed to simulate ocular pathology, including dilatation of the ONS [4,8,9] however, these models have not yet been validated or studied in relation to *in vivo* ONS. Our phantom is particularly low-cost and easy to assemble, and provides an excellent approximation of the ONS, as evidenced by its indistinguishability from *in vivo* images among EM residents. Comparing mean Likert values, there was no difference in subjective "realness" between *in vivo* and phantom ONSD ultrasound images among EM residents, although ultrasound fellowship-trained EM attendings aptly differentiated between the two. The observed distinction has minimal implications for the phantom's utility as the model is intended to be used as a means of teaching ONSD measurement and ocular ultrasound technique to trainees.

Notable limitations of this study are that our ocular phantom does not simulate anterior structures of the eye (e.g., lens), and therefore limits its ability to fully teach the technique of obtaining mideye images for proper ONSD measurement. Secondly, this study involved only a limited number of static, previously acquired images evaluated by each operator, thus limiting study power. Lastly, this was a convenient sample of available volunteers. Such methodology is vulnerable to selection bias favoring participants more interested or adept at ocular ultrasound in choosing to participate.

Conclusion

Our ocular phantom simulates *in vivo* posterior ocular anatomy. EM resident physicians found the phantom indistinguishable from *in vivo* images. Our ONS model provides an inexpensive and realistic educational tool to teach bedside ONSD sonography.

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