The Development and Application of a Cost-Effective Cervical Spine Phantom for Use in Fluoroscopically Guided Lateral C1–C2 Spinal Puncture Training

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ABSTRACT

BACKGROUND AND PURPOSE: Lateral C1–C2 spinal punctures are uncommon procedures performed by radiologists for access to CSF and contrast injection when a lumbar approach is contraindicated and an alternate method of access becomes necessary. There are limited opportunities to learn and practice the technique. We aimed to develop and assess the efficacy of a low-cost, reusable cervical spine phantom for training in fluoroscopically guided lateral C1–C2 spinal puncture.

MATERIALS AND METHODS: The phantom was constructed with a cervical spine model, an outer tube representing the thecal sac, an inner balloon representing the spinal cord, and polyalginate to replicate soft tissue. The total cost of materials was approximately US $70. Workshops were led by neuroradiology faculty experienced in the procedure using the model under fluoroscopy. Survey questions were assessed on a 5-point Likert scale. Participants were given pre- and postsurveys assessing comfort, confidence, and knowledge of steps.

RESULTS: Twenty-one trainees underwent training sessions. There was significant improvement in comfort level (Δ: 2.00, SD: 1.00, P value $<$ .001); confidence (Δ: 1.52 points, SD: 0.87, P value $<$ .001); and knowledge (Δ: 2.19, SD: 0.93, P value $<$ .001). Eighty-one percent of participants found the model "very helpful" (5/5 on Likert scale), and all participants were "very likely" to recommend this workshop to others.

CONCLUSIONS: This cervical phantom model is affordable and replicable and demonstrates training utility to prepare residents for performing lateral C1–C2 spinal puncture. This is a rare procedure, so the use of a phantom model before patient encounters is invaluable to resident education and training.

Lateral C1–C2 spinal punctures are uncommon procedures performed by radiologists under fluoroscopic guidance for various purposes, including CSF collection and contrast injection when a lumbar approach is contraindicated.[1] A 2009 survey of neuroradiology program directors showed that 14.3% of programs have <1 C1–C2 spinal puncture performed, on average, every year, and that 47.6% average between 1 and 5 C1–C2 spinal punctures annually.[2] Due to the infrequency of this procedure, there are limited opportunities for trainees to learn and practice the technique.[3] While lateral C1–C2 spinal puncture is considered a safe procedure when performed by a skilled radiologist, with <0.05% of cases having a major complication such as an arterial bleed, epidural hematoma, intramedullary contrast injection, permanent neurologic deficit, or death, these potential complications have high morbidity.[1,4] The potentially major or fatal consequences of this procedure if performed incorrectly make it difficult for trainees to gain experience with the procedure without a form of simulation training. Additionally, due to the rarity of this procedure, along with potentially serious complications, it is often found that a single neuroradiologist will be trained at an institution and will perform all lateral C1–C2 spinal punctures at the institution, further limiting training opportunities for other faculty and residents.

To enrich education and training of medical professionals while also improving patient safety, throughout all phases of medical training, simulation training has become increasingly popular for teaching and practicing techniques before using them on a patient.[5] Research has shown that simulation training improves reported confidence levels and success rates of the first procedure performed by the student on a patient.[6] Fluoroscopically compatible anthropomorphic head, cervical spine, and spinal cord phantoms are available for purchase. However, the price of commercially available fluoroscopically compatible models exceeds US $6000, and these models do not include components mimicking CSF that can be used to replicate C1–C2 spinal punctures.[7] Due to the infrequency of

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From the Department of Radiology, University of North Carolina at Chapel Hill School of Medicine, Chapel Hill, North Carolina.

Please address correspondence to Yueh Z. Lee, MD, PhD, The University of North Carolina at Chapel Hill School of Medicine, Department of Radiology, 2000 Old Clinic CB No. 7510, Chapel Hill, NC 27599-9500; e-mail: leey@med.unc.edu

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these procedures, a costly model is not practical for training. Additionally, the current models available on the market for phantom fluoroscopic cervical spines would require modifications to mimic CSF. There have been cost-effective phantom models created for practicing lumbar punctures under fluoroscopic guidance,[8,9] but no cost-effective fluoroscopically compatible cervical phantoms with simulated CSF have been created to date. We aimed to develop and assess the efficacy of a low-cost, reusable cervical spine phantom for use in fluoroscopically guided lateral C1–C2 spinal puncture training.

MATERIALS AND METHODS

Model Construction

A more detailed guide on the materials and step-by-step instructions to create the model can be found in the Online Supplemental Data. To summarize, the phantom was constructed using a modified polyvinyl chloride cervical spine model: an outer latex tubing with 1.58-mm-thick walls, similar in thickness to spinal dura mater (mean, 1.106 [SD, 0.244] mm); an outer diameter of 15.875 mm (0.625 inches), similar to that in a study by Ulbrich et al[10] examining the typical diameter of a normal cervical spinal canal at the C1 level (range, 10.7–19.7 mm) and an inner diameter of 12.7 mm; an inner latex modeling balloon with an approximate diameter of 7.5 mm after being filled with 10 mL of fluid representing the spinal cord, also similar to the estimated anterior-posterior diameter of the spinal cord at the C1–C2 level (mean, 8.2 [SD, 1.6] mm); and an alginate substance encompassing the model to replicate soft tissue.[11,12]

The commercially available cervical spine model used was meant for patient education and anatomic training. The spinal cord portion of the cervical model was removed, and the outer latex tubing was fed through the spinal canal. A polyvinyl chloride on/off valve for an 0.5-inch-tube inner diameter was placed on one end of the outer tubing, and a hemostat was used to secure the other end. The outer tube was filled with clear water, and the tube was sealed by closing the valve and using a hemostat on the opposite end to maintain the pressure and shape of the canal. The model was then placed in a cylindrical container approximately the diameter of a neck (in our model, we used part of a standard 2-L soft drink bottle, but other containers can be used), and the container was filled with the polyalginate molding mixed at a 1/4 ratio of powder to water (by weight, ie, 60 g of powder per 240 g [1 cup] water). To extend curing time, we used refrigerated water (at 35°F), and allowed the mixture to cure for approximately 10–15 minutes in the cylindrical container. After we removed it from the cylindrical container, the outer latex tube was unsealed and drained, and the inner latex modeling balloon was passed through the outer tubing using a metal rod and then filled with approximately 15–20 mL of water dyed with red food coloring so that the spinal tap would reveal dyed water if the spinal cord was punctured (Fig 1).

Additional clamps were secured to the outer tubing, posterior to the inner balloon to ensure anterior placement of the balloon to better mimic the anatomic positioning of the spinal cord. Then, the outer tubing was refilled with clear water. This tube-within-a-tube approach enabled refilling of the spinal canal and replacement of the latex balloon “spinal cord” if the balloon was punctured in a previous attempt. Before use in training sessions, the model was wrapped in plastic wrap to retain moisture and kept refrigerated at 4°C. We found that the model lasts 7–10 days refrigerated before the alginate begins to mold, requiring recasting. Ideally, the model should be assembled in close time proximity to training sessions to prevent expiration of the alginate. The total cost of materials for 1 model was approximately US $70. We have also developed an alternate approach with silicone material that will resist spoiling but at a greater cost. A list of materials and costs is available in the Online Supplemental Data. Immediately before use, the open end of the outer dural tube was mildly pressurized by injecting an extra 10–15 mL of fluid into the model. The final phantom construction can be seen in Fig 2.

FIG 1. Puncturing the spinal cord. The photograph demonstrates the result of puncturing the inner latex balloon, which represents the spinal cord. Red dye returns from the spinal needle.

Assessment of Training Efficacy

Training sessions were held at a single institution, conducted using the phantom model under fluoroscopic guidance and led by 1 neuroradiology faculty member with >15 years of experience with lateral C1–C2 spinal punctures. A fluoroscopic image of the phantom model during training sessions can been see in Fig 3, with a real-life fluoroscopic image during a lateral C1–C2 spinal puncture provided in Fig 4 for comparison. Each session comprised 4–6 trainees, including radiology assistant students, medical students, radiology residents, and attending physicians. Training sessions began with a group demonstration of a C1–C2 spinal puncture by the neuroradiology faculty member facilitating the training using the phantom under fluoroscopy, followed by individual practice by training participants. Attempts of C1–C2 spinal puncture by participants were directly supervised by the neuroradiologist leading the training, with direct feedback provided during training to ensure competency of trainees.

FIG 2. Constructed cervical phantom model. The photograph shows the fully-constructed phantom model. The cervical spine model is covered with polyalginate. There is a latex tube running through the spinal canal of the cervical model, with an inner latex balloon within the tube. The inner latex balloon is filled with dyed water, and the outer tube is filled with clear water. Two hemostats on either end of the phantom are occluding the posterior third of the latex tube to ensure that the balloon is in a more accurate anatomic position relative to the spinal cord. The hemostat at the distal end of the latex tube is used to maintain water pressure within the latex tube.

Participants were provided with a pre- and posttraining survey completed immediately before and after participating in training sessions. An example of the pre- and postsurveys given to workshop participants can be seen in the Online Supplemental Data.

Surveys assessed prior experience in witnessing or performing a lateral C1–C2 spinal puncture, comfort level in performing a C1–C2 spinal puncture before and after the training session with the model, confidence in performing a successful C1–C2 spinal puncture before and after the training session, and the perception of current knowledge of the steps in a C1–C2 spinal puncture before and after the training session. Pre- and postworkshop ratings of comfort level, current knowledge, and confidence in performing a C1–C2 spinal puncture were assessed using a 5-point Likert scale, with 1 being not comfortable, no knowledge, and not confident, respectively, and 5 being very comfortable, having extensive knowledge, and feeling very confident, respectively. Each trainee was expected to correctly orient the model in the lateral position, select an appropriate entry point, and advance the needle into the posterior canal at the C1–C2 level under fluoroscopy. Successful access to the CSF space was evident when clear CSF was returned through the 3.5-inch spinal needle. Penetrating the spinal cord would result in a return of red fluid.

Participants were also surveyed on the helpfulness of the workshop, the usefulness of the information learned in the workshop, and the likeliness of recommending this workshop to others. Survey questions were assessed on a 5-point Likert scale, with 1 being not helpful, not useful, and not likely to be recommended, respectively, and 5 being very helpful, very useful, and very likely to be recommended, respectively.

We assessed whether there were differences between pre- and postworkshop ratings of comfort level, current knowledge, and confidence using a Wilcoxon signed-rank test. We considered a P value $< .05$ as evidence of a difference in medians pre- versus postworkshop.

FIG 3. Fluoroscopic visualization of the phantom model shows the appearance of the model under fluoroscopy during a training session. The spinal needle can be seen within the C1–C2 space. The 2 screws seen in this image connect the skull base to the cervical spine and could not be removed in order to preserve integrity of the phantom.

FIG 4. Real example of a fluoroscopic image of a lateral C1–C2 spinal puncture that shows a lateral view of a C1–C2 spinal puncture performed on a patient for comparing the performance of the phantom in replicating fluoroscopic views during the procedure.

Comparison of phantom performance in replicating actual lateral C1–C2 spinal punctures

Component of Phantom/ Procedure	Comparison with Real-Life Experience of Lateral C1–C2 Spinal Punctures
Feel of alginate/soft tissue	Similar
Positioning of phantom/ patient	Different: The patient is usually positioned prone for this procedure, while the training simulated the patient being in the lateral decubitus position due to constraints of the fluoroscopy room available for training (not related to the phantom itself)
Force required to penetrate outer latex tubing/dura	Different: The amount of pressure required to pop through the outer latex tube dura was greater than in real life; this difference was emphasized to the trainees who participated
Landmarks visualized under fluoroscopy	Similar
Speed of CSF egress	Variable: depending on how much pressure we applied to outer latex tubing via a syringe and the PVC on/off valve; future directions include construction of a model with a pressure gauge so that we could fill the tubing to match normal CSF pressure (~15 cm H_2O)

Note:—PVC indicates polyvinyl chloride.

RESULTS

In comparing the phantom's performance at simulating the actual lateral C1–C2 spinal puncture procedure, the neuroradiology faculty member with >15 years of experience who led the training sessions noted similarities and differences of the phantom to real punctures (Table). Four training sessions were held at a single institution during a 6-month time span. The sample size of the training group was 21, with 1 resident participating in 2 training sessions, but only the first workshop attendance of this participant was included in analyses. Participants were at various stages of training, from radiology assistant and medical students to attending physicians. Distributions of the training levels of participants can be found in Fig 5. Two-thirds of participants were either postgraduate year 6 residents or attending physicians; 71.4% (15/21) of training session participants had never seen a lateral C1–C2 spinal puncture procedure performed; and 90.5% (19/21) of participants had never performed a lateral C1–C2 spinal puncture before attending training sessions.

Figure 6 summarizes pre- and postworkshop ratings of comfort, confidence, and knowledge performing a C1–C2 spinal puncture. The mean difference in comfort level in performing a C1–C2 spinal puncture for post- versus preworkshop was 2.00 (SD, 1.00) (an increase from 1.29 to 3.29).The mean difference in confidence in the ability to successfully perform a C1–C2 spinal puncture for post- versus preworkshop was 1.53 (SD, 0.87) (an increase from 1.76 to 3.29). The mean differences in the perception of current knowledge for post- versus preworkshop was 2.19 (SD, 0.93) (an increase from 1.86 to 4.05). There was evidence that these outcomes were higher postworkshop for all 3 outcomes ($P < .001$ for all). Eighty-one percent of participants found the phantom to be very helpful (5/5 on Likert scale), and all participants were very likely (5/5 on Likert scale) to recommend that others sign up for this workshop. Ninety-one percent of participants rated the likeliness of using knowledge gained in the workshop in the future at either a 4 or 5 on the Likert scale.

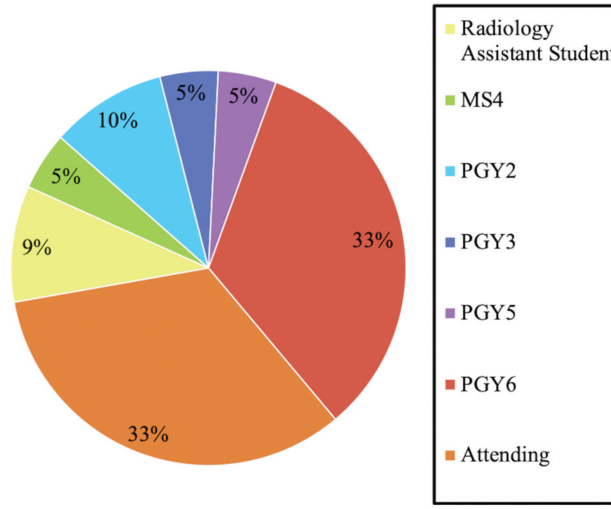

FIG 5. Stages of training of workshop participants. The graph shows the distribution of participant training levels during lateral C1–C2 spinal puncture training. A total of 21 individuals participated in training workshops, with 1 resident participating in 2 training workshops. PGY indicates postgraduate year; MS4, fourth-year medical student.

DISCUSSION

Simulation-based training workshops have been increasingly used among a wide variety of specialties—including anesthesiology, surgery, and radiology—to train residents and fellows on the steps of a procedure and to provide them with the opportunity to practice these methods before their clinical use.[13-16] More common radiologic procedures, such as fluoroscopically guided lumbar puncture, have had low-cost phantom models created for simulations for training medical professionals to learn and practice procedures.[8,9] However, a fluoroscopically compatible C1–C2 spinal puncture with functional CSF has not been demonstrated thus far. Because this procedure is rare, residents and fellows needed to learn the procedure of lateral C1–C2 spinal punctures on real patients, which creates a risk to the patient secondary to the inadequate training. Worse yet, practitioners may not have even had a chance to see these procedures during training and are not adequately prepared to provide this service to patients, which is sometimes necessary to obtain critical diagnostic information. Additionally, lateral C1–C2 spinal punctures are often not the first-choice procedure and are frequently chosen due to the complexities of a patient and contraindications to lumbar puncture, so these cases are often not straightforward procedures and carry inherent risks not due to infrequency of the procedure being performed.[4] These factors make it even more important for trainees to

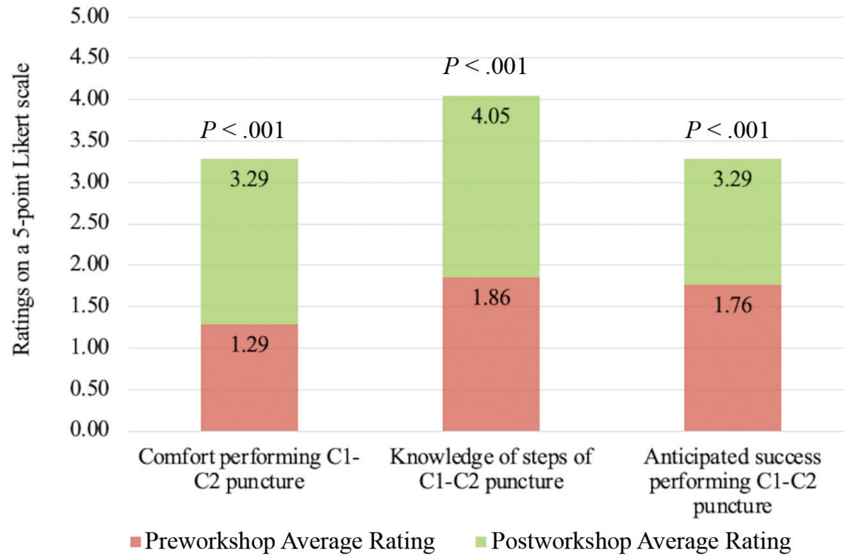

FIG 6. Pre- and postworkshop ratings of comfort, knowledge, and confidence of C1–C2 lateral cervical puncture. The image shows pre- and post-survey results of participants' ratings of their comfort performing, knowledge of steps, and anticipated success of lateral C1–C2 spinal puncture before and after taking part in an educational workshop using the cervical model developed in this article. Ratings were on a 5-point Likert scale.

have nonpatient opportunities to learn and practice this procedure to gain more experience before clinical application.

This cervical phantom model successfully provided residents and fellows with a simulation of an uncommon procedure, lateral C1–C2 spinal puncture, at a low cost with little technical expertise needed to recreate the model. Considering the improvement in comfort with the procedure, confidence in having a successful procedure, and knowledge of the steps of the procedure, this model delivers a high benefit-to-cost ratio for lateral C1–C2 spinal puncture training. By providing step-by-step instructions for creating a cervical model, this project provides easily accessible, low-cost, highly effective training opportunities for other programs interested in implementing similar training. We have also begun to use similar approaches in phantom design for other procedural phantoms. The model is somewhat "self-healing," allowing at least 10 trainees to participate on the same model. We did not have any difficulty with model degradation with 13 trainees participating in a single session. The latex tube dura simulant was also resistant to leaking due to the resealing nature of the latex rubber under low pressures.

This project has limitations related to application at a single institution. Because all trainees came from our institution, there is concern for selection bias. However, this project has shown that a low-cost homemade model can have clinical utility in the training of our medical professionals. This particular model is moderately prone to spoiling due to the polyalginate material because we did not add any form of preservative. In our experience, this model is useful for approximately 7–10 days if preserved in a refrigerator when not in use. Future directions for this project include working with other neuroradiology programs to develop these training workshops with the C1–C2 phantom at other institutions. The how-to guide will enable other programs to create a replica of the phantom and conduct training sessions at their own institutions. The intent of expanding to other institutions would be to increase the sample size of the project if we conduct a meta-analysis in the future. We have also begun to recreate this model using a more stable soft-tissue replica material, adding a pressure gauge to more accurately represent normal CSF pressure (15 cm H_2O) and have started to expand these methods to other radiologic procedures to increase simulation teaching at our institution.

This article discusses training on the procedure of lateral C1–C2 spinal puncture under fluoroscopic guidance. Some neuroradiologists prefer using other imaging modalities, such as CT or MR imaging, for guidance during this procedure. These modalities are not covered under the scope of this project, and the model has not been formally assessed for similarity to the human cervical spine under CT or MR imaging. However, additional future directions for this phantom include assessing the potential utility of this model under other imaging modalities for training using CT or MR imaging guidance. There are 2 metal screws in the model that had to remain in place to maintain integrity between the base of the skull and the cervical spine. These would have to be replaced with screws made from an MR imaging–compatible metal to safely visualize this model using MR imaging.

CONCLUSIONS

Simulation teaching is increasingly being used at teaching institutions to expand training for medical procedures before interactions with patients. This low-cost cervical spine model helped bridge the gap in clinical training for fluoroscopically guided lateral C1–C2 spinal punctures. The phantom and educational workshops enabled participants to gain hands-on, low-pressure experience practicing techniques for a relatively uncommon procedure, which increased participants' knowledge of the steps of the procedure, comfort in performing the procedure, and confidence in having success in the procedure. The release of open-access guidelines for creation of this model will increase training opportunities for using a low-cost training phantom at other institutions and increase the replicability of this project. Simulation training in radiology can be a useful educational tool in all stages of training.

Disclosure forms provided by the authors are available with the full text and PDF of this article at www.ajnr.org.

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