A Low-Cost, Durable, Combined Ultrasound and Fluoroscopic Phantom for Cervical Transforaminal Injections

Imanuel R. Lerman, MD, MS, Dmitri Souzdalnitski, MD, PhD,† and Samer Narouze, MD, MS‡*

Background: This technical report describes a durable, low-cost, anatomically accurate, and easy-to-prepare combined ultrasound (US) and fluoroscopic phantom of the cervical spine. This phantom is meant to augment training in US- and fluoroscopic-guided pain medicine procedures.

Methods: The combined US and fluoroscopic phantom (CUF-P) is prepared from commercially available liquid plastic that is ordinarily used to prepare synthetic fishing lures. The liquid plastic is heated and then poured into a metal canister that houses an anatomical cervical spine model. Drops of dark purple dye are added to make the phantom opaque. After cooling, tubing is attached to the CUF-P to simulate blood vessels.

Results: The CUF-P accurately simulates human tissue by imitating both the tactile texture of skin and the haptic resistance of human tissue as the needle is advanced. This phantom contains simulated fluid-filled vertebral arteries that exhibit pulsed flow under color Doppler US. Under fluoroscopic examination, the CUF-P–simulated vertebral arteries also exhibit uptake of contrast dye if mistakenly injected.

Conclusions: The creation of a training phantom allows the pain physician to practice needle positioning technique while simultaneously visualizing both targeted and avoidable vascular structures under US and fluoroscopic guidance. This low-cost CUF-P is easy to prepare and is reusable, making it an attractive alternative to current homemade and commercially available phantom simulators.

(*Reg Anesth Pain Med* 2012;37: 344–348)

Ultrasound (US)–guided interventions continue to be a rapidly developing field in both regional anesthesia and pain medicine.[1] In accordance with the growing interest in US-guided interventions, training with US phantoms has been shown to be an effective teaching tool.[2–4] Ultrasound phantoms have been made from materials, such as water, tofu, gelatin, plastics, and various animal meats.[5–7] In addition, plastic- and foam-based fluoroscopic phantoms have been developed as training tools in fluoroscopic-guided pain medicine.[8,9] Training in US-guided procedures with the use of phantom simulators is recommended, because phantom simulation likely improves proficiency in US-guided procedures and can identify dangerous novice behaviors.[10–12] Recent literature has shown that practice on phantom simulators can translate into improved performance in the clinical care setting.[2,13] Although there are likely similar benefits from training on fluoroscopic phantoms, at this time there is a paucity of available literature on this topic.[8,9]

The combined US and fluoroscopic phantom (CUF-P) is easily visualized under both fluoroscopy and US and can be used for training in interventional pain medicine. The CUF-P was developed to simulate interventional pain procedures that focus on the visualization of both neurovascular and bony anatomical structures. Vascular compromise during cervical transforaminal epidural steroid injections (CTFESIs) has been postulated to result in potential devastating complications, including paraplegia, quadriplegia, spinal cord infarction, brain infarction, brain herniation, coma, and death.[14–17] The cervical spinal nerve is in close approximation (2 mm) to variable small arteries that can demonstrate anatomical variation and are thought to be a source of serious complications during CTFESI.[18,19]

With an aim to enhance the visualization of the underlying anatomy, US guidance has been successfully combined recently with both CT and fluoroscopy to carry out CTFESI and cervical selective nerve root blockade.[20,21] As advanced imaging technology continues to improve, pain physicians will likely find it helpful to practice interventional pain procedures under both fluoroscopy and US.

Current phantoms available for pain medicine do not include functional vasculature, and most cannot be visualized under both US and fluoroscopy. This report describes the preparation of a durable, reusable, low-cost CUF-P that can be used for simulation of US- and fluoroscopic-guided interventional pain procedures.

METHODS AND MATERIALS

The CUF-P was prepared, using materials that are readily available at hardware stores and over the Internet. A plastic cervical spine model that consists of cervical levels from the second to seventh cervical level was purchased from an anatomical model supplier. Two 3/16-in-diameter × 12-in-length, steel metal rods were purchased from a local hardware store and inserted into the vertebral foramina of the cervical spine model. The cervical spine model was then placed in a metal canister (6 × 5 in), which was filled with a liquid polyvinyl-chloride plastic compound that is ordinarily used to mold fishing lure worms (Plastisol; M-F Manufacturing, Fort Worth, Texas). Spirou et al[22] have previously demonstrated that M-F Plastisol can be used to create a US phantom. Plastisol material has been shown to simulate human tissue when examined under US. First, the velocity of sound waves traveling through Plastisol is very similar to that when traveling through human tissue. In addition, the density of Plastisol is similar to that of water.[22] The manufacturer's instructions for preparing fishing lures were used with minor modification that included increasing the volume of Plastisol material heated and increasing the amount of the color dye added.[23]

One quart of Plastisol material was heated in a metal pot on an electric hot plate to 325°F. It is recommended that heating

From the *Massachusetts General Hospital, Boston, MA; †Anesthesiology Institute, Department of Pain Medicine, Cleveland Clinic Foundation, Cleveland, OH; and ‡Center for Pain Medicine, Summa Western Reserve Hospital, Cuyahoga Falls, OH.
Accepted for publication February 2, 2012.
Address correspondence to: Imanuel R. Lerman, MD, MS, Massachusetts General Hospital, Department of Anesthesiology Critical Care and Pain Medicine, 55 Fruit St. Boston MA (e-mail: irlerman@partners.org).
This study was supported by the Yale New Haven Hospital Resident Education Fund.
This information was presented as an abstract at the spring 2010 Annual ASRA Regional Anesthesia Pain Meeting, Toronto, Canada.
The authors declare no conflict of interest.

ISSN: 1098-7339
DOI: 10.1097/AAP.0b013e31824f3763

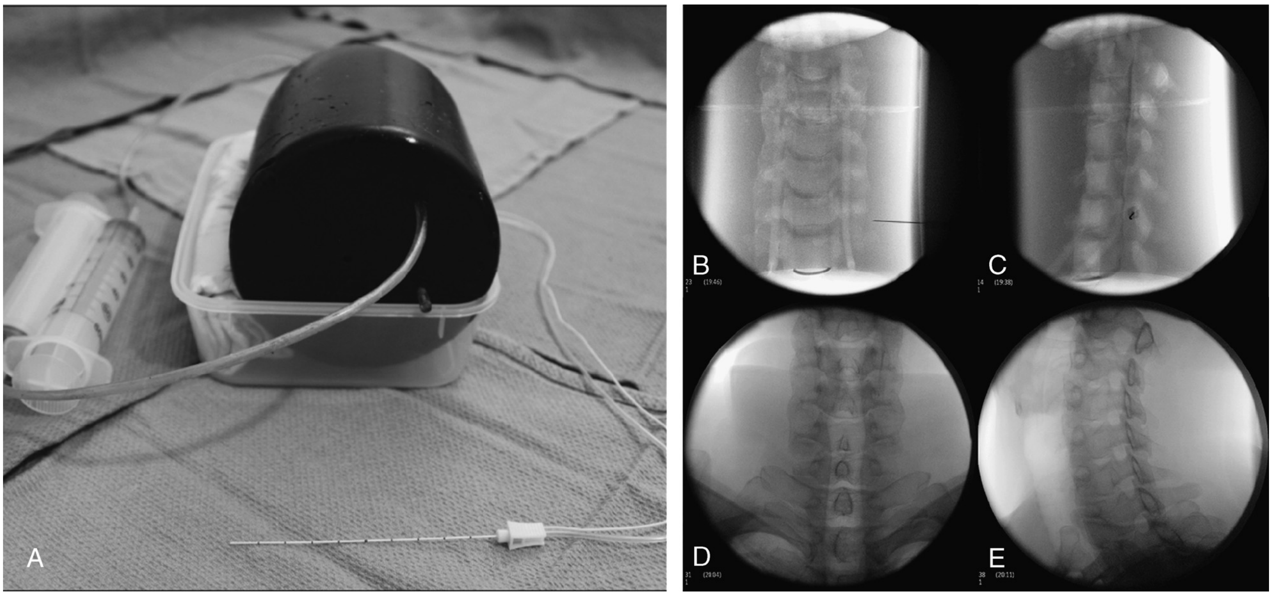

FIGURE 1. The cervical ultrasound (US) and fluoroscopic phantom. A, The tubing exits the phantom and is connected to two 25-mL syringes that cycle water. A 21-gauge echogenic needle is placed in the forefront. The combined US and fluoroscopic phantom is visualized under in the anteroposterior (AP) (B) and right oblique view (C). A healthy human volunteer cervical spine is visualized for comparison in the AP view (D) and right oblique view (E).

Plastisol be carried out in a well-ventilated area: either outside or under a laboratory hood.[22] We wore protective eyewear, in addition to gloves, when preparing the CUF-P. Five drops of dark purple dye were added to the heated Plastisol. After 5 to 10 mins of heating, the Plastisol thickened slightly, and the color of the solution changed from light purple to dark purple.[23] Alternatively, the CUF-P can be molded as a clear nonopaque model, without the addition of the dark purple dye. The melted Plastisol solution was then poured into a cylindrical tin metal canister containing the cervical spine model. The mold was cooled for 1 to 2 hrs at room temperature. Once cooled, the cylindrical mold and metal rods were removed. To simulate vertebral arteries under US and fluoroscopy, the CUF-P can be fitted with tubing connected to both caudad and cephalad vertebral foramina openings that allow fluid to cycle between 2 attached 25-mL syringes at each end (Fig. 1). A Philips BV Pulsera C-arm (Andover, Massachusetts) was used to image the CUF-P and a healthy volunteer's cervical spine, (Fig. 1). A Sonosite M-Turbo US machine (Bothell, Washington) was used with an L-25 10-5 MHz 25-mm broadband linear array transducer with color Doppler mode to examine the CUF-P. A General Electric Neurovasc 9800 Elite C-arm (Salt Lake City, Utah) was used to carry out fluoroscopic guidance with the CUF-P. A 21-gauge, 4-in Havels polymer-coated needle (Cincinnati, Ohio) was used during the CUF-P simulation trials (Fig. 1).

RESULTS

The CUF-P was initially visualized under fluoroscopy and compared with a healthy human volunteer cervical spine in the anteroposterior and right oblique views (Fig. 1). We then examined the CUF-P with US guidance, followed by confirmatory fluoroscopic imaging. The CUF-P was stabilized in a lateral decubitus position, with the US probe oriented in the short-axis transverse approach (Fig. 2). To simulate a US-guided procedure, a 21-gauge needle was inserted posterior and advanced parallel to the probe using the in-plane approach (Fig. 2). Using the short-axis transverse approach, a clear sonographic view of both the posterior tubercle and anterior tubercle of the transverse process was visualized. Color Doppler sonograms of the CUF-P corresponding cervical levels in a healthy human volunteer (Fig. 3).

To study vascular encroachment under US and fluoroscopy, a 21-gauge needle was advanced under color Doppler US guidance at the C7 intervertebral foramen. If the needle was erroneously advanced too far, the tip was visualized as it had penetrated the vertebral artery under color Doppler US (Fig. 4). Intravascular needle placement was then confirmed by fluoroscopic imaging. Using real-time fluoroscopy, 2 mL of 39% contrast dye was injected. In the case of accidental vertebral artery puncture, contrast uptake was visualized under both continuous fluoroscopy and digital subtraction imaging (Fig. 4).

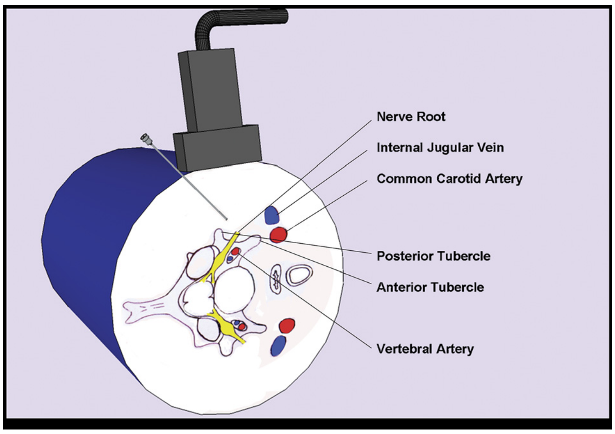

FIGURE 2. Cross-sectional anatomy at the C6 level in the lateral decubitus position, with the probe positioned the short-axis transverse orientation. Needle advancement in an in-plane approach from posterior to anterior. Under color Doppler sonography, the underlying arterial and venous blood flow can be visualized.

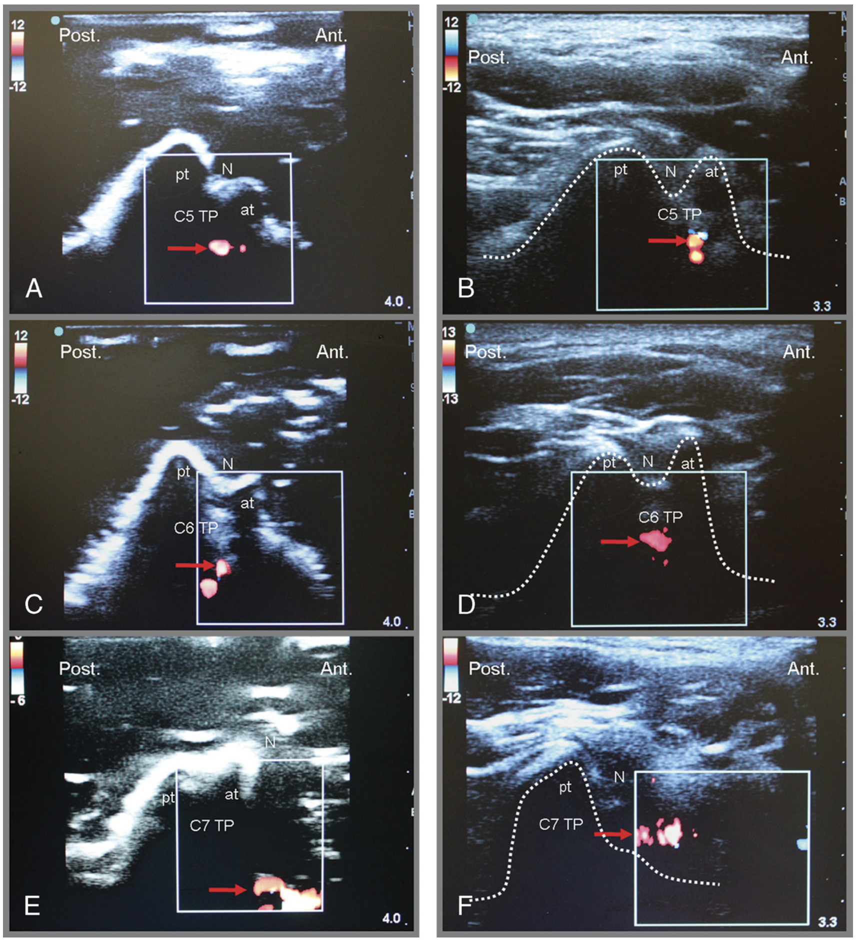

FIGURE 3. Comparison of sonograms of the combined ultrasound and fluoroscopic phantom (CUF-P) (left column) to a healthy human volunteer (right column). A short-axis transverse sonogram with color Doppler demonstrates vertebral artery flow (red arrow), cervical nerve root (N), anterior tubercle (at), and posterior tubercle (pt) of transverse process (TP), at levels C5, C6, and C7. In the CUF-P (left column) and the healthy human volunteer (right column), the vertebral artery travels anterior at the C7 transverse process. In the healthy human volunteer (right column), the transverse process is marked by a dotted white line. A, Sonogram of the CUF-P at the C5 level. B, Sonogram of a healthy human subject at the C5 level. C, Sonogram of the CUF-P at the C6 level. D, Sonogram of a healthy human subject at the C6 level. E, Sonogram of the CUF-P at the C7 level. F, Sonogram of a healthy human subject at the C7 level.

The CUF-P is an inexpensive US and fluoroscopic phantom. Our total cost for the CUF-P was approximately US $140. The CUF-P is easy to prepare and continues to be both durable and reusable; our current model has withstood many practice sessions and has been stored for 1 year without degradation or any signs of fungal or bacterial growth. The CUF-P can be stored in a sealable plastic bag at room temperature. After use, the CUF-P is easily cleaned with water and a paper towel to remove US gel. Needle track marks can develop with repeated use. However, they are easily erased by heating the CUF-P in an oven at 300°F for 10 mins and then allowing it to cool for 1 hr.

DISCUSSION

The CUF-P is a versatile learning tool that can be used to practice US-guided interventional techniques, including maintaining needle and needle tip visualization while simultaneously keeping both the targeted and avoidable vascular structures in view. The CUF-P can be examined under US with color Doppler and fluoroscopy with contrast injection, which allows the trainee to appreciate the underlying anatomy under both imaging modalities.

The CUF-P mold closely simulates the haptic feel and resistance of human tissue as the needle is advanced. The current CUF-P does not simulate layers of human tissue or muscle and fascia planes. More expensive US phantoms can simulate tissue fascia layers; however, none are in production that simulate the cervical spine or can be examined under US and fluoroscopy. The CUF-P is fashioned from polyvinyl-chloride Plastisol, a durable form of flexible plastic that can be used to make many different US phantoms.[24] Other low-cost gelatin phantoms undergo degradation with use and have a limited shelf life requiring frequent replacements.[25] The CUF-P does not need to be frequently replaced, which can translate into a reduced cost that will likely offset the total expense of replacing multiple gelatin-based phantoms.[25] When compared with prefabricated, commercially available US or fluoroscopic phantoms (US $160 to $11,000), the current CUF-P costs significantly less (US $140).

There are several limitations to the CUF-P phantom model. Although the CUF-P simulates vertebral arteries easily

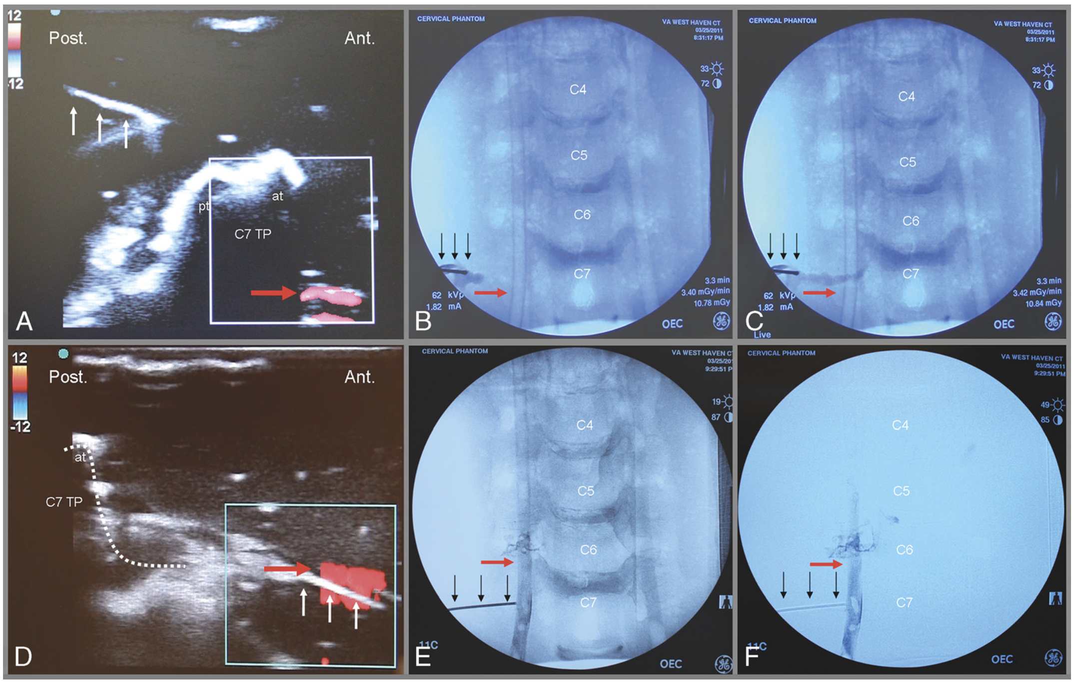

FIGURE 4. Short-axis transverse sonogram with color Doppler demonstrates the posterior tubercle (pt) and anterior tubercle (at) of the combined ultrasound and fluoroscopic phantom (CUF-P) at the C7 transverse process, in addition to vertebral artery flow (red arrow). A, The needle (white arrows) is clearly visualized as it approaches the posterior tubercle. D, The needle was erroneously advanced past the C7 transverse process and inserted into the vertebral artery. B, Anteroposterior view of the CUF-P under continuous fluoroscopy, with the needle (black arrows) positioned at the C7 transverse process. C, Anteroposterior view of the CUF-P under continuous fluoroscopy, with the needle positioned at the C7 transverse process, demonstrating contrast that traverses the simulated vertebral artery without vascular uptake. E, Anteroposterior view of the CUF-P under continuous fluoroscopy, with the needle advanced past the C7 transverse process and inserted into the simulated vertebral artery that demonstrates contrast uptake. F, Anteroposterior view of the CUF-P under digital subtraction angiography imaging, with the needle advanced past the C7 transverse process and inserted into the simulated vertebral artery that demonstrates contrast uptake.

visualized with US and contrast injection under fluoroscopy, it does not simulate the ascending cervical or radicular arteries. This is a significant limitation to the current CUF-P model because these smaller arteries are thought to contribute to the devastating complications associated with CTFESI.[18,19] Considerations for future versions of CUF-P models include incorporating more advanced simulated vascular structures. Although the CUF-P does provide valuable simulation of both US and fluoroscopic procedures, its educational utility has not yet been compared with either US or fluoroscopic phantoms. Future studies are needed to validate the educational value of this phantom versus that of both homemade and commercially available US and fluoroscopic phantoms.

Mastering US-guided interventions is a challenging skill that many pain physicians are eager to learn. The CUF-P is inexpensive, easy to prepare, and a durable and reusable phantom model that offers the added advantage of visualizing vulnerable vascular structures under both US and fluoroscopy. Interventional pain physicians are likely to benefit from training on such phantoms as the combined field of "sono-fluoroscopy" continues to advance.

REFERENCES

1. Narouze SN, Peng PH. Ultrasound-guided interventional procedures in pain medicine: a review of anatomy, sonoanatomy, and procedures: part II: axial structures. *Reg Anesth Pain Med*. 2009;35:386–396.
2. Barsuk J, Cohen E, Feinglass J, McGaghie W, Wayne DB. Use of simulation-based education to reduce catheter-related bloodstream infections. *Arch Int Med*. 2009;169:1420–1423.
3. Dessieux T, Estebe JP, Bloc S, Mercadal L, Ecoffey C. Evaluation of the learning curve of residents in localizing a phantom target with ultrasonography. *Ann Fr Anesth Reanim*. 2008;27:797–801.
4. Yoo MC, Villegas L, Jones DB. Basic ultrasound curriculum for medical students: validation of content and phantom. *J Laparoendosc Adv Surg Tech A*. 2004;14:374–379.
5. Li JW, Karmakar MK, Li X, Kwok WH, Kee WD. Gelatin-agar lumbosacral spine phantom: a simple model for learning the basic skills required to perform real-time sonographically guided central neuraxial blocks. *J Ultrasound Med*. 2011;30:263–272.
6. Souzdalnitski D, Lerman I, Halazynski T. In: Narouze S, ed. *Atlas of Ultrasound-Guided Procedures in Interventional Pain Management*. 1st ed. New York, NY: Springer Science + Business Media; 2011.
7. Hocking G, Hebard S, Mitchell CH. A review of the benefits and pitfalls of phantoms in ultrasound-guided regional anesthesia. *Reg Anesth Pain Med*. 2011;36:162–170.
8. Atallah J, Fahey BG, Gibson T. Pain simulator can improve the training of residents and pain fellows in performing pain management procedures. *Pain Physician*. 2007;10:511–517.
9. Hutcheson K, McKenzie-Brown K, Hutcheson K, Hanowell D. Simulation for interventional pain procedures—a novel educational tool. *Reg Anesth Pain Med*. 2007;32:A3.
10. Sites B, Spence B, Gallagher J, Wiley C, Bertrand M, Blike G. Characterizing novice behavior associated with learning ultrasound-guided peripheral regional anesthesia. *Reg Anesth Pain Med*. 2007;32:107–115.

11. Sites B, Gallagher J, Cravero J, Lundberg J, Blike G. The learning curve associated with a simulated ultrasound-guided interventional task by inexperienced anesthesia residents. *Reg Anesth Pain Med*. 2004;29:544–548.
12. Neal JM, Brull R, Chan VS, et al. The ASRA evidence-based medicine assessment of ultrasound-guided regional anesthesia and pain medicine. *Reg Anesth Pain Med*. 2010;35:1–9.
13. Domuracki KJ, Moule CJ, Owen H, Kostandoff G, Plummer JL. Learning on a simulator does transfer to clinical practice. *Resuscitation*. 2009;80:346–349.
14. Scanlon GC, Moeller-Bertram T, Romanowsky SM, Wallace MS. Cervical transforaminal epidural steroid injections: more dangerous than we think? *Spine*. 2007;32:1249–1256.
15. Rozin L, Rozin R, Koehler SA. Death during transforaminal epidural steroid nerve root block (C7) due to perforation of the left vertebral artery. *Am J Forensic Med Pathol*. 2003;24:351–355.
16. Ludwig MA, Burns SP. Spinal cord infarction following cervical transforaminal epidural injection: a case report. *Spine*. 2005;30:266–268.
17. Rathmell J, Michna E, Fitzgibbon D, Stephens L, Posner K, Domino K. Injury and liability associated with cervical procedures for chronic pain. *Anesthesiology.* 2011;114:918–926.
18. Huntoon MA. Anatomy of the cervical intervertebral foramina: vulnerable arteries and ischemic neurologic injuries after transforaminal epidural injections. *Pain Suppl*. 2005;117:104–111.
19. Hoeft MA, Rathmell JP, Monsey RD, Fonda BJ. Cervical transforaminal injection and the radicular artery: variation in anatomical location within the cervical intervertebral foramina. *Reg Anesth Pain Med*. 2006;31:270–274.
20. Galiano K, Obwegeser AA, Bale R. Ultrasound-guided and CT-navigation–assisted periradicular and facet joint injections in the lumbar and cervical spine: a new teaching tool to recognize the sonoanatomic pattern. *Reg Anesth Pain Med*. 2007;32:254–257.
21. Narouze SN, Vydyanathan A, Kapural L, Sessler DI, Mekhail N. Ultrasound-guided cervical selective nerve root block: a fluoroscopy-controlled feasibility study. *Reg Anesth Pain Med*. 2009;34:343–348.
22. Spirou GM, Oraevsky AA, Vitkin IA, Whelan WM. Optical and acoustic properties at 1064 nm of polyvinyl chloride–Plastisol for use as a tissue phantom in biomedical optoacoustics. *Phys Med Biol*. 2005;50:141–153.
23. M-F Manufacturing Liquid Plastic Purchasing Web site, Fort Worth, TX. Available at: http://www.fishingworld.com/M-Fmanufacturing/Details.tmpl?ID=98238113879895&Cart=13029813841688222. Accessed April 1, 2011.
24. Lerman IR, Souzdalnitski D, Mill D, Dai F, Stanton K, Halaszynski T. Ultrasound simulation of phantom femoral nerve blockade decreases time to perform femoral nerve blockade. *Reg Anesth Pain Med*. 2011:A29. ASRA Spring Meeting.
25. Bellingham GA, Peng PW. A low-cost ultrasound phantom of the lumbosacral spine. *Reg Anesth Pain Med*. 2010;35:290–293.