JOURNAL OF Surgical Simulation

Journal of Surgical Simulation (2017) **4**, 35–40
DOI: https://doi.org/10.1102/2051-7726.2017.0007

ORIGINAL ARTICLE

Ultrasound-guided central line placement: is a gelatine phantom a good and affordable alternative?

Bart J.M. Leenders,[a,*] Stefan T.G. Bruijnen[b] and Jan-Willem Elshof[a]

[a]*VieCuri Medical Centre, Tegelseweg 210, 5912 BL Venlo, Netherlands;* [b]*VU Medical Centre, De Boelelaan 1118, 1081 HZ Amsterdam, Netherlands*

**Corresponding author at: VieCuri Medical Centre, Tegelseweg 210, 5912 BL Venlo, Netherlands. Email: bleenders@viecuri.nl*

Date accepted for publication: 16 June 2017

Abstract

Background: Central venous catheter (CVC) insertion is a common procedure. However, it has a complication rate of up to 15%. Ultrasound-guided (USG) central venous catheter insertion (USG-CVC) is recommended to reduce complications. USG punctures require hand–eye coordination. USG puncture training requires an adequate training phantom that mimics the ultrasound characteristics and in addition provides haptic feedback of tissue and veins. However, the commercially available phantoms are expensive. The aim of this proof of concept study was to produce a low-cost, realistic phantom to improve hand–eye coordination. The quality and utility of the phantom were reviewed by several participants experienced in USG punctures. **Methods**: This study took place in a peripheral teaching hospital and an academic centre. All available participants ($n = 20$) experienced in USG-CVC insertion were asked to perform a USG puncture on the phantom. In addition, participants reviewed the quality and different properties of the phantom by completing a questionnaire. **Results**: The age of the participants ranged from 24 to 55 years. Participants were surgical residents and surgeons with an average experience of 10–50 blind CVC procedures and 20–50 USG-CVC procedures. The phantom was rated moderate (mean, 3 out of 5) from a realistic perspective and good (mean, 4 out of 5) from a procedural perspective. Training of hand–eye coordination and the overall rating was good (mean, 4 out of 5). **Conclusions**: Overall, the phantom was rated good, especially for training of hand–eye coordination. These findings confirm the feasibility of this easy to make, affordable home-made phantom for USG puncture training.

Keywords: *central venous puncture; phantom; home-made; training; ultrasound; gelatine*

Introduction

Central venous catheter (CVC) insertion is a common procedure in medical practice. Insertion of these catheters facilitates the measurement of haemodynamic variables and administration of medication and nutrition that cannot be administered safely through peripheral venous catheters. However, CVC insertion has a complication rate of up to 15%.[1-3] In order to reduce these complications, ultrasound-guided central venous catheter (USG-CVC) insertion is recommended, because it allows direct visualization of intravenous needle and catheter insertion. USG-CVC insertion is a widely accepted method that improves successful insertion and reduces the complication risk of CVC placement.[1-5] For this reason, various international guidelines (such as the NICE and the AAGBI guidelines) support the use of ultrasound in CVC puncture to improve the safety of vascular accesss.[6,7]

In addition to CVC puncture, ultrasound (US) is also more frequently used in dialysis shunt puncture and guided punctures in young children.[8-10] Ultrasound-guided punctures require good hand–eye coordination. It is important to practice these skills in vitro before performing them on patients. Simulation-based instead of patient-based technical skills training has generated much enthusiasm and is becoming common practice.[2,11-13]

Ultrasound-guided puncture training requires an adequate training phantom that mimics the US characteristics and provides haptic feedback of real tissue and veins in a sufficient way. Phantoms are available (e.g. Blue Phantom) in various forms with one thing in common: they are expensive, with prices up to $6000 (http://www.sonositeeducation.com/). Many institutions do not have access to funds for these expensive models and therefore cheaper phantom models are warranted. The aim of this proof of concept study was to evaluate whether it is feasible to produce and evaluate a low-cost, but realistic, phantom to provide training for dual-handed movements and the hand–eye coordination needed for USG-CVC and other US-guided punctures. In addition, the quality and utility of the phantom as experienced by participants during US-guided punctures was reviewed. Training for further procedural steps after gaining successful venous access fell outside the aims of this study.

Methods

All materials for the production of the phantom had to be available in a general hospital or regular store (Table 1). After a literature search (PubMed, Google Scholar and other non-conventional websites such as YouTube.com), we found several articles describing a home-made US phantom.[13-17] We combined several techniques and eventually came up with a durable phantom made from gelatine. This model differs from other models because of the prefilled tubes, the affordable silicone layer, which mimics the skin and, most importantly, the relatively long expiration date due to the addition of antiseptic solution to the gelatine solution.

There was no need for any form of institutional review board approval for this proof of concept study as no patients were involved and there were no additional health care costs.

Preparing the phantom

A step by step approach is shown in Table 2. The primary ingredient for the phantom was a gelatine mixture (Dr. Oetker gelatine powder). First, the desired volume for our model was defined. For every 250 mL, 35 g of gelatine powder was mixed with 250 mL of water just below boiling point to minimize excessive water evaporation. The

Table 1 Materials

Water
Unflavoured gelatine powder
Sugar-free Metamucil
Latex/silicone tubes (thin walled and variable diameters)
Thin silicone dressing (e.g. a silicone baking mat)
Aseptic alcohol-based solution
Red colour additive
Plastic container
Hot glue gun

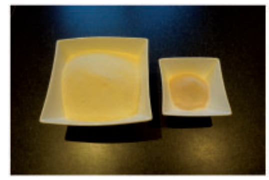
Table 2 Preparation guide

Step 1: prepare the gelatine mixture

Mix 35 g of gelatine powder per 250 mL of water just below boiling temperature

Add one tablespoon (15 g) of Metamucil for every 250 mL of water

Add 15 mL of alcohol-based antiseptic solution (chlorhexidine 0.5% in alcohol 70%, Orphi Farma) per 250 mL of water




Step 2: prepare the vein and artery

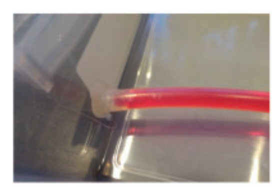
Fill the silicone tubes with red-coloured water (tap water coloured with red food colouring) and seal them off at each end with hot glue (standard hot glue gun will suffice)


Step 3: prepare the container

Place the tubes in the container, in the desired configuration and location, fix the tubes to the container wall with hot glue

Make sure the tubes are placed at a minimum depth of 1.5 cm from the surface

Rinse the container with antiseptic solution

Step 4: fill the container

Pour the gelatine solution into the container after it has cooled down but is still liquid

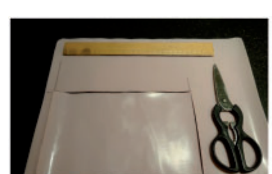
Place the container in the fridge

Step 5: the artificial skin

Cut the silicone (baking) mat to the desired size

Place this silicone layer on the chilled gelatine solution to mimic the skin

Rinse the silicone layer and the surface of the gelatine with antiseptic solution




gelatine was completely dissolved in the water before one tablespoon (15 g) of Metamucil for every 250 mL of water was added. These fibres mimic the echo-density or scattering of human tissue seen with ultrasound. When partially cooled down, 15 mL of alcohol-based antiseptic solution (chlorhexidine 0.5% in alcohol 70%, Orphi Farma) per 250 mL of water was added to optimize aseptic properties and hence durability.

Container

A plastic container (26 × 15 × 7 cm) was used. A gelatine mixture with a total volume of approximately 2.75 L was needed to fill this container (Table 2). The tubes simulating the vessels were measured so that they would just fit in the container. If desired, curves can be made using a slightly longer tube, to mimic a curved vein to increase the level of difficulty. We used silicone tubes normally used as laparoscopic gas tubes in the operating theatre (silicone, inner diameter 5 mm, wall thickness 1 mm). The silicone tubes were filled with red-coloured water (tap water coloured with red food colouring) and were sealed at each end with hot glue (a standard hot glue gun was sufficient). To mimic veins, the tube was not entirely filled with water to make it easily compressible. To mimic an artery, a tube of smaller diameter with less compressibility was used. We used a silicone tube (inner diameter 2 mm, wall thickness 1 mm) but other materials, for example, a stiff gastric tube could also be used to mimic the lesser compressibility of an artery. Both tubes were placed inside the container and attached to the container wall with hot glue. The vein and artery were placed parallel to each other in the same model in order to mimic a real-life situation, but other anatomic variations can also be mimicked (Fig. 1). Finally, the container and tubes were cleaned with alcohol to improve aseptic properties. In addition to the silicone gas tubes just described, other non-conventional tubes can also be used, for example, a racing bicycle tyre.

Filling the container

The hand-warm gelatine mixture was poured into the container. Debris was filtered out with a spoon. The container was filled in such a manner that the tubes were situated approximately 1.5–2 cm beneath the gelatine surface. This is important to seal puncture holes automatically when training. The phantom was chilled in a refrigerator at 5–7°C for approximately 2–3 h until the gelatine hardened.

Skin top layer

A silicone dressing (La Cucina silicone baking mat) was cut in the shape and dimensions of the container and placed on the gelatine surface to mimic the skin. The gelatine and silicone dressing were covered with a thin layer of alcohol, again for better aseptic properties.

Questionnaire

In two hospitals, one peripheral teaching hospital and one academic centre in the south of the Netherlands, a total of 20 medical practitioners with experience in USG-CVC insertion were asked to perform a US-guided puncture on this model. In addition, they were asked anonymously to assess the quality of the phantom by completing a questionnaire. We collected personal information (e.g. age, gender, hand preference), general medical experience and specific ultrasound and CVC insertion experience from all participants. To assess the quality of the phantom, participants were asked to rate realism and procedural aspects using a 5-point Likert scale, ranging from 1 (absolutely unrealistic/negative/bad compared with the real-life situation) to 5 (very realistic/positive/excellent compared with the real-life situation). For example, with regard to vein compressibility/compliance a score of 1 was considered absolutely unrealistic compliance compared with the real-life situation and a score of 5 indicated very realistic compliance. Participants were also asked to give a free text commentary after

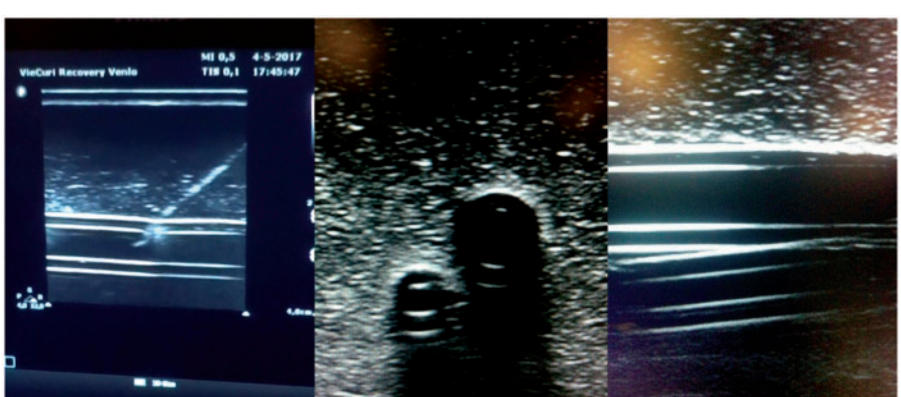


Figure 1. Ultrasound image. From left to right: longitudinal image with needle; transverse image; longitudinal image with two vascular structures, vein above artery.

completing the questionnaire. No additional information or instructions were given before testing the model.

Results

Six females and 14 males aged 24–55 years (mean 35 years, SD ± 9.0) participated in the study. All but two were right-handed. Participants were surgical residents and surgeons, with an average experience of 10–50 non-USG-CVC procedures and 20–50 USG-CVC procedures.

The results of the questionnaire are shown in Table 3. Realism, including global impression, movement of the transducer head over the surface and haptic feedback of the gelatine mixture and veins to compression and needle puncture were rated moderate (mean, 3 out of 5) by participants. Procedural aspects, such as US-guided puncture training and training of hand–eye movement were rated good (mean, 4 out of 5*)*. Taking realism and procedural aspects into account, participants rated the phantom as good (mean, 4 out of 5).

Table 3 Outcomes questionnaire

No. of participants	20
Age, years (range, ± SD)	35 (24–55, ± 9.0)
Realism, mean (range)	
Global impression	3 (2–5)
Transducer motion over surface	4 (2–5)
Haptic feedback of the tissue	3 (2–4)
Resistance of the materials on needle puncture	3 (2–4)
Compliance of the veins	3 (2–5)
Compliance of the artery	3 (2–4)
Procedural aspects, mean (range)	
Is it possible to perform the different steps of USG puncture on this model?	4 (1–5)
Is this a good tool for training USG puncture?	4 (3–5)
Do you think hand–eye coordination will improve when training on this phantom?	4 (4–5)
What's your overall opinion about the phantom? (mean, range)	4 (3–5)

Discussion and conclusion

As the costs of current US phantoms are high, there is a need for the development of low-cost phantoms. The present proof of concept study shows that it is possible to produce a realistic phantom for training on US-guided punctures using inexpensive and easily accessible products.

There are only a few published articles describing phantoms made out of gelatine, all with different compositions. In addition, several sets of instructions for manufacturing silicone phantoms can be found on online.[13-15] However, no structured evaluations of the performance of these models in practice are available in the literature.

Our model differs from others due to the combination of prefilled tubes, the affordable silicone layer mimicking the skin and, most importantly, the relatively long expiration date due to the addition of the antiseptic solution to the gelatine mixture.

The phantom used in the present study was rated good (mean, 4 out of 5) by 20 independent medical professionals in terms of realism and procedural aspects. This confirms the feasibility of these phantoms for US-guided puncture training.

US-guided punctures, in any form, require simultaneous bimanual hand movements and hand–eye coordination. In daily practice, residents often practice these procedures directly on the patient, guided by their supervisors. However, it is common to practice surgical techniques on simulation models and the available literature indicates the benefits of these simulation models.[16-19] Our model is especially designed to practice these skills without increasing the cost of educational programmes. The total costs are less than $10 per phantom and, when stored in a cooler, it can be used for longer than a month. Production time depends on experience with the phantom; our average production time was 20–30 min.

To reduce costs, readily available materials were used and gelatine was the core substance for the phantom. Although the gelatine substance used in our model gave results resembling the ultrasound signal in human tissue, the different ultrasound signals for different layers (e.g. epidermis, muscle) of real human tissue are not taken into account in this model. In addition, the use of tubes does not optimally mimic compliance of vessels. Usage of other materials would probably optimize the overall performance of the model, although this might increase the costs. It is debatable if these improvements are necessary as the training of hand–eye coordination needed for US puncture is the main purpose of this model. Training on further procedural steps after gaining successful venous access is not possible with this model.

There are some limitations to this proof of concept study. The handling of this basic model was assessed by a small group of 20 experienced medical professionals in only two medical centres. There was no comparison with an alternative model, therefore randomization or blinding was impossible. The questionnaire was structured but not validated, although its design was based on other comparable studies.[20-22]

Even though the questionnaire was not validated, most participants rated the phantom as useful and representative and as a good tool to train US-guided venous punctures. Despite the limitations discussed, the authors believe that the results are representative and reproducible. At a cost of less than $10 per model, hand–eye coordination can be practised in a safe in vitro environment.

In conclusion, the present study shows that a home-made, gelatine phantom is a promising alternative to expensive commercial phantoms for training of US-guided punctures. Consequently, these easily accessible models could be used as a basic training tool for other medical workers such as specialized nurses for dialysis shunting or for punctures in paediatric patients. The model from this study is currently in development. In the future, it is important to test this model in a structured educational course to evaluate whether training with this model will improve procedural performance of the trainee. This also requires further development and testing. A multi-centre, blinded, head-to-head comparison with an official/commercial phantom would be interesting to assess the additional value of an expensive model over a gelatine-based model.

Funding

No specific grants from funding agencies of the public, commercial, or not-for-profit sectors were received for this study.

Conflict of interest

The authors have no conflicts of interest to declare.

References

1. Lamperti M, Bodenham AR, Pittiruti M, Blaivas M, Augoustides JG, Elbarbary M, et al. International evidence-based recommendations on ultrasound-guided vascular access. Intensive Care Med 2012; 38: 1105–1117. https://doi.org/10.1007/s00134-012-2597-x.
2. Ma IW, Brindle ME, Ronksley PE, Lorenzetti DL, Sauve RS, Ghali WA. Use of simulation-based education to improve outcomes of central venous catheterization: a systematic review and meta-analysis. Acad Med 2011; 86: 1137–1147. https://doi.org/10.1097/ACM.0b013e318226a204.
3. McGee DC, Gould MK. Preventing complications of central venous catheterization. N Engl J Med 2003; 348: 1123–1133. https://doi.org/10.1056/NEJMra011883.
4. Rando K, Castelli J, Pratt JP, Scavino M, Rey G, Rocca ME, et al. Ultrasound-guided internal jugular vein catheterization: a randomized controlled trial. Heart Lung Vessel 2014; 6: 13–23. PMCID: PMC4009593.
5. Dolu H, Goksu S, Sahin L, Ozen O, Eken L. Comparison of an ultrasound-guided technique versus a landmark-guided technique for internal jugular vein cannulation. J Clin Monit Comput 2015; 29: 177–182. https://doi.org/10.1007/s10877-014-9585-3.
6. National Institute for Health and Care Excellence (NICE). Guidance on the use of ultrasound locating devices for placing central venous catheters. Technology appraisal guidance [TA49]. 2012. Available at: https://www.nice.org.uk/guidance/ta49 (accessed 20 June 2017).
7. Bodenham Chair A, Babu S, Bennett J, Binks R, Fee P, Fox B, et al. Association of Anaesthetists of Great Britain and Ireland: safe vascular access 2016. Anaesthesia 2016; 71: 573–585. https://doi.org/10.1111/anae.13360.
8. Marticorena RM, Mills L, Sutherland K, McBride N, Kumar L, Bachynski JC, et al. Development of competencies for the use of bedside ultrasound for assessment and cannulation of hemodialysis vascular access. CANNT J. 2015; 25: 28–32. PMID:26964424.
9. Mills C, Pritchard T. A competency framework for nurses in specialist roles. Nurs Times 2004; 100: 28–29.
10. Shime N, Hosokawa K, MacLaren G. Ultrasound imaging reduces failure rates of percutaneous central venous catheterization in children. Pediatr Crit Care Med 2015; 16: 718–725. https://doi.org/10.1097/PCC.0000000000000470.
11. Laack TA, Dong Y, Goyal DG, Sadosty AT, Suri HS, Dunn WF. Short-term and long-term impact of the central line workshop on resident clinical performance during simulated central line placement. Simul Healthc 2014; 9: 228–233. https://doi.org/10.1097/SIH.0000000000000015.
12. Moureau N, Lamperti M, Kelly LJ, Dawson R, Elbarbary M, van Boxtel AJ, et al. Evidence-based consensus on the insertion of central venous access devices: definition of minimal requirements for training. Br J Anaesth 2013; 110: 347–356. https://doi.org/10.1093/bja/aes499.
13. Gresens AA, Britt RC, Feliberti EC, Britt LD. Ultrasound-guided breast biopsy for surgical residents: evaluation of a phantom model. J Surg Educ 2012; 69: 411–415. https://doi.org/10.1016/j.jsurg.2011.10.015.
14. Tutorial for silicon phantom simulating an arm with vessels for ultrasound research. Available at http://www.instructables.com/id/Tutorial-for-silicon-phantom-simulating-an-arm-wit/ (accessed 30 June 2017).

15. Marticorena RM, Mills L, Sutherland K, McBride N, Keys C, Kumar L, et al. Making home-made phantom models for hemodialysis ultrasound vascular access assessment and real-time guided cannulation training. CANNT J 2016; 26: 34–38. PMID: 27215060.
16. Wells M, Goldstein L. The polony phantom: a cost-effective aid for teaching emergency ultrasound procedures. Int J Emerg Med 2010; 3: 115–118. https://doi.org/10.1007/s12245-009-0156-1.
17. Siegfried E. Homemade ultrasound IV model. 30 November 2012. https://www.youtube.com/watch?v=ypw8vjZ2DN0 (accessed 20 June 2017).
18. Davidson IJ, Lok C, Dolmatch B, Gallieni M, Nolen B, Pittiruti M, et al. Virtual reality: emerging role of simulation training in vascular access. Semin Nephrol 2012; 32: 572–581. https://doi.org/10.1016/j.semnephrol.2012.10.009.
19. Davidson IJ, Yoo MC, Biasucci DG, Browne P, Dees C, Dolmatch B, et al. Simulation training for vascular access interventions. J Vasc Access 2010; 11: 181–190. https://doi.org/10.5301/JVA.2010.5826.
20. Botden SM, Berlage JT, Schijven MP, Jakimowicz JJ. Face validity study of the ProMIS augmented reality laparoscopic suturing simulator. Surg Technol Int 2008; 17: 26–32. https://doi.org/10.1097/01266021-200600130-00016.
21. Botden SM, Buzink SN, Schijven MP, Jakimowicz JJ. Augmented versus virtual reality laparoscopic simulation: what is the difference? A comparison of the ProMIS augmented reality laparoscopic simulator versus LapSim virtual reality laparoscopic simulator. World J Surg 2007; 31: 764–772. https://doi.org/10.1007/s00268-006-0724-y.
22. Xiao D, Jakimowicz JJ, Albayrak A, Buzink SN, Botden SM, Goossens RH. Face, content, and construct validity of a novel portable ergonomic simulator for basic laparoscopic skills. J Surg Educ 2014; 71: 65–72. https://doi.org/10.1016/j.jsurg.2013.05.003.

Supplementary material

Video 1. A low cost gelatine phantom for simulating ultrasound guided central line placement: demonstration of use. Available online at https://youtu.be/EnH9rmjelRk