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Introducing ultrasound-guided vein catheterization into clinical practice: A step-by-step guide for organizing a hands-on training program with inexpensive handmade models

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KEYWORDS
Central vein catheterization;
Ultrasound;
Handmade models;
Training.

Abstract *Introduction:* Central vein catheterization (CVC) plays a central role in hospital patient management. Compared with the use of traditional anatomical landmarks, ultrasound-guidance is associated with higher CVC success rates, fewer complications, and more rapid central venous access. The use of US-guided CVC in clinical practice has not become widespread, largely because anesthesiology and general surgery residents receive limited training in this technique. To increase the use of US-guided CVC in our surgical department, we organized a hands-on training program based on the use of handmade models.
Methods: Three different models were constructed using plastic food-storage containers, segments of rubber tourniquet and silastic tubing (to simulate vessels), and agar gelatin.
Results: The hands-on training course allowed progressive acquisition of the basic hand—eye coordination skills necessary for performing US-guided venipuncture. The overall cost for each model was less than €5.00.
Discussion: The models described in this report are useful tools for teaching US-guided CVC. Thanks to their low-cost, they can be widely used to facilitate the introduction of this technique in clinical practice.

Sommario *Introduzione:* Il catetererismo venoso centrale (CVC) riveste un ruolo fondamentale nella gestione del paziente ospedalizzato. La tecnica eco-guidata è la metodica che assicura una più elevata percentuale di successo e permette un più sicuro e rapido posizionamento di CVC rispetto alla tecnica tradizionale. Tuttavia, la diffusione di tale metodica è ostacolata dall'assenza di uno specifico training durante i corsi di specializzazione in anestesia e chirurgia.

Al fine di introdurre la tecnica eco-guidata, abbiamo organizzato un training producendo e utilizzando modelli in agar.

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Metodi: Sono stati costruiti tre differenti modelli utilizzando contenitori per alimenti, segmenti di laccio emostatico, tubo in silicone e gelatina a base di agar.
Risultati: Un training specifico per la puntura eco-guidata è stato effettuato utilizzando i modelli prodotti. Il training ha consentito una rapida acquisizione delle basi tecniche per effettuare il posizionamento di CVC eco-guidato. Il costo medio di ogni modello è risultato inferiore a 5 euro.
Discussione: I modelli prodotti in agar si sono rivelati un utile strumento per acquisire la coordinazione di base necessaria per la puntura eco-guidata. Il loro basso costo ne può permettere una ampia diffusione e può incentivare la realizzazione di nuovi percorsi educativi al fine di introdurre tale tecnica nella pratica clinica.

Introduction

Central venous catheterization (CVC) plays an important role in patient management in a wide range of clinical settings: it is extensively used for perioperative hemodynamic monitoring and for central administration of medications and fluids. Guidance for CVC is traditionally based on external anatomical landmarks, but this approach is associated with complication rates that generally range from 5% to 10% [1—3] and may be as high as 40% if the operator is inexperienced [4]. In addition to the physician's experience and the characteristics of the patient, the catheterization technique is also a strong determinant of success and complication rates. In difficult cases, several needle passes are frequently required to locate the vessel, and this increases the incidence of complications, including arterial puncture, hematoma, pneumothorax, hemothorax, cardiac tamponade, nerve injuries, and death [5,6].

Ultrasound (US) guidance offers clear benefits over the landmark-based method. The physician can visualize the vessels, check their patency, and carry out the puncture under direct vision. The result is a higher rate of success on the first attempt, lower rates of technical failure, fewer complications, and faster access [7,8]. Continuous improvement of cost-accessible portable scanners has placed US technology in the hands of specialists in numerous fields other than radiology. The use of US-guided CVC in clinical practice has not become widespread, largely because anesthesiology and general surgery residents receive limited training in this technique. To introduce US-guided CVC in our department, we organized a hands-on training course with low-cost handmade models.

Materials and methods

Basic materials

Using common plastic food-storage containers filled with agar-based gelatin, we created three models that can be used to train physicians in US-guided CVC. Large vessels were simulated within the models by segments of common rubber tourniquet tubing with an outer diameter of 9 mm and inner lumen of 7 mm. Segments of silastic tubing (outer diameter, 6 mm, inner lumen 2.5 mm) were used to represent small vessels (Fig. 1). The gelatin solution was prepared with 100 g of standard agar powder in 4 l of water. The solution was heated slowly to the boiling point, stirred for 1 min, and transferred to the containers.

Model A

Model A was designed to represent two pairs of vessels with different diameters beneath a flat surface (Fig. 2a). It was constructed with a rectangular plastic container (1 l), two segments of rubber tourniquet tubing, two segments of silastic tubing, two strips of common boxboard, eight pins, and transparent plastic adhesive tape (Fig. 2b). Four pins were pushed through each strip of boxboard, at equal distances from one another (Fig. 2c), and the segments of tubing used to simulate vessels were attached to the pins (Fig. 2d). The suspended vessels were placed inside the

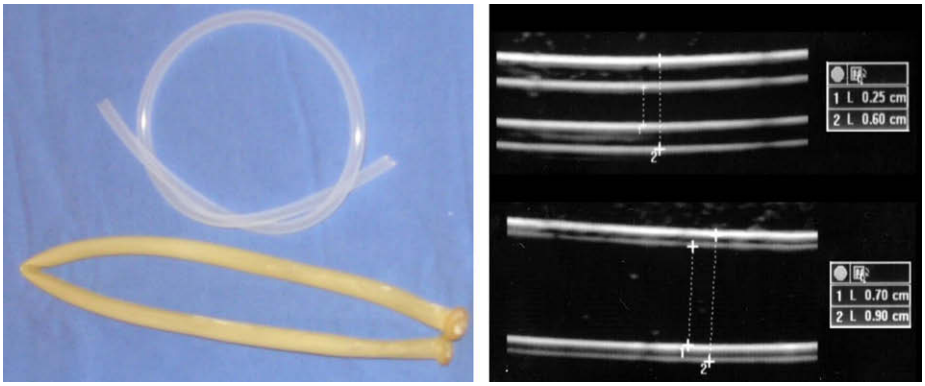

Fig. 1 Left: segments of silastic tubing (top) and common rubber tourniquet tubing (bottom) were used to simulate vessels. Right: the ultrasound appearance and measured diameters of the simulated vessels within the agar models.

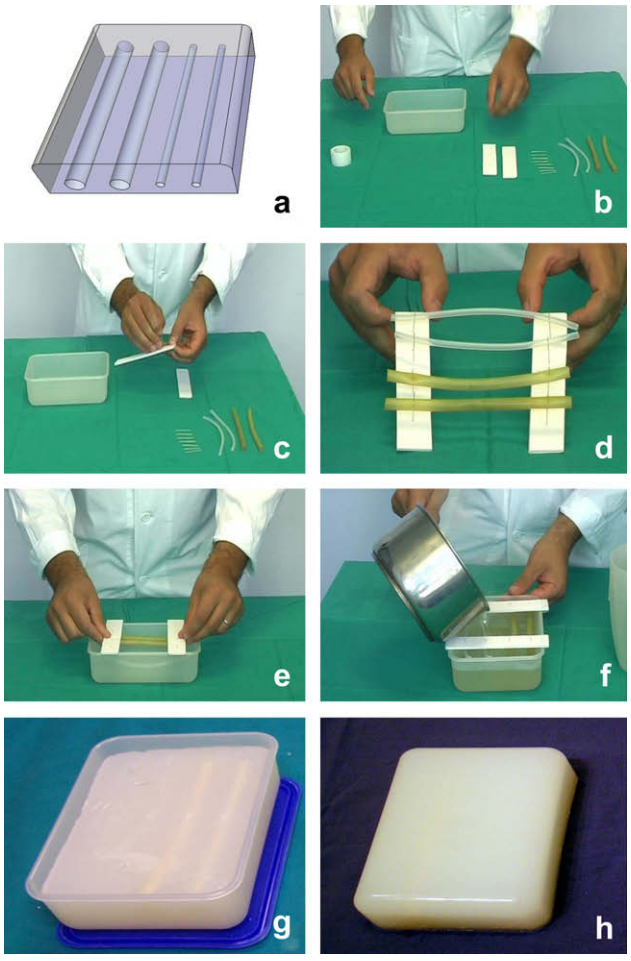

Fig. 2 Creation of Model A: schematic representation of the model (a) and the materials used to construct it (b). Pins are pushed through the boxboard strips (c) and used to suspend the segments of tourniquet and silastic tubing (d). The position of the simulated vessels within the model is controlled by moving the pins (e). The liquid agar is then poured into the container (f) and allowed to set overnight in the refrigerator (g). The final appearance of the model (h).

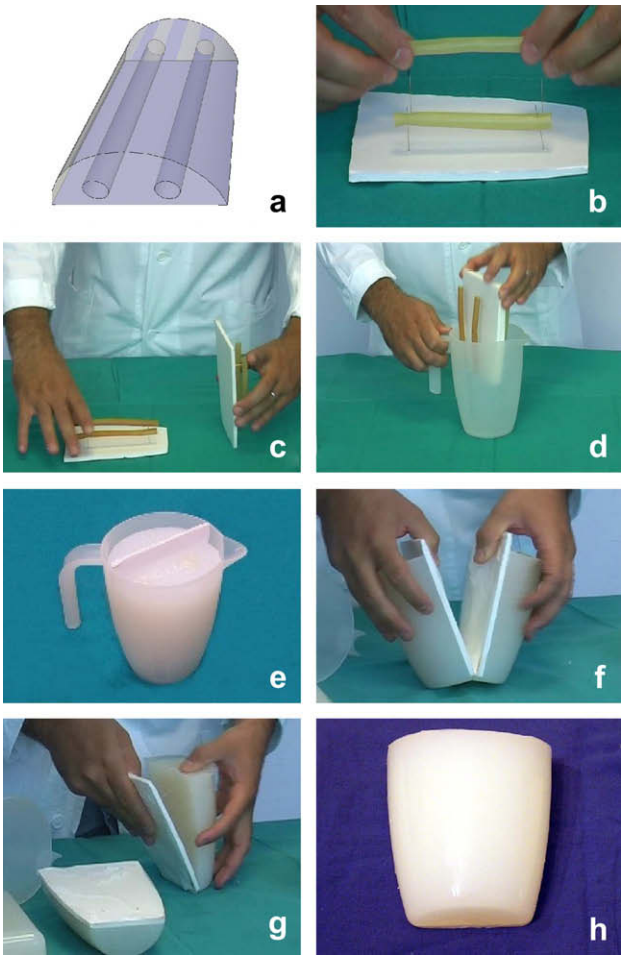

Fig. 3 Creation of Model B: schematic representation of the model (a). Segments of rubber tourniquet tubing are suspended from pins on two identical boxboard panels (b). The panels are placed back-to-back and inserted into a 2-l plastic pitcher (c, d). The pitcher is filled with liquid gelatin and placed in the refrigerator (e). The solidified gelatin block is removed from the container and the two halves are separated (f). The boxboards and pins are easily detached (g). The result is two copies of Model B (h).

plastic container, and the boxboard strips fixed with tape. The final position of the ''vessels'' was adjusted by moving the pins upward and downward (Fig. 2e).

The container was then filled with the gelatin solution (Fig. 2f) and placed in the refrigerator (4 °C) overnight. Once the gelatin had set, the boxboards and the pins were easily removed (Fig. 2g), and model was removed from the plastic container (Fig. 2h).

Model B

Model B was characterized by the presence of large vessels under a curved surface (Fig. 3a). As in the construction of Model A, two segments of rubber tourniquet tubing were suspended by pins from a boxboard panel (Fig. 3b). A second identical panel was constructed, and the two were placed back-to-back inside a 2-l plastic pitcher (Fig. 3c, d). The pitcher was filled with gelatin solution, which was allowed to solidify in the refrigerator (Fig. 3e). The gelatin block was then removed from the jug, and the two boxboard panels separated (Fig. 3f). The boxboards and pins were removed (Fig. 3g). The result was two identical copies of Model B (Fig. 3h).

Model C

A loop of silastic tubing under a curved surface was the distinctive feature of Model C (Fig. 4a). A length of silastic tubing was attached to a panel of boxboard with three pins (Fig. 4b). Two identical panels of this type were coupled back-to-back and inserted into a 1-l plastic pitcher, as in Model B (Fig. 4c, d). The gelatin solution was then poured into the container (Fig. 4e). When the gelatin had set, the two halves were divided and the boxboards detached (Fig. 4f, g). The two ends of the silastic-tube loop protruded from the end of the gelatin model (Fig. 4h).

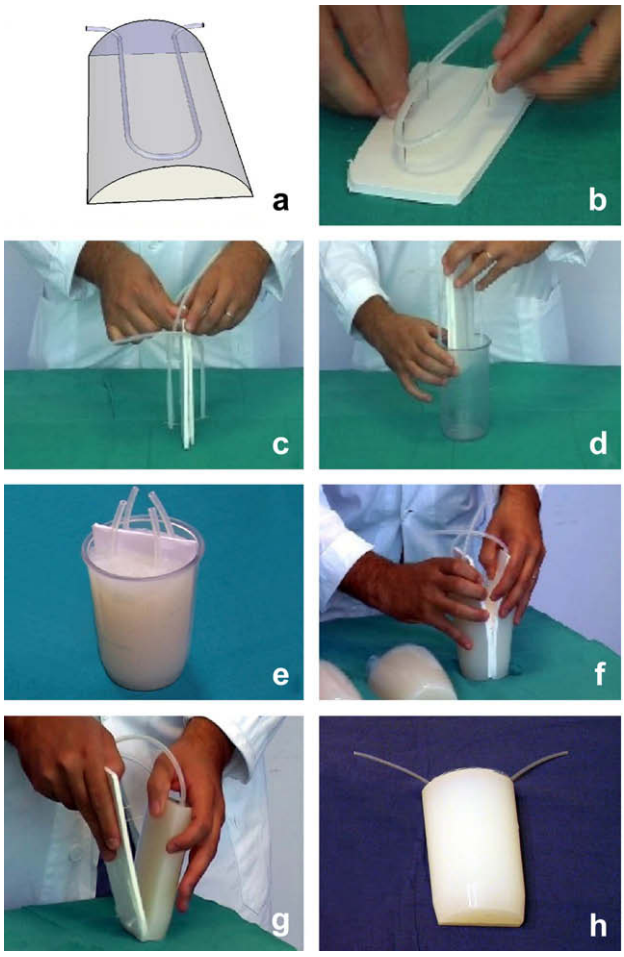

Fig. 4 Creation of Model C: schematic representation of the model (a). Loops of silastic tubing are fixed to boxboard panels with pins (b), and the two panels are placed back-to-back inside a 1-l plastic pitcher, as in Model B (c, d). The gelatin solution is poured into the jug (e). The two halves of the model are separated and the boxboard panels removed (f, g). The final appearance of Model C with the ends of the silastic loop protruding from the gelatin (h).

Training

The training session began with a 30-min lecture that covered basic ultrasound concepts, vascular image interpretation, and the US-guided vessel puncture technique. For the hands-on sessions, we used a portable ultrasound unit with a linear probe (8—10 MHz) (LOGIQ™ Book XP, GE Medical System, Milwaukee, Wisconsin, USA). To prolong the ''life-expectancy'' of the models, we used an 18-gauge spinal needle with a central stylet, which minimized needle-track persistence within the gelatin after each puncture.

Each trainee who completed the course also received additional supervision by the course instructors the first times he or she was called upon to perform US-guided CVCs on patients hospitalized in our department. Informed consent was obtained from all of these patients, and the protocol for the training course itself was approved by the Medical Research Ethics Committee of our institute.

Results

We created three different agar-based models with specific features that allowed us to organize a training course in US-guided CVC with progressive complexity.

Model A represented a situation characterized by large vessels under a flat surface. It was used to introduce the basic skills of US-guided vessel puncture. The trainee visualized the simulated vessels in both transverse and longitudinal scans, and the technique of US-guided puncture was explained and then demonstrated. Particular emphasis was placed on the importance of following the progress of the needle tip during the procedure (Fig. 5). The vessels were located on a transverse US view. Once the vessel has been viewed in the center of the US screen, the needle was introduced perpendicularly to the middle portion of the probe with variable angle of entrance with respect to the surface of the model. The position of the needle tip was assessed by moving the needle back and forth, and control of the direction and depth was obtained by moving the US probe in the direction of the needle progression. Placement of the needle was considered correct when the tip was clearly seen within the lumen of the tubes (Fig. 6).

Once the technique of US-guided puncture of large vessels had been mastered by the trainees, the technique of small vessel puncture was introduced with Model A

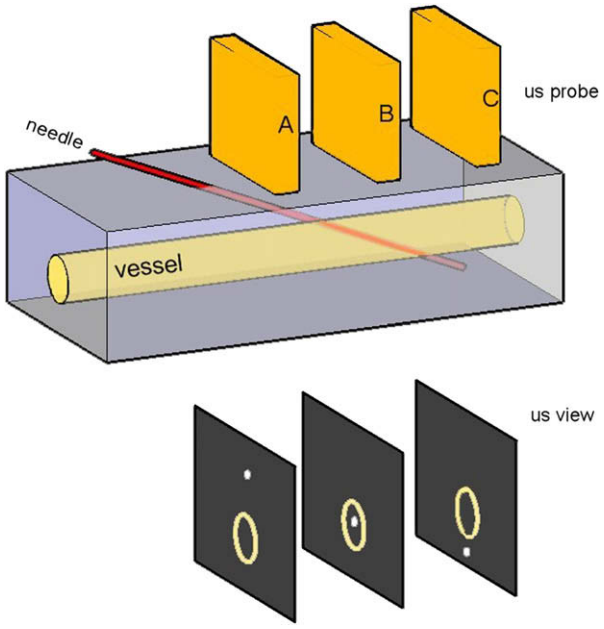

Fig. 5 Basic concepts of needle placement are demonstrated. Upper panel: needle advancement through the model is shown in three different positions (a, b, and c) in relation to the vessel. Lower panel: transverse ultrasound views of the needle (white spot) and the vessel (gray circle). To determine the actual position of the needle tip, the operator moves the ultrasound probe in the direction of the needle advancement, from point A to point B. If the probe remains in position A while the needle is advanced to position B or C, the ultrasound image will not show the actual position of the needle tip.

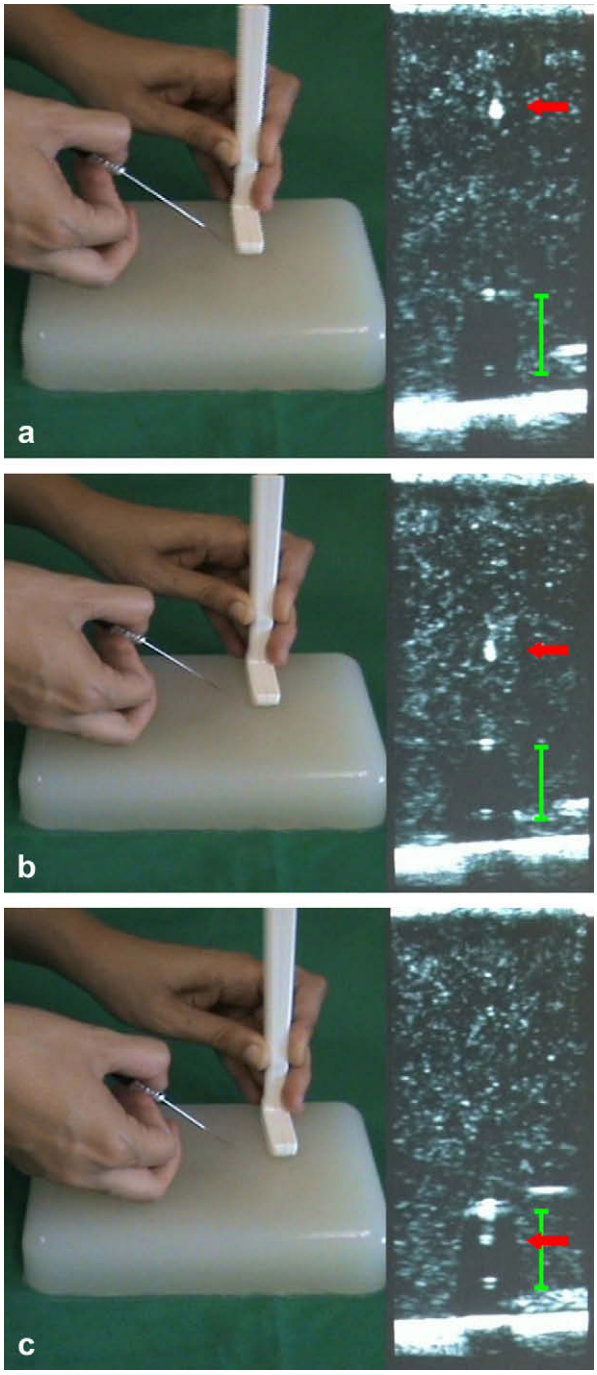

Fig. 6 Demonstration of ultrasound-guided vessel puncture. Images on the left show the external view; those on the right side are US images of the needle tip (red arrow) and the vessel in transverse view (green bar). The vessel is centered on the US screen, and the needle is introduced perpendicularly to the middle portion of the probe (a). The tip of the needle appears as a white spot on the US image. The needle is advanced (b) till it reaches the vessel lumen (c). The US probe is moved in the same direction as the needle.

(Fig. 7). Model B was then used to teach trainees to puncture a large vessel under a curved surface. The training session progressed with techniques that required increased dexterity. The particular features of Model C allowed us to introduce more advanced skills: assessment of blood flow. A bag of saline was attached to one end of the loop with standard intravenous infusion tubing, and an empty bag was attached to the opposite end of the loop. The fluid was allowed to flow through the loop, where it could be visualized in the color Doppler modality (Fig. 8). The correct position of the needle in the lumen could be also verified by visualizing fluid dripping from the needle when the stylet had been removed and the distal end of the loop clamped (Fig. 9).

Fig. 7 An anesthesiology resident practices her technique with Model A. To her right, Model C can be seen, connected to saline bags.

The exercises described above were completed by all trainees. The rate of successful first punctures increased steadily as the trainees progressed from simpler to more advanced techniques (Fig. 10).

Five models were produced. Between training sessions, they were stored at 4 °C. They were used repeatedly by 20 trainees for three consecutive weeks without any irreversible damage. The overall cost for all models was approximately €24.00 (€20.00 for the agar, €4.00 for the reusable materials).

Discussion

The US-guided technique is the safest and quickest approach to CVC, as shown by several authors [9—12]. For this reason, the Agency for Healthcare Research and Quality in the United States and the National Institute of Clinical Excellence in the United Kingdom both recommend the use of this method for CVC [13,14]. Despite its obvious advantages, US-guided CVC is not widely used in clinical practice, partly because residency programs in anesthesiology and general surgery do not provide specific training in this technique [15].

The US-guided technique requires accurate control of hand movements without direct vision, a specific skill (hand—eye coordination) that can be acquired and maintained only with practice. Proficiency in image interpretation and specific psychomotor skills is also essential. They can be acquired through lectures, demonstrations, and hand-on practice supervised by a skilled

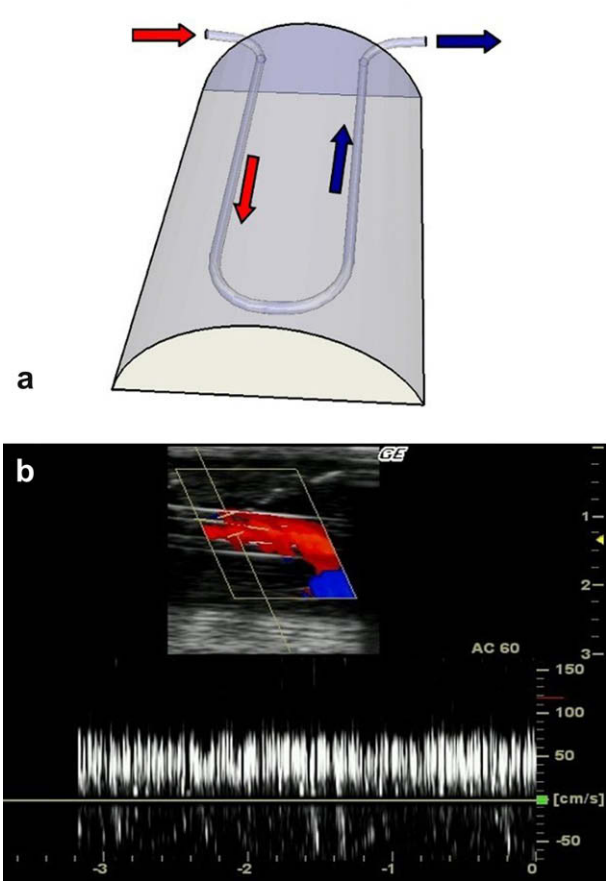

Fig. 8 Saline flowing through the loop of tubing in Model C simulated blood flow (a) that could be visualized in the color Doppler modality (b).

sonographer [16]. It seems reasonable and advisable to prepare and test trainees with hands-on simulation, and patients must also be protected from the high rate of complications associated with novice activity.

Commercial models and manikins are available and could be used to train residents, but their use is limited by their high-cost. In-house production of agar-based models represents an alternative solution, and experiences with this approach (for different purposes and with different models) are documented in the literature [17—19].

In order to render our experience more reproducible, we produced our models with materials that are easily accessible: plastic food-storage containers, which are present in every kitchen; agar powder, which can be bought in most herbalist shops or on Internet; and rubber tourniquet and silastic tubing, which can be found in medical-supply centers and hardware shops and are also available in every hospital.

As a tissue simulator, agar gelatin offered satisfactory ultrasound penetration, and the vessels and needle could be clearly identified within the model. The solidified gelatin was opaque, so the vessels were not visible from the outside. It had a firm texture that allowed smooth passage of the needle. The needle's penetration of the simulated vessel wall is visualized as a deformation of the vessel contour, and it can also be felt by the trainee.

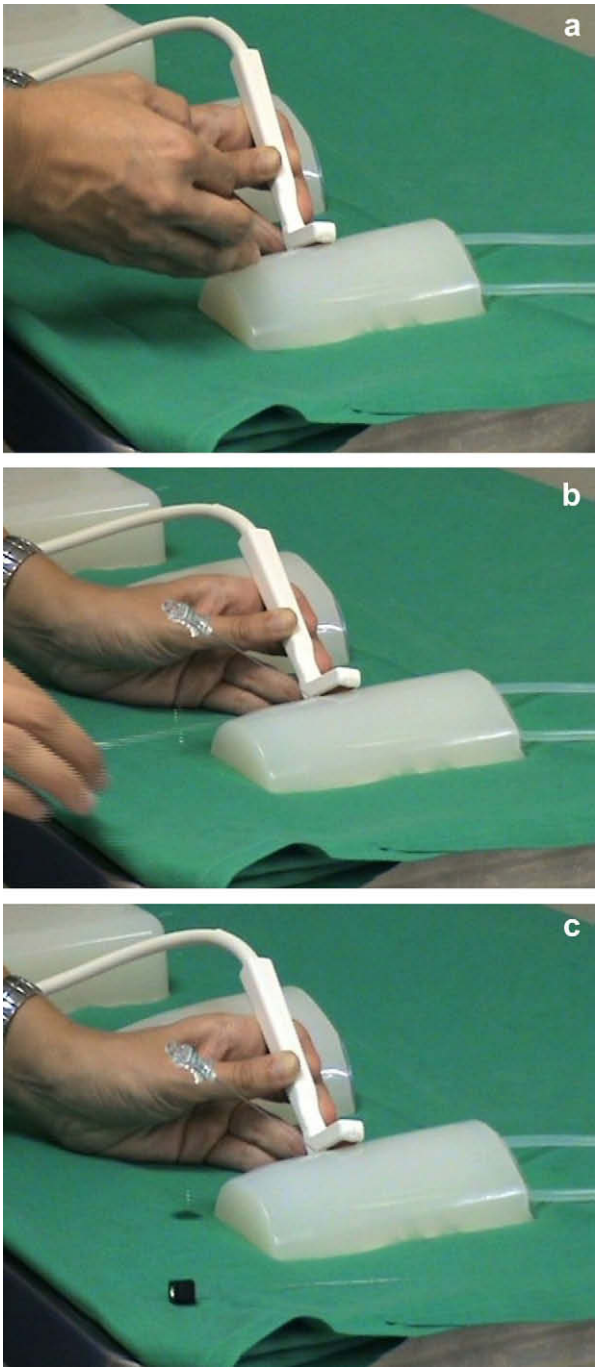

Fig. 9 During the puncture of the vessel in Model C (a), the correct position of the needle in the lumen can also be verified by removing the stylet (b). If the tip is in the lumen of the vessel, the simulated blood (saline) flows out through the shaft of the needle (c).

Our protocol allowed trainees to gradually acquire the basic hand—eye coordination skills necessary for performing US-guided vessel puncture. The participants initially learned to puncture different-sized vessels beneath a flat surface. Later, vessels under curved surfaces were punctured.

Although the basic skills of US-guided CVC are learned quickly, application of these skills in a clinical setting is

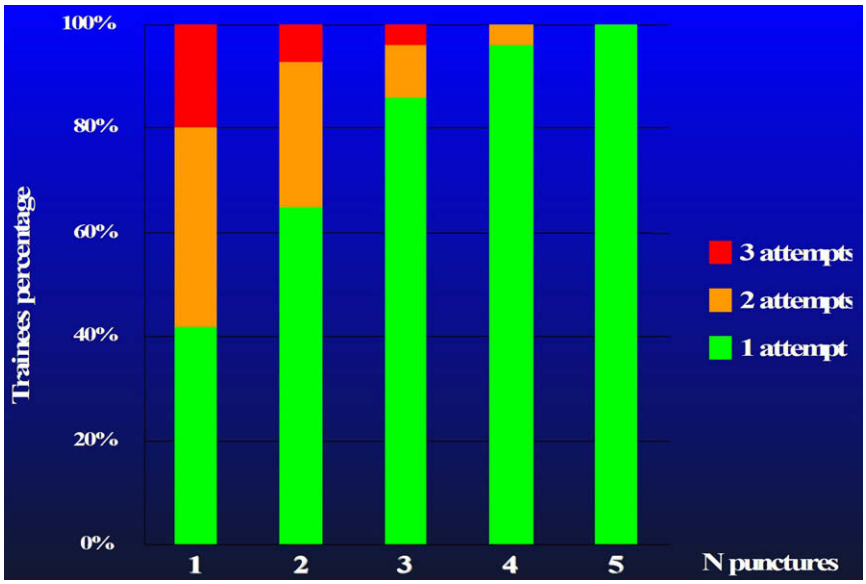

Fig. 10 The percentage of trainees who achieved correct needle positions on the first attempt increased steadily with repeated punctures, showing a quick acquisition of the basic skills of US-guided puncture.

not straightforward. For this reason, trainees received supplemental hours of supervision during their first CVCs performed on patients [16]. In our preliminary experience with this training protocol, the overall use of ultrasound-guidance increased markedly in our unit (from 2% to 23% of all CVCs) during the first month after the course [20].

In conclusion, agar-based models are useful tools for teaching residents the basic skills of US-guided CVC. Our experience shows that training sessions based on the use of are relatively simple to organize. Practice with these models before attempting CVC on a real patient may have potential benefits, and it may help to introduce this technique. Agar-based models are easy to prepare, and they can be made in different shapes in order to simulate increasingly complex clinical situations. Their cost (less than €5.00 per model) is also much lower than that of commercial training systems, making them ideal for use in hospitals with limited resources for medical training. They provide a simple, low-cost way to incorporate training in US-guided CVC into our anesthesiology and general surgery residency programs.

Conflict of interest

The authors have no conflict of interest.

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