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Simulators for training in ultrasound guided procedures

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Abstract

The four major categories of skill sets associated with proficiency in ultrasound guided regional anaesthesia are 1) understanding device operations, 2) image optimization, 3) image interpretation and 4) visualization of needle insertion and injection of the local anesthetic solution. Of these, visualization of needle insertion and injection of local anaesthetic solution can be practiced using simulators and phantoms. This survey of existing simulators summarizes advantages and disadvantages of each. Current deficits pertain to the validation process.

Keywords: ultrasound, skill, simulators, validity

Introduction

Simulation has been defined as "*a situation in which a particular set of conditions is created artificially in order to study or experience something that could exist in reality*" [1]. Simulation provides a safe and supportive educational climate [2]. Unlike patients, simulators do not become embarrassed or stressed; they have predictable behaviour; are available at any time to fit curricular needs; can be programmed to simulate selected findings, conditions, situations and complications; allow standardized experience for all trainees; can be used repeatedly with fidelity and reproducibility; and can be used to train for both clinical skills and examinations [3]. Increased attention to patient care and ethical issues, demands for innovation in clinical education and accelerating advances in diagnostic and therapeutic procedures have all prompted a growing interest in the use of simulators for medical training [4].

The skill set associated with proficiency as defined by the American Society of Regional Anesthesia and Pain Medicine (ASRA) and the European Society of Regional Anaesthesia and Pain Therapy (ESRA) joint committee recommendations for education and training in ultrasound-guided regional anesthesia are summarized in the Table I. The four major categories of skill sets associated with proficiency are 1) understanding device operations, 2) image optimization, 3) image interpretation and 4) visualization of needle insertion and injection of the local anesthetic solution. Of these, image optimization and image interpretation can be practiced on one self, colleagues and appropriate animal or cadavers models. Visualization of needle insertion and injection of local anaesthetic solution can be practiced using simulators and phantoms [5].

Deliberate practice entails the repetitive performance of carefully defined cognitive or psychomotor skills in a focused domain, coupled with rigorous skills assessment that provides the learner with specific, detailed feedback, to enable sustained improvement in performance [6]. A common feature of experts, in addition to gaining experience, is that they have performed years of deliberate practice. The attained level of expertise in the performance of

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Table I. Skill sets associated with proficiency (adapted from [5])

Understanding US image generation and device operation	**Image optimization**	**Image interpretation**	**Needling and injection**
Basic principles of image generations	P	Identification of nerves	In-plane technique
Selection of appropriate transducer	A	Identification of muscles and fascia	Out-of-plane technique
Selection of appropriate depth and focus	R	Identification of artery and vein	Benefits and limitations of both techniques
Appropriate use of time gain compensation and overall gain	T	Identification of bone and pleura	Recognition of intramuscular needle placement
Application of colour Doppler		Identification of acoustic artifacts	Proper ergonomics
Archiving images		Identification of anatomic artifacts	Minimize unintentional transducer movements
Follow ASRA-ESRA standardization for screen orientation to the patient		Identification of vessels in the needle pathway	Recognize intraneural needle placement

PART = Pressure, **A**lignment, **R**otation, **T**ilt

Table II. Characteristics of the ideal phantom for ultrasound guided procedures

An ideal phantom should:
Reproduce the texture and resistance of human tissue
Inhibit sideways movement of the needle
Have sufficient ultrasound penetration to enable identification and location of targets up to a depth of 10 cm
Be easily repairable, from the damage caused by needle insertion
Have targets that must be clearly distinguished from the surrounding medium in the ultrasound image
Have targets that do not corrode over time
Identify clearly to the operator when contact between needle and target has been made
Be affordable
Have a long shelf life
Have no infection issues
Be easily transportable
Be composed of non-perishable material
Have different levels of difficulty/complexity that can easily be changed
Be easily reproducible

sportsmen and musicians is related closely to the time devoted to deliberate practice [7-9]. Experts deliberately construct and seek out training situations to attain desired goals that exceed their current level of performance and that often require problem-solving and better methods of performing the tasks [7,10].

Simulation provides an opportunity for deliberate practice with immediate feedback that is not usually available in the operating theatre. Growing evidence demonstrates that simulation has a valuable role to play in the acquisition of procedural skills [11]. A simulator is simply a device, whose application determines its utility.

This paper describes the simulators currently available for learning ultrasound-guided procedures.

The ideal phantom

Characteristics of the ideal phantom are summarized in Table II. Additional features not presented in the table are as follows [12]:

– Approximate matching of the velocity of sound is desirable as this determines distances in the ultrasound image; however close matching of the attenuation of the medium with tissue is otherwise unnecessary;

Table III. Simulators currently available for training in US-guided procedures

Simulators currently available for training in US-guided procedures		
Simulators	**Positive Points**	**Negative Points**
Turkey and chicken breast model [13] Porcine shoulder [14] Leg of lamb with metal rod [15]	Realistic feel for tissue Natural structures present, can embed targets	Short shelf life Infection risk Messy Expensive Need preparation time
Tofu model [16]	Simple, affordable, portable, degree of complexity can be changed, target can be inserted but not embedded	Not easily available, breaks down on pressure, Cannot embed target, Seeps water over time Needs refrigeration Too uniform in echographic appearance Not injectable Infection issue
Blue Phantom [17]	Portable Realistic No infection issues Large scanning surface May be possible to inject, Long shelf life Reusable	Expensive Preformed Cannot embed additional targets Fixed targets Needle track Non tissue like haptics
Gelatin based model [12]	Cheap, Portable, Large scanning surface Injectable targets can be embedded Appearance and shape can be modified Transparency can be changed Reproducible	Needs preparation time Needle tracks after every use, Shelf life of 2 - 3 weeks Uniform appearance Breaks on excessive pressure
Agar based [18]	Targets can be placed Level of difficulty may be increased Portable	Growth and transmission of infection as organic base and a culture medium Agar is not easily available Memory (needle tracks) after each needle pass Need for preparation time May be expensive according to geographical location
Premisorb based [19]	No infection issue Cheap Portable	Availability Dangers of chemical exposure Haptics may be inaccurate Target placement may not be reproducible
Silicone based [21]	No infection issue, Produces sound on needle contact with nerve structure Flow identifiable via Doppler	Price has not been quoted Memory after each needle pass Little space for needling
Cadavers [22, 23]	Anatomical relevance	Infection issue, Availability Storage problems
Computer [24]	No infection issues Level of difficulty/complexity may be changed	Expensive Need for IT support Not easily portable Inaccurate haptics

– The targets must be clearly distinguished from the surrounding medium in the ultrasound image, but the difference in acoustic impedances should not be so great as to produce reverberations;

– The level of difficulty/complexity should be amenable to change according to the level of the trainee or requirement of the trainee.

The advantages and disadvantages of each of the different phantoms available or reported in the literature are summarized in Table III.

Animal Models

Turkey and chicken breast model

Turkeys are purchased whole and the legs and wings removed. The breast is left intact, attached to the sternum. A space is bluntly dissected between the pectoral muscles beginning at the cavity of the turkey on the side opposite the sternum, at the edge of the rib cage. Small Spanish pimento-filled olives are placed between the muscles in the turkey breast while it is submerged in water. The target is identified as the pimento within the olive (mean antero-posterior diameter 3 mm; mean width 3 mm; mean length 10 mm). Turkey and chicken breast may be used with a number of targets that can be imbedded using dissection techniques [13].

Advantages include wide availability, realistic feel of the tissues (haptics), presence of blood vessels, bones and nerves and the possibility of imbedding targets in the model. These allow a realistic feel of tissue handling and ultrasound image acquisition for the learner.

Porcine joint/ shoulder or leg of lamb with metal rod

In this described model the tendon is used instead of nerve because nerves are generally not available for purchase. A piece of pork shoulder, preferably with the humerus attached, is carved to approximately 20 x 12 x 8 cm (length x width x height) in dimension. After removing the skin, the pork specimen is deodorized by soaking it in 20 to 30 mL of 70% alcohol inside a plastic bag for 8 to 10 hours at 4°C. A solid metal or plastic rod approximately 1.5 cm in diameter is used to pierce through the muscle layers and create a tunnel approximately 3 cm from the surface. A bovine tendon approximately 8 cm long and 1 cm in diameter is then pulled inside the tunnel. The whole phantom is then wrapped up in a transparent film, reinforced exteriorly by a surgical paper towel, and stored at 4°C until use.

A fresh leg of lamb weighing 1.5 to 2.5 kg may be acquired at the local halal butcher at a price of 20 to 30 Euro. It must contain a heel (Achilles) tendon, which is then softened by wrapping a gauze swab soaked in distilled water around it. The tendon is then cut off and used as a nerve. A 40-cm-long blunt metal rod is threaded between the muscles of the posterior thigh, with the intent of separating but not penetrating the muscles. The end of the tendon is sutured to the wide end of the metal rod and pulled inside the leg, so that only nylon sutures are visible outside. This model has muscles, fascia, and bone. The tendon has the echographic appearance of a nerve, the needle approach is visible just as in humans and injection of a normal saline solution is visible, albeit for a shorter time than in a patient. Injection of fluid inside this nerve model is also possible using high pressure and shows disruption of fibers. Short- and long-axis nerve scans, in-plane and out-of-plane needle insertion, visualization of a catheter advancement, and fluid injection through the catheter are all feasible [14,15].

Advantages include low cost, wide availability, ultrasonographic appearance of muscles and bone, and the embedded tendon mimicking a nerve appears predominantly hyperechoic. The “fibrillar pattern” seen on ultrasound resembles nerve fascicles. The tendon diameter may be varied and may be used for multiple needle passes. Needle-track artifacts are less likely to show after repeated needle punctures compared to a gelatin-based phantom, and saline injection around the target simulates a local anaesthetic injection.

Disadvantages of animal phantoms in general include high expenses, the issue of infection control, a short shelf life of a few days, the need for refrigeration, the time needed to prepare the model with the targets and the possibility of air trapping while preparing models [13-15].

Tofu model

The tofu model is a simple, inexpensive, portable and variable complexity design. It allows novice learners the opportunity to practice target localization and ultrasound-guided needle advancement towards a target. Targets structures (wood and wire) can be inserted [16]. The focus of this model is not on the skill of anatomical scanning, but rather to gain the technical skills necessary to direct the needle toward an established target, which is confirmed by both ultrasound image and tactile sense of needle contacting the target.

Advantages include easiness to construct including embedded targets, low price (although this may vary between countries), suitability for novices learning hand-eye co-ordination.

Disadvantages include availability of extra firm tofu (as the normal tofu easily breaks down on pressure for insertion of targets), too uniform an echogenic appearance, requirement for storage in a refrigerator, the seepage of water from the model over time, its non-injectable nature. In addition, the model constitutes an excellent growth medium for bacteria, hence raising infection control issues.

Blue Phantom

The blue phantom is a commercially available product [17]. It has been used for simulation for intravenous access as well as for other parts of the human body. Its use in regional anaesthesia training is limited.

Advantages include portability, a large scanning surface, long shelf life and the fact that it is reusable. The developers claim that in can be injected into as well.

Disadvantages include expense, preformed with fixed targets, additional targets cannot be imbedded, needle tracks are visible for a while (has a memory) and non-tissue like haptics.

Gelatin and agar based models

Gelatin based models have been used by radiologists for learning and teaching of ultrasound guided procedures [12]. The models are easily constructed by using basic kitchen utensils and have a lot of characteristics of the ideal model [12,18]. Like the tofu model, the gelatin and agar based models are suitable to learn hand-eye co-ordination. Any number of targets can be imbedded into the model, including starch blocks, raisins, peapods, wires, wood, tubing, etc.

Advantages include extremely low price, wide availability of ingredients, can be prepared with readily available kitchen utensils, portability, a large scanning surface, the possibility of embedding any number of targets. The model can be made clear or colored, of any size and shape according to the container used and is easily reproducible. Once used, the model can be disposed of safely as it does not contain any biohazard material. The gelatin model may be stored in the fridge for up-to two weeks if an anti-septic is used when preparing the model. Over time it seeps water much like the tofu model mentioned above.

Disadvantages pertain to the fact that for learning of regional anaesthesia, gelatin and agar based models pose problems with the haptics. Depending on the concentration used, the models can be easily damaged and the sideways needle movement may not be inhibited. Models are transparent unless color is added and have a uniform appearance on sonography unless additives (husk, corn flour, thickening agent) are used. Needle tracts are visible and may be mistaken for the needle. These models cannot be injected into unless it is in the target or if a potential space is made available. Agar may not be easily available in certain parts of the world.

Premisorb based model

This model can be constructed using materials available in the operating theatre complex. These include a clean used 500-mL plastic bag of IV fluids, a rubber stopper from the bag of IV fluids, a bottle of Premisorb, a piece of tape, a piece of foam padding, and scissors. Premisorb is a solidification product designed to absorb and encapsulate blood vomit or any fluid with at least 6% water content [19,20]. Premisorb in water creates a semi-transparent gel-like material with an ultrasound image similar to human muscle tissue. The imbedded blue color foam padding is easily visible through the transparent plastic bag and produces a relatively hyperechoic target comparable with a nerve on the ultrasound image. The gel-like semisolid material seals needle holes and also allows the instructor to move the simulated nerve target to different depths or positions in the bag.

Advantages: it is inexpensive, nonperishable, reusable, and easily transportable.

Disadvantages: Premisorb is not freely available in all theatre complexes. Furthermore, direct contact with the skin and chemical exposure may pose safety issues, such as contact dermatitis. Of note, the manufacturers do not recommend direct skin contact. As it is water based, haptics may not resemble human tissue and the placement of the target may be difficult.

Silicone based model

The silicone based model incorporates electrical components and equipment for pulsatile flow. The novelty of this model is that it produces a sound when the needle makes contact with the target structure. The model comes preformed with a structure that shows pulsatile flow [21].

Advantages include no infection issues, a long shelf life and its transportability.

Disadvantages include persistence of needle tracts after multiple uses, a small surface area for scanning, and the high market price. Other disadvantages are the preformed shape and size, the embedded target structure and the need for electronic/battery power.

Cadavers

Cadavers are useful tools for practical training in regional anaesthesia. Specific elements that may be taught utilizing cadavers include probe handling on irregular surfaces, needle- probe alignment, sono-anatomy and needle tracking to target structure [22,23].

Disadvantages include unavailability of cadavers, the ethical approval needed for such procedures, the cold storage needed, infection issues, and the absence of pulsatile flow.

Computer based simulators

Computer based high fidelity simulators have been used for training with ultrasound guided procedures but the obvious *disadvantages* are the costing, the need for IT support, and the altered haptics [24].

Advantages include the complete absence of infection control issues, the possibility of altering the level of complexity/ difficulty. The machines can be set up in a non-clinical setting such as a training room. The simulator may be available any time of the day or night.

Additional advantages include the size of the machine and the validity of the machinery and of the soft.

Current deficits

All of the described simulators have been used or are being used for training, not only of regional procedures but also for other procedural skills (vascular access, core biopsy, etc). Little is known about the validation process.

Validity is defined as “the property of being true, correct and in conformity with reality” [25]. Validity is not a simple notion; it is comprised of a number of first principles. A number of benchmarks have been developed to assess the validity of a test or testing instrument (Table IV).

All these validations have merit; however, predictive validity is the one most likely to provide clinically meaningful assessment. The others focus on the assessment of the training or test rather than the clinical outcome. There is a need for improved training strategies in all types of procedural skills. These skills have proved much harder to teach and master. The most important question to ask is does this device train or assess the skill it is supposed to? [25].

Skill generalization, skill transfer and skill acquisition

Skill generalization refers to the training situation where the trainee learns fundamental skills that are crucial to completion of the actual procedure. Skill transfer refers to a training modality that directly emulates the task to be performed in vivo or in the testing condition [25]. For skill generalization the simulator should teach basic psychomotor skills fundamental to performing a basic procedure as well as some skills required for more challenging procedures. For skill transfer the simulated procedure should look and feel similar to the actual procedure and should train skills that will directly transfer to the performed procedure.

Psychomotor skill acquisition is an essential pre-requisite for performance of a safe procedure. Traditionally, procedural skills have been acquired by trainees through an apprenticeship model. Trainees observe the supervisors and perform under their supervision until “mastery” has been achieved. With the reduction in training hours and hence patient exposure, the supervision and number of procedures performed during training have dropped drastically. The issues of patient safety, accountability in medical performance, professional requirements for uniformity in training and cost effectiveness in training arise with this reduction in trainee-patient exposure. The most reasonable solution seems to be simulation [25].

Future direction

There is a need for a safe, stress free environment for trainees for skill acquisition, generalization and transfer

Table IV. Types of validity of training/assessment systems

Types of Validity	Definition
Face	A type of validity that is assessed by having experts review the contents of a test to see if it seems appropriate
Content	An estimate of the validity of a testing instrument based on a detailed examination of the contents of the test items
Construct	A set of procedures for evaluating a testing instrument based on the degree to which the test items identify the quality, ability or trait it was designed to measure
Concurrent	An evaluation in which the relationship between the test scores and the scores on another instrument purporting to measure the same construct are related
Discriminate	An evaluation that reflects the extent to which the scores generated by the assessment tool actually correlate with factors with which they should correlate
Predictive	The extent to which the scores on a test are predictive of actual performance.

via deliberate practice. The reduction in training opportunity has a huge impact on skill acquisition. The numbers of simulators are ever increasing. The increase in fidelity is associated with an increase in cost. Trainees can acquire skill sets from different simulators according to their level of training. The trainers need to know how a trainee is progressing and where they are on their learning curve. Simulators are only part of the training solution confronting residency programs and credential committees around the world [25]. The true benefit of a simulator can only effectively be realized if they are integrated into a well thought out curriculum.

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