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ORIGINAL ARTICLE

# Learning curve of medical students in ultrasound-guided simulated nerve block

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**Abstract**

*Background* Good hand-eye coordination is a prerequisite for safe ultrasound-guided peripheral nerve blocks. However, new skills have to be acquired when compared to the traditional nerve stimulation technique. We tested and mathematically described the learning curve of these skills in inexperienced ultrasound users employing a simple phantom of a peripheral nerve.

*Methods* A simple phantom made from a piece of spaghetti to simulate a nerve, within a starch core and embedded in gelatine was used for ultrasound-guided simulation of a peripheral nerve block. Eighteen medical students who were novices to ultrasound were enrolled. Serial time to successful injection was measured. Quality of injection was rated by two independent observers.

*Results* Time to successful injection improved from a median of 66.5 s (49.5–90) for the first trial to 37 s (23.5–53.5) for the 11th trial. A plateau of 30 s was reached for $t_{1/2}$ after 2.7 trials and $4 \times t_{1/2}$ after 7.8 trials when described as first-order exponential decay. Time to successful injection was significantly shortened after 5 trials. Quality of injection with numbers of trials followed a sigmoidal shape with 50 % of maximum quality after 3.6 trials and a plateau after 8.5 trials. Likewise, a significant improved quality of injection was reached after 5 trials.

*Conclusion* Based on our mathematical analyses of the learning curve, inexperienced ultrasound users can improve their hand-eye coordination within 5 subsequent trials in a simple model of a peripheral nerve block.

**Keywords** Ultrasound · Peripheral nerve block · Education

## Introduction

Ultrasound in regional anesthesia for peripheral nerve block is becoming more popular but has its potential risks [1]. These include not visualizing the needle tip correctly: needle advancement can potentially injure the target nerves or adjacent tissue, including vessels [2, 3]. Despite this, training for ultrasound-guided peripheral nerve blocks (USPNB) has not reached a curricular level yet. An advantage of ultrasound seems to be its direct visualization as opposed to the nerve stimulating technique, which needs more experience and skills. However, so far there has not been enough evidence to conclude that USPNB is superior to comparable nerve identifying techniques [4]. Fundamental knowledge of anatomy and its variations are only the foundation of USPNB. Good hand-eye coordination is an important skill for safely advancing and placing a needle. Guidelines recommend that this skill should not be learned in patients, but rather be taught in a safe environment with the use of a phantom. Calculations from learning curves are useful for predicting numbers of trials before an ultrasound-inexperienced physician can safely perform an USPNB [5, 6]. We present a simple phantom of a peripheral nerve block which enables inexperienced ultrasound users to achieve good hand-eye coordination within a reasonable time as calculated by a mathematical model.

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## Methods

### Construction of an ultrasound phantom

Gelatine was used to form the basis of the ultrasound phantom. The use of gelatine provided an elastic, tissuelike characteristic for multiple fluid injections, and no outer membrane was needed. Gelatine (15 g) was dissolved in water and mixed with 1 g red food coloring to a total volume of 200 ml. A frame sized 12 × 7.5 × 5 cm was filled with liquid gelatine mass. Red food coloring was used to obscure the simulated nerve. Before the gelatine set, a straw with a 0.5 cm diameter was placed in the middle of the form as a placeholder for the simulated nerve and removed after the gelatine set. The cavity was filled with starch (16 g/100 ml water) and a dry piece of spaghetti (No. 5, Barilla$^{TM}$, Parma, Italy) was inserted in the middle. The spaghetti was at a depth of 2 cm from the surface. Strict care was taken to prevent air bubble inclusions which would produce ultrasound artifacts. To allow drainage and use of multiple injected fluids, the phantom was open at the edge. The choice of materials sufficiently mirrored tissue echogenicity in ultrasound (Fig. 1a). Instead of local anesthetics, a 0.9 % sodium chloride solution was used for injection. The phantom allowed multiple punctures and injections at different sites without changes in ultrasound visibility (Fig. 1b). However, each individual participant started with a new phantom.

### Ultrasound data acquisition

An ultrasound machine (Flex Focus 400, BK Medical, Quickborn, Germany) was employed which was equipped with a 12-MHz linear ultrasound probe. Cine loops were recorded to document each trial.

### Study participants

Eighteen medical students with no previous ultrasound experience were enrolled, i.e. no regular use and no previous participation in a course.

The students were introduced to the use of peripheral nerve blocks in anesthesia and an exemplary application of the 0.9 % sodium chloride solution with the ultrasound device was demonstrated. The introduction to ultrasound technique was performed as an on-screen presentation with a time duration of approximately 7 min followed by a short demonstration in how to operate the study ultrasound machine. Participants could not ask any questions between their trials or receive any further advice.

### Study protocol

Participants were not allowed to observe each other during the trials. One attempt was defined as the time duration between placing the transducer onto the model (start time) and the full application of saline solution (stop time). The quality of block was evaluated for each trial. Individual participants had a total number of 11 trials. There was no time interval between each trial. Participants had to move forward to the next trial puncture. A 2-ml syringe was directly connected to the needle, filled with 2 ml 0.9 % sodium chloride. The participants had to inject the solution themselves. As soon as the syringe was empty the trial was ended. Only an out-of-plane technique was used in this study. For the application, stainless chrome-nickel steel Sterican (B. Braun Melsungen AG, Melsungen, Germany) disposable needles with a silicone coating 20G × 1.5″ were used.

### Evaluation

Gradations were made with respect to the flushing of the simulated nerve by two independent observers (two

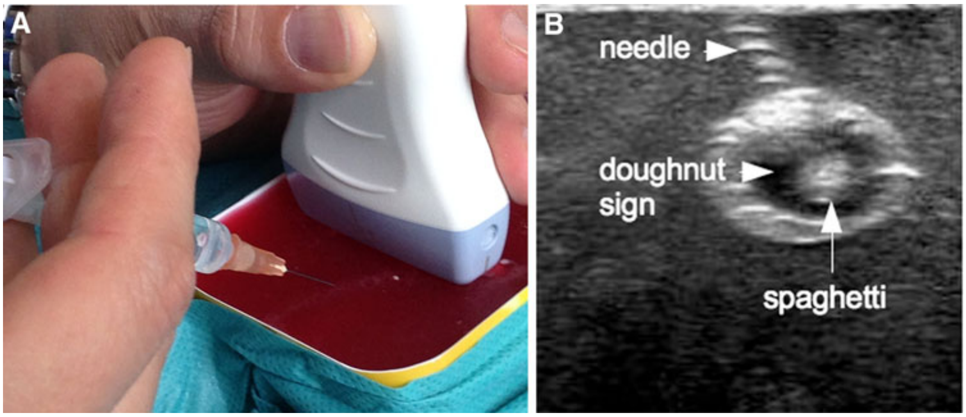

**Fig. 1** **a** Ultrasound phantom with ultrasound probe and injection needle in place after multiple puncture trials. **b** B-mode ultrasound of a simulated nerve in out-of-plane technique. Hyperechoic needle is visible at the 11 o'clock position. Hypoechoic fluid surrounds the simulated nerve as fluid is injected, the so-called doughnut sign

graduate students) familiar with the handling of the gelatine model. The quality of block was assessed using a numeric rank scale from 0 to 10, with 0 for an incorrect application, 10 for an ideal attempt (Fig. 2). Gradations by the two observers were averaged for each trial. Ideal distribution was obtained when a complete doughnut sign was achieved, indicating complete enclosure of the simulated nerve with fluid.

### Statistical analysis

One-way ANOVA with a Kruskal–Wallis test and non-linear regression were performed, respectively (Prism 5, GraphPad, La Jolla, CA, USA). Statistical significance was reached with $p < 0.05$.

## Results

Demographic data for each student included information regarding age, gender and study semester (Table 1). Median time for the first trial was 66.5 s (49.5–90 s). After 11 trials, the time had improved to a median of 37 s (23.5–53.5 s). A statistically significant reduction of the trial time could be reached after the 5th trial (Fig. 3, $p < 0.01$). The course can be described as a one phase exponential decay curve reaching a plateau at 30 s and $t_{1/2}$ after 2.7 trials and 4 × $t_{1/2}$ after 7.8 trials (Fig. 4).

Initially, quality of block was rated with a median of 4 (0–6). However, quality of block improved significantly after the 5th trial ($p < 0.001$) and reached a median of 8 (8–9) after 11 trials (Fig. 5).

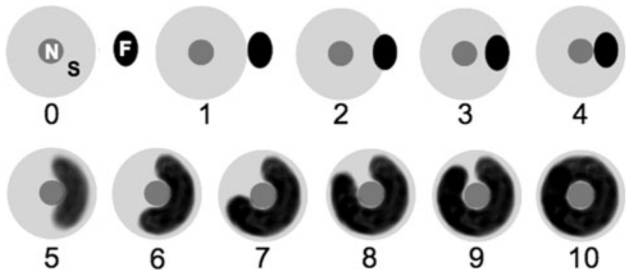

**Fig. 2** Scheme of quality of block gradation. *0–4* distance of injected fluid to nerve, *5–10* half to fully encircled simulated nerve (*N*; 1 mm diameter) by injected fluid (*F*). The starch core (*S*) had a diameter of 0.5 cm

**Table 1** Study participants' demographic data

| | |
|---|---|
| Age (years) | 25.67 ± 0.62 |
| Male (*n*) | 7 |
| Female (*n*) | 11 |
| Study semester | 8.89 ± 0.61 |

The course of quality of block improvement could be assessed with a sigmoidal curve. After 3.6 trials, 50 % of the maximum quality ($Q_{max}$50 %) was reached, and there was a plateau after 8.5 trials (Fig. 6).

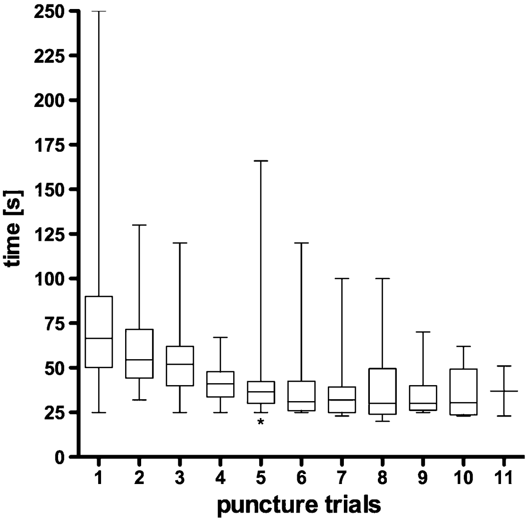

**Fig. 3** Box plot of median time to first successful puncture which was defined by the doughnut sign. Time is plotted against puncture trials. Whiskers represent minimum and maximum of data respectively. *$p < 0.01$

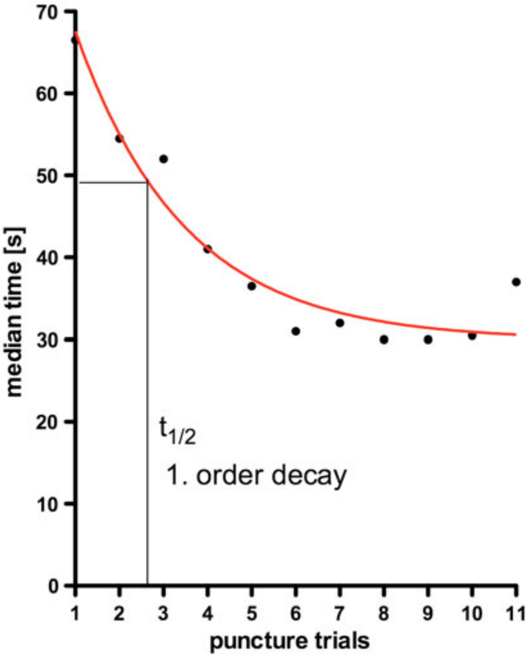

**Fig. 4** Fitted median time curve. The course is described as a one phase exponential decay curve reaching a plateau at 30 s, $t_{1/2}$ after 2.7 trials and 4 × $t_{1/2}$ after 7.8 trials

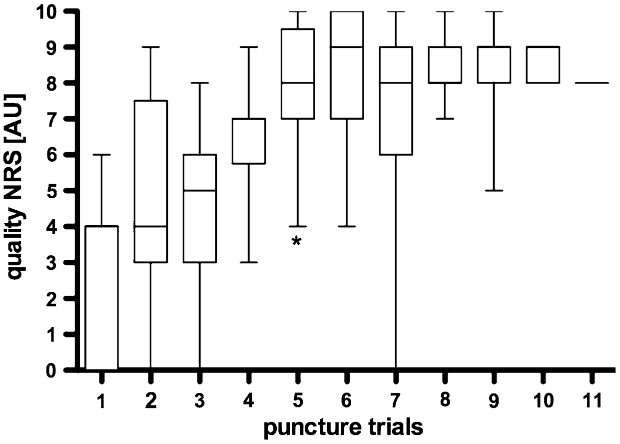

**Fig. 5** Box plot of quality of puncture. Whiskers show minimum and maximum of data. Quality was rated by two independent observers on a numeric rank scale (NRS). *AU* arbitrary units, $*p < 0.001$

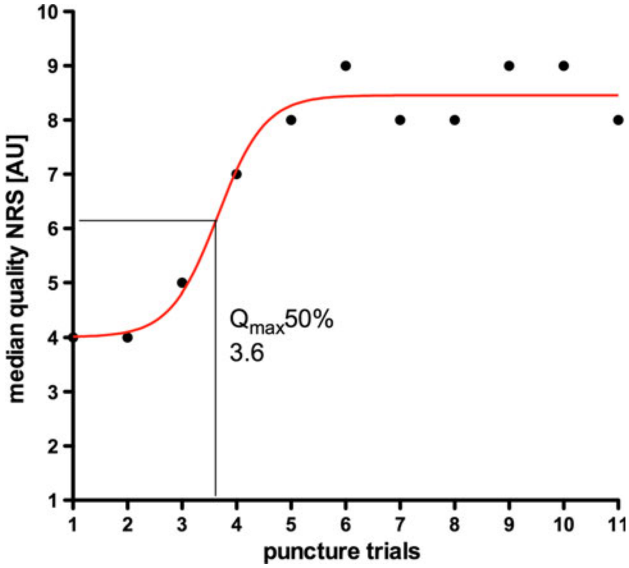

**Fig. 6** Fitted median quality. Median quality is plotted against puncture trials. Median quality can be fitted to a sigmoidal curve with a $Q_{\max}$ of 50 % after 3.6 trials (*NRS* numeric rank scale, *AU* arbitrary units)

## Discussion

The main findings of this study are that (1) ultrasound novices can achieve good hand-eye coordination, resulting in good quality blocks within 5 puncture trials in a simple reusable ultrasound phantom and (2) a mathematical model was used to describe the puncture time and quality of block.

Sites et al. assessed a learning curve in anesthesiology residents using an olive buried in a turkey breast. Although correct advancement of a needle to the anterior wall of the olive was observed, their study does not cover correct injection of fluids which should be the basis of a good quality block [6]. In a study by Baranauskas et al., ultrasound phantoms made from gelatine were used to simulate an epidural anesthesia. The authors found that the more training time that was allotted to anesthesia residents, the faster they could fulfill the task. Training of 2 h resulted in 37 s for a successful injection without a mistake, which is consistent with a median of 37 s after 11 trials in our study [7]. Interestingly, with no training 94 s was needed to complete the task as opposed to 66.5 s for the first trial in our study, which indicates that possibly our phantom is technically less challenging.

### Limitations of this study

Training of USPNB with ultrasound phantoms can only be a part of a comprehensive resident teaching course which should lay the ground for residents and medical students to learn and improve their technical skills in a safe environment [8]. Orebaugh et al. [9] reported that ultrasound combined with nerve stimulator technique for peripheral nerve blocks improved time to successful block and decreased number of needle insertions and accidental blood vessel puncture as well. However, the authors could not conclude safety advantages because the study population was too small. In the present study, advancing the needle too far beyond the simulated nerve resulted in longer trial time and lower quality of block, respectively which is rather unspecific in terms of safety. Thus, future studies with ultrasound phantoms could also incorporate other vulnerable structures, e.g. vessels in close proximity to the simulated nerve to have additional measurable safety features. Gelatine-based models and blue gel phantoms have been criticized for their uniform, untissuelike appearance in the ultrasound B-mode, and lack of variability [10]. However, these models have the advantage that they are simple and easy to handle and have a longer shelf-life than other meat-based models. More sophisticated models have been developed which allow simulation of all anatomic structures but are cost-intensive because of initial costs and replacement costs of inserts [11]. It has to be underlined that the target structure and the needle have to be identified and discriminated from other potentially vulnerable structures like vessels which can be achieved by color flow, compression of veins and use of doppler signal. Additionally, in clinical practice a nerve stimulator is often used as dual guidance. It remains to be elucidated whether models with a more tissuelike appearance can improve the sonographer's ability to identify the target structure and the injection needle or if simple models can satisfy this educational goal.

## Conclusion

We presented a simple model for ultrasound-guided peripheral nerve block which can be used for education and practice with ultrasound novices. This simple and inexpensive phantom could be used as a first educational step in a curriculum. Our mathematical model predicts the number of trials that are necessary for a satisfying ultrasound-guided injection in our phantom. The next educational step for the ultrasound novice should be to proceed to a more sophisticated model. This stepwise approach will extend the life of high-fidelity models and save replacement costs. Future studies have to evaluate if the use of USPNB models likewise improves the learning curve of USPNB in patients.

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