Effectiveness of a phantom based learning model for medical students to achieve ultrasound-guided vascular access – a prospective study

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Abstract

Background: This prospective study evaluated the learning curve of inexperienced medical students in successfully establishing an ultrasound guided vessel access. **Methods:** Medical students (n=11) with no experience in ultrasound imaging were asked to perform an ultrasound- guided vessel access simulated by a gelatin based phantom model. Success rates and time of procedures were measured. Afterwards, every student underwent peer-teaching with both theoretical information given and practical training skills applied. Then, every student had to perform the very same procedure again and results were compared in a prior- to post-teaching scenario with paired t-test. **Results:** After theoretical and practical teaching lessons all students were able to successfully establish an ultrasound-guided vascular access. Prior to teaching sessions, only 4 out of 11 students managed to successfully perform the procedure. Success rate rose from 36.4% to 100%. Mean number of attempts were 2.5 ± 1.3 before, and 1.2 ± 0.4 after teaching ($p < 0.05$). Overall time to successful guide wire placement improved from 291 ± 8 seconds to 151 ± 37 seconds ($p < 0.05$). **Conclusions:** In a gelatin based phantom model for ultrasound-guided vascular access medical students demonstrate significantly improved practical puncture skills and thus a steep learning curve.

Background:

Ultrasound-guided needle placement for medical interventions is widely used by physicians throughout almost all medical specializations and is a very well established procedure (1–3). Multiple clinical trials have shown a significant decrease in complications as well as a significantly improved success rate of needle punctures if performed with ultrasound (4;5). Particularly, adequate needle tip visualization during ultrasound guidance plays the most important role in successfully performing the desired intervention compared to the traditional landmark technique without ultrasound(6). Therefore, guidelines for ultrasound guided vascular cannulation have been implemented in order to optimize vascular access procedures in patients (7).

However, for students, early hands-on experience is very limited and often non-existent during study-time. The main reason for this is the lack of opportunities for realistic practice, because “trial and error”-scenarios for warranted catheter placements in (critical care) patients is at least inadequate and often not acceptable to be performed by relatively inexperienced staff members, particularly students.

Thus, we intended to establish a phantom-based learning model in a prospective trial for inexperienced students in order to get early hands-on experience and to render practical experience prior to their lives as doctors. Moreover, we intended to prove effectiveness by evaluating the learning curve of each student and to aim for every student to be able to successfully perform ultrasound guided vascular cannulation in a realistic scenario.

Methods:

Study design

This was a prospective trial of novice ultrasound users applying realtime ultrasound-guided vascular access on a phantom. Neither Institutional review board approval, nor informed consent was necessary for this in vitro study as no patients were included.

Study setting and participants

This trial was conducted at our institutional ultrasound training course with two experienced radiologists as supervisors. The participants included 11 medical students with little to no experience with ultrasound usage and no experience in ultrasound-guided interventional procedures.

Study protocol

In a first session, all participants were asked to perform ultrasound-guided needle cannulation after being given oral instructions of how to use and hold the transducer and how the silicone tube is visualized in B-Mode images (Mindray, M7 Diagnostic Ultrasound System, 9 MHz linear transducer). Subjects did not receive prior hands-on practice and only had very limited knowledge in theoretical aspects of ultrasound and ultrasound guided interventional procedures before participation.

In the first session, the first task was to search, identify and to visualize the silicone tube in the gelatin phantom and to depict the short and long axis (see Fig. 1 and Fig. 2) of the tube in B-mode. Then, an 18-gauge introducer steel needle was inserted under real-time ultrasound visualization (see Fig. 3). Duration time of both short and long axis depiction, time from first phantom tissue puncture to successful vessel puncture (as judged by a guide wire tip visualization at the end of the silicone tube sticking out of the gelatin container) as well as the number of attempts to puncture the silicone tubes were recorded.

Afterwards, all participants took part in a 30-minute didactic session consisting of a dedicated power-point presentation of ultrasound-guided procedures including physics, basic image adjustment, knowledge of medical instruments encompassing the ultrasound device as well as puncture needles. Additionally, example video clips and images of ultrasound-guided vascular access on the used tissue phantom as well as in real patients (such as central venous catheter placement, femoral artery punctures e.g.) were demonstrated.

In a second session, all students performed the procedure again and the aforementioned parameters were again recorded.

Results of both sessions were compared in a prior- to post- test scenario.

Gelatin based phantom model

The phantom model is related to comparable gelatin based phantoms used and previously described by Clemmensen et al.(8;9).

All materials necessary for creating the phantom model were available in regular stores and supermarkets (see Table 1).

The first step in preparing the phantom models was to create a gelatin mixture (Dr. Oetker gelatin powder) of 1.25 l volume. Thus, for every 250 mL volume, 35 g of gelatin powder was mixed with 250 mL of hot water just below boiling point. The gelatin was completely dissolved in 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 render antiseptic properties and to improve durability.

An alcohol cleaned plastic container (14 cm x 24 cm x 8 cm) was used and thin and smooth silicone tubes (wall thickness 0.5 mm, inner diameter 6 mm) were placed and fixed near the bottom of the container approximately 5 cm below the gelatin surface with the help of glued power strips. Both ends of the silicone tube stick out of the plastic container to preserve visual control of guide wire placement. Finally, the gelatin solution described above was filled into the container and cooled down in a refrigerator (5 °C) for 3 h until the gelatin was stiffened. Figure 4 shows the phantom based gelatin model.

Statistical analysis

Time (in sec.) and number of attempts were documented for each participant before and after theoretical and practical training. Data was analysed concerning normal distribution by using a Kolmogorov-Smirnov test. *Paired t-test* was used to evaluate the difference in performance; $p < 0.05$ was applied for statistical significance.

Results:

Results of both training sessions before and after dedicated teaching lessons are depicted in Fig. 5 and Fig. 6 respectively.

Normal distribution was confirmed by using the Kolmogorov-Smirnov analysis with KS distances ranging between 0.1448 to 0.2270, with each p-value not stating a statistical significance ($p > 0.1$ for all distributions).

In the first session without any proper training or teaching, only 4 out of 11 students (36.4%) managed to somehow place the guide wire correctly into the silicone tube.

Mean number of attempts were 2.5 ± 1.3 , mean time to short axis visualization was 52 ± 36 seconds, time to long axis visualization 67 ± 61 seconds, time to tube perforation 167 ± 59 seconds and time to successful guide wire placement (applicable only in 4 out of 11 participants) was 291 ± 8 seconds.

In the second session after dedicated didactic lectures and supervised hands-on training success rate rose to 100%; 11 out of 11 students correctly placed the guide wire into the silicone tube.

Mean number of attempts were 1.2 ± 0.4 ($p = 0.0222$). Mean time using short axis visualization was reduced to 31 ± 22 seconds ($p = 0.0414$). Time to long axis visualization was reduced to 21 ± 17 seconds ($p = 0.0113$) and time to tube perforation diminished to 82 ± 39 seconds ($p = 0.0003$). Time to successful guide wire placement was significantly reduced to 151 ± 37 seconds ($p = 0.0038$) with 11 out of 11 participants.

In our results statistically significant differences were found for every comparison measured between the first and the second practice session.

Discussion:

Our results indicate a highly beneficial impact of hands-on training with regard to clinical skills development. Procedural times in ultrasound visualization and number of cannulation attempts showed a statistically significant decrease indicating a highly improved practical proficiency in our student group. Moreover, success rate of ultrasound guided endoluminal guide wire placement rose from 36.4–100%, thus every student was able to perform the procedure.

These results are comparable to the review of literature by Gottlieb et al., wherein between 89.1% and 97.7% of medical students ($n = 198$) of three independent studies successfully performed cannulation and consecutive guide – wire placement via short or long axis imaging (10).

Likewise, McKay and Weerasinghe demonstrated that teaching basic interventional ultrasound skills to novice junior doctors in a single focused session is an achievable outcome with very high success rates of up to 99% of the students (11).

In accordance to our results, in the study group of Vitto et al. 100% of participants using real-time ultrasound-guidance successfully achieved cannulation. After theoretical and practical training Vitto et al. also had nearly identical mean number of attempts ($n = 1.31$) compared to our study collective ($n = 1.2$) (12).

Moreover, Wagner et al. showed with thirty-nine inexperienced physicians significantly decreasing rates of failure of guide-wire insertion into 2-mm tubes after dedicated teaching courses, using both long axis ($p = 0.001$) and short axis imaging ($p = 0.004$) techniques. The numbers of successful cannulations on the first attempt increased after the teaching in all methods ($p = 0.001$), a result to be considered negatively proportional to our statistically significantly reduced mean number of attempts (13).

Multiple training scenarios have been described and deemed equally effective with regard to impact on novice's learning curve (14–16).

In general, training must include image acquisition, image interpretation, real-time use of ultrasound, and an experienced instructor who is able to demonstrate how to translate 2D imaging to perform a 3D task. Moreover, cognitive motor skills with the gain of a haptic feedback are mandatory to develop a sufficient

proficiency in ultrasound guided intervention. Additionally, education should include a combination of didactic lectures with live videos or photos of real vascular access cannulation guided by ultrasound.

Our study setup comprised all the steps and requirements mentioned beforehand, thereby yielding a statistically significant progress of skill development in novice, untrained medical students.

This clinical trial had some limitations. Due to the lack of strictly comparable literature data no statistical power analysis was possible. Nevertheless, the relatively low number of participants yielded already highly significant results. A higher number of participants would have been favorable and could have had a higher statistical impact. But since hands-on practice played an important role for this study, a larger group size could also have led to a decrease in practical proficiency in this close peer teaching setup.

The gelatin phantom model differs from human tissue and the silicone tube used could not near perfectly mimic the human vasculature. Therefore, haptic feedback was different while using artificial silicone tubes compared to human veins or arteries. Regardless of these differences, the beneficial impact of artificial phantom models has been previously described (8;9) and likewise our results strongly indicate skill improvement, which was the primary aim of this trial.

Conclusion:

A phantom based training model for ultrasound guided vascular procedures using real-time ultrasound is highly recommended as a dedicated training tool. The production of a gel phantom- as used in this study- is relatively easy, fast and cheap. Consequently, a comparable setup should be introduced into medical training of all students and should be made available wherever and whenever possible to improve vascular cannulation skills.

Abbreviations:

B-Mode	Brightness modulation
MHz	Mega Hertz
G	Gauge

Declarations:

Ethics approval and consent to participate:

No ethics approval applicable, since novice ultrasound users applied realtime ultrasound-guided vascular access on a gelatin phantom model. Neither Institutional review board approval, nor informed consent was necessary for this in vitro study as no patients were included. All medical students involved in this study gave verbal consent to participate.

We have sent our study project to the responsible ethics committee. According to e-mail correspondence, our study does not require a written ethics committee approval according to the “Ärztchamber des Saarlandes” (responsible ethics committee). We have added our e-mail correspondence with the ethics committee as a separate PDF file.

Consent for publication:

All medical students involved in this study gave consent for publication.

Availability of data and materials:

The datasets used and analysed during the current study are available from the corresponding author on reasonable request.

The materials used for the phantom model are stated in Table 1.

Competing interests

The authors declare that they have no competing interests.

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This study did not receive any specific funding.

Author's contribution

P.J. initiated the conception of the study, participated in the primary acquisition of medical students and helped in the analysis and interpretation of data for this study. P.R. helped in the acquisition of medical students, performed the analysis and first interpretation of data for this study, performed the initial drafting the manuscript and first critical revision of the manuscript. P.J. and P.R. created the phantom model used for the student's interventions.

J.G., F.F. and J.S. participated in the critical review of the manuscript and acquisition of data. A.B. participated in the critical revision of the manuscript.

All authors gave final approval of the submitted manuscript and agreed on its publication.

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Tables

Table 1: Materials

Water (1250ml total volume)
Unflavoured gelatin powder (35g per 250 ml volume; 0.30 €)
Sugar-free Metamucil (15 g per 250 ml volume; 0.49 €)
Silicone tubes (length variable; 30 cm, wall thickness .5 mm, inner diameter 6 mm; 1.50 €)
Aseptic alcohol-based solution (~ 1-2 €)
Blue colour additive (0.69 €)
Plastic container (size variable, 14cm x 24cm x 8 cm used for this study; 2.49 €)
Glued power strips for fixation (Tesa e.g.; 1.50 €)

Figures

Figure 1

short axis visualization of the silicone tube in B-Mode, circle= outer border of the tube; asterisk = inner lumen of the tube; triangle = bottom of the gelatin based phantom model

Figure 2

long axis visualization of the silicone tube in B-Mode, arrows= outer border of the tube; asterisk = inner lumen of the tube. The bottom of the gelatin based phantom model is directly adjacent to the lower wall of the tube

Figure 3

visualization of a steel needle cannulation in B-Mode, arrows= steel needle; asterisk = inner lumen of the tube. In the upper picture (A) the needle tip is directly adjacent to the upper wall of the tube. In the lower picture (B) after successful cannulation the needle tip is visualized inside the lumen of the tube.

Figure 4

The gelatin based phantom model with an 18 gauge steel needle which was used for cannulation. Both ends of the silicone tube are depicted on the left and right and stick out of the gelatin mixture.

Figure 5

comparison of procedural durations: The vertical lines represent standard deviation with mean indicated as a horizontal line. 25%- and 75%-quartiles are depicted as a box plot. * = statistically significant with $p < 0.05$ for all comparisons between session 1 and session 2.

Figure 6

: comparison of number of cannulation attempts: The vertical lines represent standard deviation with mean indicated as a horizontal line. 25%- and 75%-quartiles are depicted as a box plot. * = statistically significant with $p < 0.05$.