Original Article

Evaluation of Training in Pediatric Ultrasound-guided Vascular Cannulation Using a Model

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Abstract

Background: The study objective was to evaluate a training program and a training model for pediatric ultrasound-guided vascular cannulation (USGVC) by inexperienced operators. **Methods:** An observational descriptive study was conducted at the pediatric intensive care unit of a level-III hospital. The study protocol comprised the following parts: (1) pretraining test; (2) theory and practice training session consisting of an explanation of basic vascular ultrasound concepts plus performing vascular cannulation in a model; (3) posttraining test; and (4) evaluation of the training model. **Results:** A total of 25 health-care professionals participated in the study. All of them possessed the skills to locate vessels and ultrasound planes, and they performed USGVC using the training model. On a 1–5 scale, the model was rated to have 87.6% fidelity with real pediatric patients; the best regarded aspect of it was utility (93%). Differences were found between pre- and post-training scores: 2.72 ± 0.84 versus 4.60 ± 0.50; $P < 0.001$ (95% confidence interval: −2.28, −1.47). Altogether, 300 ultrasound-guided cannulation procedures were carried out (12 per participant) distributed along the longitudinal axis in plane and the transverse axis out of plane, with 150 punctures in each of them. The success rate for USGVC in the training model was 79.7%, the mean time for the procedure was 115.6 ± 114.9 s, and the mean time for achieving successful cannulation was 87.69 ± 82.81 s. The mean number of trials needed for successful USGVC was 1.49 ± 0.86. **Conclusion:** After undergoing the theory–practice training, participants: (a) improved their knowledge of ultrasound-guided vascular access; (b) positively evaluated the USGVC training model, in particular its utility and fidelity as compared with cannulation in pediatric patients; and (c) achieved a high USGVC success rate in a relatively short time.

Keywords: Pediatrics, simulation, ultrasound, vascular access

Introduction

Cannulation of a central vessel is a procedure associated with health-care practice. Conventionally, the vascular cannulation technique has been based on anatomical references, and it is therefore also called a "blind technique."[1,2] In pediatric patients, this technique is associated with higher difficulty and is not free of risks and complications. Achieving vein access in children may be challenging both for doctors and nurses.[3-7] Occasionally, several punctures are needed, which increase the difficulty of the procedure, as well as patient pain and anxiety, eventually influencing parental perception of the quality of health care provided to their child. The use of ultrasound facilitates vascular cannulation (ultrasound-guided vascular cannulation [USGVC]); however, acquiring the necessary skills for this technique requires a learning curve, especially in the case of pediatric patients.[8-13]

USGVC training programs pursue the acquisition of essential concepts on vascular ultrasound and its practical applications, and are generally conducted with simulation models.[14-16] All of these contribute to acquire the necessary skills and abilities

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and improve the learning curve, usually associated with any technique of new implantation.

There is no consensus opinion on the duration of training and the ideal training model. The latter should be as similar to the patient as possible and should allow reproducing the vascular cannulation technique as accurately as possible.[14-16]

The chosen model[17] can simulate diameter and depth variations usually present in pediatric vessels, according to the patient's weight and tallness.

Objectives

- To evaluate a USGVC training program for inexperienced operators
- To evaluate a training model for pediatric USGVC.

Materials and Methods

The 4-h training program was divided into 2-h theory plus 2-h practice, using the model developed by Pérez-Quevedo *et al*.[17] [Figure 1]. Participants had to perform a total of 300 punctures (12 punctures per operator) uniformly distributed along the longitudinal axis in plane (LA-IP) and transverse axis out of plane (TA-OP), with 150 punctures in each of them.

The ultrasound equipment was Sonosite NanoMaxx® Linear Probe (FUJIFILM Sonosite, Inc. 21919 30th Drive SE Bothell, Washington 98021-3904. USA) L25n frequency 13–6 MHz. The ultrasound-guided vessel punctures in the training model allowed to evaluate the model's utility and the associated rate of success and time required to cannulation.

After the theory–practice training, all of the participants were asked to evaluate the fidelity of the USGVC training model to actual pediatric patients by completing a questionnaire, where five aspects of fidelity (muscular structure, vascular structure, global model, maneuvers to facilitate cannulation, and utility) could be scored from 1 (lowest) to 5 (highest). The total score could thus vary from 25 (20%) corresponding to "minimum fidelity" to 125 (100%) corresponding to "maximum fidelity" [Table 1].

Qualitative variables were expressed as frequency and percentage; numerical variables were expressed as mean,

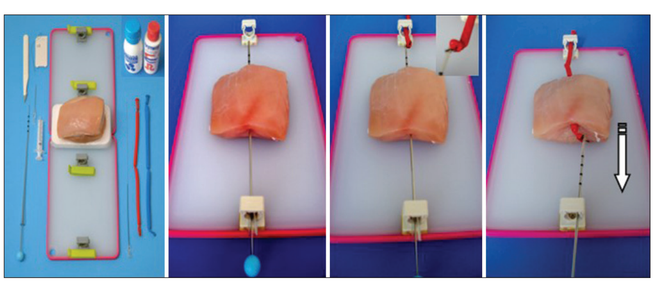

Figure 1: Components and assemblage of the model for ultrasound-guided vascular cannulation training

standard deviation, and median. To test for normality of the numerical values, the Kolmogorov–Smirnov test was used. To assess for possible associations between continuous variables, the Student's *t*-test for independent samples was used, as well as for comparing the means of two associated variables. Statistical significance level was 5%. Statistical analysis was carried out with the Statistical Package for Social Sciences software version 19 for Windows (SPSS Inc., Chicago, IL, USA).

Ethical considerations

The study adhered to the essential principles of the World Medical Association included in the Declaration of Helsinki.[18] The highest level of professional behavior and confidentiality was applied and the relevant national laws for data protection were observed.

Participants' right to confidentiality was granted, and their personal information was codified. Only authorized staff had access to their identity information whenever data verification processes required so.

This research project was approved by the Committee for Ethics in Clinical Research of the Mother and Child University Hospital of the Canary Islands (Id: CEIm-CHUIMI-2016/883). Participants were volunteers and anonymous, and they consented publication of the results obtained in the workshop. All of them were asked to sign an informed consent form.

Results

Twenty-five trainees (56% doctors and 44% nurses), inexperienced in USGVC, carried out a total of 300 punctures in the model (12 punctures per operator), uniformly distributed along the LA-IP and TA-OP, as part of the USGVC training program [Figures 2 and 3].

The participants had an average working experience, including vessel cannulation (peripheral vessels or central vessels using the traditional "blind technique"), of 13.04 ± 9.69 years. The success rate was 79.7%; the mean number of trials was 1.8 ± 1.2 globally and 1.49 ± 0.86 for successful USGVC procedures; and the mean time required for the procedure was 115.6 ± 114.9 s and the time to successful USGVC was 87.69 ± 82.81 s [Table 2].

Participants rated the fidelity of the model to "*in vivo*" puncture [Figure 4] in pediatric patients as 87.2%. The results of model evaluation were positive for all the five assessed aspects (muscular structure, vascular structure, global model, maneuvers to facilitate cannulation, and utility). The best regarded aspect was utility (92.8%), which indicated that the participants considered it a good training model for subsequent "*in vivo*" USGVC and that they accepted it widely. Figure 5 shows the results of this evaluation. An analysis of the mean scores before and after the program revealed statistically significant differences: 2.72 ± 0.84 versus 4.60 ± 0.50; $P < 0.001$ (95% confidence interval: −2.28, −1.47).

Table 1: Fidelity and utility of the ultrasound-guided vascular cannulation training model as compared with vascular puncture in actual pediatric patients as evaluated by the participants in the training program

Evaluated aspects of the USGVC training model	1	2	3	4	5
Muscular structure of the training model (chicken breast) as compared to the skin or muscle of a pediatric patient upon vessel puncture and cannulation					
Vascular structure of the training model (balloon), as compared to the venous or arterial structure of a patient upon vessel puncture and cannulation					
Global model for training vessel puncture and cannulation in a pediatric patient					
Maneuvers to facilitate cannulation, for example, slightly withdrawing the needle, varying the angle of needle insertion, and rotating the bevel of the needle					
Utility of the "simulation model" to train the ultrasound-guided vessel cannulation for subsequent application in children					

1: None, 2: Few, 3: Some, 4: Much, 5: Total, USGVC: Ultrasound-guided vascular cannulation

Table 2: Description of the main variables in the training model and ultrasound-guided vascular cannulation by inexperienced operators

	n	Minimum	Maximum	Median	Mean±SD
Depth (cm)	300	0.50	1.90	0.85	0.90±0.34
Diameter (cm)	300	0.20	0.65	0.40	0.41±0.10
N° trials	300	1.00	11.00	1.00	1.80±1.24
N° trials to successful USGVC	239	1.00	7.00	1.00	1.49±0.86
Time for procedure (s)	300	14.00	958.00	72.00	115.63±114.98
Time to successful USGVC (s)	239	14.00	780	53	87.69±82.81

USGVC: Ultrasound-guided vascular cannulation, SD: Standard deviation

Figure 2: Practical workshop of the ultrasound-guided vascular cannulation training program

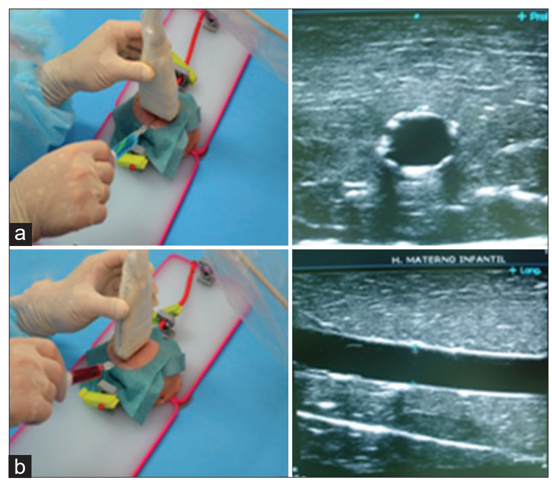

Figure 3: Ultrasound-guided vascular cannulation in the transverse axis out of plane (a) and the longitudinal axis in plane (b) in the training model, and the corresponding ultrasound images (right)

Discussion

The main problem at the implantation of a novel technique in pediatric patients is the need to train on it. Acquiring skills in vascular ultrasound requires practice and frequent use. Such skills include: (a) knowledge and understanding of the device, in this case the ultrasound equipment; (b) acquiring and optimizing images of the vessel and the needle; and (c) developing the ability to use an ultrasound probe while inserting the needle and conducting cannulation guided by ultrasound images.[15]

Evidence shows that simulation plays a role in the acquisition of the necessary skills to perform invasive procedures.[16] Through simulation, certain conditions are artificially created, which resemble reality, thus serving as a training tool for a novel medical procedure.[14]

The use of simulation models to train on diagnostic or therapeutic procedures: (a) enhances the quality of the provided health care, especially when using techniques that are not devoid of risks and complications; (b) reduces the stress derived from applying a novel technique directly to actual patients; and (c) can be used as many times as the model is replicated, additionally helping to solve potential problems that could emerge while using the technique "*in vivo*."[19,20]

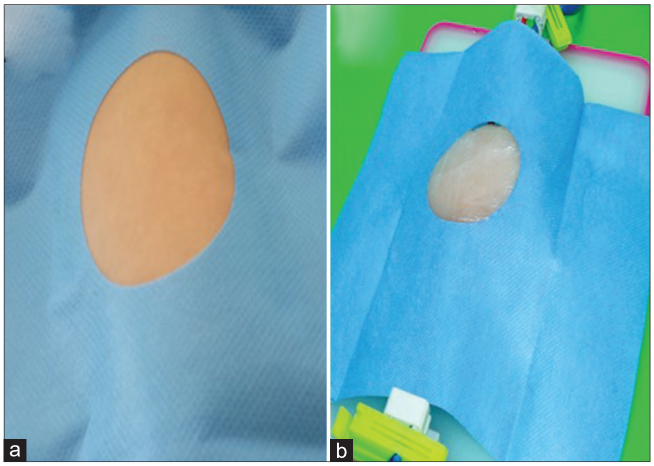

Figure 4: Vascular access in an actual patient (a) and in the ultrasound-guided vascular cannulation training model (b)

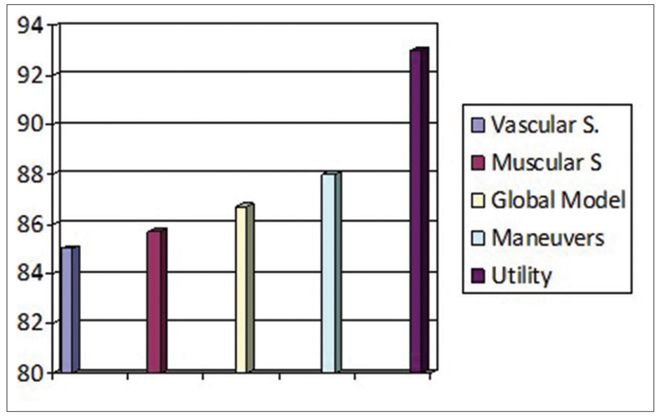

Figure 5: Evaluation of the ultrasound-guided vascular cannulation training model in percentage, as scored by the participants in the training workshop (S: Structure)

In this study, operators inexperienced in USGVC but experienced in "blind" vessel cannulation achieved a global success rate of 79.7% ("blind" vessel cannulation includes peripheral intravenous cannulation, central vessels access via peripheral cannulation based on anatomical references and/or central venous access). In a training program for resident doctors using a commercially available USGVC model designed by Thomas *et al*.,[21] similar success rates were observed (80.8%). Other authors, for example, Erickson *et al*.[22] presented a study, where participants holding professional experience similar to that of our participants attained 100% success rate with a USGVC commercially available model. The difference might be due to the degree of difficulty associated with the simulation model because the mean vessel caliber in their study was 0.56 cm, whereas in ours, it was 0.40 cm.

The number of trials required to successful cannulation was 1.8, similar to the results reported by Thomas *et al*.,[21] where the mean number of trials decreased from 1.5 to 1 punctures after a period of training and explanation of the basic USGVC concepts. In other studies involving adult patients, for example, in the study by Barsuk *et al*.,[23] a reduction from 1.74 attempts required with the traditional "blind technique" to 1.32 with USGVC was described.

The time until successful cannulation in our model was 87.69 s. We considered the time since the moment the needle was inserted in the skin until confirmation that the cannulation had been correctly placed within the vessel. Erickson *et al*.[22] reported a mean time of 11 s, but they only considered the time since the needle penetrated the skin until the fluid within the vessel appeared. Similar results were described by Phelan *et al*.,[24] who reported 17.56 s until the moment the fluid in the vascular structure of the model emerged, when echorefringent needle was used versus 19.22 s when a normal vessel puncture needle was used. Notice that in their study, the mean vessel diameter was 0.8 cm, which corresponded to an average adult patient and was significantly larger than our 0.40-cm mean vessel diameter. Furthermore, because the time needed for vessel cannulation, namely the introduction of the guide or catheter within the vessel, was not included, the total time may have been underestimated and consequently, the success rate would have been overestimated (because occasionally, vessel puncture is adequate, but subsequent cannulation is not possible).

The utility of simulation-based training models was supported by Barsuk *et al*.,[23] who concluded that residents using such models achieved higher success rates, needed less punctures, and attained significantly lower complication rates, as compared with residents who had trained by "watching and doing," that is, through direct observation of the technique without theoretical explanation and practical training.

The evaluation of the training program yielded positive results; in terms of improvement of acquisition of knowledge, the score was 2.72 before training which significantly increased to 4.60 after training. Besides positively evaluating the model's versatility to simulate depth and vessel diameter variations within the desired ranges, the participants especially valued its fidelity toward vessel cannulation in pediatric patients with a higher than 85% qualification and a 93% qualification when it came to the model's utility.

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Conflicts of interest

The authors declare that: (a) no financial or personal relationship exists that could bias or inadequately influence the making of this work and (b) they have not received and will not receive in future, any funding for designing the study, collecting the data, analyzing or interpreting the data, writing the manuscript, or submitting the manuscript for publication.

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