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Ultrasound-guided pediatric vascular cannulation by inexperienced operators: outcomes in a training model

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Abstract

Objective To present the results of an ultrasound vascular cannulation (UGVC) training program for inexperienced operators using a training model.

Method This was a descriptive observational study developed in the paediatric intensive care unit (PICU) of a third-level hospital. Operators received basic theoretical training in the USVC technique, followed by practical training with a model designed for USVC-inexperienced healthcare professionals.

Results The study included 25 healthcare professionals, who carried out a total of 300 ultrasound-guided cannulation procedures (12 per participant) at equidistant sites on the longitudinal axis/in-plane (LA/IP) and the transverse axis/out-of-plane (TA/OP). The mean depth of cannulated vessels was 0.90 (0.34) cm and their mean diameter was 0.41 (0.1) cm. In 41.7% of cases, complete view of the needle (CVN) was accomplished; in 49% of cases, repositioning of the needle/guidewire (RNG) was necessary for successful UGVC. The rate of successful UGVC in the training model was 79.7%. The mean time required for the procedure was 74.70 (73.72) seconds. The time to successful cannulation was 58.72 (56.87) seconds. The mean number of attempts needed until successful UGVC was 1.31 (0.72). Complications were: (a) 26.3% vessel perforation/wrong guidewire positioning (VP/WGP) and (b) 4.3% successful vessel puncture followed by failure to accomplish subsequent cannulation.

Conclusions Through the present theoretical–practical training program for inexperienced operators using a training model: (a) high success rates and short procedural times were attained; (b) complete view of needle and need for repositioning the needle/guidewire occurred in half of the procedures; and (c) complications occurred in a third of the procedures.

Keywords Simulation · Ultrasound · Vascular access · Paediatrics

Introduction

Central vessel cannulation entails more difficulties in paediatric patients than in adult ones, and is not devoid of risks or complications. Obtaining vein access in paediatric patients may be a challenge for both medical and nursing staff [1–6]. Great advances were achieved using ultrasound-based guidance [7–15]. However, such an approach requires a training process, which should ideally be completed in simulation models. Simulation models artificially reproduce conditions that may be encountered in the real world, thus allowing operators to train and acquire the necessary skills to perform a novel medical procedure [16–18]. Simulation models: (a) help improve the quality of patient assistance, especially with techniques that are not free of risks or complications; (b) reduce the stress associated to the use of a

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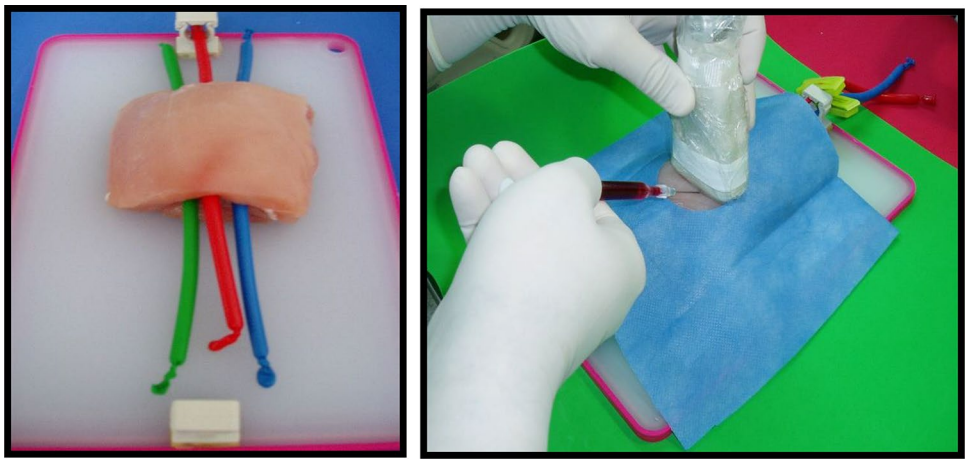

Fig. 1 Training model for ultrasound-guided vascular cannulation and puncture on the transverse axis/out-of-plane

novel technique directly on patients; and (c) may be used as many times as the model is reproduced, helping solve problems that may emerge during in vivo application of the technique [19, 20]. Ultrasound-guided vascular cannulation (UGVC) training programs facilitate the acquisition of basic knowledge on vascular ultrasound and its practical applications, and are generally carried out with simulation models [16, 17]. The skills and abilities acquired with a model diminish the learning curve associated to the implantation of any technique [7–12]. The model used in this study [18] offered the possibility to adjust the technique to the vessel diameters and depths of paediatric patients. The results were used to evaluate the UGVC success rate, the manoeuvres that may potentially improve the procedure and the most frequent complications of the technique.

Many ultrasound-guided vascular cannulation simulators have been described [16–20]. The model presented here shows the following differential characteristics: (a) possibility to be adapted to different vascular sizes and depths, similarly to what occurs in a paediatric population, as this population shows a huge variability of weight, age and size, and, as a consequence, a high variability of vascular diameter and depth; (b) repeatability, reuse and easy transportation; (c) high fidelity as compared to patient puncture 'in vivo', given that it is a natural model; and d) low price [18]. The objectives of our study, which used this model, were to establish a UGVC training program for inexperienced operators and to present the results of a training program with a simulation model for paediatric UGVC.

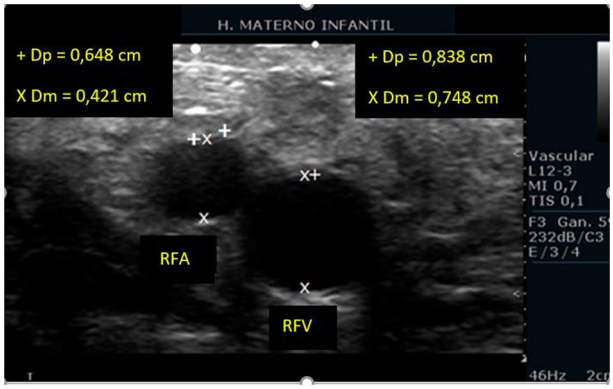

Fig. 2 Measurement of depth (Dp) and diameter (Dm) of the right femoral artery (RFA) and vein (RFV) in a 12-year-old patient

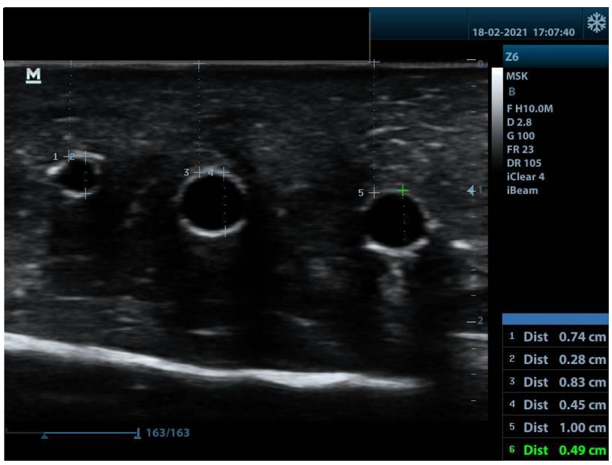

Fig. 3 Ultrasound image within the transverse axis of three vessels of different sizes and different depths, obtained by the simulation model

Method

During the course of a 4-h UGCV training program (2 h theory plus 2 h practice), 25 operators without previous experience carried out a total of 300 punctures (12 per operator) at equidistant sites along the transverse axis out-of-plane (TA/OP) or the longitudinal axis in-plane (LA/IP) using the simulation model developed by Pérez-Quevedo/López-Alvarez [18] (Fig. 1). The depth and diameter (Figs. 2, 3) of the

vascular structures to be cannulated were established on the basis of previous determinations in paediatric patients [13, 14]. 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 results of ultrasound-guided vessel punctures in the training model were used to evaluate the success rate of cannulation, the time needed for the procedure, the number of attempts needed to achieve successful cannulation, manoeuvres that might facilitate UGCV and potential complications during the application of the technique. Qualitative variables were expressed as frequencies and percentages. Numerical variables were expressed as mean, standard deviation, and median. Normality of the continual numerical variables was evaluated with the Kolmogorov–Smirnov test. The statistical analysis was conducted with the Statistical Package for the Social Sciences version 19 for Windows (SPSS Inc., Chicago, IL, USA).

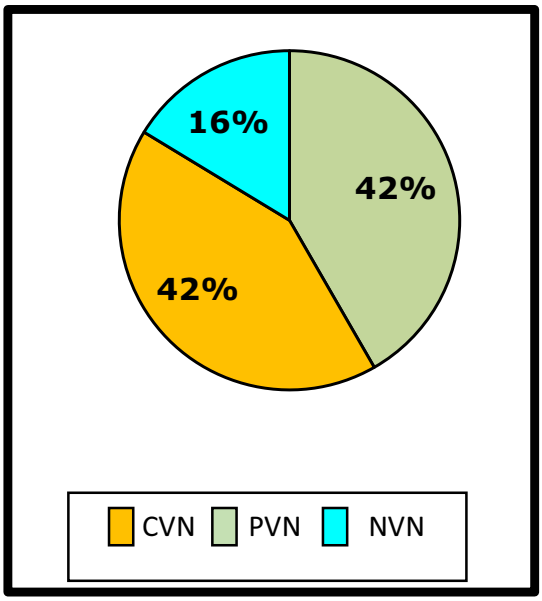

Fig. 4 View of the needle during UGVC (CVN: complete view of the needle; PVN: partial view of the needle; NVN: no view of the needle)

Results

Twenty-five participants (56% physicians and 44% nurses) without prior experience in UGCV carried out a total of 300 punctures (12 per participant) at equidistant sites along the TA/OP or LA/IP using the designed training model (Fig. 1). Table 1 shows the main characteristics of the UGVC model for inexperienced operators; notice that the mean depth of vessels to be cannulated was 0.90 (0.34) cm and their mean diameter was 0.41 (0.1) cm. The mean number of attempts was 1.48 (0.93) and the mean number of attempts until successful UGVC was 1.31 (0.72). In more than 50% of cases, only one attempt was needed to achieve UGVC. The mean time needed for the procedure was 74.70 (73.72) seconds; the mean time to successful cannulation was 58.72 (56.87) seconds. Complete view of the needle (CVN) was accomplished in 41.7% of procedures, while partial view of the needle (PVN) occurred in 42% of procedures (Figs. 4, 5, 6). Repositioning the needle/guidewire (RNG) was necessary for successful UGVC in 49% of procedures (Fig. 7). Complications included: (a) 26.3% vessel perforation/wrong guidewire positioning (VP/WGP) and (b) 4.3% successful vessel puncture, followed by failure to accomplish subsequent cannulation. The global success rate in the training model was 79.7% (79.3% in TA/OP and 80% in LA/IP); the rate of success on first attempt was 66.9%. Table 2 presents the frequencies of the number of attempts necessary for successful UGVC.

Table 1 Descriptive presentation of the main variables of the ultrasound-guided vascular cannulation for inexperienced operators (cm: centimeters; s: seconds; SD: standard deviation)

n = 300	Minimum	Maximum	Median	Mean	SD
Depth (cm)	0.50	1.90	0.85	0.90	0.34
Diameter (cm)	0.20	0.65	0.40	0.41	0.10
Number of attempts	1.00	7	1.00	1.48	0.93
Time for procedure (s)	14.00	349.00	40.00	74.70	73.72

Discussion

Ultrasound has been established as a therapeutical-diagnostic tool to be used on paediatric patients, as it is a non-invasive and highly profitable system for health screening. In addition, this system makes it possible to assess different organs and organic systems and to diagnose infrequent complications [22–26] Vascular cannulation has experienced a major advance with the use of ultrasound-based guidance. However, such an approach requires a learning process, which should ideally be carried out in simulation models. The learning curve was not evaluated in this study, because the main objective of this work was the theoretical–practical training of inexperienced/untrained operators on ultrasound-guided vascular cannulation. To achieve that, a training model was used [18]. Consideration was given to the model's similarities with paediatric patients, its versatility, repeatability and its low cost, as these were its most relevant differential characteristics with respect to other simulation models or simulators [16, 17, 19, 20]. In an earlier study by our group [13, 14], more than 80% paediatric patients showed femoral and jugular vessel depths between 0.5 and

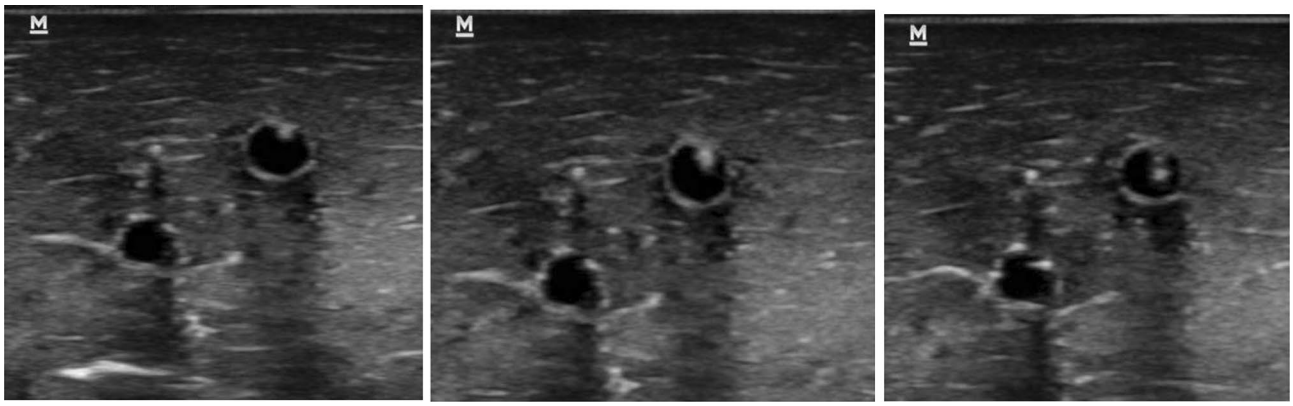

Fig. 5 Visualisation of the needle tip in the out-of-plane vascular cannulation. It can be observed the deformity of the vessel anterior wall in its contact with the puncture needle

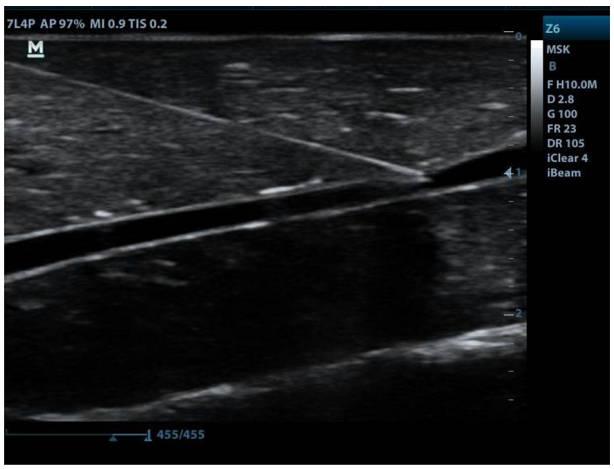

Fig. 6 Visualisation of the needle track in the in-plane vascular cannulation. It can be observed that the vessel anterior wall is deformed by its contact with the puncture needle

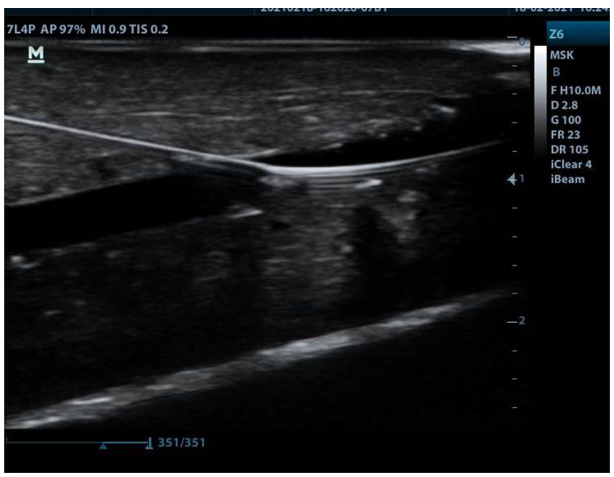

Fig. 7 Advance of the guide inside the vascular structure during the in-plane cannulation in the simulation model

Table 2 Percent distribution of the number of attempts needed for successful UGVC in the training model

Number of attempts	% Success
1	66.9
2	22.2
3	7.5
4	2.1
5	0.8
7	0.4

1 cm, and more than 50% of patients showed femoral vessel diameters between 0.20 and 0.30 cm and jugular vessel diameters between 0.50 and 0.65 cm (Figs. 3, 4). On this basis, we designed a training model to emulate the different scenarios that could potentially occur in paediatric UGVC. The mean depth of vessels to be cannulated was 0.90 cm and the mean diameter was 0.41 cm. These data support the reliability of the model for use in paediatric patients. A good view of the needle is essential in UGVC to perform the technique safely and prevent complications. This is, however, a controversial and subjective matter, associated to large inter-observer variability [33–38]. We addressed this issue by subdividing this variable into three subcategories: complete view of the needle (CVN); partial view of the needle (PVN); and no view of the needle (NVN) during the procedure. These subcategories were determined by an independent observer with previous experience in this technique, so as to reduce subjectivity. In this study, CVN was accomplished in less than 50% of procedures, while NVN occurred in 16% of them. The needle tip can subjectively be considered to have been visualized in the ultrasound machine or scanner while it is not so in practice, due to it being a part of this, or an artifact developed during the insertion of the needle. This fact can be related to complications, such as vessel posterior wall perforation or cannulation of a wrong

vessel. In a series published by Moak et al. [34], the CVN rate was 66% according to the operators, but only 6% according to reviewers experienced in analysing video records of this technique. In a review of relevant literature [35–39], repositioning manoeuvres were necessary for successful UGVC. In our study, repositioning the needle or guidewire (RNG) was necessary in half the procedures and was more frequent with smaller vessel diameters, TA/OP punctures and punctures perpendicular to vessel (since the tip of the needle might reach the posterior vessel wall thus impairing insertion of the guidewire). The global success rate with our training model was 79.7%. In a training program for resident physicians, in which a commercially available UGVC model designed by Thomas et al. [40] was used, a similar success rate was accomplished (80.8%). However, Erickson et al. [35] reached a total success rate of 100%. Such differences could be due to the degree of difficulty associated to every simulation model; for example, the mean diameter of the punctured vessels was 0.41 cm in our series, but 0.56 cm in theirs. In a peripheral vein UGVC study with a population of 169 adult patients, Panebianco et al. [36] reported a 90% success rate in 3 attempts. This rate fell below 56% in vessels with less than a 0.3 cm diameter, and rose to 92% in vessels with more than a 0.6 cm diameter. The authors concluded that the probability of success increased 1.79 per millimetre in vessel diameter, but dropped in vessels located more than 1.6 cm deep. This finding was also reported by Grebenik et al. [41] in a comparison between adult and paediatric patients, as well as in comparisons between paediatric patients of different age and weight ranges. They reported the lowest success rates in patients with less than 10 kg body weight or those younger than 1 year. The mean time needed to cannulation in our model was 58.7 s. We measured the time from skin penetration until verification of a correct position of the needle within the vessel. In a series by Erickson et al. [35], a mean of 11 s for vessel penetration was reported, although they measured the time from skin penetration until the emergence of the fluid within the vessel. Other series described similar results. For example, Phelan et al. [38] reported 17.56 s until extraction of the fluid within the vascular structure of the model for UGVC with an echorefractory needle, as compared with 19.22 s for UGVC with a standard puncture needle. Notice that the diameter of cannulated vessels in the mentioned study was 0.8 cm, which corresponded to an average adult patient. Furthermore, since the time required for inserting the guidewire or catheter into the vessel was not included, the time to vascular cannulation was underestimated. Moreover, it can be speculated that the success rate might be overestimated based on the fact that in up to 4% of our correct punctures, subsequent cannulation was not possible. The rate of success on first attempt was 67% in our study. In general, the mean number of attempts needed to achieve cannulation is inversely correlated with success in performing the technique. In this study, 1.48 attempts were required on average. Tomas el al. [40] reported similar results with a training model, where the number of attempts fell from 1.5 to 1 after participants received a period of training plus explanation of the essentials of the technique. In other studies carried out with adult patients, e.g. Barsuk et al. [42], a reduction in the number of attempts was described, from 1.74 with the traditional 'blind' cannulation to 1.32 with the UGVC technique. Ueda et al. [43] found a significant association between the rate of success on first attempt and the magnitude of vessel diameter. A further advantage of the UGVC approach, described in the literature, is a reduction in the complications rate [29, 37, 44, 45].

Stone et al. [24] emphasized the importance of monitoring the needle tip to reduce the rate of vascular complications, because failure to see it may lead to unadvertised puncture of vital anatomical structures or posterior vessel walls, or to unsuccessful cannulation [37, 45]. In a published series of adult patients, Vogel et al. [37] reported around 20% prevalence of accidental puncture of the posterior wall of the internal jugular vein; a finding also reported by Song et al. [44] in a paediatric study involving the radial and posterior tibial arteries. In other studies, e.g. that of Blaivas et al. [45], who used a mannequin torso, 64% operators accidentally punctured the posterior wall of the jugular vein during cannulation. With our model, we found both wrong guidewire positioning and 26.3% vessel perforation (the latter could be underestimated, since cannulation is sometimes successfully achieved in spite of unadvertised perforation of the posterior wall). In a study by Moon et al. [46], where a 34% incidence of posterior wall perforation was reported, such complication was verified by dissembling the model, refilling the vascular structure with fluid and observing whether the fluid emerged from one side or both sides of the structure. Fluid emerging from two orifices indicated perforation of the posterior wall was confirmed. In our study, we did not carry out such verification; thus the rate of posterior wall perforation might potentially be higher than described. Finally, we would like to highlight that even with a UGVC training model used by inexperienced operators who carried out a restricted number of punctures, a global view of the technique, as well as the success and complication rates, could be obtained, which contributed to lessening the UGVC learning curve.

Declarations

Conflict of interest The authors declare that: (a) they have no financial or personal relationship, present or past, which could bias or inadequately influence the making of this work; (b) they have not and

will not receive any financial compensation for the study design, data collection or analysis, manuscript preparation or submission for publication.

Ethical statements This study was designed according to the basic principles of the Declaration of Helsinki of the World Medical Association [21]. The highest levels of professionalism and confidentiality were applied and the national regulations for data protection were observed. Participants' right to confidentiality was granted and their identities were coded. Only authorized staff had access to identification-related personal information for data verification purposes. This research project was approved by the Ethics Committee for Clinical Research of the Mother and Child University Hospital of the Canary Islands (Complejo Hospitalario Universitario Insular-Materno Infantil de Canarias; Id: CEIm-CHUIMI-2016/883). Trainees participated voluntarily and anonymously, and they agreed to results publication.

Informed consent All participants (operators and patients collected data) were asked to sign informed consent.

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