Arterial Cannulation Simulation Training in Novice Ultrasound Users

Julien Raft, Léo Coinus, Anne-Sophie Lamotte, Côme Slosse, Isabelle Clerc-Urmès, Cédric Baumann, Philippe Richebé, and Hervé Bouaziz

BACKGROUND: Arterial cannulation is an important procedure for hemodynamic monitoring and blood sampling. Traditional radial artery cannulation is performed by using anatomical knowledge and pulse palpation as a guide. Arterial cannulation using ultrasound (US) requires specific training, especially for new US users. We hypothesized that even for new US users, US guidance would facilitate the successful puncture by lower attempts before successful intraluminal cannulation of a simulation model of the radial artery. METHODS: A prospective randomized controlled crossover study was conducted with new US users on a gelatin phantom wrist. Three sessions of training were proposed: US-guided technique with low blood pressure (BP), palpation-guided technique with high BP, and one secondary comparison with low BP. For the 2 first sessions, all volunteers performed each technique but not in the same order. The main criterion was the number of attempts before successful catheterization of the model artery. A secondary criterion was the number of needle movements (the number of attempts plus the number of needle directional changes). RESULTS: Twenty new US users participated in the study. Numbers of attempts before successful catheterization were significantly lower when using the US technique: 1.1 (± 0.4) for US versus 1.6 (± 0.8) for palpation high BP ($P = .02$) versus 2.5 (± 1.4) for the secondary comparison, palpation low BP ($P < .001$). All of the participants achieved success after the 12th needle movement for US technique, after the 19th needle movement for palpation high BP, and after the 25th needle movement for the secondary comparison, palpation low BP. The total time before success was not significantly different between the 2 first sequences (US vs palpation high BP). CONCLUSIONS: US technique was more successful than traditional palpation technique for novice US users performing arterial cannulations for the first time. A study in the clinical practice is needed to confirm these results. *Key words: arterial cannulation; ultrasound; simulation; novice training; randomized trial.* [Respir Care 2022;67(9):1154–1160.

Introduction

Arterial cannulation is an important procedure for hemodynamic monitoring and blood sampling. The radial artery is one of the most preferred sites for arterial cannulation because of a low incidence of complications.[1] Traditional placement of radial arterial cannulation is performed by using anatomical knowledge and pulse palpation as a guide. However, this approach is sometimes difficult, especially with the presence of low blood pressure (BP) and could be especially challenging for novices. However, ultrasound (US) guidance provides an adept alternative to traditional placement methods and can facilitate cannulation through real-time visualizations of different structures and even puncture of the artery itself. Seven meta-analyses suggested a clear benefit from US for radial artery cannulation compared with traditional palpation, and all reported higher first-attempt success rates in arterial cannulation.[2-8] The variation of other criteria in favor of US depended on each analysis: fewer mean number of attempts to success,[3,4,8] decreased failure rate,[7] shorter mean time to success,[3,4,8] and reduced occurrence of hematoma.[3,8]

Tang et al suggested that the operator's experience plays an important role in using US for arterial cannulation.[3] There were significant similarities between studies included in previous meta-analyses about operator experience.[2-8] In 18 studies of those studies, all physicians had some experience with US. In only 3 studies, the operator's experience was unknown.[9-11] Since these meta-analyses, one study in a teaching institution was in favor of US, showing a lower mean time, fewer attempts, and an improved success rate.[12] But in this study, all residents performed at least 5 blind

palpation and 5 US radial arterial cannulations before being part of the study.[12] In another recent study, not included in the meta-analyses, operators had US experience.[13] To date, and to our knowledge, no published studies are reporting on arterial cannulation in novice US users using US versus palpation techniques. This study aimed to compare the mean number of attempts to success for arterial cannulation between US and palpation techniques on a simulation model with novice US users.

Methods

This prospective randomized controlled crossover study was conducted at the simulation center of the Virtual Hospital of Lorraine (Nancy University Hospital, Nancy, France) in January 2019. The medical review board of the Nurse Anesthetist School of the University of Lorraine approved this study. In France, nurse anesthetists and nurse anesthetist students are permitted to perform arterial cannulation after a medical prescription. They study it during their training. Nurse anesthetist students voluntarily participated in this study, and written informed consent was obtained for each participant. This study was an audit of an educational intervention on an arterial-puncture wrist phantom trainer model; thus, a formal ethics committee approval was not required in France. The inclusion criterion for this study was experience in radial arterial puncture, such as arterial blood sampling. The exclusion criterion for this study was previous experience in arterial cannulation and any experience using US at all.

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QUICK LOOK

Current knowledge

Arterial cannulation is an important procedure for hemodynamic monitoring and blood sampling. Ultrasound guidance provides a clear benefit of success from alternative to traditional placement methods. Arterial cannulation using ultrasound requires specific training, especially for new ultrasound users.

What this paper contributes to our knowledge

This study was conducted with new ultrasound users on a gelatine phantom wrist. Ultrasound was more successful than traditional palpation technique for novice ultrasound users performing for the first time arterial cannulations after only an information.

Study Protocol

Nurse anesthetist students of the school who completed mandatory arterial cannulation and US lecture courses were allowed to participate in the study. This 30-min lecture included the presentation of the study and theoretical and practical information on arterial cannulation and US. The Seldinger technique was also described in the lecture: After puncture of the artificial blood vessel with an introducer needle, a separate guidewire is advanced into the vessel; the introducer needle is removed; the catheter is inserted into the vessel, and the guidewire is withdrawn.

During the introduction, the instructors (LC or HB) demonstrated how to use the arterial cannulation device and the US machine. The nurse anesthetist students were permitted to use the US on the arterial-puncture wrist phantom model and to practice out-of-plane views. However, they were restricted from actually piercing the model and visualizing the needle on the US screen.

The equipment used in the exercise consisted of an arterial-puncture wrist phantom trainer model M99 (Kyoto Kagaku, Kyoto, Japan) with one artificial blood vessel of 3-mm diameter (silicone tubing) that could be punctured with a needle. All participants used the exact same model. The arterial-puncture wrist phantom trainer model was connected to a pump and a simulator base (Fig. 1). Arterial pulsation was palpable at the same levels for each model and at the same frequency of 100 beats/min for the entire study. Simulated red blood was prepared. The artery tube was the same for the 3 sessions of each participant and changed between every participant. The skin cover was changed in the exact same position by the same supervisor. The skin cover of 1.7-cm thickness came from a US-compatible tissue from a central venous catheterization training device (CentraLine, Seattle, Washington). Flashback of artificial

Fig. 1. Simulation equipment. 1 = Arterial puncture training wrist; 2 = circulation pump; 3 = ultrasound machine; 4 = probe; 5 = probe gel.

blood into the needle could be observed. No puncture trace of the injection needle remained on the injection site. A US machine (Logiq E, GE Healthcare, Madison, Wisconsin) equipped with a linear 4–12 MHz transducer without a transducer cover was used (Fig. 1). Arterial catheterization sets Seldicath (Prodimed, Le Plessis-Bouchard, France) were used with a 19-G 5.5-cm guidewire introducer needle, with a diameter of 19 G and a length of 55 mm, a 30-cm guide, and an 18-G 11-cm catheter.

For this study, 3 separate training modules were proposed: US-guided technique with low BP and palpation-guided technique (with high BP and one with low BP). High BP was set at 160 mm Hg, and low BP was set at 80 mm Hg. BP was the same for each group during the entire study. All volunteers participated in each session but not in the same order for the 2 first sessions of training (US and palpation high BP). In the US session, low BP was set as standard to avoid bias due to the subjects palpation of the pulse. Participation in the first 2 sessions was randomized by computer, and after each participant concluded both sessions continued the exercise with the final session (palpation low BP). All 3 sessions were performed one to another without any break for each participant. This study was performed on the same experimental day and with the same device. All volunteers attempted arterial cannulation until success for each session. The end of a session was defined as arterial cannulation success.

US settings were standardized with a depth of 3 cm. A single operator performed the procedure by palpation or by holding the probe with an out-of-plane approach. In this study, only the out-of-plane approach was permitted for the needle insertion. When the operator observed the introducer needle successfully enter the artificial blood vessel with flashback of artificial blood into the needle (or with dynamic US), they then inserted the guidewire through the introducer using the Seldinger technique. Then they introduced the catheter around the guidewire and removed it. Successful arterial cannulation was defined as the introduction of the guidewire introducer and the catheter without any resistance. Sometimes, on wrist phantom trainer models and even real patients, artificial blood does not always flashback, so this criterion was not considered for successful arterial cannulation.

Data Collection

The main evaluation criterion was (1) the number of attempts (new artificial skin puncture) before success. Confirmation of success was standardized by the introduction of the guidewire introducer and the catheter without any resistance. Using an anonymous file, an instructor trained in palpation and US arterial cannulation closely monitored the students' performance of each technique. The

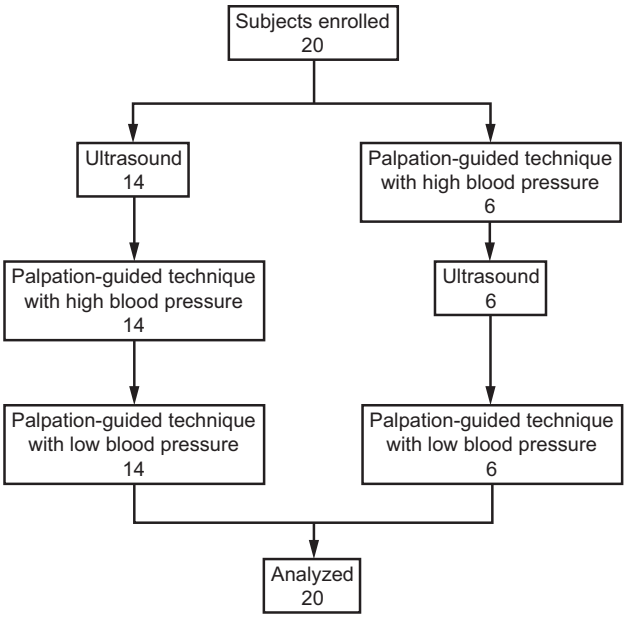

Fig. 2. Flow chart.

students were allowed to refer to the summary sheet related to the allocated technique during the procedure. The following outcomes were measured: (2) success of cannulation at the first puncture, (3) success of cannulation during the first 5 min, (4) number of needle directional changes, (5) time to check the artery before the first skin puncture (the count started when the fingers of the operator or the probe was on the model; the count stopped at the first puncture), (6) total time before success (the count started when fingers of the operator or the probe was on the model), and (7) the number of needle movements (the number of attempts (1) plus the number of needle directional changes (4).

Sample Size Calculation

The sample size calculation was based on previously published data [14] and our study's main evaluation criterion: the number of attempts to succeed. We assumed that in the palpation high BP group the number of attempts to succeed would be 1.5 (SD = 0.5) versus 1 (SD = 0.5) in the US group. With an alpha risk at 2.5 (taking into account the presence of a third subgroup, palpation low BP/secondary comparison), a statistical power of 80%, and a 1:1 ratio, 19 volunteers per subgroup had to be included to show a mean absolute difference of 0.5.

Statistical Analysis

To account for the crossover design, the number of attempts (primary end point) was analyzed using repeated-measures analysis of variance models accounting for the group (US, palpation high BP) and the order of the 2 techniques (US first then palpation high BP or palpation high BP first then US) to test the carry-over effect and the group effect. In case of no significant carry-over effect, data from both periods were retained to produce group comparison. Categorical variables were described by percentages and continued variables by mean (SD). A comparative analysis was conducted in intention to treat using a Fisher exact test for categorical variables and a Wilcoxon signed-rank test for continuous variables. Alpha risk was set at 5%. Finally, graphical representations completed the statistical analyses. Randomization and analyses were performed using SAS v9.4 software (SAS Institute, Cary, North Carolina).

Results

Twenty nurse anesthetist students were screened and included in the study: None had previous US experience at all nor arterial cannulation, but all had previous experience with an arterial puncture for blood gas analysis. These demographic results ensured consistent practices for this study. All students had completed the lecture before the study. The 20 students were randomized for the order of passage of the first 2 sessions (US or palpation high BP) (Fig. 2).

US technique proved better for our main criterion: The number of attempts before success using the US technique was significantly lower, 1.1 (± 0.4) for US versus 1.6 (± 0.8) for palpation high BP ($P = .02$) versus 2.5 (± 1.4) for the secondary comparison, palpation low BP ($P < .001$) (Table 1). When analyzing the number of attempts under the crossover design, no carry-over effect was detected from US technique to palpation high BP ($P = .80$), but such a small sample size may be insufficient to show a carry-over effect. All of the participants achieved success after the 12th needle movement for US, after the 19th needle movement for palpation high BP, and after the 25th needle movement for the secondary comparison, palpation low BP (Fig. 3). These variations of results of the training sessions are strong reasons to use US especially for new users. The results of the secondary comparison showed us a largest utility of US for novices for difficult conditions of cannulation.

Two secondary outcomes were significantly better for US than palpation high BP, with higher cannulation at the first puncture, 95% ($n = 19/20$) versus 60% ($n = 12/20$) ($P = .03$), and lower number of needle directional changes, 2.8 (± 3.0) versus 5.7 (± 5.1) ($P = .04$) (Table 1).

The time to check the artery before the first skin puncture and total time before success were not significantly different between the first 2 sequences (US vs palpation high BP) (Table 1). But these 2 lengths of time were significantly longer for the secondary comparison, palpation low BP, comparing to the two other models: approximately 30 s longer for checking the artery and approximately 45 s longer to succeed (Table 1).

Table 1. Study Protocol Results

	US Guided ($n = 20$)			Palpation High BP ($n = 20$)			Palpation Low BP ($n = 20$)			P**		
							For a secondary comparison					
	n	% or mean	SD*	n	% or mean	SD*	n	% or mean	SD*	US vs Palpation High BP	US vs Palpation Low BP	Palpation High BP vs Low BP
(1) Number of attempts	20	1.1	0.4	20	1.6	0.8	20	2.5	1.4	.02	< .001	.01
(2) Success of cannulation at the first puncture	19	95		12	60		5	25		.03	.49	.56
(3) Success of cannulation during the 5 min	20	100		18	90		13	65				
(4) Number of needle directional changes	20	2.8	3	20	5.7	5.1	20	8.8	6	.04	< .001	.09
(5) Time to check the artery before the first skin puncture (s)	20	20	13	20	16.5	9.9	20	50	49	.34	.01	.004
(6) Total time before success (s)	20	81.5	44	18	73.9	51	13	124.7	72	.62	.04	.03
(7) Number of needle movements = (1) + (4)	20	3.9	3.1	20	7.3	5.7	20	11.3	7	.03	< .001	.052

** Wilcoxon test for quantitative variables; Friedman test for qualitative variables.
US = ultrasound
BP = blood pressure

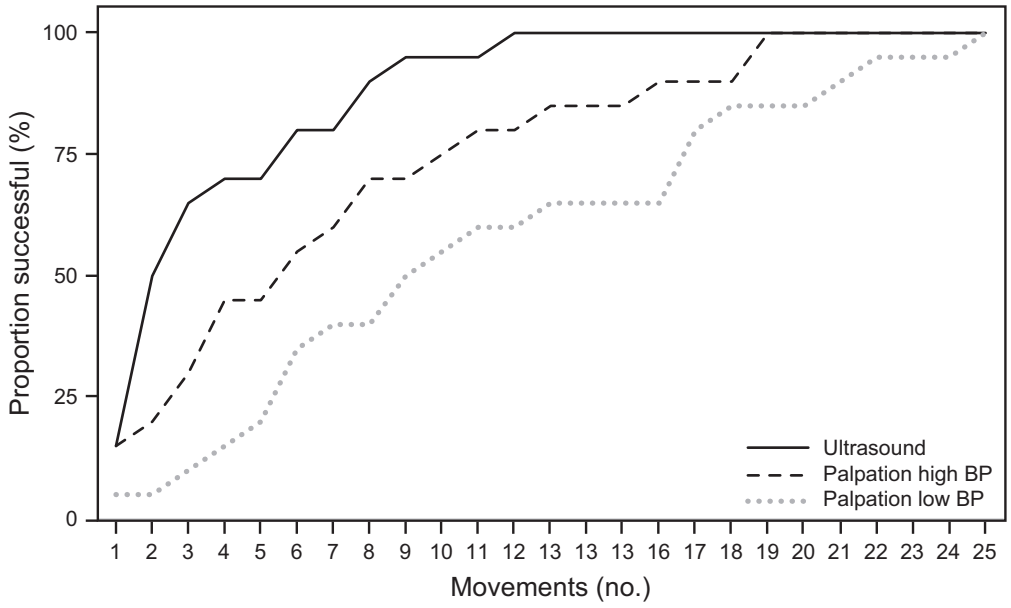

Fig. 3. Learning curve by group ($P < .05$). BP = blood pressure.

Discussion

By significantly lowering attempts before success, the use of US guidance for arterial cannulation is useful even for new US users. The utility of US for arterial cannulation is well documented.[2-8,15,16] This is the first study to primarily focus on participants without any prior experience in US. Our results suggest that arterial cannulation of the radial artery using US is far more successful than traditional means performed by using anatomical knowledge and pulse palpation as a guide in novice users. In our study, all students had prior experience in radial arterial puncture, such as arterial blood sampling. So despite a felling experience, new US users are more efficient with US. Guidelines have recognized that US arterial cannulation success is higher when trainees have developed general experience, skill,

and dexterity.[15] With our study, we can argue that trainees without any previous experience in arterial cannulation are more efficient with US than the palpation technique only after participating in a theoretical and practical information session. However, whereas US can be used without any palpation experience, a theoretical and practical information session on arterial cannulation and US is still necessary.

Our model was intended to simulate arterial cannulation but was limited as we used commercial tissue phantoms that do not fully reflect all the challenges faced in the clinical setting. In real patients, repeated attempts increase the risk of hematoma and may cause arterial spasm, making subsequent attempts more difficult.[17] In one review, hematoma was seen in 14% of radial arterial lines.[7] US significantly reduced the occurrence of radial artery hematoma by 28%.[3] The number of attempts presented in our study may differ if the trainees performed arterial cannulation on real patients. With US, our study showed significantly fewer needle directional changes, which may translate into less risk of hematoma in real patients. We chose the out-of-plane approach because in another study on phantom models this technique allowed for a better success rate in a population of novice US users.[18] But in a study comparing out-of-plane versus the in-plane US for arterial catheter cannulation, they showed significantly higher posterior wall damage and hematoma with the out-of-plane technique.[19] So a specific in-plane approach for novice US users must be evaluated and compared. The artificial blood vessel diameter of our study was 3 mm and corresponded more to an adult arterial size. The US mean (SD) diameters of 6 y old infants are 1.0 (0.2) mm during the systole and 1.2 (0.2) mm during the diastole.[20] Thus, different sizes of arteries must be evaluated by novices as well.

The radial artery is the most common site for arterial cannulation because of its superficial location, dual arterial supply to the hand, and low rate of complications.[21,22] The ability to palpate the arterial pulse in patients who are critically ill may technically be challenging by peripheral edema, hypotension, and obesity.[7,23] Low systolic blood pressure was associated with increased failure rates during arterial cannulation.[24] The overall failure rate of artery catheterization is under 10% but may be as high as 50% for patients in shock.[25] Our study showed better results with US despite artificial low BP than with the palpation technique (high and low BP). US technique for new users is not a hindrance; rather, it may provide safer and more effective means to perform arterial cannulation in critical conditions. In our study, the time to check the artery and total time before success were significantly shorter with US than the palpation technique during low BP. So US could save valuable time, especially during critical conditions. However, our study on a simulator did not study the time to install the probe protection covers.

Conclusions

US was more successful than traditional palpation technique for novice US users performing first time arterial cannulations. The number of attempts was significantly lower with US especially for difficult conditions of cannulation with low BP, without additional time. US permitted significantly higher cannulation at the first puncture and lower number of needle directional changes during the procedure. However, these results were possible after a theoretical and practical information session. Before affirming that US is the standard technique to perform arterial cannulation, a study in clinical practice of novice US users is needed.

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