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The efficacy of ultrasonography on learning curve and inter-subject performance variability in radial artery cannulation in standardized training for residents: a randomized controlled trial

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Abstract

Aim: To evaluate the effect of ultrasound (US) on learning curve and inter-subject performance variability of residents in radial artery cannulation. **Material and methods**: Twenty non-anesthesiology residents who received standardized training in an anesthesiology department were selected and divided into two groups: anatomy group or US group. After training of relevant anatomy, US recognition and puncture skill, residents selected 10 patients either under US or anatomical localization performing radial artery catheterization. The number and time of successful cases of catheterization were recorded, success rate of first attempt and catheterization, as well as the total success rate of catheterization were calculated. The learning curve and inter-subject performance variability of residents were also calculated. Complications and the residents' satisfaction for teaching and self-confidence before puncture were also recorded. **Results:** Compared to the anatomy group, total success rate and the success rate at first attempt were higher in US-guided group (88% vs. 57%, 94% vs. 81%). The average performance time in the US group was significantly less (2.9±0.8 min vs. 4.2±2.1 min) and the mean number of attempts was 1.6, while 2.6 for the anatomy group. With performing cases increasing, the average puncture time of residents in the US group decreased by 19s, while 14s in the anatomy group. More local hematoma occurred in the anatomy group. The satisfaction and confidence degree of residents were higher in US group ([98.5±6.5] vs [68.5±7.3], [90.2±8.6] vs [56.3±5.5]). **Conclusion:** US can significantly shorten the learning curve, reduce the inter-subject performance variability, improve the first attempt and total success rate of radial artery catheterization for non-anesthesiology residents.

Keywords: radial artery cannulation; ultrasonography; learning curve; residents; standardized training

Introduction

Radial artery cannulation is the most important part of the standardized training for residents [1]. Traditionally, residents can learn how to perform artery catheterization through theoretical learning, demonstration of puncture and exercising using models with anatomical positioning method before performing on patients [2,3]. However, radial artery cannulation can be difficult, leading to hematoma formation, bleeding, or spasm of the artery [4]. Catherization can be challenging for some reasons: the variation of radial artery, at times particularly in some specific scenarios such as hemodynamically unstable patients, altered vascular anatomy or in obese patients and more importantly, lack of residents' experience [5]. Comprehension of puncture skill and one's own feeling of pulse strength may differ among residents. Thus, radial artery catheterization success rate varied greatly among novice residents. Recently, ultrasound-guided vessel catherization had won so much compliment in clinical practice [6-8]. Variations of the vessel can be seen and puncture site can be located precisely with ultrasound

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(US) [9]. With US, one may visualize the needle tip in the vessel, hence success rate of cannulation improved [9,10].

However, few studies were designed to assess the influence of US on residents with seldom experience on radial artery cannulation. This study focused on non-anesthesiology residents to assess the effect of US on the learning curve and inter-subject performance variability of residents in radial artery cannulation.

Material and methods

Subjects

Twenty non-anesthesiologist residents receiving standardized training for more than there months in the anesthesiology department and with seldom experience in radial artery cannulation, with or without US, from May 2019 to August 2021, were enrolled and randomly divided into two groups: anatomical palpation group (n=10) or US-guided group (n=10). The study flow in both groups was presented in Fig 1.

Training method

All residents received three sessions of theoretical training, with each session being 45 minutes. The first session was a common class, including anatomy, as well as the indications and contraindications of radial artery catheterization. In the second session, residents learnt basic skill and method of catheterization with or without ultrasound in either group, respectively. After that, the same teacher displayed how to perform catheterization on a model and in patients. In the third session, all residents practiced radial artery cannulation on a model independently with or without ultrasound. Once finished practicing, all residents received theoretical assessment. Scores less than 80 were not qualified for performing on patients. Then, each resident in both groups selected 10 patients to perform radial artery cannulation.

Study population and performing method

With institutional ethical approval, patients received arthroscopic rotator cuff repair were selected from May 2019 to August 2021, age 18~65y, ASA I~II grade, and allocated into two radial artery cannulation groups: ultrasound-guided or anatomical palpation group. Contradictions: (1) unconscious patients; (2) PLT<75 or coagulation dysfunction; (3) positive Allen's test; (4) received radial artery cannulation recently or infection at puncture site.

Interventions

All catheterizations were performed in the operation room. If necessary, patients were sedated using midazolam 0.05 mg/kg and sufentanil 1μg/kg in case of uncomfortable experience. Before puncturing, local anesthesia was conducted. In the anatomy group: all patients stayed supine with their arms abducted 20°~30° degree and palm upward, placing the gauze roll under the patients' wrist to raise the wrist joint up. After local disinfection with Iodophor, the index, middle and ring finger were placed on the strongest pulse site of the patient's radial artery. The point indicated by the index finger was the puncture site. The line indicated by the three fingers was the direction of the needle entrance. Entering the needle slowly with an angle of about 30°~45°, once blood was seen from the needle core, the needle was laid down and pushed forward about 2~3 mm. If blood flushed from the core of the needle continuedly, the outer sleeve was pushed forward and the needle core was withdrawn. Thereafter, connecting the arterial sensor, catheterization was successful, if the wave form still existed.

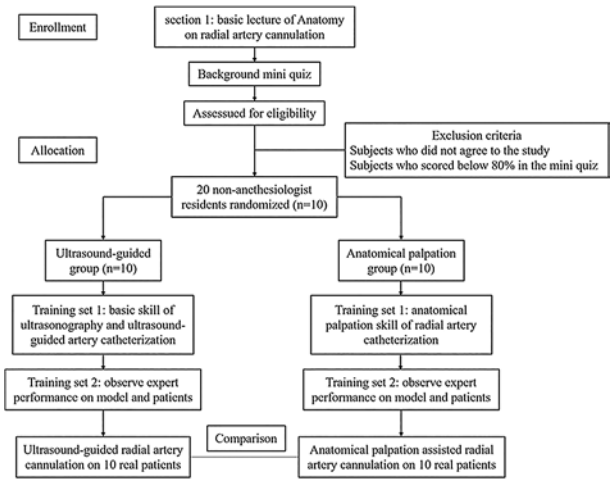

Fig 1. Flow diagram of study

US group: High frequency probe (6~13 MHz, Sonosite, America) was used with depth of 2 cm. Punctures were performed using the dynamic needle positioning technique. The details of the technique have been described in several reports [11,12]. A 20-gauge, 48 mm needle (BD Vialon™ Material, Utah84070, USA) was inserted close to the transducer (within 1 mm), at about 30~45° to the skin, and the needle tip was visualized as a white dot on the ultrasound screen. Then, the transducer was shifted slightly proximally toward the patients until the white dot disappeared from the screen. Subsequently, the needle was advanced until the white dot reappeared on the screen again. The needle and the transducer were alternately moved proximally toward the patients several times to visualize the needle tip in real time. After penetrating the anterior wall of the artery and confirming initial blood return, the steps were repeated a few more times with a smaller insertion angle to visualize the white dot in the artery. Then, the outer catheter was advanced into the artery.

Outcomes

Depth and area of radial artery were measured by a single anesthesiologist before performing. The primary outcome was the first-attempt success rate of artery catheterization. If the needle did not withdraw from the skin and the needle direction was only adjusted, it was still regarded as the first attempt. The secondary outcomes were the overall success rate, performance time, and number of attempts within 10 minutes. Performance time was defined as the time from the needle penetration through the skin to the appearance of arterial waveform connected to the sensor. The inter-subject performance variability of residents was calculated. Inter-subject performance variability was defined as the average difference of performance time among residents [13]. If performance time was more than 10 min or the number of attempts was more than 3 times, the same experienced anesthesiologist will complete the puncture instead, which was defined as a failed puncture. The occurrence of related complications such as infection, hematoma and fistula were recorded. Satisfaction for teaching and self-confidence before puncture of all residents were recorded in the form of a questionnaire survey with a maximum score of 100 points.

Statistical analysis

The sample size of patients was predetermined according to the difference of first attempt success rate between groups. Sample size was calculated based on a previously reported first attempt success rate in ultrasound-guided radial artery cannulation. The first attempt success rate was 65% in a previous study [12], while a pilot study in our center involving only novice residents of anatomy based radial artery cannulation had a first attempt success rate of 35%. Assuming a difference in means of 30% in first attempt success rate between the ultrasound group and the anatomy group, the necessary minimum sample size to achieve the desired power of 0.8 and alpha error of 0.05 was 80 artery cannulations (40 per group). To account for a 5% drop out rate, and increasing the reliability of this study, 120 additional cannulations were recruited. Therefore, the first attempt success rate was measured in a total of 200 artery cannulations. Since this study consisted of 20 nonanesthesiology residents in our tertiary academic medical center, ten real patients per resident were recruited. All radial artery cannulation on real patients were considered as separate cases.

SPSS 22.0 statistical software was used for data analysis. The measurement data of normal distribution were expressed as mean ± standard deviation or standard error. The counting data were presented as rate (%). The chi-square test was used to compare the first attempt success rate between the two groups. The trend line of learning efficiency was calculated by linear regression analysis to analyze the puncture operation time. Data normalization for the mean performance times was made by bounding the data between the minimum and maximum mean times. Data were presented as mean (standard deviation). p-values less than 0.05 were considered to be statistically significant.

Results

Twenty non-anesthesiology residents participated in and completed the study with 10 residents in each group. Training year, baseline clinical experience of palpated and ultrasound-guided radial artery cannulation were all comparable between the two groups (Table I).

The age, gender, BMI, blood pressure, radial artery subcutaneous depth and cross-sectional area were all comparable between the two groups, statistical significance were not seen ($p>0.05$) (Table II).

Compared to the anatomy group, the average performance time was shorter with US [(2.7±2.1 min) vs. (4.3±2.9 min)]. The success rate of first and total attempt was higher in the US group, with statistical significance ($p<0.05$). There were 14 cases of local hematoma at the puncture site in the anatomical palpation group and 4 cases of local hematoma at the puncture site in the US group,

Table I. Baseline characteristics of non-anesthesiology residents.

	Ultrasound group (*n*=10)	**Anatomy group (*n*=10)**
Age (years)	24.4±1.7	25.3±1.6
Gender (male/female)	5/5	4/6
Training year (year, 1/2 /3)	4/3/3	4/4/2
Palpated artery cannulation (times, <10/10–50/>50)	4/4/2	5/4/1
US-guided artery cannulation (times, <10/10–50/>50)	8/2/0	9/1/0

Table II. Patients and their radial artery characteristics.

	Ultrasound group (*n*=10)	**Anatomy group (*n*=10)**
Age (years)	49.4±9.7	51.8±7.6
Gender (male/female)	47/53	42/58
BMI (kg/m^2)	26.8±3.9	25.3±5.7
Blood pressure (mmHg)	125/67	120/64
Radial artery subcutaneous depth (cm)	0.35±0.13	0.37±0.16
Radial artery cross sectional area (cm^2)	0.05±0.03	0.05±0.04

the difference was statistically significant ($p<0.05$) (table III). The aggregate mean number of attempts per trial before succeeding for all residents were 1.56 (0.21), and 2.58 (0.37) for the US and anatomy group respectively.

The average number of attempts in the ultrasound group was less than that in the anatomy group, and the difference was statistically significant, as shown in figure 2 ($p<0.05$).

The aggregate mean times for each of the 10 trials for all residents are shown in figure 3 for both US and anatomy group. The equations on these graphs model the rate at which the performance time for the corresponding procedure changed from one trial to the next: a negative slope denotes a decrease in time to perform a radial artery cannulation for each consecutive trial. The average decrease in time between consecutive trials for all residents for US-guided radial artery catheterization was significantly greater than the decrease seen for the anatomy group.

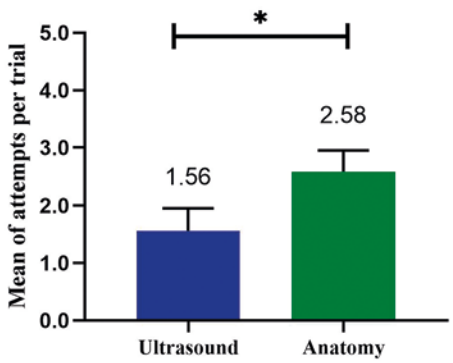

Fig 2. Average number of attempts per trial

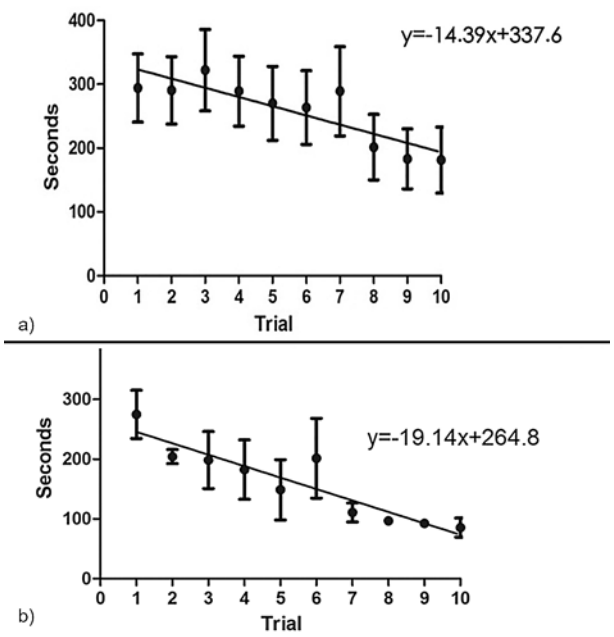

Fig 3. Mean times for each of the 10 trials for all residents using a) anatomy landmarks and b) ultrasound.

Table III. Radial arterial cannulation performance data in real patients.

	Ultrasound group (*n*=100)	**Anatomy group (*n*=100)**	**p-value**
Average performance time (min)	2.7±2.1	4.2±2.9	<0.05
First attempt success rate	88	57	<0.01
Total attempt success rate	94	81	<0.01
Hematoma	4	14	<0.01
Number of attempts	1.56±0.37	2.58±0.35	<0.01

As the performance time ranges between the anatomy and US guidance trials differed, the data were also normalized and the trend lines re-calculated. Figure 4 illustrates that the magnitude of the normalized average decrease in time between consecutive trials for the US-guided group was greater than the anatomy assisted group for both the raw and normalized data ($p<0.05$).

After each training set, all participants self-reported their changes in confidence for vascular cannulation performance. Residents in the US group responded that they were confident enough about the procedure. The questionnaire scoring results showed that the satisfaction degree and confidence degree of the residents in the US group of radial artery catheters were higher than that of the anatomical location group ([98.5±6.5] vs. [68.5±7.3], [90.2±8.6] vs. [56.3±5.5]), and the difference was statistically significant ($p<0.05$).

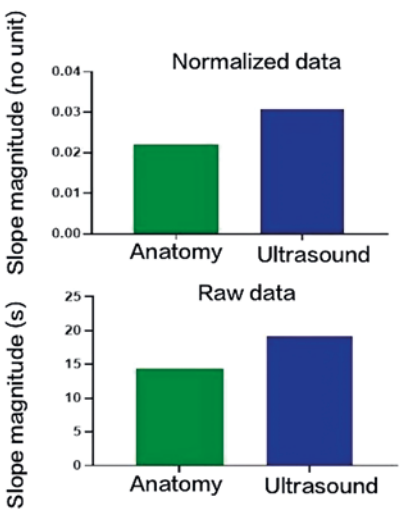

Fig 4. Mean magnitudes of the slopes of the linear trend line for ultrasound and anatomy assisted radial artery canulation, both for normalized and raw data.

Discussion

Radial artery catheterization is a common invasive monitoring method and clinical skill that residents must master in clinical practice. Studies showed that the first attempt success rate of radial artery cannulation by residents was only 34% ~ 38% [14]. The main reason was that the residents lacked operational experience and could not accurately locate the radial artery puncture point and insert the catheter smoothly. Arterial puncture catheterization is divided into three steps: the first is to determine the puncture point, the second is puncture, and the third is cannula placement. Among them, accurate location of the puncture point is particularly important. How to help resident doctors accurately locate puncture point is the focus and difficulty of residents training.

Recently, US has been widely used in clinical practice [15,16], but its application in clinical teaching has not been widely carried out. In traditional teaching, radial artery puncture catheterization is still performed by anatomical palpation. This method is limited by the residents' hand feeling and the strength of the patients' arterial pulse, and repeated puncture reduced residents' confidence and patients' satisfaction. Therefore, it is extremely urgent to explore the application of US-guided radial artery catheterization in clinical teaching [17].

This study applying US to radial artery cannulation demonstrates that the use of US can reduce the mean number of attempts, shorten performance times, improve first attempt and total success rate in non-anesthesiology residents. In this study, a certain number of patients in both groups failed to cannulation, while this occurred less in the US group, which may be attributed to the variety variation of the radial artery. With US, the radial artery's shape, variation and adjacent relationship with surrounding tissues can be observed, so as to determine the best puncture point and angle, improving the artery catheterization success rate.

The results of this study showed that the average number of attempts in the US group was 1.6 times less than that in the blind puncture group (2.6 times), indicating that US can reduce the variation of ability among residents. In addition, with the number of catheterizations increasing, the performance time of residents in the US group reduced by 19s, and 14s in the anatomical group on average for each case. Due to the difference in the performance time between the anatomical palpation group and the US group, the data was standardized, and the trend line was recalculated. The results indicated that the average performance time of residents in the US group decreased much more in the original data or after the data standardized. The results showed that: firstly, the time required for radial artery catheterization decreased with the increasing of puncture experience; secondly, compared with anatomy-based cannulation, US guidance can shorten the learning curve of radial artery puncture and catheterization for non-anesthesiology residents with seldom experience, enabling them to complete radial artery catheterization faster and better.

In this study, hematoma at the puncture site occurred in both groups, while the incidence of hematoma at the puncture site in the US group was much less which may be due to the lack of puncture experience of residents and the failure of timely and effective pressure on the puncture site when the puncture was unsuccessful, resulting in the formation of local hematoma. Meanwhile, the first attempt success rate and total attempt success rate were both higher in the US group, which reduced the number of puncture failure cases and thus reduced the occurrence of hematoma at the puncture site. The questionnaire scoring results of this study showed that the satisfaction degree and confidence degree of standardized training residents in US assisted radial artery cannulation were higher than that of anatomical location method ([98.5±6.5] points vs [68.5±7.3] points, [90.2±8.6] points vs [56.3±5.5] points). The results showed that the application of US-assisted positioning in the teaching of residents could make residents more easily integrate into the clinical work and improve their clinical working ability faster.

There were several limitations to our study. Firstly, this study had a limited sample size; each of the residents only performed 10 artery cannulations and the patients' artery images may differ, further studies with a larger sample size should be conducted. Another limitation is that the needle we used was not a specialized arterial puncture needle, its large diameter may influence successful catherization rate and number of attempts.

In **conclusion**, US allows for faster learning of radial artery catheterization over anatomical palpation, shortens radial artery puncture catheter learning curve of residents, reduces inter-subject performance variability, improves the first and total success rate of radial artery cannulation, which is more effective and safer, worthy of popularization and application in standardization training novices.

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Conflict of interest: none.

References

1. Troianos CA, Hartman GS, Glas KE, et al. Special articles: guidelines for performing ultrasound guided vascular cannulation: recommendations of the American Society of Echocardiography and the Society Of Cardiovascular Anesthesiologists. Anesth Analg 2012;114:46–72.
2. Amini R, Stolz LA, Breshears E, et al. Assessment of ultrasound- guided procedures in preclinical years. Intern Emerg Med 2017;12:1025–1031.
3. Laack TA, Dong Y, Goyal DG, Sadosty AT, Suri HS, Dunn WF. Short-term and long-term impact of the central line workshop on resident clinical performance during simulated central line placement. Simul Healthc 2014;9:228–233.
4. Gu WJ, Wu XD, Wang F, Ma ZL, Gu XP. Ultrasound guidance facilitates radial artery catheterization: a Meta-analysis with trial sequential analysis of randomized controlled trials. Chest 2016;149:166–179.
5. Bardin-Spencer AJ, Spencer TR. Arterial insertion method: a new method for systematic evaluation of ultrasound-guided radial arterial catheterization. J Vasc Access 2021;22:733-738.
6. Kiberenge RK, Ueda K, Rosauer B. Ultrasound-Guided Dynamic Needle Tip Positioning Technique Versus Palpation Technique for Radial Arterial Cannulation in Adult Surgical Patients: A Randomized Controlled Trial. Anesth Analg 2018;126):120-126.
7. Wu G, Chen C, Gu X, et al. Ultrasound-Guided Dynamic Needle-Tip Positioning Method Is Superior to Conventional Palpation and Ultrasound Method in Arterial Catheterization. J Clin Med 2022;11:6539.
8. Lan-Pak-Kee V, Ackland GL, Egan TC, Abbott, TE, Elsheikh, F. Arterial cannulation with ultrasound: clinical trial protocol for a randomised controlled trial comparing handheld ultrasound versus palpation technique for radial artery cannulation. BJA open 2022;4:100111.
9. Bhattacharjee S, Maitra S, Baidya D K. Comparison between ultrasound guided technique and digital palpation technique for radial artery cannulation in adult patients: an updated meta-analysis of randomized controlled trials. J Clin Anesth 2018;47:54-59.
10. Sultan SF, Shorten G, Iohom G. Simulators for training in ultrasound guided procedures. Med Ultrason 2013;15:125-131.
11. Oh EJ, Lee JH, Kwon EJ, Min JJ. Simulation-based training using a vessel phantom effectively improved first attempt success and dynamic needle-tip positioning ability for ultrasound-guided radial artery cannulation in real patients: An assessor-blinded randomized controlled study. PloS one 2020;15:e0234567.
12. Seto AH, Roberts JS, Abu-Fadel MS, et al. Real-time ultrasound guidance facilitates transradial access: RAUST (Radial Artery access with Ultrasound Trial). JACC: Cardiovasc Interv 2015;8:283-291.
13. Morse J, Terrasini N, Wehbe M, et al. Comparison of success rates, learning curves, and inter-subject performance variability of robot-assisted and manual ultrasound-guided nerve block needle guidance in simulation. Br J Anaesth 2014;112:1092-1097.
14. Ye P, Shi Y, Liu LF. Modified dynamic needle tip positioning ultrasound-guided radial artery cannulation in clinical teaching. China Continuing Medical Education 2019;11:53-56.
15. Hansen MA, Juhl-Olsen P, Thorn S, Frederiksen CA, Sloth E. Ultrasonography-guided radial artery catheterization is superior compared with the traditional palpation technique: a prospective, randomized, blinded, crossover study. Acta Anaesthesiol Scand 2014;58:446-452.
16. Gopalasingam N, Hansen MA, Thorn S, Sloth E, Juhl-Olsen P. Ultrasound-guided radial artery catheterization increases the success rate among anaesthesiology residents: a randomised study. J Vasc Access 2017;18:546-551.
17. Li XX, He HL, Quan ZF. Application of development line ultrasound positioning technology in radial artery puncture in interns. Journal of Nanchang University (Medical Sciences). 2020;60:26-30.