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Ultrasound-guided radial artery catheterization at different sites: a prospective and randomized study

X.-L. WU[1], J.-J. WANG[2], D.-Q. YUAN[3], W.-T. CHEN[3,4]

[1]Department of Emergency Medicine, Huangyan Hospital Affiliated to Wenzhou Medical University, Taizhou First People's Hospital, Taizhou, Zhejiang Province, China
[2]Department of Medicine, The First People's Hospital of Wenling, Zhejiang Province, China
[3]Department of Intensive Care Unit, Taizhou Integrated Chinese and Western Medicine Hospital, Wenling, Zhejiang Province, China
[4]Department of Emergency Medicine, Linhai First People's Hospital, Taizhou, Zhejiang Province, China

Xianlong Wu and Jinjin Wang are co-first authors contributed equally to this work

Abstract. – OBJECTIVE: Herein, we aimed to compare ultrasound (US)-guided radial artery catheterization at the wrist joint and mid-forearm level to evaluate the success rate of US-guided radial artery catheterization at the mid-forearm level.

PATIENTS AND METHODS: This prospective randomized controlled study included 240 consecutive patients who were admitted to the intensive care unit of Taizhou Hospital of Integrated Traditional Chinese and Western Medicine and underwent radial artery catheterization between January 1, 2019, and October 1, 2021. All patients were randomly allocated to the mid-forearm and wrist groups, with 120 patients in each group. Patients in the mid-forearm and wrist groups underwent out-of-plane US-guided radial artery catheterization at wrist and mid-forearm levels, respectively. The overall success rate, first-attempt success rate, and related complications were recorded and compared between the two groups.

RESULTS: The first-attempt success rate and overall success rate of radial artery catheterization were significantly higher in the mid-forearm group than in the wrist group (75.0% *vs.* 60.0%, p=0.013; 90.8% *vs.* 80.8, p =0.026, respectively). The incidence of hematoma was significantly lower in the mid-forearm group than in the wrist group (9.2% *vs.* 28.3%, p <0.001).

CONCLUSIONS: US-guided radial artery catheterization at the mid-forearm level increased the first-attempt success rate and overall success rate, decreased the incidence of hematoma during puncture, and improved nurse satisfaction. This puncture site may afford a new choice to replace the traditional wrist site.

Key Words:
Ultrasound guidance, Radial artery catheterization, Mid-forearm, Point-of-care ultrasound.

Introduction

Arterial puncture is an invasive technique commonly used in operating rooms and intensive care units (ICUs) to facilitate accurate blood pressure monitoring and repeated arterial blood sampling. The radial artery is the first choice to perform an arterial puncture owing to its superficial location, blood supply to the hand, and low risk of complications following arterial puncture[1,2]. Traditionally, the radial artery is localized using anatomical landmarks and palpation of the radial pulse. However, arterial puncture can be difficult to perform in patients with edema, hypotension, obesity, and in those who undergo repeated punctures. Repeated punctures can potentially cause hematomas, thrombi, infection, and nerve damage, as well as complicate catheterization[3,4]. Moreover, multiple unsuccessful radial artery punctures can induce discomfort in patients and lead to vasospasm.

Ultrasound (US) has been used as an auxiliary tool for radial artery puncture to improve the puncture success rate, as US allows the visualization of target blood vessels[5]. Based on accumulated evidence, US-guided radial artery puncture could improve the success rate of radial artery catheterization when compared with the palpation technique; however, the success rate of US-guided radial artery catheterization remains low, ranging between 53 to 62%[6,7]. Therefore, it is particularly important to improve US technology to increase the puncture success rate.

Currently, two methods are employed for US-guided radial artery catheterization, includ-

Corresponding Author: Weiting Chen, MD; e-mail: chenweitingwl@sina.com

ing in-plane and out-of-plane approaches[8]. In the case of the out-of-plane approach, advantages include visualization of related structures during the puncture process, such as vascular anatomic variants and the relationship between adjacent nerves and blood vessels; however, accidental posterior wall penetration remains the main disadvantage. Considering the in-plane US-guided approach, the entire needle tip and target blood vessels are visible on the screen in real-time, which can help avoid potential complications. However, it is difficult to maintain the probe on the best plane when approaching small blood vessels. Therefore, the failure rate increases during the puncture of small blood vessels. There is currently no corresponding guideline recommending a preferred approach, and the best strategy may be to utilize the most comfortable and proficient technique[9]. A previous study[10] has evaluated factors affecting the success of radial artery catheterization and reported that the depth from the skin surface to the artery could be strongly related to the first-attempt success rate and overall success rate. Moreover, the authors revealed that catheterization was faster and more reliable when the radial artery was 2-4 mm below the skin surface than <2 mm and >4 mm below the surface[10]. The puncture success rate is associated with the guidance method, as well as the depth of the blood vessel from the skin, blood vessel diameter, and the tilting angle of the wrist joint during puncture[11]. The radial artery at the wrist is the most frequently employed site for arterial puncture[12]. According to a previous report[13], the overall success rate of radial artery catheterization at the wrist site using different US-guided approaches was only 60-90%, and the first-attempt success rate was 27-62%. The radial artery at the wrist is superficial, and the palpation technique should be the first choice for localizing the artery. However, few studies[9] have examined whether US guidance can be employed as the first choice for localizing the radial artery and improving the puncture success rate. In the present study, we aimed to compare US-guided radial artery catheterization at the wrist joint and mid-forearm level to evaluate the success rate of US-guided radial artery catheterization at the mid-forearm level.

Patients and Methods

The present study was a randomized controlled study, which included consecutive patients who were admitted to the ICU of our hospital and required radial artery catheterization between January 1, 2019, and October 1, 2021. The exclusion criteria were as follows: age <18 years; patients who had a positive Allen test; patients who underwent radial artery catheterization at the puncture sites within 30 days or who underwent radial artery puncture at the puncture site after admission; patients who had peripheral artery disease, infection, burns, and a previous history of surgery at the puncture site.

Grouping and Randomization

SAS 9.4 was used to generate random numbers, and patients were randomly allocated to control and study groups using a balanced randomization method. The allocation sequence was concealed in sequentially numbered, opaque, sealed envelopes, which were then maintained by a researcher. The envelopes were sequentially opened after enrolled participants met the eligibility criteria and patient consent was received. The patients were then assigned to the mid-forearm or wrist groups according to the information written on the sealed randomization envelopes. Patients in the wrist group underwent US-guided radial artery catheterization at the wrist level using the out-of-plane approach. Patients in the mid-forearm group underwent US-guided radial artery catheterization at the mid-forearm level using an out-of-plane approach (Figure 1). The present study complies with the CONSORT guidelines, and no changes were made to the methods after study commencement. The study was approved by the Ethics Committee of Taizhou Integrated Chinese and Western Medicine Hospital; informed consent was obtained from all patients.

Technique of Radial Artery Catheterization

After Allen's test was confirmed to be negative, the patient was placed in a supine position with the forearm placed on a flat surface and the wrist in a moderate dorsiflexed position with a towel under the dorsal aspect. The forearm was disinfected and covered with a drape. To ensure a sterile and aseptic technique, To ensure a sterile and aseptic technique, the ultrasound coupling agent was applied to the probe surface, and the probe was then covered with a sterile glove, and the probe was then covered with a sterile glove. US was performed using a GE LOGIQ E portable ultrasound machine (GE Healthcare, Milwaukee, WI, USA). The machine was adjusted to a preset

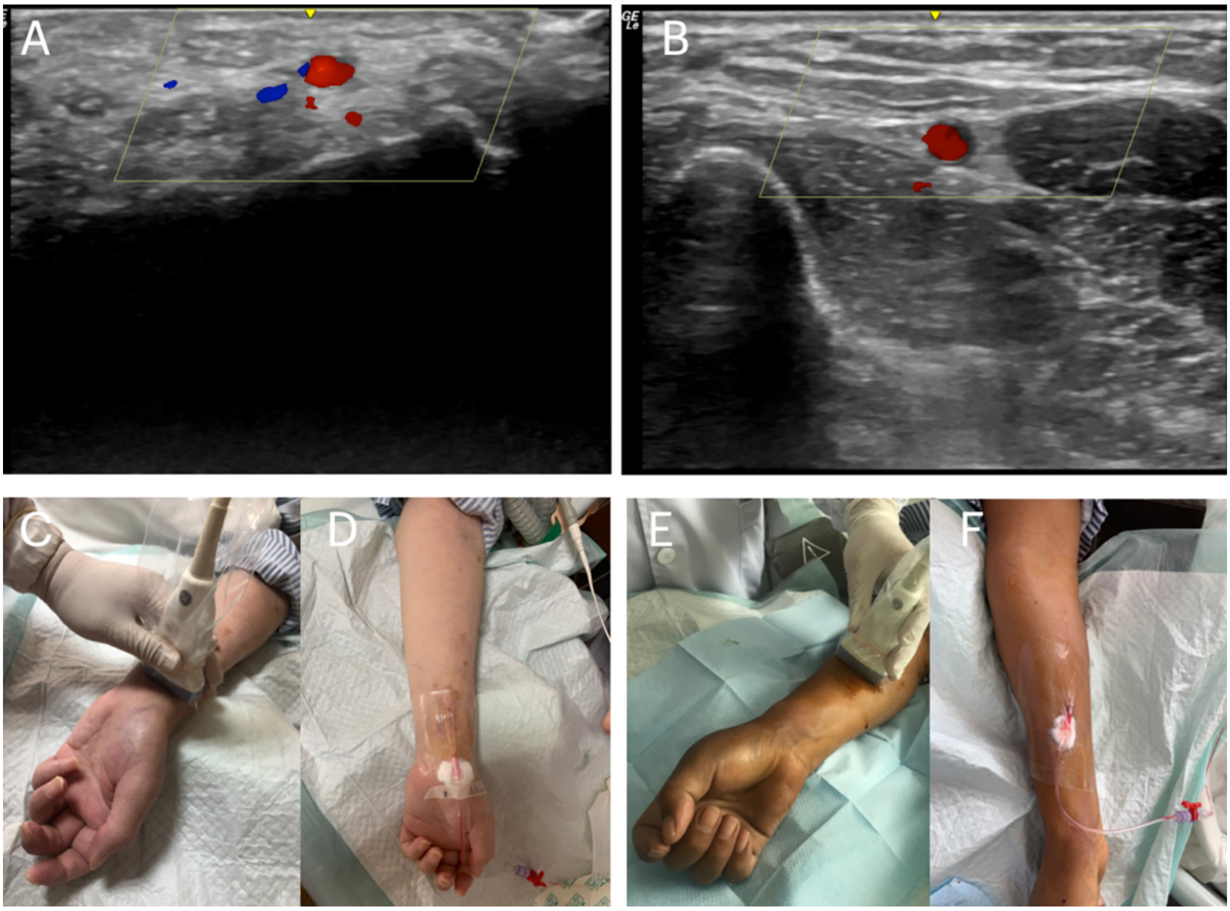

Figure 1. Ultrasound-guided radial artery catheterization. **A,** Short-axis view of the radial artery at the wrist level displaying arterial blood flow. **B,** Short-axis view of the radial artery at the mid-forearm level displaying arterial blood flow. **C,** Radial artery at the wrist localized by ultrasound. **D,** Radial artery catheterization at the wrist level. **E,** Radial artery in the mid-forearm localized by ultrasound. **F,** Radial artery catheterization at the mid-forearm level.

mode (Vascular), with an 8 MHz frequency and 3 cm depth. The gain and depth were adjusted to obtain the best view acceptable to the operator. A 20-GA intravenous catheter was used as the puncture needle (BD Angiocath^{TM}, Sandy, UT, USA).

After opening the sealed randomization envelopes, the puncture site was determined according to the information on the piece of paper within the envelope. First, the radial artery was imaged using US in the short-axis view. The operator did not measure the depth, area, or blood vessel diameter. Local anesthesia was then administered by injecting lidocaine into the needle entry site. Under US guidance, a needle was inserted at an angle of 30-45° until visualized entering the blood vessel, which appeared as a hyperechoic point on the US screen. Pulsatile blood was collected. The operator fixed the probe, inserted the catheter, and pulled out the stylet after insertion. The initial measurements (depth, area, and diameter) were obtained on the machine by a researcher.

Catheterization time was defined as the interval between skin puncture and confirmation of the arterial waveform on the monitor. If the catheter cannot be placed within 5 min, other puncture sites can be selected for arterial catheterization. First-attempt success was defined as the successful acquisition of arterial waveform on the screen with one skin puncture at the first attempt. The incidence of hematoma was defined as the proportion of patients in whom local swelling occurred during or within 3 days after the puncture. The incidence of bleeding was defined as the proportion of patients in whom bleeding occurred at the puncture site within 3 days after the puncture. In addition, nurse satisfaction was assessed with different puncture sites for radial artery catheterization. All operators had independently performed more than 30 cases of successful punctures prior to participation in this study. All operators verbally agreed to participate in the present study.

Observation Indicators

Baseline patient characteristics (age, sex, body mass index [BMI]), first-attempt success rate, number of attempts, time for successful arterial catheterization, and mean arterial pressure at insertion were recorded and compared between groups. All procedures were video-recorded, and the time was accurately recorded during video playback. In addition, relevant indicators were recorded by a third person.

Sample Size Determination and Statistical Analysis

The Walters approximation method was used for calculating the sample size. According to the results reported by Berk et al[14], the first-attempt success rate of radial artery catheterization at the wrist level was 51% using an out-of-plane approach. The first-attempt success rate of radial artery puncture at the mid-forearm level has not been reported; the pre-experimental results were approximately 70%. A sample size of 226 patients was required for a study power of 80% and an α error of 0.05. An additional 14 patients were included to compensate for dropouts, and a total of 240 patients were included in this study.

All data were tested for normality. Normally distributed continuous data were expressed as mean ± standard deviation (SD), and continuous data that were not normally distributed and had unequal variance were presented as median (interquartile range). Differences in continuous data were assessed using the *t-test* or Mann-Whitney U test. Categorical data were expressed as percentages, and comparisons were performed using the Chi-square (χ^2) test. The test level was α=0.05, and a *p*-value <0.05 was considered a significant difference. All statistical analyses were conducted using SPSS 19.0 (IBM, Armonk, NY, USA).

Results

A total of 240 patients indicated for radial artery catheterization were included in the present study (Figure 2). The mean age of patients was 64.1±15.9 years, including 150 (65%) males and 84 (35%) females. Patients were randomly assigned to the wrist and mid-forearm groups, with 120 patients in each group.

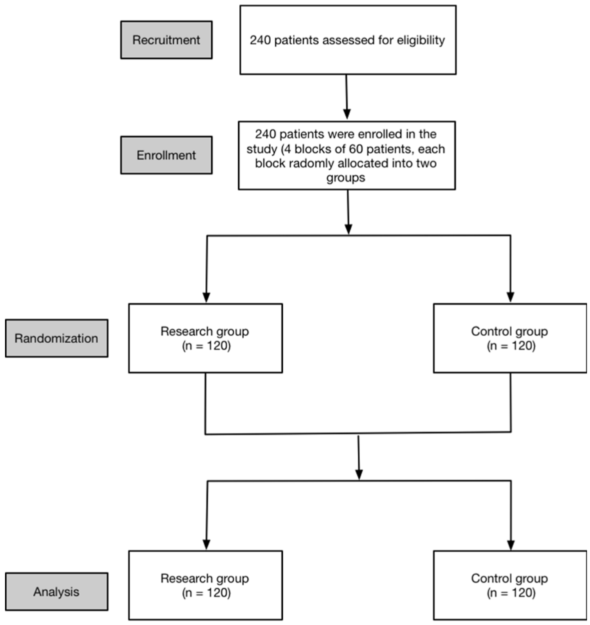

Figure 2. Study flowchart.

No statistically significant difference was observed between the two groups in terms of patient age, BMI, heart rate at insertion, mean arterial pressure at insertion, sex, and coagulation function, such as prothrombin (PT), activated partial thromboplastin time, and platelet (PLT) (Table I). As shown in Table II, the first-attempt success rate and overall success rate of radial artery catheterization were significantly higher in the mid-forearm group than in the wrist group (75.0% *vs.* 60.0%, *p*=0.013; 90.8% *vs.* 80.8%, *p*=0.026, respectively). In addition, the incidence of hematoma was significantly lower in the mid-forearm group than in the wrist group (9.2% *vs.* 28.3%, *p*<0.001). However, no significant difference was noted in the catheterization time, the number of attempts, and incidence of bleeding within 3 days after surgery between the two groups (*p*>0.05). No ischemic necrosis or local infection of the hand occurred within 3 days after catheterization in either group.

Discussion

Establishing arterial vascular access is an important factor governing patient care, especially for critically ill patients with hemodynamic

Table I. Patient characteristics in the two groups.

	Mid-forearm group (n = 120)	Wrist group (n = 120)	*p*-value
Age (years)	67.0 (57.0, 77.5)	63.0 (50.5, 76.0)	0.069
Body mass Index	22.1 (19.9, 23.4)	21.9 (19.5, 24.2)	0.404
Mean arterial pressure at insertion (mmHg)	86.5 (73.5, 96.0)	85.5 (76.0, 94.0)	
Sex (males/females)	84/36	72/48	0.104
Prothrombin (PT, s)	13.2 ± 1.0	13.5 ± 0.9	0.112
Activated partial thromboplastin time (APTT, s)	44.5 ± 10.1	42.4 ± 9.8	0.094
Platelet (PLT, 10^9)	110.6 ± 34.1	112.4 ± 30.8	0.524

instability and those undergoing major surgical interventions in the operating room[15,16]. Given the superficial location of the radial artery, it is often the first choice for radial artery catheterization[17]. Two approaches are currently used for US-guided radial artery catheterization: the in-plane and out-of-plane approaches[8]. The advantage of the US-guided approach is that it allows visualization of related structures, such as vascular anatomic variants, and establishes the relationship between adjacent nerves and blood vessels during puncture. Accidental posterior wall penetration is the main disadvantage associated with the out-of-plane US-guided approach. Considering the in-plane US-guided approach, the entire needle tip and target blood vessels can be visualized on the screen during the real-time US guidance, which can help avoid complications. However, it is difficult to retain the probe on the best plane when approaching small blood vessels, increasing the failure rate during the puncture of small blood vessels. A previous study[13] has shown that the overall success rate of artery catheterization at the wrist level using different US-guided approaches was only 60%, and the first-attempt success rate was 27-62%. Furthermore, repeated punctures may result in the formation of hematomas and thrombi, induce infection and nerve damage, and complicate catheterization[3,4]. Therefore, it is necessary to continuously refine existing technology or determine the best puncture site to enhance the first-attempt success rate and reduce potential complications.

The puncture success rate is not only related to the guidance method but also the depth of the blood vessel from the skin, the blood vessel diameter, and the tilting angle of the wrist during puncture[11,18]. Compared with the wrist site, the puncture site at the radial artery in the mid-forearm has a greater depth from the skin and provides a good ultrasound window, which is beneficial for imaging and adjusting the direction of the puncture needle. Accordingly, the radial artery puncture site at the mid-forearm level may be a new choice for arterial puncture.

In the present study, we described a new radial artery puncture site at the mid-forearm level to replace the wrist puncture site. Compared with the wrist site, US-guided puncture of the radial artery in the mid-forearm increased the overall success rate and first-attempt success rate of radial artery catheterization and improved nurse satisfaction during daily care management.

Berk et al[14] showed that the first-attempt success rate of radial artery catheterization at the wrist level was 51% using the short-axis out-of-

Table II. Outcomes for the two groups.

	Control group (n = 120)	Study group (n = 120)	*p*-value
Success rate, n (%)	97 (80.8)	109 (90.8)	0.026
First-attempt success rate, n (%)	72 (60.0)	90 (75.0)	0.013
Succesfull catheterization time (s)	86.5 (64.0, 125.0)	81.0 (54.0, 168)	0.612
Number of attempts	1 (1, 2)	1 (1, 1.5)	0.096
Complications			
Hematoma, n (%)	34 (28.3)	11 (9.2)	0.000
Staxis around stoma, n (%)	5 (4.2)	2 (1.7)	0.250
Ischemia, n (%)	0	0	
Local infection, n (%)	0	0	

plane approach. Another study[13] revealed that the overall success rate of radial artery catheterization at the wrist level was 90% using the US-guided oblique approach, while the first-attempt success rate was 63%. In the present study, we found that the overall success rate of out-of-plane US-guided radial artery catheterization at the mid-forearm level was 90.8%, the first-attempt success rate was 75%, and the incidence of local hematoma was only 9.2%, which was significantly lower than the incidence reported in previous studies[13,19]. Thus, our results indicated that radial artery catheterization at the mid-forearm level presented a superior overall success rate, higher first-attempt success rate, and shorter catheterization time, which may improve the patient's prognosis, reduce infection and nerve damage, and facilitate hemodynamic stability.

Patients in the ICU often experience agitation or delirium, and wrist movements can affect blood pressure monitoring. In some patients, the wrists need to be restrained using restraints, the pressure induced by these restraints can cause errors in blood pressure measurement; continuous arterial bleeding caused by the slipping of the tube cannot be immediately detected due to the occlusion by restraints, increasing the workload and challenges among nurses to a certain extent. On surveying a subset of nurses, radial artery catheterization at the mid-forearm level reportedly shows relatively less invasive blood pressure fluctuations with good nurse satisfaction when compared with radial artery catheterization at the wrist level. In clinical practice, the radial artery at the wrist is frequently used as the standard point to collect arterial blood samples for blood gas analysis, and radial artery puncture is often performed at admission in the emergency unit; the failure rate at the first attempt is approximately 10%, potentially necessitating multiple attempts, and inevitably accompanied by the presence of local hematoma, affecting US imaging[20]. In addition, repeated punctures have important long-term effects on radial artery patency[21]. These conditions may increase the incidence of complications and decrease success rates. Accordingly, selecting the radial artery in the mid-forearm as the puncture site can avoid these problems.

The current study had certain limitations. First, sedation status was inconsistent among patients; some conscious patients were not sedated, and the diameter of the blood vessels may be reduced owing to pain-induced muscle contraction caused during puncture, potentially inducing a bias in puncture results. Second, hematomas were evaluated by observing the presence and absence of swelling or ecchymosis at the puncture site. The puncture site at the radial artery in the mid-forearm was deeply located, and blood vessels passed between muscles. Therefore, bleeding can occur between the blood vessels and muscles in some patients, which cannot be detected by the naked eye, thus reducing the incidence of complications, such as hematoma or bleeding.

Conclusions

In summary, our findings suggest that US-guided radial artery catheterization at the mid-forearm level improved the imaging quality by increasing the visible area and enhancing needle tip visualization. Radial artery catheterization at the mid-forearm level demonstrated a higher first-attempt success rate and overall success rate, with greater nurse satisfaction in routine care. Therefore, this novel puncture site could be a new choice for replacing the traditional wrist site during ultrasound-guided radial artery puncture.

Conflict of Interest

The Authors declare that they have no conflict of interests.

Acknowledgements

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