Original research article

JVA The Journal of Vascular Access

The Journal of Vascular Access
1–8

DOI: 10.1177/11297298221126284
journals.sagepub.com/home/jva
SAGE

The distal quarter of the forearm is the optimal insertion site for ultrasound-guided radial artery cannulation: A randomized controlled trial

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Abstract

Background: Current guidelines recommend the use of ultrasound guidance for arterial cannulation. However, there are no recommendations on the best insertion site for radial artery cannulation in terms of catheter dwell time and incidence of complications.

Methods: In this randomized controlled study 94 patients were randomly assigned into three groups, corresponding to three different sites of insertion for radial artery cannulation: hand wrist: (Site/group 1, $n = 29$), distal quarter part of the forearm (Site/group 2, $n = 30$) and the midpoint of the forearm (Site/group 3, $n = 35$). Age, height, weight, and diagnosis of each patient were recorded prior to insertions which were performed by a single investigator experienced in ultrasound-guided vascular access.

Results: Radial artery diameters were similar (2.4 ± 0.4 vs 2.5 ± 0.3 vs 2.6 ± 0.4 mm), however skin to vessel distances were different between groups, and the depth of the radial artery increased progressively from distal to proximal sites. There was a significant difference between groups in terms of success rates at the first attempt. Only two cannulations were successful at first attempt, and overall, only 17 of 35 cannulations were successful at Site 1. Arterial cannula dislodgement rate was highest at Site 1(8/29, 26.7%), while the longest dwell time was at Site 2 with a median of 4 (IQR 3) days.

Conclusions: Considering the high removal rate at the wrist region and the high failure rate at the midpoint of the forearm, the distal quarter of the forearm can be identified as "the optimal insertion site' for ultrasound-guided radial artery cannulation.

Keywords

Ultrasonography, radial artery, dwell time, catheterization, device failure, intensive care

Date received: 20 April 2022; accepted: 1 August 2022

Introduction

Arterial cannulation is a common procedure for continuous blood pressure monitoring, recurrent arterial blood gas samplings and cardiac output measurements in intensive care unit. The radial artery is reported to be the most favored location for arterial cannulation. The rationale behind this lies within the presence of a rich collateral circulation at this location which presumably decreases the risk of ischemia along with a superficial and straight course which facilitates needle and catheter insertions.[1–3]

Current guidelines recommend the use of ultrasound guidance for arterial cannulation.[4–7] Furthermore, there are several systematic reviews and meta-analyses reporting that ultrasound guided cannulation increases first attempt

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success, decreases complication rates and reduces the time to successful cannulation.[1,8,9] Recent reviews suggest moving the insertion site to a slightly more proximal zone can increase catheter functionality and decrease mechanical complications.[10,11] When catheter is placed at the wrist level, where the radial artery pulse is most superficial, it can easily be damped or dislodged due to movement, dressing change, nursing care, and is difficult to secure on the moving joint.[12]

Studies investigating the effect of insertion site for radial arterial line on dwell time report that moving the cannula away from range of motion might increase stability.[13,14] An arterial line inserted at more than 4–10 cm away from the wrist is found to be more durable and may be safer in terms of nerve injury risk.[15] Other complications, such as ischemia, hematoma, and infection, in relation to insertion site for radial artery are not investigated. Moreover, it is unclear if even more proximal sites (more than 10 cm) may increase success, safety and catheter's functionality.

This study sought to answer the question if more proximal cannulation sites, as compared to traditional distal site, may increase the dwell time of the cannula offering a more secure site meanwhile not increasing complications. It is hypothesized that the most proximal site would offer increased success, safety and functionality. Therefore, this study aimed to determine an "optimal insertion site" with emphasis on the dwell time of the arterial catheter and considering the initial success rate, number of attempts and the duration of the insertion.

Methods

This randomized, prospective, open-label study was conducted in the general intensive care unit of a tertiary medical center following the approval of Clinical Trials Ethics Committee (app.nr: 28.02.2018/02) between March 2018 and March 2019. The study was prospectively registered to clinicaltrials.gov (NCT04001764). Written and informed consent was obtained from the patients or the next of kin (a first-degree relative as ordered by the local clinical trials directives) when the patient was incapable or unconscious. Patients or their next of kin were given a consideration time of 24 h before written consents are signed. The study was conducted in compliance with Declaration of Helsinki and was reported according to CONSORT 2010 guidelines.[16]

Adult, non-pregnant patients for whom an arterial line placement was planned, and those who were not receiving inotropic/vasopressor or vasodilator treatments were included. Pregnant patients, patients under the age of 18, those who have any contraindications for arterial line placement and those receiving inotropic/vasopressor or vasodilator treatments were excluded. Forty-five of the 190 eligible patients needed urgent catheterization and the lines were inserted before the study consent could be obtained. Two of the remaining 143 patients refused to participate, 16 patients were transferred to wards during the 24-h pending period and 9 patients died before the assignment. Finally, 94 patients were assigned into three groups with simple random assignment via the online randomization tool "Research Randomizer" (https://www.randomizer.org/), as shown in Figure 1. Each group corresponded to a different insertion site for radial artery cannulation:

- Group 1 insertions were performed from the wrist area (Site 1),
- Group 2 lines were inserted at the distal quarter of the forearm, which is the midpoint between Sites 1 and 3 (Site 2).
- Group 3 cannulations were performed from the midpoint of the forearm (Site 3) (Figure 2).

Although patients' sight was not blocked during the insertion, they were not aware of the difference between sites and thus were considered blinded to different insertion sites.

All insertions were performed by a single operator who is an anesthesiologist with experience in venous and arterial ultrasound guided vascular access procedures. A short axis ultrasound scan technique with a 10 MHz linear probe was utilized for cannulations. Doppler assisted Allen test was performed to test collateral circulation and local anesthetic infiltration (2–3 ml Lidocaine 2%) was administered prior to cannulations. Procedures were carried out preferably from the non-dominant arm with a catheter over needle technique using a 20G 1.1 × 45 mm arterial cannula (Medbar™, Izmir, Turkiye) in following sequence:

1. Radial artery diameter and perpendicular distance of the upper wall of artery to skin was measured.
2. Local anesthetic was administered.
3. Cannulae were inserted at a 30°–45° angle (while wrist extended with a towel roll for Site 1 and 2 and at neutral position for Site 3) when arterial wall penetration is visualized the needle was withdrawn.
4. Line was connected to the transducer and when the arterial waveform was visualized, successful cannulation was confirmed.

Demographics (age, height, weight, diagnosis) of each patient were recorded before insertions. Total duration of insertion including measurements, was recorded by a chronometer with the help of an assistant. Cannulation success was defined as acquiring a regular arterial waveform on the monitor. Procedure was abandoned when either it took longer than 30 min in total or more than 6 cannulae were used. Every patient was allocated only to one group and no cross over between groups were allowed (i.e. cannulation from another site after a failed attempt was not included).

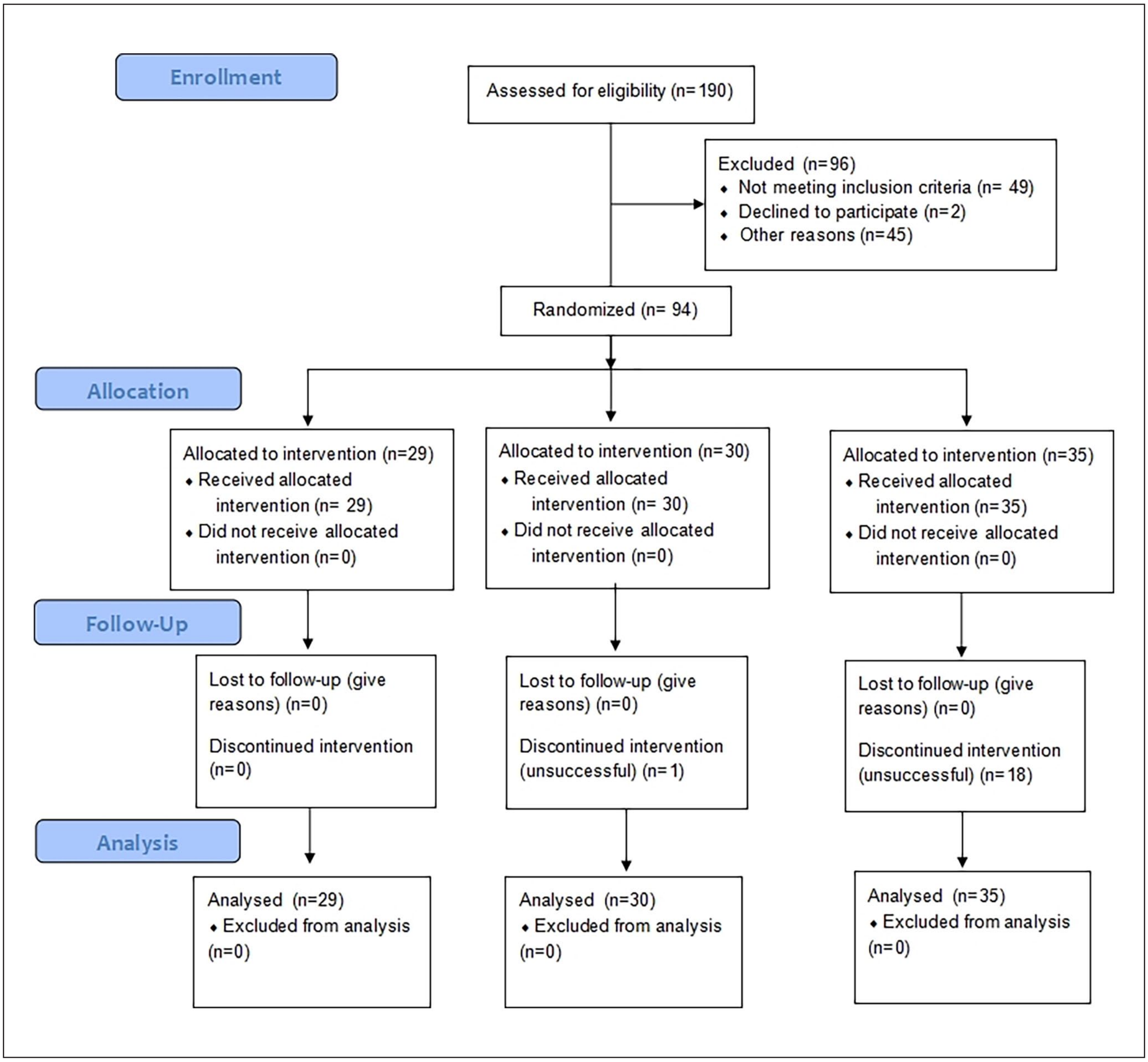

Figure 1. Flow diagram.

Catheter functionality was assessed by dwell time length, which was defined as in-situ time of successfully inserted cannulae in days until removed by any cause.

Early and late complications were observed and recorded for each patient. Early complications were defined as the complications that occurred during cannulation, such as bleeding and early hematoma, while late complications were defined as complications that occurred in the period starting from successful cannulation until the removal of the catheter. These complications were loss of trace, ischemia, dislodgement, late hematoma and infection. Ischemia was defined when presented with skin pallor, regional temperature decrease, paresthesia or gangrene, and confirmed with ultrasound. Although patients were observed for signs and symptoms of infection, no infectious complications were encountered.

Depending on the obtained information, "optimal insertion site" was defined as the site where the cannulation procedure can be successfully performed in the shortest time, with the smallest number of attempts and allowed a longer effective in-site duration of the catheter.

Sample size was calculated a priori with G*power version 3.1.9.2 (HHU, Düsseldorf, Germany). As there were no similar studies available at the time when this research was designed, power analysis was based on a hypothetical effect size. It is calculated that for an assumed Cohen's effect size f=0.40, at least 84 patients were necessary to achieve a statistical power of 90% with an alpha error rate 5%.

Statistical analyses were performed with IBM SPSS Statistics for Windows, version 21 (IBM Corp., Armonk, NY, USA). Descriptive values were expressed as mean ± standard deviation, number, and percentage (n, %) or

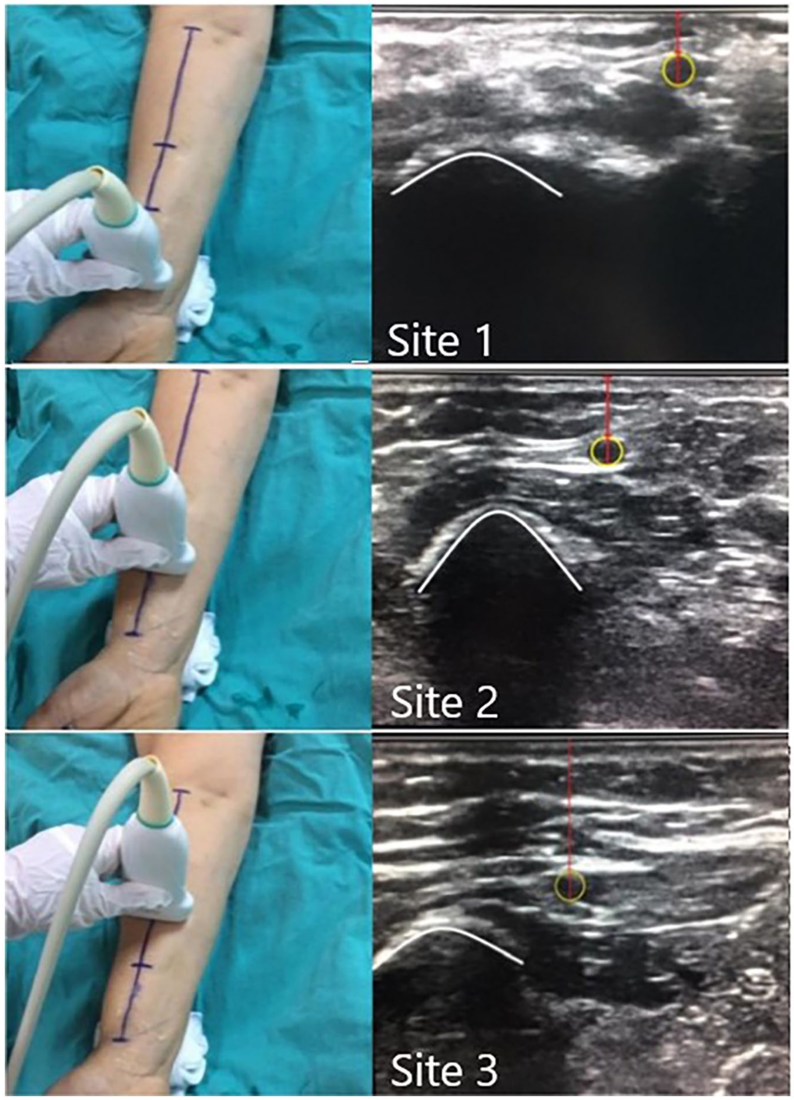

Figure 2. Demonstration of three different insertion sites. Insertions are made from horizontal lines.

median and interquartile range [m, (IQR)]. Normality of distribution was assessed with Shapiro-Wilks's test and normally distributed data were compared with one-way ANOVA. Tukey's HSD test was performed for post-hoc analyses. Non normally distributed data was tested with a Kruskal Wallis test, and a Mann Whitney *U* test was applied for post hoc analyses. Quantitative data was compared through chi-squared test. Statistical significance was defined as $p < 0.05$ with a 95% confidence interval.

Results

Ninety-four patients were enrolled in this study. Number of patients randomly allocated in insertion sites 1, 2, and 3 were 29, 30, and 35, respectively. There was no statistically significant difference between groups for patient demographics (Table 1). Cannulation at Site 1 was successful in all 29 patients (100%); one insertion at Site 2 and 18 insertions at Site 3 were defined as unsuccessful, resulting in a success rate of 96.7% and 48.6%, respectively. The overall success rate was 79.8%.

Overall success rate at first attempt was 37.8% ($n = 34$), which corresponded to a first attempt success rate of 55.2% ($n = 16$) in Site 1, 53.3%($n = 16$) in Site 2 and 5.7% ($n = 2$) in Site 3. There was a statistically significant difference between groups which resulted from Site 3 ($p < 0.001$).

Mean radial artery diameters were measured as 2.4 ± 0.4 mm in site 1, 2.5 ± 0.3 mm in site 2 and 2.6 ± 0.4 mm in Site 3, with no statistically significant difference ($p = 0.13$). Radial artery to skin depth was significantly different in each of the groups compared to the other two ($p < 0.001$). The median depth was 3.3 mm (min: 2.20,

Table 1. Patient demographics within each group.

	Site 1 ($n=29$)	Site 2 ($n=30$)	Site 3 ($n=35$)	p
Gender n (%)				
Female	12 (41.4%)	12 (40%)	16 (47.5%)	0.89
Male	17 (58.6%)	18 (60%)	19 (52.5%)	
Age (years) median (IQR)	72 (16)	67 (15)	75 (19)	0.79
Height (cm) median (IQR)	165 (10)	170 (15)	165 (10)	0.55
Weight (kg) median (IQR)	70 (20)	75 (13)	70 (20)	0.11
BMI (kg/m^2) median (IQR)	25.9 (4.2)	27.6 (4.9)	25 (4.1)	0.15
Systolic Blood Pressure (mmHg) mean ± SD	120.3 ± 24.3	125.1 ± 23.2	120.1 ± 21.7	0.67

Site 1: wrist area; Site 2: distal quarter of the forearm; Site 3: midpoint of the forearm; IQR: interquartile range; n: number; SD: standard deviation.

Table 2. Number of used cannulae, total durations of insertion and successful cannulation durations by group.

	Site 1 ($n=29$)	Site 2 ($n=30$)	Site 3 ($n=35$)	p
n of attempts median (IQR)	1 (1)	1 (1)	6 (2)	<0.001
n of cannula used median (IQR)	1 (1)	1 (1)	6 (3)	<0.001
Total duration of insertion (s) median (IQR)	138 (112)	145 (90)	640 (880)	<0.001
Duration of successful insertion (s) median (IQR)	78 (76)	85 (86)	74 (64)	0.90
Catheter dwell time (days) median (IQR)	3(2)	4(3)	2(3)	0.001

IQR: interquartile range; n: number.

max: 6.76) in Site 1, 6.76 mm (min: 3.80, max: 9.80) in Site 2 and 10.85 mm (min: 4.12, max: 17.28) in Site 3. The median depth from skin in patients with successful first attempt was 5.19 mm (IQR 4.2) and 7.74 mm (IQR 7.10) in patients with unsuccessful first attempt, which translated to a statistically significant difference in depth between successful and unsuccessful first attempts ($p=0.002$).

There were significant differences between groups for both number of attempts and number of used cannulae ($p<0.001$ for both). Median number of attempts were 1 in Sites 1 and 2, and 6 in Site 3. Likewise, median number of cannulae used were 1 in sites 1 and 2 and, 6 in site 3. Although, durations of successful insertions were similar for all sites, durations of all insertions (i.e. successful and unsuccessful) were significantly different between sites ($p<0.001$). Minimum durations of insertion were 12, 8, and 12 s in Sites 1, 2, and 3, respectively. While maximum durations of insertion were 386 s in Site 1, 373 s in Site 2 and 1458 s in Site 3. Catheter dwell time was significantly greater in Site 2 with a median lifetime of 4 days (min: 1, max: 6 days, IQR 3) in comparison to both Site 1 (median 3, min: 2 and max: 5 days, IQR 2) and Site 3 patients (median lifetime 2, min: 1 and max: 4 days IQR 3) ($p=0.001$). See Table 2 for details.

Although there was no statistically significant difference between groups for bleeding ($p=0.07$), incidence of bleeding was higher in Site 3 (25.7%, $n=9$) which may be clinically relevant. Early hematoma formation was present only in 8 (22.9%) patients cannulated in Site 3, which was a statistically significant difference ($p<0.001$). The most frequent complication in all groups was loss of trace, but there was no statistically significant difference between groups in this aspect ($p=0.16$). Ischemia was observed only in two patients in our study and there was no statistically significant difference between groups ($p=0.46$). Early and late complications are presented in detail in Table 3.

Dislodgement was significantly more frequent in Site 1 patients compared to the other groups ($p=0.04$). Late onset hematoma was present in two patients in group 2 ($p=0.20$).

Discussion

This study sought to define an "optimal insertion site" for radial arterial catheterization with ultrasound guidance. Our results demonstrate that cannulation at wrist region is related with better success, but shorter cannula lifetime. Cannulations at the distal quarter of the forearm is comparably successful without increasing rate of complications and has a longer cannula lifetime. Finally, cannulations at the midpoint of the forearm are related with lower success rates, shorter cannula lifetime and increased complication rates, suggesting that the distal quarter of the forearm may be an optimal insertion site for radial catheters.

Several reports showed first attempt success rates between 53% and 95%.[9,17–20] This variability in first attempt success rates may be attributed to many factors including population differences, insertion technique, clinical setting, experience of the operator and difficult anatomy. One reason of relative lower first attempt success rates in our study may be related to the use of out of plane technique for insertion. Arora et al. found that using in plane approach for radial artery cannulation in

Table 3. Early and late complications.

	Site 1 (*n* = 29) (%)	Site 2 (*n* = 30) (%)	Site 3 (*n* = 35)	*p*
Early complications				
Bleeding *n* (%)	3 (10.3)	2 (6.7)	9 (25.7)	0.07
Early hematoma *n* (%)	0 (0)	0 (0)	8 (22.9)	<0.001
Late complications				
Loss of trace *n* (%)	20 (68.9)	25 (83.4)	15 (42.9)	0.16
Ischemia *n* (%)	1 (3.4)	0 (0)	1 (2.9)	0.46
Dislodgement *n* (%)	8 (27.6)	2 (6.7)	1 (2.9)	0.04
Late hematoma *n* (%)	0 (0)	2 (6.7)	0 (0)	0.20

n: number.

cardiothoracic patient population significantly increased first attempt success compared to out of plane approach (85.7% vs 57.1%, respectively).[21] Another reason lowering first attempt success in our study might be the use of fixed cannulation sites rather than insertion zones.

Another factor related to first attempt success in our study was depth of radial artery to skin. Skin to radial artery depth was significantly lower in patients who were successfully cannulated at first attempt and greater in those with unsuccessful first attempts. This is in contrast to the findings of Kucuk et al.[22] and Lee et al.[23] Catheterization failure in deeply located veins is generally attributed to use of devices that are insufficient in length and is avoidable by consideration of Pythagorean theorem.[24] Pandurangadu et al. suggested that at least 65% of the device should reside inside the vein for cannulation to result in success.[25] Unfortunately, this triangulation technique is not applicable in every clinical setting. Firstly, this technique forfeits the advantage of tracking the needle tip. Secondly, it may not work when there are structures (i.e. another vessel, nerve) or pathologies (calcification at the upper wall or the artery) to avoid on the track of the needle. Arterial devices with a length of 45 mm were used for cannulation across all three sites which may not have been sufficient for deeper vessels. Our results show that use of 45 mm devices should be reserved for vessels not deeper than 7.74 mm to ensure a sufficient length to vessel depth.

Most recognized early complications for radial artery cannulation are bleeding and hematoma.[26] Bleeding rate was 14.9% ($n=14$), early hematoma rate was 8.5%($n=8$), and late hematoma rate was 2.1% ($n=2$) in our study (hematoma rate in total was 10.6%, $n=10$). Most of these complications were observed in cannulations from the midpoint of the forearm (25.7% for bleeding and 22.9% for hematoma). Increased rate of complications in midpoint of the forearm is probably related with increased number and/or time of attempts which, in some cases, is due to insufficient length of devices in relation to vessel depth and due to difficult access in others. A meta-analysis by Bhattacharjee et al. found a hematoma formation rate of 12.5% which is similar with our findings.[9] Permanent ischemic damage is a rare complication reported at a rate of 0.09% by Scheer et al.[27] Ischemic complication rate was 2.1% ($n=2$) in our study. Both patients presented with pallor, and definitive diagnosis was made with doppler by a radiologist who is not involved in the study. Luckily, both patients improved after removal of the cannula. Catheter dislodgement is a complication that generally occurs during dressing change, patient care or transportation. Dislodgement was most frequent in Site 1 in our study. This might be explained by the increased range of motion and wrist mobility in this site.

Our findings show that while cannulation from the wrist level is relatively easier, the cannula is more easily dislodged or removed as it falls within the range of motion. Furthermore, it is understood that cannulae inserted at the distal quarter of the forearm had the longest dwell time. In-situ duration of the catheters inserted at the wrist crease came second, while it was shortest for cannulae inserted at the midpoint of the forearm. Bardin-Spencer and Spencer suggested that transferring the cannulation site 4 cm proximal to range of motion (green zone) may reduce mechanical complications and increase catheter performance and longevity.[13] Saima et al. described that cannulation at 6.8 cm from wrist in males and at 5.4 cm from wrist in females could be safe to prevent nerve damage.[15] Imbriaco et al. found that cannulations from 4 to 10 cm proximal of the wrist has double in-situ time compared to more distal catheterizations.[14] These studies support our findings which show that the Site 2, which is the distal quarter of the forearm, has similar success and complication rates, and better catheter longevity. Moreover, the authors found that catheterization from Site 3, which is the midpoint of forearm, is significantly harder to cannulate, has a higher rate of complications and lower longevity, and therefore, should be avoided.

Limitations

There were some limitations in this study. Firstly, a power analysis was performed to determine a sample size. As there were no similar studies available at the time this study was designed, power analysis was based on a Cohen's effect size f (0.40). The choice of using fixed points as insertion sites may have decreased overall success rates and increased total insertion durations. This choice was adopted to make intergroup comparisons easier and more precise. Rather than a fixed point, future studies may choose to use insertion areas. These fixed points were defined in proportions according to patients' forearms rather than distances to minimize the effect of weight and height differences between patients. However, reporting the distance of these points might have increased the impact of our findings, which unfortunately was not recorded for every patient. Another limitation might be use of single length catheter across all insertion sites. This obviously was attempted for standardization purposes, but a 45 mm catheter may not have been long enough for deeper vessels and other catheter lengths should be considered for vessels deeper than 7.74 mm. Adoption of out of plane approach may be a limitation. As stated previously, in plane approach is reported to increase first attempt success. Exclusion of patients receiving vasopressor, inotropic or vasodilator therapy may have reduced the number of eligible patients. However, it was considered necessary for obtaining correct measurements of radial artery and creating a homogenous sample, to reduce the effect of shock or vasodilation on success rates. Lastly, catheter insitu durations were reported as the time until arterial catheter was removed because of death/ discharge or accidental removal, and not classified according to the cause of removal. This might pose a potential source of bias. Accidental removals were reported separately as dislodgement.

Conclusion

In conclusion, our data shows that "the optimal insertion site' for ultrasound-guided radial artery cannulation may be the distal quarter of the forearm. There is a high accidental removal rate at the wrist region and a high failure rate at the midpoint of the forearm. Thus, another relevant result of our study is that the arterial cannulation with from the midpoint of the forearm should be avoided, as it is difficult to cannulate and has higher complication rates.

Data availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

Ethics approval and registry

This randomized controlled study was conducted in Izmir Bozyaka Training and Research hospital following the approval of the Clinical Trials Ethics Committee of the hospital (app.nr: 28.02.2018/02). The study was registered prospectively to protocol registry system of the United States National Library of Medicine's clinical study registry "clinicaltrials.gov" with the protocol registry number NCT04001764.

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