A Randomized Controlled Trial of Radial Artery Cannulation Guided by Modified Long Axis Ultrasound Versus Short Axis Ultrasound Versus Palpation

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Abstract

Background: Given the low first-pass success rate of the conventional short-axis (SAX) or long-axis (LAX) approach, ultrasound-guided radial artery cannulation in adults with radial artery diameters less than 2.2 mm may still be challenging. In this study, we compare the efficacy of modified long-axis in-plane(M-LAIP) versus short-axis out-of-plane (SAOP) or conventional palpation(C-P) approaches for ultrasound-guided radial artery cannulation.

Methods: This was a prospective, randomized and controlled trial, conducted from 1 July 2018 to 24 November 2018. A total of 201 patients (age 18 to 85 years, the diameter of the radial artery less 2.2 mm) were included. All patients were randomized 1:1:1 to the M-LAIP, SAOP or conventional palpation (C-P) approach. The primary outcome was the cannulation success rate. Secondary outcomes included first location time and cannulation time, number of attempts. The Chi-square ($\chi 2$) test was used to compare categorical data between 3 groups.

Results: The cannulation success rate was significantly higher in the M-LAIP group than in the SAOP or C-P groups (first success rate: 80.3% vs 53.8% or 33.8%; $p < 0.001$; total success rate: 93.9% vs 78.5% or 50.8%; $p < 0.001$). First location time (seconds) was significantly longer in the M-LAIP group (31(28-35[12-44])) than in the SAOP (15(14-17[10-21]); $p < 0.001$) and C-P groups (12(8-13.5 [6-37]). However, the cannulation time (seconds) in the M-LAIP group (29(24-45[16-313])) was significantly shorter than that in the SAOP (45(28.5-135.5[14-346]); $p = 0.002$) and the C-P groups (138(27-308[12-363]); $p < 0.001$). The number of attempts was lower in the M-LAIP group compared with SAOP or C-P group (1.29±0.63 vs 1.8±0.89 or 2.22±0.93, $p < 0.001$).

Conclusions: The use of the M-LAIP approaches significantly improved the success rate of radial artery cannulation in adults with radial artery diameters less than 2.2 mm, compared with that achieved with the use of traditional short-axis out-of-plane approach.

Trial registration: ClinicalTrials.gov; No: ChiCTR-IOR-17011474; URL: http: // www. chictr.org. cn/index.aspx. Registered 24 June 2018.

Background

Radial arterial cannulation is a common and frequently invasive procedure for continuous arterial pressure monitoring and arterial blood sampling in operating rooms, intensive care units, and emergency departments [1, 2]. However, radial artery cannulation may be particularly challenging in some difficult cases such as when the artery has a small caliber or when there is anatomic distortion [3], and multiple attempts for radial artery catheterization may cause serious complications, including hemorrhage, hematoma, vasospasm, and posterior wall damage [1–6].

Recently, ultrasound-guided radial artery catheterization has become a research hotspot for the visualization of the targeted artery [1]. Many studies have shown that ultrasound-guided radial artery cannulation is an effective technique that may increase the first attempt success rate in small children and adults [2, 7].

The structures of the radial artery may be viewed with ultrasound via three approaches: the short axis (SAX), the long axis (LAX), and the oblique axis (OAX) approach [8]. Nevertheless, there is insufficient evidence to definitively support the use of the LAX, SAX, or OAX approaches in patients undergoing ultrasound-guided radial artery cannulation [8, 9]. Although the SAX approach easily allows the target artery to be visualized, it makes needle tip visualization and control more difficult [8, 10, 11]. The needle visualization can be optimized with the LAX approach, but it is difficult to determine the central axis of the vessel because of the narrow ultrasonic plane [12], which may lead to unclear visualization of vessels. Additionally, ultrasound section thickness may introduce artifacts, which can lead to dislocation of the needle tip when using LAX ultrasonic guidance [13].

Several studies have shown that using the conventional SAX or LAX approach has a low first-pass success rate of radial artery cannulation, ranging from 51%-76% [12, 14–16]. To our knowledge, the mean diameter of the adult radial artery was 2.2–2.8 mm [4, 17]. However, for adults with radial artery diameters less than 2.2 mm, information on the effect of ultrasound-guided radial artery cannulation is lacking.

Therefore, we designed a randomized controlled trial to evaluate the benefit of ultrasound-guided radial artery cannulation using the modified long-axis in-plane (M-LAIP) technique in adults with radial artery diameters less than 2.2 mm. The primary hypothesis was that the M-LAIP ultrasound-guided technique would provide a higher success rate of cannulation, fewer attempts, and less time of cannulation than the short-axis out-of-plane (SAOP) and conventional palpation (C-P) approaches.

Methods

Study design

This study was a prospective, randomized and controlled clinical trial. Ethical approval for this study (Ethical Committee 2018YF017-01, http: // www. chictr. org. cn/index. aspx) was provided by the Ethical Committee for Clinical Investigations, Fujian Medical University Union Hospital (Chairperson Prof Libin Liu) on 24 June 2018.

Study Patients

Written informed consent was obtained from 201 patients undergoing elective surgery between 1 July 2018 and 24 November 2018. Adult patients with radial artery diameters less than 2.2 mm were included in the study. Patients with a history of forearm surgery, ulnar artery occlusion, ipsilateral radial cannulation within a week before the procedure, coagulation dysfunction, abnormal Allen test, or skin infection at the puncture site were excluded from the trial.

Randomization

Random allocation was performed using SPSS software (Version 24.0, IBM, USA); randomization was stratified by an anesthesiologist who was not associated with the procedure, and allocations were placed in sealed opaque envelopes to ensure a balance between the four operators and each technique. Patients were randomized 1:1:1 to the M-LAIP, C-P, or SAOP approach. The envelope was broken by a trained investigator only after the control measurements had been made.

Study Procedure

In the preanesthesia preparation room, a specialist anesthesiologist who did not perform artery cannulation measured the diameter and depth of all the arteries, using the caliper tool on the ultrasound machine. The same ultrasound machine (SonoSite M-Turbo Color Doppler Ultrasound Diagnostic instrument, Linear Array probe (L25N/13–6; SonoSite Inc)) was used for all the ultrasound-guided cannulation groups. All cannulations were performed in the operating room using a 22-gauge intravenous catheter (Jelco; Smith Medical International Ltd, Rossendale, UK) by four anesthesiologists who had previously performed more than 160 arterial cannulations (including 30 M-LAIP, 30 SAOP, and 100 palpation approaches). All procedures were performed before the induction of general anesthesia, and 2% lidocaine could be used for local anesthesia at the puncture site.

The M-LAIP approach was different from that of the conventional long axis in-plane (Fig. 1). In the M-LAIP group, after obtaining the view of the long axis artery, the probe was slid laterally to maximize the artery diameter in the ultrasound image. The needle was inserted at the point at which the centerline of the probe contacted the skin. Guided by the centerline on the probe, the needle should always be kept in the virtual ultrasound plane formed by two parallel centerlines on the sides of the probe during the procedure (Fig. 1C, D). As the needle was advanced, the tip of the needle and the artery were continuously visualized in the dynamic ultrasonic image. Once the upward bevel of the needle tip was advanced into the vascular lumen, the needle was rotated 180° to make the tip bevel downward.

The M-LAIP approach was a relatively simple one, but the operators could still encounter a common situation: the needle tip had been inserted into the artery lumen in the ultrasound image, but there was no backflow of blood in the hub of the needle. First, through real-time ultrasonography and adjusting the probe position, the maximum diameter of the radial artery can be obtained. Second, The needle tip was withdrawn to the anterior wall of the artery but not out of the skin by a real-time ultrasound assessment. The position of the needle tip should be estimated according to the direction of the needle away from the virtual ultrasonic plane that was determined by the two parallel centerlines on the sides of the probe. Then, the needle was kept in the virtual ultrasound plane by gently swinging the needle rod, and the strong echo structure of the needle tip could be easily obtained in the ultrasound image. Third, it was advanced again until the catheter was within the lumen of the radial artery and the blood appeared in the hub. Then, the needle was slid out of the catheter 1–2 cm with the right index finger and thumb. Next, the catheter with the needle was pushed into the lumen of the vessel. Finally, the needle was completely pulled out, and the catheter was connected to the transducer. More details about this technique have been previously described [18].

In the SAOP group, after viewing the artery in a transverse approach and keeping the radial artery in the middle line of the ultrasound screen, the needle was inserted at the puncture point at which the centerline of the probe contacted the skin at an angle of 15°–40° to the skin. The needle tip position was identified by the needle bar vibration in the ultrasound image. When the needle tip and the catheter were inserted into the arterial lumen and the blood started to flow into the hub, the catheter was slid into the arterial lumen after the needle withdrawal and attached to the transducer after the needle was removed.

In the palpation group, the operator performed radial artery cannulation by palpating the radial artery pulse, which has been previously described [18].

Data Collection

The study data were collected by three dedicated anesthesiologists who were not associated with the performance of the procedure. Follow-up was performed by three anesthesiologists who were not aware of the grouping on the first and third days after surgery. We had standardized data collection forms and written methods that detailed the procedures for collecting the outcomes data.

Measurement Of Outcomes

The primary outcome was the success rates of the first and total cannulation attempts. The success of the first cannulation attempts was defined as the successful insertion of the cannula with one skin puncture for the first time and the acquisition of arterial waveforms [19].

Secondary outcomes included cannula insertion failure (considered to be greater than 3 cannulation attempts for a single arm or the attempted cannulation time more than 5 minutes), the number of attempts (defined as the number of skin perforations caused by the needle), the cannulation time (seconds) (defined as the interval between the first skin penetration and confirmation of the arterial waveform on the monitor), first location time (considered to be the interval between the first skin contact of the finger or probe and skin penetration), complications (hematoma, thrombosis, edema or infection), vasospasm was considered to be any significant resistance during radial artery cannulation manipulation and identified by the operator [20]. Posterior wall puncture was defined as no backflow of blood after extracting the stylet [16] and backflow reoccurred when the catheter was slowly withdrawn.

Sample Size Calculation

According to a previous pilot study with 120 adult patients (40 patients in each group), the success rate of the first cannulation attempts with the M-LAIP, the SAOP, and C-P were (33/40) 83%, (23/40) 58%, (12/40)

30%, respectively. With use of the Z-pooled normal approximation method, a sample size of 195 patients (65 per group) provided a 90% power, at a 0.05 two-sided significance level. With an expected 10% loss rate per group, the sample size was finally determined to be 216 patients and 72patients for each group.

Statistical Analysis

Statistical analysis was processed using SPSS software (Version 24.0, IBM, USA) and R software (Version 4.0.2, R Foundation for Statistical Computing, Austria). The statistical data were expressed as the mean ± standard deviation, frequencies (%), median (interquartile range [IQR]), and odds ratios (95% confidence interval [CI]). The student's t-test was used for continuous variables after assessing the normality of the variables and the homogeneity. Nonparametric tests were used to compare groups when the normality assumption was not met. The Chi-square (χ^2) test was used to compare categorical data between 3 groups. An analysis of variance (ANOVA) was used for the comparison between continuous variables between 3 groups. The 95% confidence intervals were calculated by the Woolf method. P values < 0.05 were considered statistically significant. The cumulative rates of success at 5 minutes were estimated using Kaplan–Meier (K-M) curves and compared among groups using the log-rank test. Spearman rank correlation coefficient analysis was used to examine correlations between variables that were not normally distributed.

Results

In the trial, 216 patients were consented and enrolled. Twenty patients were excluded, and 196 patients were randomized into the final analysis (Fig. 2). The general basic characteristics of the patients are summarized in Table 1, and there were no significant differences between the study groups.

Table 1
General basic characteristics of the patients

Parameter	M-LAIP (N = 66)	SAOP (N = 65)	CP (N = 65)	χ2 /F	P
Female	51(77.3)	49(75.4)	52(80)	0.402	0.818
Left radial artery access	36(54.5)	41(63.1)	33(50.8)	2.1	0.350
ASA				0.828	0.935
I	7(10.6)	8(12.3)	7(10.8)		
II	51(77.3)	52(80.0)	52(80.0)		
III	8(12.1)	5(7.7)	6(9.2)		
Medical history					
Hypertension	21(31.8)	25(38.5)	24(36.9)	0.691	0.708
Diabetes mellitus	9(13.6)	9(13.8)	11(16.9)	0.350	0.839
Coronary disease	2(3.0)	5(7.7)	6(9.2)	2.209	0.331
PVD	5(7.6)	6(9.2)	6(9.2)	0.151	0.927
Age (y)	67.5 ± 13.8	67.5 ± 17.8	68 ± 8.5	0.374	0.829
BMI (kg/m2)	22.2 ± 3.5	21.9 ± 3.5	23.0 ± 4.0	1.612	0.202
Systolic pressure (mmHg)	136.3 ± 27.2	138.4 ± 23.9	136.2 ± 25.9	0.151	0.860
Diastolic pressure (mmHg)	73.3 ± 13.1	74.9 ± 12.6	74.6 ± 12.1	0.301	0.740
Heart rate (beats /minute)	74.9 ± 12.0	72.5 ± 12.7	72.4 ± 10.4	0.930	0.396
Height(cm)	158.9 ± 6.7	157.5 ± 6.1	158.1 ± 6.2	0.861	0.424
Weight (kg)	56.1 ± 8.9	54.7 ± 9.8	57.7 ± 10.4	1.553	0.214
Inner diameter of left artery (mm)	1.82 ± 0.21	1.83 ± 0.16	1.85 ± 0.16	0.177	0.838
Inner diameter of right artery (mm)	1.86 ± 0.20	1.85 ± 0.17	1.86 ± 0.16	0.005	0.995
Depth of Left radial artery (mm)	2.43 ± 0.59	2.33 ± 0.59	2.53 ± 0.61	1.872	0.157
Depth of right radial artery (mm)	2.43 ± 0.58	2.34 ± 0.60	2.56 ± 0.63	2.045	0.132

Values are mean ± SD, n (%). BMI = body mass index. PVD = peripheral vascular disease. ASA = American Society of Anesthesiologists physical status classification system.

The cumulative rates of first successful cannulation in 100 seconds were significantly higher in the M-LAIP group than in the SAOP and C-P groups (80.3% (95% CI: 70.5% − 90.2%) vs 53.8% (95% CI: 41.4% − 66.3%) and 33.8% (95% CI: 22.4% − 46.3%), respectively; $p < 0.0001$) (Fig. 3A). The 5-minute cumulative rates of successful cannulation were 93.9% (95% CI: 88.0% − 99.9%), 78.5% (95% CI: 68.2% − 88.7%) and 50.8% (95% CI: 38.3% − 63.3%) in the M-LAIP -, SAOP -, and C-PT groups, respectively ($p < 0.0001$) (Fig. 3B).

Patients in the M-LAIP group required fewer attempts than patients in the SAOP group (1.29 ± 0.63 vs 1.8 ± 0.89, $p < 0.001$, Table 2). Compared with the C-P group, the number of attempts was lower in the SAOP group (1.8 ± 0.89 vs 2.22 ± 0.93, $p = 0.011$, Table 2).

Table 2
Second outcomes of radial artery cannulation for three groups

Parameter	M-LAIP N = 66	SAOP N = 65	CP N = 65	Analysis		M-LAIP vs SAOP	M-LAIP vs CP	SAOP vs CP
				χ2	P	P	P	P
Cannulation attempts								
First attempt	53 (80.3%)	35 (53.8%)	22 (33.8%)	28.9	< 0.0001*	0.002	< 0.001	0.033
Second attempt	7 (10.6%)	10 (15.4%)	7 (10.8%)					
Third attempt	2 (3.0%)	6 (9.2%)	4 (6.2%)					
failure	4 (6.1%)	14 (21.5%)	32 (49.2%)	32.9	< 0.001	0.01	< 0.001	0.001
First location time (s)**	31(28–35[12–44])	15(14–17[10–21])	12(8-13.5[6–37])	123.8	< 0.001	< 0.001	< 0.001	< 0.001
Cannulation time (s)**	29(24–45[16–313])	45(28–135[14–346])	138(27–308[12–363])	17.42	< 0.001	0.002	< 0.001	0.098
Hematoma***	1.5(0.08 to 9.3)	13.8(6.9 to 25.2)	29.2(18.9 to 42)	20.02	< 0.001	0.008	< 0.001	0.054
Vasospasm***	3.0(0.5to 11.5)	3.1(0.5 to 11.6)	6.2(2.0 to 15.8)	1.06	0.587	1.00	0.68	0.44
Posterior wall puncture***	4.5(1.2 to 13.6)	41.5(29.7 to 54.4)	55.4(42.6 to 67.5)	40.5	< 0.001	< 0.001	< 0.001	0.16
Thrombosis	0	0	0					

* For the dichotomy of one vs more than one attempt; **M (IQR[min-max]); ***Rate%(95%CI), The P-value and 95% CI are calculated from χ2 test; M = Median; IQR = Inter-Quartile Range; min-max = minimum and Maximum. M-LAIP, Modified Long-Axis In-Plane; SAOP, Short-Axis Out-of-Plane; CP, Conventional Palpation.

The first location time (seconds) was significantly longer in the M-LAIP group (31(28–35[12–44])) than in the SAOP (15(14–17[10–21]); p < 0.001) and C-P groups (12(8-13.5 [6–37]); p < 0.001, Table 2). However, Kaplan–Meier analysis showed that the total procedure time to successful cannulation of the radial artery was shorter in the M-LAIP group (29 (24–45 [16–313])) than in the SAOP group (45 (28.5-135.5 [14–346]); p = 0.002) and C-P group (138 (27–308 [12–363]); p < 0.001, Table 2).

The rate of vasospasm did not differ significantly among the three groups (p = 0.587, Table 2).

The rate of hematoma was significantly lower in the M-LAIP group than in the SAOP group (1.5% vs 13.8%, p = 0.008, Table 2). However, there were no significant differences between the SAOP and C-PT groups (p = 0.054, Table 2).

The posterior wall puncture rates in the SAOP group were significantly higher than those in the M-LAIP group (4.5% vs 41.5%; p < 0.001; odds ratio (OR) 14.92; 95% CI, 4.23 to 52.54). However, there were no statistically significant differences between the C-P group and the SAOP group (55.3% vs 41.5%, p = 0.16, Table 2).

Compared with the group of patients without vasospasm, the time of cannulation was longer, and the number of attempts was greater in the vasospasm group (Supplementary-Figure 1, p = 0.009; Supplementary-Figure 2, p < 0.001). Spearman's rank correlation coefficient analysis revealed a significant correlation between hematoma and the number of attempts (rho = − 0.428, p < 0.001).

The success rates of cannulation for four operators are summarized in the supplement table, and there were no significant differences between the operators. (χ^2 = 1.384, p = 0.709, Supplement table).

Discussion

In this trial, we found that the M-LAIP approach could increase the first-pass success rate and total cannulation and reduce the number of attempts in adults with radial artery diameters less than 2.2 mm compared with the SAOP or C-P approach. We also found that it may take longer to complete the first location with the M-LAIP approach, but it required a shorter cannulation time, and the incidence of hematoma complications was lower.

Currently, the conventional LAX is superior to C-P in radial artery cannulation, however, there are still some insufficiencies or deficiencies in the inaccuracy of locating the needle tip and the lower first-pass success rate [12, 21]. There are two key issues to be well solved: one is how to keep the center axis of the artery in the ultrasonic plane, the other is how to avoid the needle tip deviation from the center axis of the radial artery or insertion into the artery wall. The ultrasound devices assume that all received echoes come from structures located precisely on the central line of the US beam [22]. Therefore, we define the plane that passes through the center of the ultrasonic section as the ultrasonic plane(abcd), as depicted in Fig. 4A. We designed two special centerlines on the sides of the probe, which were formed by the junction point between two pieces of the transducer. (Fig. 4A). The two centerlines are parallel and determine a plane (mnba) that coincides with the ultrasonic plane. The centerlines are contributable to the assessment of the position of the ultrasound plane, and thereby offer a precise localization and orientation for puncture.

The elevation beamwidth of ultrasound varies with depth and has a measurable thickness [23]. The artifacts caused by ultrasound section thickness introduce errors in locating the needle tip during the process of ultrasonic guidance [13]. Only when the ultrasound plane deviates from the radial artery central axis, the needle tip is inserted into the artery wall (Fig. 4B, □, □) or close to the outside of the artery wall (Fig. 4B, □, □), and the arterial lumen and the needle tip are both still in the ultrasound section, can the above-mentioned situation of no backflow blood in the hub of the needle occur. (Fig. 4B, (1), (2), (4), (5)). In practice, we determine the optimal location of the ultrasound probe at the wrist by evaluating the diameter of the radial artery in the long-axis ultrasound view (Fig. 4B). Only when the center axis of the artery is held in the ultrasonic plane, can the maximum diameter of the artery in the ultrasound image be obtained (Fig. 4B, 2, (3), □), and this approach can significantly reduce the incidence of the error in locating caused by the elevation beamwidth of ultrasound.

The M-LAIP ultrasound technique is significantly different from the conventional LAIP ultrasound technique [12, 14, 2527, Supplemental-Appendix] concerning the centerlines of the probe, the obtaining of the maximum diameter of the artery in the ultrasound view, the operator's seated position, and the manners of holding the needle and probe with hands (Fig. 1, Fig. 4B). In the M-LAIP approach, the operator's special seated position and needle-holding mode were adopted, which have the advantages of stabilizing the hand-held probe, optimizing the visual field, keeping the needle perfectly aligned with ultrasonic plane, and more precise needle tip control. These factors may be the main reason for the higher success rate of the M-LAIP approach.

Compared with the SAX approach [28], the LAX approach is relatively easy to view the whole needle and the vessel [16] continuously and the relative position of the needle tip to arteries posterior wall [14], which reduces the incidence of posterior wall penetrations and hematoma in our study. The higher rates of posterior wall puncture may be due to the difficulty in tracking a high echo dot image of the needle tip. The small radial artery (diameter < 2.2 mm) and the 2–4 mm 2-point discrimination limit of fingertip palpation [20] may be the cause of the higher cannulation failure rate and higher incidence of complications in the C-P group. Compared with the other study [4], the lower success rate of the C-P in our study may be linked to the small caliber radial artery (1.8 mm), the high proportion of female patients (75%-80%), etc. Besides, the differences in the first location time in the study groups are in seconds, which may not have much clinical benefit for a procedure.

Berk, et al [14] demonstrated that the LAX approach had advantages over the SAX approach. The first-pass success rate was similar to our study(76% VS 80.3%), but, the mean radial artery diameter showed to be larger, the proportion of female patients was lower (50% VS 78%), which might reduce the difficulty of cannulation [29].

A study [16] on radial artery cannulation in children with artery diameters of 2-2.3 mm showed that the LAX approach was not superior to the SAX approach in the first-pass success rate, which was not consistent with our findings. The reason may be attributable to the different ultrasound approaches, etc.

Research showed that the rate of vasospasm was low (3–4%), and there was a correlation between vasospasm and the number of attempts or cannulation time [20], which was consistent with our findings. Therefore, fewer attempts and shorter cannulation times may reduce the occurrence of spasms.

It has been reported [12] that the incidence of hematoma ranges from 15–18% for ultrasound-guided radial artery cannulation, which was similar to the rate found in the SAOP group in our study. The increased incidence of hematoma may be associated with more attempts.

Minimal experience with US guidance may have prevented operators from realizing their full benefit [30]. For cases with difficult cannulation, operator experience in using ultrasound-guided techniques plays a key role in successful arterial cannulation, especially for novices who need a procedure with a learning curve [16, 31]. Therefore, the results of our study were obtained by only four experimental anesthesiologists.

The current study has several limitations. General anesthesia (GA) could increase the diameter of the radial artery [32], therefore, all the procedures in this study were performed before the induction of GA. Vasospasm is difficult to standardize that definition, which may be a limitation in the study. A bias in judgment, recording of procedures, measurement, and the undoubled-blind trial design may be the potential limitation of this study. In the future, we will compare this M-LAIP approach with conventional LAX, the modified dynamic needle tip positioning ultrasound technique [33] to verify whether it has some advantages, especially for infants.

Conclusion

The M-LAIP technique significantly improves the success rate of the first attempt and total artery cannulation, shortens the time of cannulation, and lowers procedure-related complications in adults with radial artery diameters less than 2.2 mm.

Abbreviations

SAX
Short axis
LAX
Long axis
M-LAIP
Modified long axis in-plane
SAOP
Short axis out of plane
C-P
Conventional palpation
IQR
Interquartile range
CI
Confidence interval
OR
Odds ratio

Rho
The Greek letter ρ, Spearman’s rank correlation coefficienten

Declarations

Ethics approval and consent to participate

Ethical approval for this study (Ethical Committee 2018YF017-01, http: // www. chictr. org. cn/index. aspx) was provided by the Ethical Committee for Clinical Investigations, Fujian Medical University Union Hospital (Chairperson Prof Libin Liu) on 24 June 2018. Each patient agreed to participate in the trial and was free to refuse the patient’s inclusion.

Availability of data and materials

The datasets used and/or analyzed in this study are available from the corresponding author on request.

Consent for publication

Not applicable.

Competing interests

The authors declare no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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Contributions

Jiebo Wang, Liangcheng Zhang, and Xianfeng Weng drafted and reviewed the manuscript. Jiebo Wang and Zhongmeng Lai conducted the sample analysis. All authors had full access to the data in the study and take responsible for the integrity of the data and the accuracy of the data analysis, including and especially any adverse effects. All authors are the guarantors of the paper. All authors approved to publish the final version.

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Figures

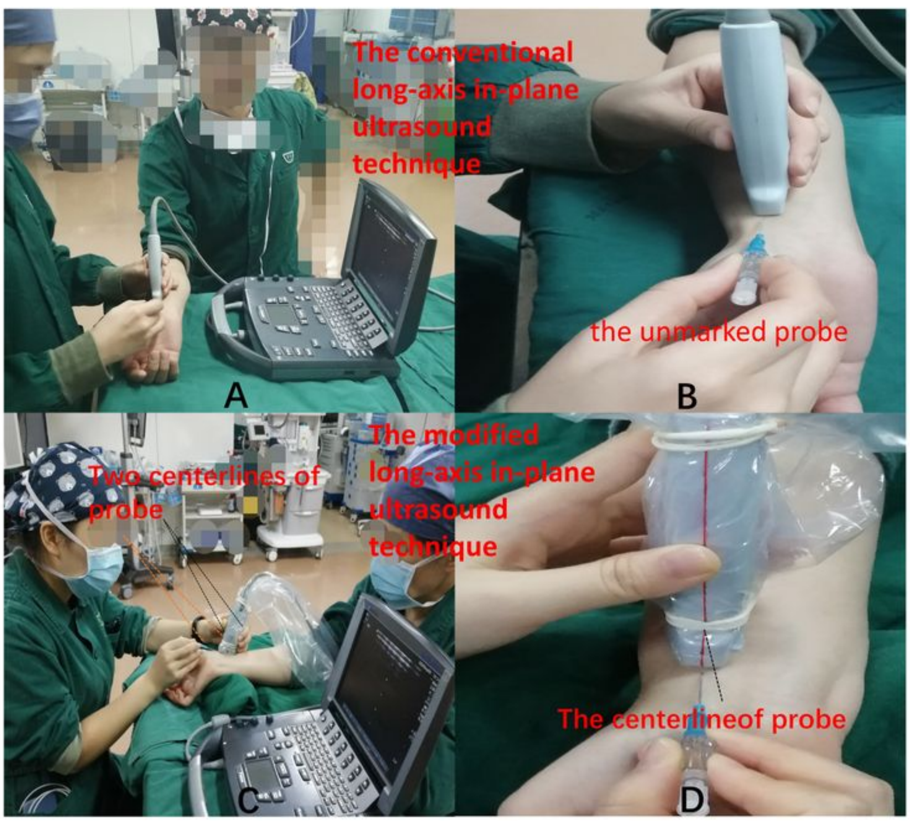

Figure 1

The difference between the conventional approach and modified approach of the long-axis in-plane ultrasound technique. First, there were two centerlines on the two sides of the ultrasound probe for M-LAIP, but there was not any marked line on the side of the ultrasound probe for conventional LAIP (Figure 1 B and D). Second, in the M-LAIP approach, the operator sat at the distal end of the patient's arm, instead of sitting on the side of the patient's arm in the conventional LAIP approach (Figure 1 A and C). Third, the side of the ultrasound probe was out the sight of the operator with conventional LAIP, on the contrary, for the M-LAIP, the operator could easily catch the vision of the clear and red central line on the side of the probe, which could facilitate to judge whether the puncture needle was aligned with the ultrasonic plane. The two centerlines were parallel and determined a plane (mnba) that coincides with the ultrasonic plane.

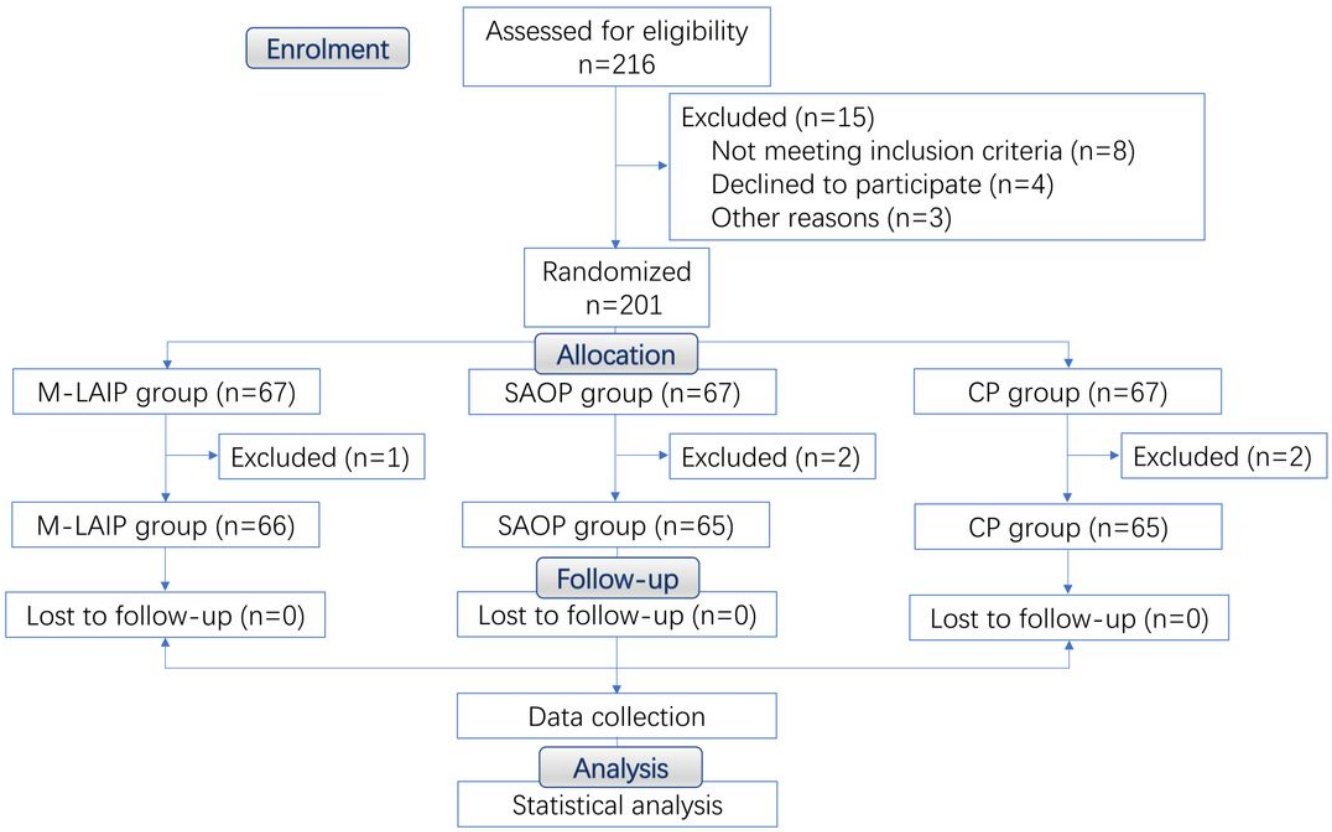

Figure 2

Flow diagram of patient recruitment and group allocation Other reasons: Patients had withdrawn earlier acceptances of the informed consent (n=3). Besides that, five were excluded due to the following reasons: canceled procedures (M-LAIP, n=1, C-PT, n=1), the loss of medical dataset (C-PT, n=1), the anatomical abnormality of radial artery (SAOP, n=1), and transducer faulty for invasive blood pressure (SAOP, n=1).

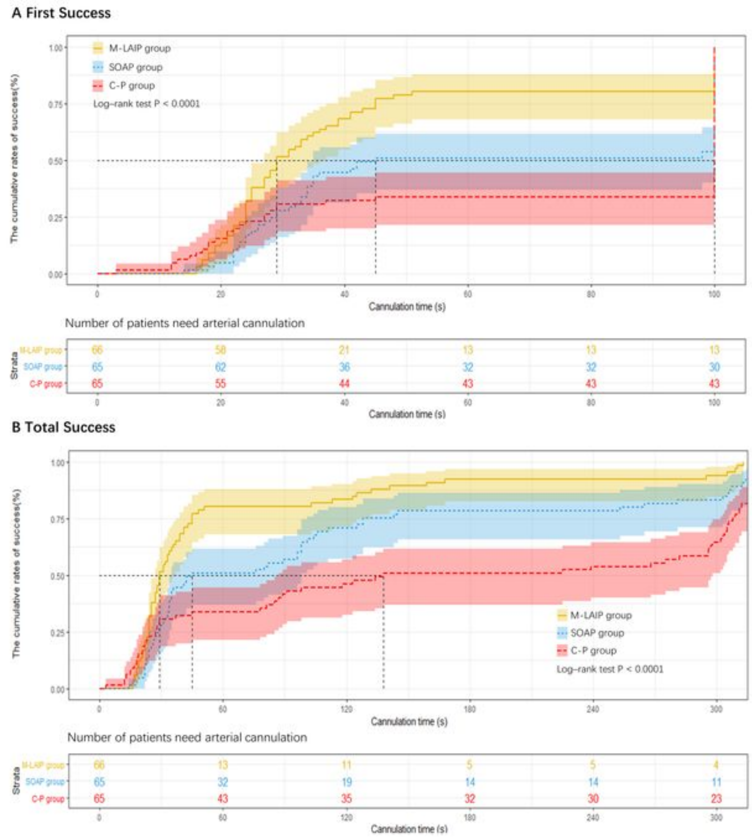

Figure 3

Cumulative success rate for the three groups. (A) Cumulative success rate of the first cannulation in 100 seconds; (B) Cumulative success rate of the total cannulation in 5 minutes.

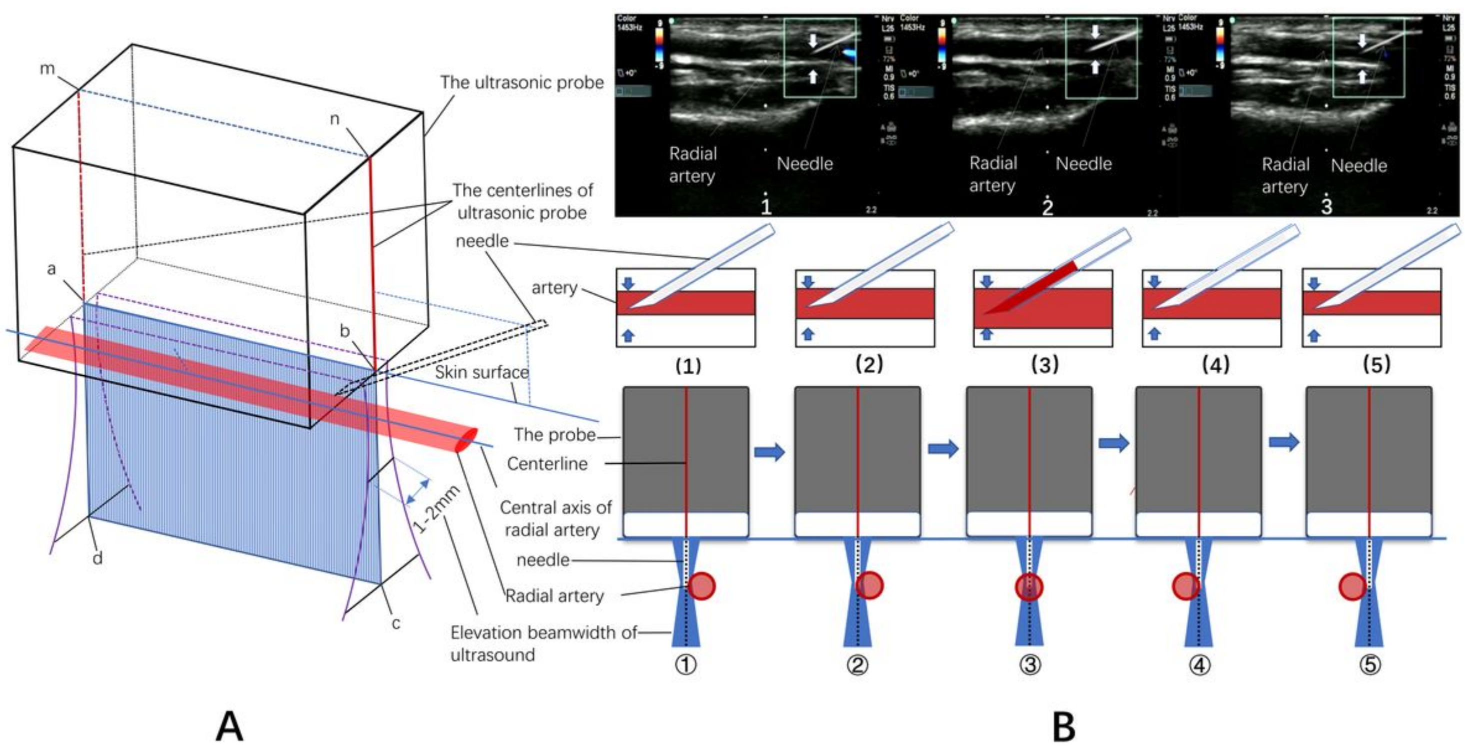

Figure 4

Orientation principle diagram of the modified long-axis in-plane (M-LAIP) technique. Two special centerlines (nb, ma) on the sides of the probe were formed by the joint of the ultrasonic transducer pieces. The two centerlines were parallel and determine a plane (mnba) that coincides with the principal plane of the middle part of the ultrasonic beam (abdc). A common situation was that the needle tip had been inserted into the artery lumen in the ultrasound image, but there was no backflow of blood in the hub of the needle with the LAIP approach (1, 3, (1), (2), (4), (5)). A theoretical explanation was that the needle tip was inserted into the lateral wall of the artery or close to the outside of the vascular wall, at the same time, the needle tip, the vascular wall, and part of the vascular lumen were still within the ultrasonic beam section (□, □, □, □). By a sliding ultrasound probe on the skin(□→□), the maximum diameter of the radial artery (2, (3)) was obtained, which meant that the center axis of the artery was in the ultrasonic plane (□). Under the guidance of the centerline of the probe, the direction and position of the needle were adjusted in the ultrasonic plane, which could easily aim the needle tip at the center axis of the radial artery.

Supplementary Files

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