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Comparison between transmural puncture combined with sensor tube technique with direct puncture in invasive blood pressure monitoring: a randomized controlled trial

Fei Xie[1,4], Guo Yu[1,4], Bin Mei[1,5]✉, Yang Liu[2,3,5]✉, Fang Chen[1], Xia Feng[1], Ziying Wang[1] & Xuena Wang[1]

This study primarily aimed to compare the efficacy of the transmural puncture combined with sensor tube technique and the direct puncture technique by examining the success of radial artery cannulation performed by nurses. The study was a prospective randomized controlled study. A total of 8 neurocritical nurses performed radial arterial insertion for 91 patients using both the transmural puncture combined with sensor tube technique and the direct puncture technique in random order. The primary outcome was successful cannulation of the radial artery in 3 or less attempts. Other collected data included the total number of attempts, total time for catheter cannulation, and occurrence of complications. In comparison with the direct puncture technique, transmural puncture combined with sensor tube increased the probability of successful initial catheterization (OR 3.27, [95% CI: 1.292–8.299]; $P = 0.012$) and demonstrated less blood exposure (6.52% vs. 80.0%, $P < 0.001$, φ=-0.742). A combination of transmural puncture and a sensor tube resulted in fewer cases of extubation due to complications. Furthermore, immediate complications caused by puncture (4.34% vs. 17.78%; $P = 0.039$, φ=-0.215) and extubation due to complications were reduced (47.8% vs. 71.1%, $P = 0.024$, $\varphi = 0.237$). Transmural puncture combined with sensor tube was demonstrated to increase the success rate of the initial arterial puncture, reduce blood exposure and reduce the occurrence of complications. Therefore, the transmural puncture combined with sensor tube technique may be an acceptable option for cannulation of the radial artery.

Keywords Arterial pressure, Vascular access devices, Cannulation, Critical care nursing, Randomized controlled trial, Patient safety, Occupational exposure

Abbreviations

ABP	Arterial blood pressure
IBPM	Invasive blood pressure monitoring
VCAI	Vessel catheter-associated infection
OBEs	Occupational blood exposures

Invasive blood pressure monitoring (IBPM) refers to the method of placing an arterial catheter into the artery to measure arterial blood pressure (ABP) directly, which has been proven to be the gold standard of arterial pressure measurement in 10–20% of high-risk patients[1,2]. IBPM enables real-time blood pressure-guided fluid resuscitation and vasoactive drug titration to maintain hemodynamic stability[3], while facilitating arterial

[1]Neurology department, Zhongnan Hospital of Wuhan University, Wuhan 430071, China. [2]Zhongnan Hospital of Wuhan University, Wuhan University, Wuhan 430071, China. [3]Economics and Management School, Wuhan University, Wuhan 430072, PR China. [4]Fei Xie and Guo Yu contributed equally to this article. [5]Bin Mei and Yang Liu equally contributed as corresponding authors. ✉email: neuromei20@163.com; dabailiu@whu.edu.cn

blood sampling for blood gas analysis and laboratory testing, which reducing patient discomfort from repeated punctures[4]. However, the invasive placement of arterial catheters may inevitably cause some injuries and complications[5–7]. In comparison with other common puncture sites such as the femoral artery, brachial artery, or dorsalis pedis artery, the radial artery near the wrist has been associated with consistent anatomic accessibility, ease of catheterization, and a low incidence of complications[8–10]. The radial artery's α1 innervation sensitivity contributes to vasospasm during cannulation, explaining the modest 15–56% first-attempt success rate with palpation[10–12], Failed attempts exacerbate vasoconstriction, while even successful cannulation temporarily reduces blood flow, making initial success critical[13–15].

Improving first-attempt success rates while reducing complications remains a key clinical challenge. While ultrasound guidance offers advantages in high-risk patients[16–18], its utility is limited by resource requirements. Existing modified techniques[19,20]often compromise safety or lack thorough complication assessments. This approach can be performed by a single operator, significantly improving workflow efficiency. The specific operation steps are as follows: First, the arterial puncture needle is inserted along the arterial direction at a 30–45° angle relative to the skin and advanced into the artery. Upon confirming intravascular placement by blood return, the needle is then further advanced approximately 0.5 cm to traverse the posterior arterial wall. Subsequently, once there is no more blood return, the needle core is withdrawn. Immediately following this, the arterial pressure sensor tubing is connected. At this point, the arterial catheter is slowly withdrawn until pulsatile arterial blood flow reappears in the tubing. Finally, with pulsatile flow confirmed, the arterial puncture catheter is advanced into the vessel at a reduced angle until full intravascular placement is achieved. Appendix 1 provides a detailed video of the operation procedures for the transmural puncture combined with sensor tube technique.

Accordingly, through a randomized controlled trial, we aimed to evaluate the efficacy and safety of transmural puncture combined with sensor tube technique compared with with direct puncture. We hypothesize that this method can improve the success rate of the initial arterial puncture catheterization, avoid the exposure of arterial blood, reduce the complications of puncture and reduce the operation stress of nurses.

Method

Inclusion criteria

This single-center, single-blind, randomized controlled study was conducted between June 5 and October 5, 2024, in the neurological intensive care unit (neuro-ICU) of a tertiary education and research hospital. Ethical approval for the study was obtained from the Medical Ethics Committee at Zhongnan Hospital of Wuhan University (Number: 2024122). The trial was posted on the Chinese clinical trial registry (registration number: ChiCTR2500100362, Date: 08/04/2025) at https://www.chictr.org.cn/. The design and implementation of the study protocol were reviewed and supervised by an ethics committee and conformed to the Declaration of Helsinki ("World Medical Association Declaration of Helsinki," 2013). Informed consent for this study was obtained from all subjects and/or their legal guardians. The detailed study protocol can be found in Xie et al.

We selected patients in the NCU who required IBPM, including hemodynamic monitoring through the arterial artery, arterial blood gas analysis, and guidance of vasoactive drugs for the control of hypertension or pressure boost. The patients or their legal surrogates agreed to participate in this study. Patients were not included in the study if they met one of the following criteria: (1) aged under 18 years; (2) positive Allen test during radial artery puncture; (3) infection, trauma, or surgery near the puncture site or severe vascular disease at the puncture side; (4) clinically significant abnormalities in hemostasis.

Sample size calculation

The sample size was established based on previous research and expected effect sizes. The initial success rate was approximately 70% when using the transmural puncture technique combined with sensor tube technique, compared to 38% with the direct puncture technique[21]. The sample size was conducted using PASS software 2023 (NCSS LLC.,Kaysville, U.T., USA). With a common alpha risk of 0.05, a beta risk of 0.20, we calculated that we needed to include 35 participants at lest in each group. Considering a potential dropout rate of 20%, 44 participants were allocated to each group.

Randomization

According to the principle of complete randomization, a randomized sequence was generated using SPSS software before starting the study. The participants were divided into the transmural puncture (TP) and direct puncture (DP) groups according to a ratio of 1:1. Sequentially numbered and sealed opaque envelopes containing one sheet of a random sequence and an article describing the radial artery puncture method were prepared. The investigator recruiting the patients was blinded to the catheterization method and opened the envelopes immediately before the procedure.

Interventions

Arterial puncture was performed by 8 nurse practitioners in the intensive care unit, each of whom had more than 5 years of experience in arterial puncture and had been trained on transcutaneous puncture with a sensor tube. Prior to the start of the study, each investigator successfully performed at least 10 cases of transmural puncture combined with a sensor tube under the direct supervision of the principal investigator. The number of puncture attempts was limited to 3. If 3 puncture attempts or catheterizations were unsuccessful, no further attempts were made for the same artery. The 22-gauge catheter with a built-in wire (Introcane. W arterio-venous catheter; B. Braun; Melgungen, Germany) and an arterial pressure transducer (TranStar® Single Monitoring Kit, MX9505T; Smiths Medical; Dublin) were used for radial artery cannulation in all participants.

Before arterial puncture, the operator rated the filling of the vessels at the puncture site using a 5-grade scale: strong, slightly strong, fair, slightly weak, and weak. Early complications were assessed during intubation (e.g., adjacent venipuncture, hematoma) and within 1 h after completion of the procedure (e.g., periarterial blood extravasation, hematoma). Continuous clinical evaluation of possible symptoms of post-surgical limb ischemia was performed. After the operation, the nurses used a 10-point scale to evaluate stress during the operation, with 0 indicating no operating stress and 10 indicating severe operating stress.

The need for maintaining the catheter was evaluated daily. The arterial catheter was removed when one of the following criteria was met: (1) Completion of IBPM; (2) Inaccurate arterial pressure curve; (3) Signs of limb ischemia; (4) Signs of infection at the catheter insertion site; (5) Local hematoma and bleeding at the puncture site. After removal of the catheter, pressure was applied over the arterial puncture site for 10 min with sterile dressing for protection, and pressure was maintained if bleeding persisted.

DP group
The arterial puncture needle was inserted along the direction of the artery at a 30–45°angle to the skin and penetrated the artery. When blood returned to the needle, the hose was pushed forward at a lower angle, and the needle core was withdrawn. At this point, pulsatile bleeding was observed at the tail of the cannula, which indicated successful puncture. The trocar was then connected to the IBPM pipeline. Normal saline was used to flush the blood in the sensor tube, and an ECG monitor was connected (see Fig. 1a for details).

TP group
The arterial puncture needle was inserted along the direction of the artery at a 30–45°angle to the skin and penetrated the artery. Once the needle tip entered the artery and blood return was observed, it was advanced approximately 0.5 cm to penetrate the opposite wall of the artery. When there was no more blood return, the needle core was withdrawn. At this point, the cannula needle was connected to the sensor tube, and the air port of the sensor tube was opened. Normal saline was used to flush the blood in the sensor tube, and an ECG monitor was connected. The characteristic arterial pressure waveform confirms successful arterial puncture (see Fig. 2b for details).

Outcome measures

Primary outcome
Effectiveness evaluation was as follows: (1) Success rate of the initial catheterization = number of successful times/total number of punctures × 100%; (2) Success rate of puncture = the same puncture point was successful

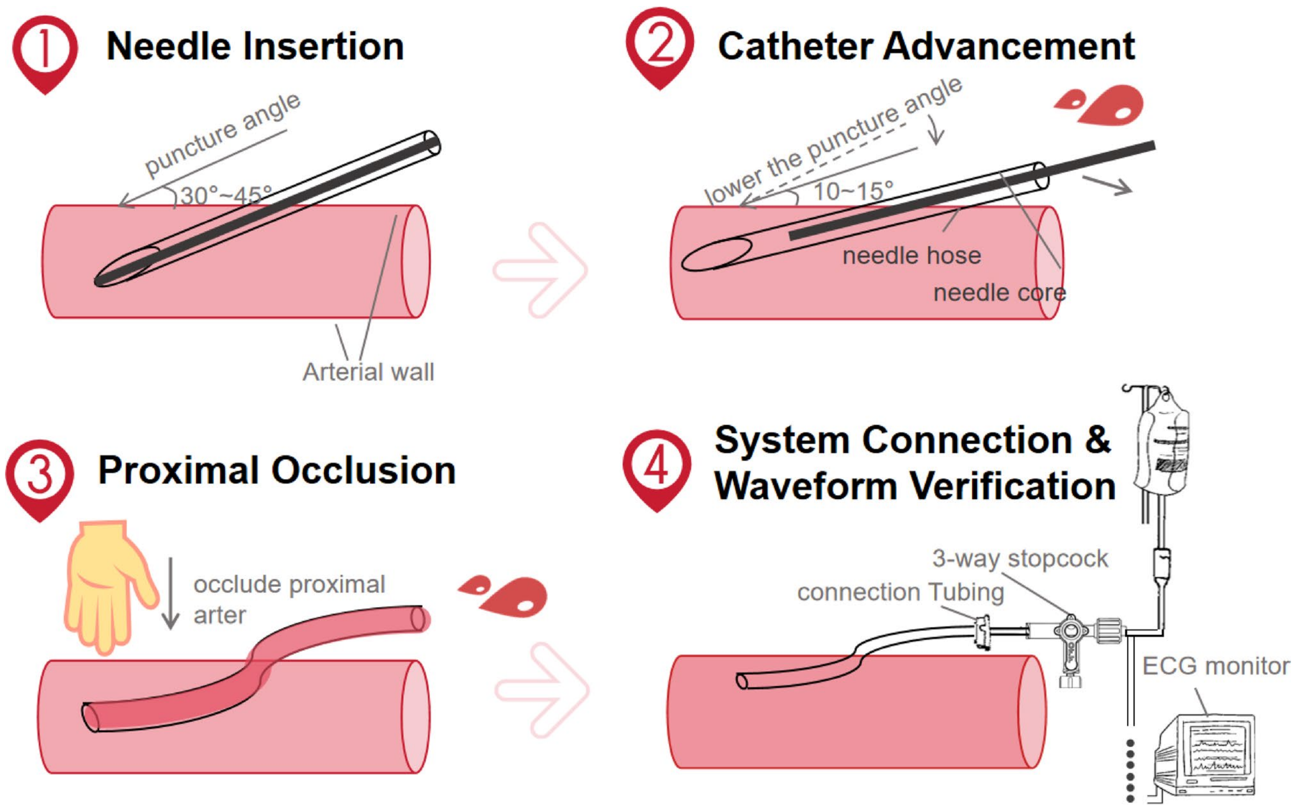

Fig. 1. DP group. Step 1: Insert the needle at a 30–45°angle along the artery's direction. Observe continuous pulsatile flow in hub. Step 2: Lower needle angle to 10°–15°.Advance catheter 2–3 mm further into lumen. Hold needle stationary, slide catheter fully off needle into artery. Step 3: Pulsating, bright red bleeding is seen. Occlude proximal artery with non-dominant finger. Step 4: Connect sensor tube and IBPM module. Flush with 0.9% saline – observe sharp arterial waveform.

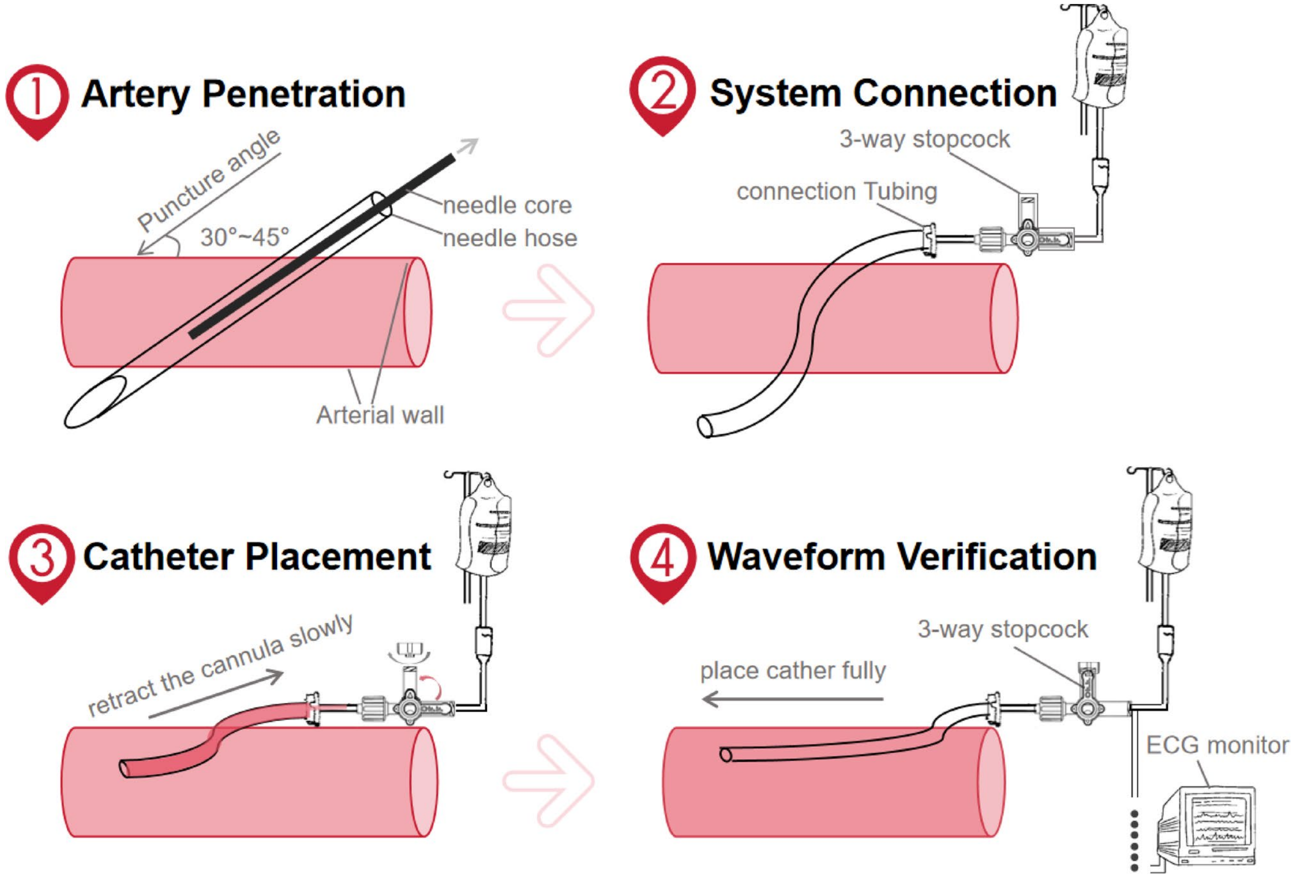

Fig. 2. TP group. Step 1: Advance the needle 0.5 cm post-flashback to penetrate the posterior wall. Withdraw the inner needle. Step 2: Connect the catheter to the sensor tube. Open the 3-way stopcock collar to align the cannula with atmospheric pressure. Step 3: Withdraw slowly until arterial blood reflux. Immediately close the stopcock to atmosphere. Step 4: Lower the catheter to a 15° angle and advance it fully into the arterial lumen. Connect the IBPM module.

within 3 attempts. Catheterization failure was defined as either the inability to aspirate arterial blood through the catheter or the absence of arterial pressure waveform after transducer connection; (3) Average time of puncture and catheterization = the time from locating the artery on the body surface to successful catheterization.

Secondary outcomes

Safety evaluation, which mainly included complications during and after the puncture, was as follows: (1) Post-puncture hematoma and ecchymosis: hematoma or ecchymosis with an area greater than 2 cm^2 appearing at the puncture site within 24 h after puncture; (2) Vessel catheter-associated infection (VCAI): primary infections occurring during catheter indwelling and within 48 h after catheter removal. Patients with local infection showed inflammatory manifestations such as redness, swelling, heat, pain, and exudation, as well as systemic infection manifestations such as fever (> 38℃), chills, or hypotension. In the microbiological blood test, positive peripheral venous blood culture for bacteria or fungi and drug sensitivity of the pathogenic bacteria from the catheter tip and peripheral blood were determined; (3) Distal limb ischemia: pain, pulseless, pallor, paresthesia, and paralysis in the limb corresponding to the puncture. The temperature, color, and capillary filling degree of the corresponding limb end were observed over time, and the blood oxygen saturation of the distal limb was continuously measured and compared with that of the contralateral limb. Blood exposure was defined as visible pulsatile bleeding during cannulation. Blood exposure was operationally defined as the gushing of patient blood beyond the catheter tip. Operator stress was measured post-procedure using a 10-point numerical scale (0 = no stress; 10 = extreme stress).

Statistical analysis

Continuous data are expressed as the interquartile range and standard deviation. For non-normally distributed data, the median (interquartile range, IQR) was reported. Normally distributed continuous variables were compared using t-test, while non-normally distributed variables were analyzed with the Mann-Whitney U test. Count data are expressed as percentages. Chi-square test and Mann-Whitney U test were used for comparison between groups. A P value < 0.05 was considered to indicate a significant difference. For independent t-tests, Cohen's d was calculated as the effect size, while Mann-Whitney U test used effect size r (computed as r =

$|Z|/\sqrt{n}$). The effect size of the chi-square test is expressed as Phi (computed as $\varphi = \sqrt{X^2/n}$). All effect sizes were interpreted using conventional benchmarks to indicate the magnitude of between-group differences.

Post-hoc logistic regression analysis was also performed to explore the association between the method of catheterization (TP vs. DP) and the probability of successful first puncture and occurrence of at least one mechanical complication. First, univariate regression analysis, including subjects characteristics (age, sex, medical history, prothrombin time, and operator career) and characteristics of catheterization (catheterization time, procedural time, number of punctures, and method of catheterization), was conducted. $P<0.10$ was considered statistically significant. Then, the selected variables were used to construct a binary logistic regression model with the input method to identify independent variables associated with successful first puncture. Covariates could be adjusted according to the clinical setting and professional knowledge. Potential multicollinearity between different covariates was quantified by calculating the variance inflation factor (VIF). A VIF of <5 was considered acceptable. Hosmer-Lemeshow test was used to evaluate the calibration of the model. A P value of <0.05 (two-tailed) was considered statistically significant. Statistical analyses were performed using IBM SPSS Statistics software (version 22, release 2013; IBM Corp.)

Results

Comparison of general data between two groups

A total of 5 patients (TP group: 2 patients; DP group: 3 patients) could not be included in the study because IBPM was eventually succeeded by another method or site. The study was carried out with the remaining 71 patients (Fig. 3). Of these 71 patients, 51 (71.8%) of them were male, and 20 (28.2%) of them were female. Age ranged 35–88 years (mean ± SD: 65.18 ± 11.79). The characteristics of the study group are presented in Table 1.

Comparison of evaluation indicators for arterial puncture between two groups

Primary outcome

In comparison with the direct puncture method, the transmural puncture with sensor tube technique demonstrated higher success rate of first puncture (67.39% vs. 37.78%, $P=0.005$, $\varphi=0.297$), and fewer puncture attempts ($Z=-3.500$, $P<0.001$, $r=0.366$). However, there was no significant difference in the overall puncture success rate (95.65% vs. 86.67%, $P=0.158$). There was no significant difference in the duration of puncture between the two groups ($Z=-1.068$, $P=0.268$). Table 2; Fig. 4 present the Primary outcomes for each group.

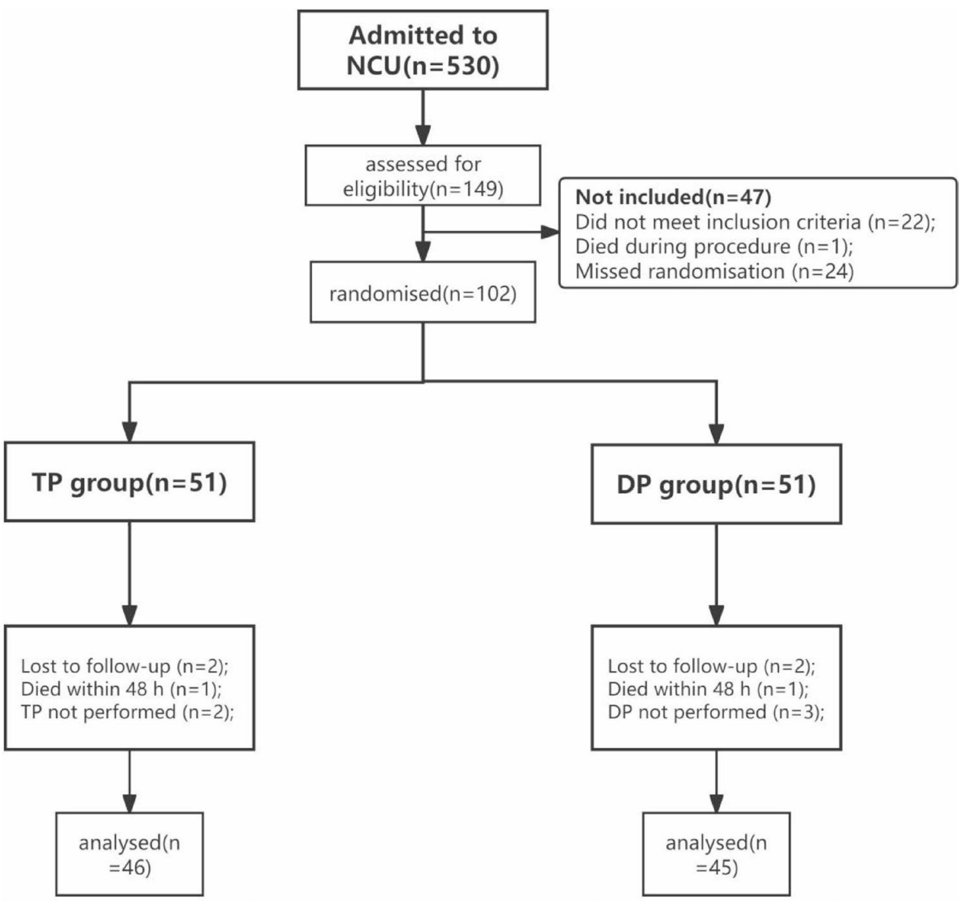

Fig. 3. Selection of participants.

		TP group ($n=46$)	DP group ($n=45$)	t/Z/ χ^2	*P*
Male, n(%)		26(56.52%)[c]	25(55.56%)[c]	0.009	0.926
Age, years		65.41 ± 11.05[a]	64.96 ± 12.62[a]	0.184	0.854
Diagnosis, n(%)				0.726	0.951
	Cerebral infarction	36(78.26%)[c]	38(84.44%)[c]		
	Cerebral hemorrhage	1(2.17%)[c]	2(4.44%)[c]		
	Intracranial infection	3(6.52%)[c]	4(8.89%)[c]		
	CVST	1(2.17%)[c]	1(2.22%)[c]		
	Others	5(10.87%)[c]	0		
Hypertension, n(%)		26(56.52%)[c]	20(44.44%)[c]	1.327	0.249
Diabetes, n(%)		12(26.09%)[c]	11(24.44%)[c]	0.032	0.857
Drinking history, n(%)		14(30.43%)[c]	6(13.33%)[c]	3.88	0.049
Smoking history, n(%)		13(28.89%)[c]	11(24.44%)[c]	0.171	0.680
Dyslipidemia, n(%)		11(23.91%)[c]	5(11.11%)[c]	2.573	0.109
PT, seconds		12.00 (1.45) [b]	12.10 (1.57) [b]	−0.154	0.945
Operator career, years		10(4) [b]	9(6) [b]	−1.315	0.188
Right radial artery puncture, n(%)		31(67.39%)[c]	30(66.67%)[c]	0.005	0.941
Arterial pulsation, level		2 (1.25) [b]	3 (1) [b]	−1.161	0.264

Table 1. Comparison of general data between two groups. [a] Data are presented as mean ± standard deviation (SD). [b] Data are presented as median (IQR). [c] Data are presented as number (percentage, %). Smoking was defined as having one or more cigarette in the 31 days. Drinking history was defined as having a drink within the past year (once a month or more). Hypertension was defined as systolic blood pressure ≥ 140mmHg and diastolic blood pressure ≥ 90 mmHg, self-reportedhistory and/or any treatment for hypertension. Diabetes mellitus was defned byself-reported history and/or any treatment for diabetes type 2. Dyslipidemia wasdefned as increased lipid concentrations, self-reported historyand/orany treatment for dyslipidemia. CVST, Cerebral venous sinus thrombosis. PT, Prothrombin time.

Outcomes		TP group ($n=46$)	DP group ($n=45$)	Z/ χ^2	*P*
Successful first puncture, n(%)		31 (67.39%)	17 (37.78%)	8.004	0.005
Successful puncture, n(%)		44 (95.65%)	39 (86.67%)	2.290	0.158
Number of punctures		1 (1)[b]	2 (2)[b]	−3.500	< 0.001
Duration of puncture, seconds		98 (65)[b]	120 (240)[b]	−1.068	0.268
Accuracy of IBPM, n(%)		43(93.48%)	39(86.67%)	1.776	0.497
Complications of puncture, n(%)		2 (4.34%)	8 (17.78%)	5.144	0.039
Blood exposure, n(%)		3 (6.52%)	36 (80.0%)	61.609	< 0.001
Retention time, days		3.025 (2.2)[b]	2.29 (2.7)[b]	−1.211	0.226
Catheter removal reasons, n(%)				10.659	0.039
	Ending treatment	24 (52.2%)	13 (28.9%)	5.1112	0.024
	Inaccurate monitoring	7 (15.2%)	8 (17.8%)	0.108	0.742
	No return of blood	9 (19.6%)	13 (28.9%)	1.079	0.299
	Hematoma	0 (0)	5 (11.1%)	3.480	0.062
	Oozing blood	5 (10.9%)	6 (13.3%)	0.130	0.781
Operational stress, level		2 (2) [b]	2.5 (3)[b]	−4.319	< 0.001

Table 2. Comparison of evaluation indicators for arterial puncture between two groups. b Data are presented as median (IQR).

Secondary outcomes

The transmural puncture with sensor tube technique significantly reduced both the incidence of immediate complications (4.34% vs. 17.78%; $P=0.039$, $\varphi=-0.215$) and the rate of catheter removal not due to complications (47.8% vs. 71.1%, $P=0.024$, $\varphi=0.237$). With a combination of transmural puncture and a sensor tube, blood exposure was reduced (6.52% vs. 80.0%, $P<0.001$, $\varphi=-0.742$). However, 1 patient in the TP group experienced unplanned extubation. Moreover, the nurses had less operating stress ($Z=-4.319$, P = < 0.001, $r=0.453$). The comparison of evaluation indicators between two groups is detailed in Table 2; Fig. 5.

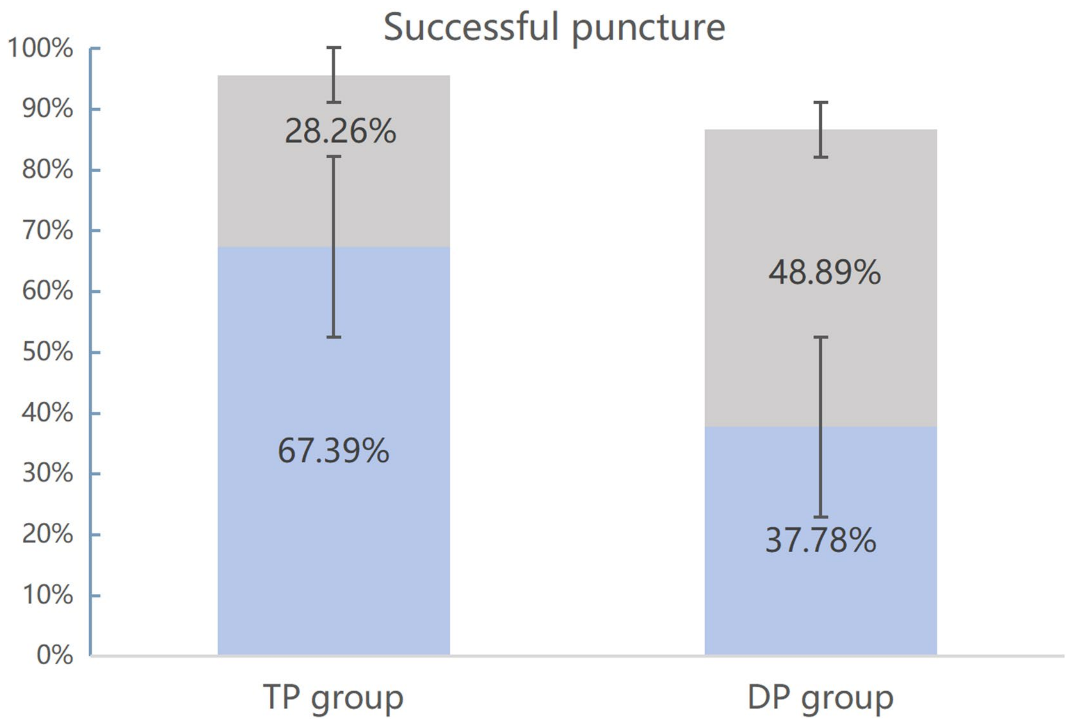

Fig. 4. Comparison of first and overall puncture success rates between the two groups.

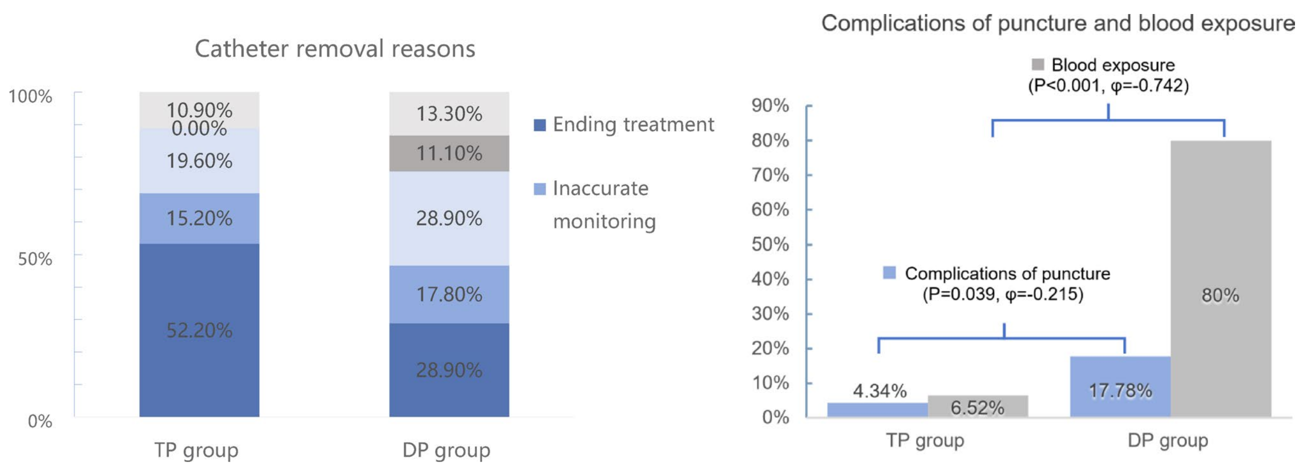

Fig. 5. Comparison of complications between the two groups.

Post-hoc analysis

In univariate analysis, the puncture technique (OR 3.404 [95% CI: 1.437–8.061]; $P = 0.005$), smoking history (OR 2.187 [95% CI: 0.825–5.798]; $P = 0.115$), operator career (OR 1.137 [95% CI: 0.098–1.295]; $P = 0.053$), and arterial pulsation (OR 0.488 [95% CI: 0.317–0.752]; $P = 0.001$) were related to the success of the first puncture. Based on the logistic regression model after adjusting for arterial pulsation, the probability of successful initial catheterization was higher when performing the transmural puncture combined with sensor tube technique compared with the direct puncture technique (OR 3.27, [95% CI: 1.292–8.299]; $P = 0.012$). A VIF of 1.017 for the covariate indicates that multicollinearity is negligible. The ROC analysis demonstrated that the predictive model incorporating puncture technique and arterial pulsation achieved moderate discriminative ability for first-attempt success, with an AUC of 0.750 [95% CI: 0.651–0.849] (Fig. 6).

Discussion

This study found that the transmural puncture combined with sensor tube technique could improve the success rate of the first puncture (67.39% vs. 37.78%, $P = 0.005$, $\varphi = 0.297$) and reduce the total number of catheterizations, thus reducing vascular function damage caused by repeated puncture and the pain of patients. We examined

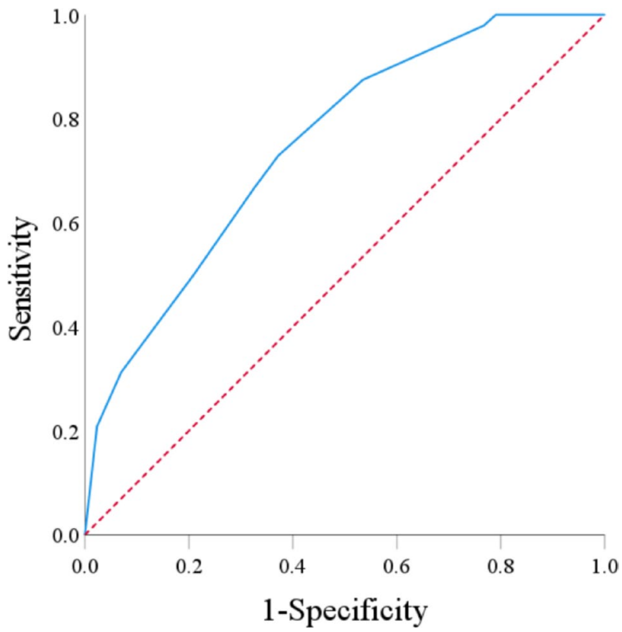

Fig. 6. ROC curve of the multivariable prediction model.

the conditions that could contribute to the unsuccess of the direct puncture method when pulsatile bleeding was observed after the indwelling needle was inserted into the artery. There was some distance between the cannula of the indwelling needle and the tip of the needle. Although the needle tip entered the blood vessel, the cannula of the indwelling needle may not be in the blood vessel at this time. If blood return was observed, the needle core was withdrawn, and the cannula was pushed forward, which may result in the hose being outside the blood vessel. However, with the transmural puncture method, penetration of the contralateral vessel wall was maintained after observing blood return, at which time the needle core was pulled out, and the hose was withdrawn. At this point, if blood return could occur again, the cannula was ensured in the vessel.

Arterial pressure transducer kit can sense the pressure signal and convert it into a usable output electrical signal and display the waveform of the artery[22]. The radial artery is The most frequently cannulated artery because of ease of access and fewer complications[23,24]. However, the overall rate of anatomical variations and access abnormalities of the radial artery is 22.8%[25], including abnormal origin of the radial artery (high radial artery), dysplasia, tortuous course, stenosis, and radioulnar artery. These anatomical variants can significantly alter arterial hemodynamics and present considerable challenges for successful catheterization[26]. Various efforts have been made to increase the success rate of radial artery puncture and accuracy of IABP. As radial artery puncture will cause a vasospasm reaction, the failure of the first puncture will affect the outcome of subsequent punctures. Researchers have found that several strategies can be used to increase access success through dilating the radial artery inner diameter, including acetylcholine infusion, sublingual nitroglycerin, subcutaneous nitroglycerin, warmed hand, and flow-mediated dilatation (FMD)[27–31]. However, whether these strategies can improve the success rate of puncture catheterization remains to be confirmed by further studies[20]. The classical (or pure) Seldinger technique is typically used in interventional radiology, whereas nurses specialized in vascular access (e.g., in ICU or interventional radiology) primarily employ the modified Seldinger technique (MST) or Micro-Seldinger technique for PICC or midline placement[32,33]. In China's clinical practice, radial artery catheterization predominantly utilizes disposable short-length arterial catheters (typically 3–5 cm) without guidewire assistance. Consequently, there remains an imperative to develop more effective arterial puncture techniques tailored to China's unique clinical environment.

The use of ultrasound-guided peripheral arterial catheterization has advanced rapidly in recent years, with multiple international guidelines now recommending ultrasound assistance for arterial line placement, particularly in obese patients, those in shock, or individuals receiving vasoactive medications[16–36]. Previous studies have demonstrated that ultrasound-guided radial artery puncture could improve the success rate of puncture and reduce vascular complications[21,37–40]. According to the meta-analysis of Bhattacharjee et al., ultrasound guidance could significantly improve the first-attempt success rate of arterial catheterization techniques (from 53% to 95%) compared with palpation[21]. Despite these advancements, traditional palpation-guided direct puncture techniques have not been entirely superseded in clinical practice[34,41]. While ultrasound-guided arterial cannulation establishes a safer standard for invasive blood pressure monitoring, cost-effectiveness considerations sustain the utility of the transmural puncture technique with transducer connectivity in resource-constrained critical settings. This protocol's procedural simplicity, minimal equipment dependency, and low technical barrier support its adoption enhancement in intensive care environments.

Approximately one-quarter of palpation-placed radial artery catheters develop clinically significant dysfunction (loss of waveform quality, impaired blood sampling, or sudden monitoring failure etc.), creating treatment delays during critical phases[42,43]. The technique demonstrated significant safety improvements:

immediate complication incidence (4.34% vs. 17.78%; $P = 0.039$, $\varphi = -0.215$), catheter removal unrelated to complications (47.8% vs. 71.1%; $P = 0.024$, $\varphi = 0.237$), puncture attempts, and hematoma incidence were all reduced - confirming its clinical advantage over conventional approaches. By minimizing repeated procedures, this approach may alleviate patient discomfort and reduce resource utilization, demonstrating both clinical and operational advantages over conventional methods. Previous studies confirmed that blood exposure in arteriovenous catheterization may cause VCAI of patients[44], and exposures to occupational blood exposures (OBEs) of medical personnel[45,46]. This study confirmed that the transmural puncture method can significantly reduce the exposure of blood (6.52% vs. 80.0%, $P < 0.001$). The closed-system design further reinforced sterility principles. While no infections, VCAI, ischemia, or thrombosis occurred in either group (hematomas were exclusive to conventional puncture, potentially due to repeated attempts), larger longitudinal studies are warranted to confirm long-term safety advantages stemming from reduced punctures and blood exposure. Less blood exposure also reduces nurses' fear caused by blood ejection and reduces the pressure of catheterization without blood ejection, directly mitigating infection risks linked to blood exposure while substantially lowering nurses' procedural stress by eliminating "blood fear". This psychological relief likely enhanced operator composure, contributing to higher first-attempt success.

This study has several limitations. First, the single-center neuro-ICU design constrains external validity, necessitating future multicenter validation. Second, while early complications were assessed, long-term data on radial nerve injury and limb function post-discharge are lacking; differentiating procedural trauma from underlying pathology requires extended follow-up with EMG/NCS. Third, although no infections occurred, the absence of microbiological analyses (e.g., catheter-tip cultures) precludes assessment of bloodstream exposure risks. Fourth, procedural pain and subjective experiences were unquantified given patients' cognitive impairment. Finally, pharmacodynamic confounders were unadjusted in intergroup comparisons. Future studies should incorporate these elements to strengthen conclusions.

Conclusion
Transmural puncture combined with a sensor was demonstrated to increase the success rate of the first arterial puncture and reduce the occurrence of complications. Therefore, the transmural puncture combined with sensor tube technique may be an acceptable option for cannulation of the radial artery of patients.

Ethical statement
All methods were carried out in accordance with relevant guidelines and regulations. Ethical approval for the study was obtained from the Medical Ethics Committee at Zhongnan Hospital of Wuhan University (Number: 2024122). The trial was posted on the Chinese clinical trial registry (registration number: ChiCTR2500100362, Date: 08/04/2025) at https://www.chictr.org.cn/. The design and implementation of the study protocol were reviewed and supervised by an ethics committee and conformed to the Declaration of Helsinki ("World Medical Association Declaration of Helsinki," 2013).

Data availability
The datasets used and/or analysed during the current study available from the corresponding author on reasonable request.

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Author contributions

The first author (F. X. and G. Y.): Conceptualization, Methodology, Software, Writing Original Draft.The corresponding author (B.M. and Y.L.): Conceptualization, Methodology, Software, Writing-0riginal Draft. Supervision, Writing-Review & Editing.F. C. was responsible for researcher training and implementation of the program.X.F. prepared Figs. 1 and 2 and Formal analysis.The other authors provided guidance and supervision of the operating technique.

Declarations

Competing interests
The authors declare no competing interests.

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Correspondence and requests for materials should be addressed to B.M. or Y.L.