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A modified arterial needle with an extended flashback chamber improves first-attempt success in radial artery cannulation: a randomized controlled trial

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Abstract

Background:

Palpation-guided radial artery cannulation has a first-attempt success rate of only 48–55%, while ultrasound guidance is often unavailable in low-resource settings. We developed a modified arterial needle with an extended flashback chamber (0.5–0.8 mL vs. standard 0.1–0.2 mL) that enables a retained-stylet technique. This study tests whether this simple, low-cost modification improves success and efficiency without additional equipment.

Methods:

In this single-center, prospective randomized controlled trial (n = 198, ChiCTR2500095957), elective surgery patients requiring radial artery cannulation were assigned 1:1 to a modified needle or standard needle. The primary outcome was first-attempt success rate. Secondary outcomes included procedural time, needle consumption, and operator-rated ease.

Results:

The modified needle significantly improved first-attempt success (70.7% vs. 52.5%, P = 0.009) and shortened procedural time [55.0 (52.0–87.0) s vs. 59.0 (54.0–107.5) s, P = 0.004]. Needle use became more consistent (IQR 1.0–1.0 vs. 1.0–2.0), and operator-rated ease was higher [10 (8–10) vs. 10 (5–10), P = 0.022]. In patients with BMI ≥ 25 kg/m², first-attempt success rose from 39.4% to 66.7% (P = 0.030). Overall cannulation success rates were similar (89.9% vs. 88.9%, P = 0.817),but the modified needle reduced procedural variability.

Conclusion:

A simple extension of the flashback chamber—costing <$0.50 per procedure—turns a blind palpation technique into a visually guided, more reliable maneuver. It achieves first-attempt success rates comparable to ultrasound (70.7% vs. 68–75%) without capital investment, offering an ideal bridge solution for resource-limited settings.

Trial Registration

Chinese Clinical Trial Registry, ChiCTR2500095957. Registered on January 15, 2025. Retrospectively registered (the first participant was enrolled prior to registration).

Introduction

Radial artery cannulation is a standard technique for continuous hemodynamic monitoring in perioperative and critical care.[1] Its reliability directly affects patient management, especially during major surgery or unstable hemodynamics.

Despite its widespread use, palpation-guided cannulation remains challenging. First-attempt success rates are only 48–55%, largely due to operator experience, patient anatomy, and the blind nature of needle insertion, which often leads to repeated punctures, longer procedure times, and complications such as hematoma or arterial spasm.[2-4] Ultrasound guidance improves success and reduces complications, but its adoption is limited by equipment cost, operator learning curve, and poor availability in low-resource settings.[5-7]

To address these barriers, we developed a modified arterial needle with an extended flashback chamber (0.5–0.8 mL vs. standard 0.1–0.2 mL) that allows the stylet to remain in place during cannulation. This design provides longer visual confirmation of arterial entry and better catheter stability. This study tests whether this simple, low-cost modification improves first-attempt success and procedural efficiency without requiring additional equipment.

Methods

Ethics and registration

This trial was approved by the Ethics Committee of Guangdong Provincial Hospital of Chinese Medicine (Approval No. ZF2024-166) and was conducted in accordance with the Declaration of Helsinki. Written informed consent was obtained from all subjects participating in the trial. The trial was prospectively registered with the Chinese Clinical Trial Registry on January 15, 2025 (registration number: ChiCTR2500095957, http://www.chictr.org.cn/). As the first participant was enrolled prior to registration, the trial is considered retrospectively registered.

Randomization and blinding

This trial adhered to the applicable CONSORT guidelines. A completed CONSORT checklist is provided as an additional file. Patients scheduled to undergo elective surgery and clinically requiring arterial cannulation were enrolled from June 2024 to July 2025. The inclusion criteria for this trial were: adult patients undergoing elective surgery clinically requiring invasive arterial blood pressure monitoring, aged 18 to 85 years, with a negative modified Allen's test and an intact radial artery puncture site. The exclusion criteria were: contraindications such as coagulopathy or the presence of an arteriovenous fistula at the intended site, emergency surgery, hemodynamic instability, and patient refusal.

Patients were randomly assigned in a 1:1 ratio to either the modified needle group or the standard needle group using a computer-generated randomization sequence. The allocation was concealed in sequentially numbered, opaque, sealed envelopes, which were opened just before the cannulation procedure by the operating anesthesiologist. Due to the nature of the intervention (different needle

devices), the operators performing the cannulation were unavoidably aware of the group assignment. However, the patients were blinded to their allocation. The research personnel responsible for outcome assessment and data collection were kept unaware of group assignment during the study. The statistician who performed the final analysis was also blinded to the group allocation. An intention-to-treat analysis was used.

Intervention Description

The modified arterial needle was constructed using a standard 20-gauge arterial catheter (B. Braun Medical Inc.). The protective cap at the stylet hub was removed, and a 15-cm sterile venous extension tube was connected to the flashback chamber（Figure-2）, effectively increasing its volume from the standard 0.1–0.2 mL to approximately 0.5–0.8 mL. This modification allowed for enhanced visualization of arterial blood return and prolonged observation time during needle manipulation.

Cannulation Technique

All procedures were performed by anesthesiologists who had completed a standardized training program, including 30 supervised puncture practice sessions prior to study initiation. Both groups employed the palpation-through technique.

In the standard needle group, upon initial flashback, the needle was advanced slightly to penetrate the posterior vessel wall. Subsequently, the stylet was withdrawn, and the catheter was retracted under negative pressure generated by a 5 mL syringe until blood reappeared, indicating intraluminal positioning. The catheter was then advanced into the artery.

In the modified needle group, the stylet was retained throughout the procedure. After observing the initial flashback, the needle was advanced slightly to penetrate the posterior vessel wall. Unlike in the standard technique, the stylet was not withdrawn at this stage. With the stylet kept in place, the needle-stylet assembly was then slowly withdrawn while monitoring for a secondary flashback in the extension tube. Upon confirmation, the catheter was advanced over the needle, after which the stylet was removed (Video 1).

Procedure Protocol

After anesthesia induction and hemodynamic stabilization, the non-dominant wrist was placed in moderate dorsiflexion. Following sterile preparation, the operator palpated the maximal radial pulse and started the timer upon needle insertion. The needle was advanced until flashback ceased, indicating posterior wall contact. The allocated technique was then applied.

Successful cannulation was defined as a clear arterial waveform on the monitor. Procedural time was recorded from needle insertion to waveform confirmation. If cannulation failed after 5 min (300 s), the attempt was recorded as a failure. Operators rated ease of maneuverability and flashback visibility on a 10-point Likert scale.

Outcome Measures

The primary outcome was the first-attempt success rate. Secondary outcomes included total procedural time, number of puncture attempts, needle consumption, number of puncture sites used, and operator-rated procedural ease.

Statistical Analysis

Sample size was calculated based on prior data [2] suggesting first-attempt success rates of 48% (standard) and 68% (modified). With $\alpha = 0.05$ and 80% power, 92 patients per group were required. Allowing for 10% dropout, 204 patients were planned; 198 completed the study.

Categorical variables were analyzed with the chi-square or Fisher's exact test. Continuous variables were assessed for normality and compared using independent t-tests or Mann–Whitney U tests. Analyses were performed with SPSS version 24.0; a two-tailed $P < 0.05$ was considered significant.

Results

Participant Characteristics

A total of 198 patients were enrolled and randomly assigned to the modified needle group (n = 99) or the standard needle group (n = 99). Baseline demographics and clinical parameters—including age, sex, body-mass index (BMI), systolic and diastolic blood pressure, heart rate, and American Society of Anesthesiologists (ASA) physical status—were comparable between the two cohorts (all $P > 0.05$; Table 1).The flow diagram of patient enrollment is presented in Figure 1.

Primary Outcomes

The modified needle group achieved a significantly higher first-attempt success rate than the standard needle group (70.7 % vs 52.5 %; $P = 0.009$). Median procedural time was also shorter in the modified group (55.0 s; IQR 52.0–87.0) compared with the standard group (59.0 s; IQR 54.0–107.5; $P = 0.004$).

Secondary Outcomes

Needle consumption was more consistent in the modified group (median 1.0, IQR 1.0–1.0) compared to the standard group (median 1.0, IQR 1.0–2.0; $P = 0.004$), and the number of skin punctures also showed lower variability in the modified group (median 1.0, IQR 1.0–2.0 vs. median 1.0, IQR 1.0–2.0; $P = 0.044$). Operator-rated ease was higher with the modified needle [median 10 (IQR 8–10) vs. median 10 (IQR 5–10); $P = 0.022$], while overall cannulation success (attainment of a satisfactory arterial waveform within 5 min) was similar between groups (89.9% vs. 88.9%; $P = 0.817$). Detailed results are summarized in Table 2.

Subgroup Analysis

Among patients with BMI ≥ 25 kg m^{-2} (n = 63), the modified needle improved first-attempt success from 39.4 % (13/33) to 66.7 % (20/30; $P = 0.030$). No significant interaction was observed between treatment effect and sex, age (> 60 vs ≤ 60 years), or ASA class.

Safety and Complications

No arterial thrombosis, symptomatic hematoma, or median-nerve injury occurred in either group. Three patients in the standard arm developed localized hematomas that resolved without sequelae. Oozing at the insertion site was reported in five patients (modified 2, standard 3; P > 0.99).

Discussion

This randomized controlled trial demonstrates that a simple modification to a standard arterial needle—extending the flashback chamber volume from 0.1–0.2 mL to 0.5–0.8 mL—enables a retained-stylet technique that significantly improves first-attempt success in palpation-guided radial artery cannulation (70.7% vs. 52.5%, P = 0.009) and shortens procedural time [55.0 (52.0–87.0) s vs. 59.0 (54.0–107.5) s, P = 0.004]. An absolute increase of 18 percentage points is clinically meaningful: in high-volume settings, fewer repeated punctures may translate into lower complication rates, less patient discomfort, and better resource utilization.

Conventional palpation-guided radial artery cannulation has a first-attempt success rate of only 48–55%, which is highly dependent on operator experience and patient anatomy.[8] Although ultrasound guidance can raise success to 68–75%,[9] its widespread use is limited by equipment cost, the learning curve, and lack of availability in low-resource environments.[5] Our study does not aim to replace existing techniques but rather to address a specific weakness of the “blind” approach. The modified needle, by enhancing visual feedback and mechanical stability, raises the first-attempt success of palpation to a level comparable to that of ultrasound guidance (70.7% vs. 68–75%), without requiring additional capital investment. Thus, it serves as a practical bridge between pure palpation and ultrasound-dependent cannulation, filling an important gap in settings with limited resources.

The effectiveness of the modified needle lies in its resolution of two interlinked failure modes of the standard technique. First, sustained visual feedback: the standard flashback chamber holds only about 0.1 mL of blood, giving the operator a fleeting signal. [10] Enlarging the chamber to 0.5–0.8 mL extends the visible window to 2–3 seconds, allowing the operator to calmly confirm that the needle tip is truly within the arterial lumen rather than in subcutaneous tissue or a vein. Second, mechanical integrity: in the conventional method, after initial flashback the operator must advance the needle to puncture the posterior wall, withdraw the stylet, and retract the catheter under negative pressure—a sequence that frequently causes the catheter to buckle, kink, or exit the vessel. By retaining the stylet until the catheter is advanced, the modified needle avoids catheter buckling. Together, these changes convert a “feel-dependent” blind step into a controlled, visually confirmed maneuver, fundamentally reducing procedural variability.

Furthermore, the modified group showed significantly lower variability in needle consumption (IQR 1.0–1.0 vs. 1.0–2.0, P = 0.004) and skin punctures (IQR 1.0–2.0 vs. 1.0–2.0, P = 0.044). This “variance-reducing” effect is particularly valuable in high-pressure, fast-paced environments such as the intensive care unit or emergency department.[11]

Beyond the specific procedure of radial artery cannulation, our study provides an example of "appropriate technology" : a device that costs an incremental US $0.50 per procedure, does not alter supply chains, and requires no extra training, yet markedly improves success. [12] This concept can be extended to other blind arterial access procedures (e.g., coronary and cerebrovascular intervention) and to medical device adaptation in low-resource settings. In low- and middle-income countries, access to ultrasound equipment remains severely constrained.[13,14] Our modified needle, made from universally available disposables, can be scaled immediately across tertiary hospitals, district hospitals, and even rural clinics. Its low-technology, high-gain characteristics make it a practical step toward global healthcare equity.

The modified needle also offers a unique teaching advantage. It transforms the "elusive feel" of palpation into a visible, step-by-step demonstration: the instructor can adjust angle, depth, and withdrawal speed in real time, while the trainee follows a reproducible checklist. This may reduce the need for expensive ultrasound-based simulation training and help novices master the key skill more quickly.[15]

In the subgroup of patients with BMI ≥ 25 kg/m², the modified needle increased first-attempt success from 39.4% to 66.7% ($P = 0.030$). Globally, obesity rates are rising—the World Obesity Atlas projects over 1.13 billion obese adults by 2030, with the fastest growth in low- and middle-income countries.[16] Obese patients have thicker subcutaneous tissue and weaker pulses, making palpation-guided cannulation more difficult.[17,18] The enhanced visual feedback of the modified needle compensates for these challenges. No significant interactions were observed with sex, age, or ASA class, suggesting broad applicability.

No arterial thrombosis, symptomatic hematoma, or median nerve injury occurred in either group. Three patients in the standard arm developed localized hematomas that resolved without sequelae. Oozing at the puncture site was reported in five patients (2 in the modified group, 3 in the standard group; $P > 0.99$). Although the trend toward fewer hematomas suggests a potential safety benefit, we did not follow up on long-term outcomes such as catheter patency, infection, or thrombotic events, which should be assessed in future studies.

Several limitations of our study should be acknowledged. First, this was a single-center trial with operators from the same training system, so the generalizability of the findings needs to be confirmed in multicenter studies. Second, the operators could not be blinded to the group assignment, which might introduce performance bias; however, the primary outcome (first-attempt success) is objective and unlikely to be influenced by expectation. Third, the operator-rated ease-of-use scores (10-point Likert scale) may have been affected by expectancy bias. Fourth, the modified needle required intraoperative assembly rather than being a pre-sterilized, ready-to-use commercial product, which could affect sterility and convenience. Fifth, we excluded emergency cases, hemodynamically unstable patients, those with coagulopathy, and pediatric patients, so our results cannot be directly extrapolated to those populations.

Based on these limitations, future research should: (1) conduct multicenter, mixed-method (quantitative and qualitative) trials to validate the robustness of the modified needle across different healthcare cultures and operator experience levels; (2) perform cost-effectiveness analyses comparing the modified needle with ultrasound guidance to inform health policy; (3) explore appropriate gauge sizes and safety boundaries in children, hypotensive patients, or those receiving anticoagulation; (4) encourage medical device companies to develop a pre-sterilized, single-piece, disposable product that eliminates intraoperative assembly; and (5) investigate its role as a “rescue” tool when ultrasound guidance fails or is unavailable.

In conclusion, extending the flashback chamber gives the operator a longer window to observe blood return. This longer window, in turn, makes the retained-stylet technique feasible—a maneuver that significantly improves first-attempt success and procedural efficiency in palpation-guided radial artery cannulation, reduces outcome variability, and offers particular benefit in obese patients. Low in cost, requiring no additional equipment, and easy to disseminate, this device is especially suitable for resource-limited settings. By converting the two main failure modes of blind palpation into controlled, visually guided steps, it achieves a clinical success rate comparable to that of ultrasound guidance without capital investment. We believe this modified device should become a practical, affordable bridge between blind palpation and ultrasound-guided cannulation.

Abbreviations

BMI: Body mass index; SBP: Systolic blood pressure; DBP: Diastolic blood pressure; HR: Heart rate; ASA: American Society of Anesthesiologists; IQR: Interquartile range; CONSORT: Consolidated Standards of Reporting Trials.

Declarations

Ethics approval and consent to participate

This trial was approved by the Ethics Committee of Guangdong Provincial Hospital of Chinese Medicine (Approval No. ZF2024-166) and was conducted in accordance with the Declaration of Helsinki. Written informed consent was obtained from all subjects participating in the trial.

Consent for publication

Not applicable. This manuscript does not contain any individual person’s data in any form (including individual details, images, or videos).

Availability of data and materials

The dataset supporting the findings of this study is not publicly available due to institutional privacy restrictions but is available from the corresponding author upon reasonable request.

Competing Interests

The authors declare no conflicts of interest.

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Authors' contributions

Xiaofei Wu: Study conception and design, data acquisition, drafting of the manuscript, technical support for the modified needle technique.

Xiaona Li: Data acquisition, performance of cannulation procedures.

Ziyi He: Performance of cannulation procedures, analysis and interpretation of data, statistical analysis.

Zhilan Tong: Data acquisition, study conception and design, patient recruitment, and coordination.

Xiangyu Li: Study conception and design, supervision of the project, critical revision of the manuscript for important intellectual content.

All authors read and approved the final version of the manuscript.

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Tables

Table 1. Patient Characteristics

Characteristic	The modified needle group n = 99	The standard needle group n = 99	*P* values
Sex (%)			0.670
Female	51 (51.5)	48 (48.5)	
Male	48(48.5)	51 (51.5)	
Age (years)	63.1 ± 12.6	61.1± 12.2	0.239
BMI	23.9 ± 3.4	23.4± 3.4	0.272
SBP	136.4 ±20.0	135.0 ±18.0	0.615
DBP	77.1 ±10.0	76.8 ±9.4	0.787
HR	72.7 ±8.7	73.1 ±9.5	0.750

Data is presented as mean ± SD ; BMI (body mass index), SBP (systolic blood pressure), DBP (diastolic blood pressure), HR (heart rate)

Table 2. Study Results

Variables	The modified needle group n = 99	The standard needle group n = 99	*P* values

First-pass success(%)	70（70.7）	52（52.5）	0.009
Overall success (%）	89（89.9）	86（88.9）	0.817
Number attempts	1.0（1.0，2.0）	1.0（1.0，2.0）	0.044[1]
Operating time	55.0（52.0，87.0）	59.0（54.0，107.5）	0.004[1]
Operational scoring	10.0（8.0，10.0）	10.0（5.0，10.0）	0.022[1]
Number of arterial pins	1.0（1.0，1.0）	1.0（1.0，2.0）	0.004[1]
BMI≥25	n=30	n=33	
First-pass success(%)	20（66.7）	13（39.4）	0.03

[1]Mann-Withney-Wilcoxon test.

Data is presented as mean ± SD and median (P25, P75); BMI (body mass index).

Figures

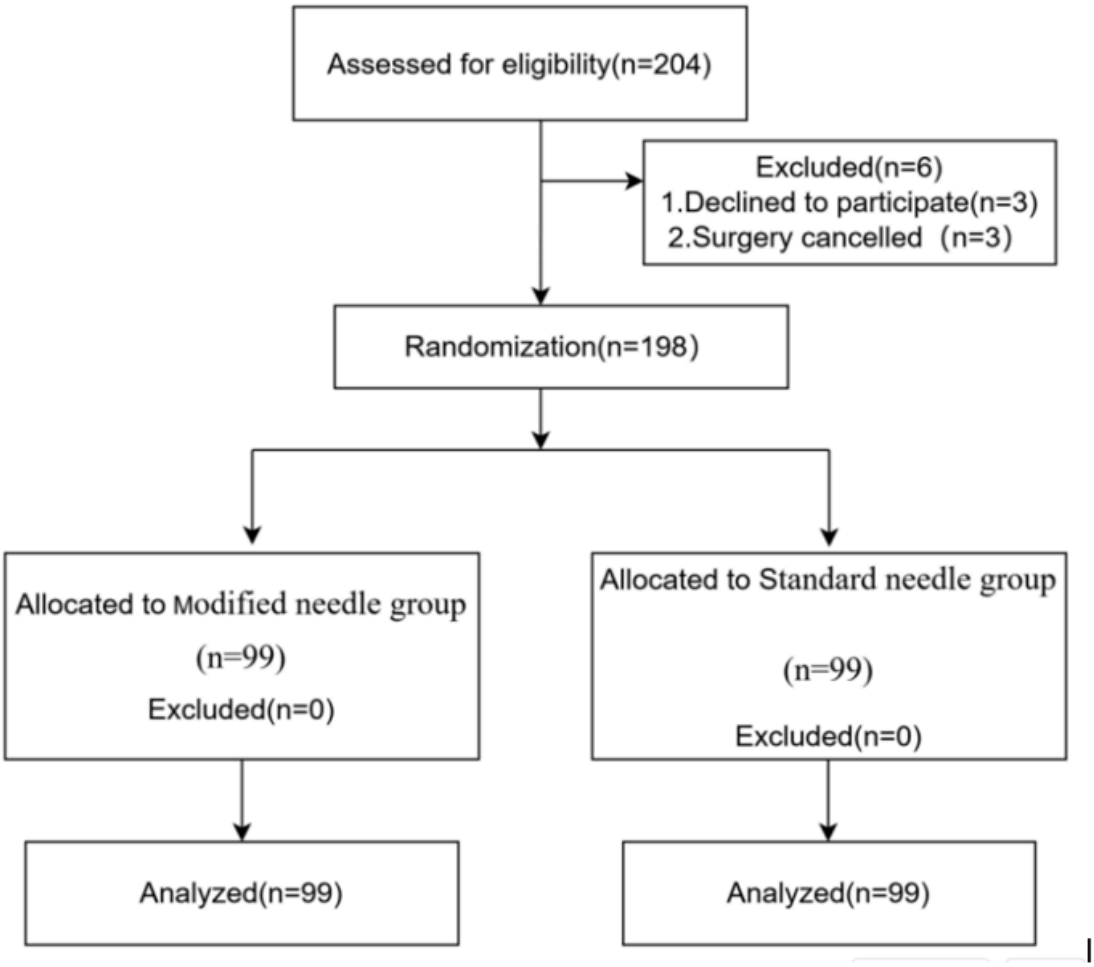


Figure 1

Flow diagram of selected studies



Figure 2

Modified arterial needle with extended flashback chamber

Supplementary Files

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- CONSORT2025editablechecklist1.docx