

Preliminary Application of Color Doppler Ultrasound Combined with Intravascular Pressure Measurement in Femoral Vein Puncture

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Abstract

Objective This study aimed to evaluate the feasibility and clinical utility of vascular ultrasound combined with intravascular pressure measurement for femoral vein puncture.

Methods A total of 105 patients undergoing femoral vessel puncture in the Department of Cardiovascular Surgery, Suining Central Hospital, between July 2018 and June 2025, were enrolled. Patients were assigned to two groups based on the puncture technique: 50 underwent femoral vein puncture guided by color Doppler ultrasound combined with intravascular pressure measurement (Group 1), and 55 underwent conventional femoral vein puncture (Group 2). Outcomes included overall puncture success rate, first-attempt success rate, puncture time, and puncture site complications (bleeding, pseudoaneurysm, arteriovenous fistula, accidental femoral artery puncture, and postoperative neurological complications).

Results The Group 1 demonstrated significantly higher overall puncture success (100% vs. 87.3%) and first-attempt success rates (98.0% vs. 81.8%), along with a shorter puncture time, compared with the Group 2 (all $P < 0.05$). The overall incidence of puncture site complications also differed significantly between groups ($P < 0.05$). Specifically, the Group 1 had lower rates of puncture site bleeding, pseudoaneurysm, and accidental femoral artery puncture. No significant differences were observed in the incidence of arteriovenous fistula or pseudoaneurysm between the two groups (both $P > 0.05$).

Conclusion Color Doppler ultrasound combined with intravascular pressure measurement offers superior first-attempt and overall success rates, streamlined procedure, and reduced vascular complications compared with conventional femoral vein puncture. This technique is particularly advantageous in patients with aberrant femoral vascular anatomy and represents a safe, clinically valuable approach.

1.Introduction

The femoral vein is a commonly used vascular access route in the diagnosis and treatment of cardiovascular diseases. Compared with venous cutdown, percutaneous femoral vein puncture has gained widespread clinical acceptance owing to its advantages of minimal invasiveness, lower complication rates, and procedural simplicity [1–3]. However, given the close anatomical proximity of the femoral vein to the femoral artery, inadvertent arterial injury during puncture remains a clinical challenge, potentially leading to iatrogenic complications such as pseudoaneurysm, retroperitoneal hematoma, and arteriovenous fistula [4, 5]. Conventional femoral vein puncture is typically performed using the anatomical landmark method, with the puncture site positioned medial to the palpable femoral arterial pulse. This approach inherently involves a blind zone, and accidental arterial puncture may result in mechanical complications [6–8]. To enhance procedural safety, various adjunctive techniques have been explored. In recent years, color Doppler ultrasound guidance has emerged as the most widely adopted approach for femoral vein puncture and catheterization, demonstrating improved success rates and a reduced risk of complications [9–11]. Notably, arterial pressure in the femoral artery is substantially higher than that in the femoral vein. Despite this physiological distinction, no studies to date have

investigated the combined use of color Doppler ultrasound and intravascular pressure measurement to guide femoral vein puncture. This study therefore aims to evaluate the clinical value of ultrasound-guided femoral vein puncture combined with vascular manometry, compare its efficacy and safety with those of conventional puncture techniques, and present the corresponding findings.

2 Materials and Methods

2.1 Study Population

A total of 105 patients who underwent femoral vein puncture in the Department of Cardiovascular Surgery, Suining Central Hospital, Sichuan Province, between July 2018 and June 2025 were enrolled in this study. All patients had an indication for femoral vein puncture. Based on the puncture technique used, patients were divided into two groups: those undergoing femoral vein puncture under ultrasound guidance combined with vascular manometry (Group 1) and those undergoing conventional femoral vein puncture (Group 2). In Group 1, there were 32 males and 18 females, with a median age of 48.00 years (interquartile range [IQR], 41.00–54.00) and a mean body mass index (BMI) of $220.76 \pm 1.93 \text{ kg/m}^2$. In Group 2, there were 29 males and 26 females, with a median age of 46.00 years (IQR, 41.00–51.00) and a mean BMI of $220.92 \pm 2.26 \text{ kg/m}^2$. No statistically significant differences were observed between the two groups in terms of age, sex, or BMI (all $P > 0.05$). Detailed baseline characteristics are presented in Table 1.

Inclusion Criteria: (1) Age ≥ 2 years; (2) Patients requiring interventional procedures via femoral vein puncture, including right heart catheterization, atrial septal defect closure, and patent foramen ovale closure; (3) Preprocedural imaging confirming identifiable anatomy of the femoral vessels; (4) Written informed consent obtained.

Exclusion Criteria: (1) History of prior femoral vessel surgery; (2) History of femoral vein thrombosis or deep vein thrombosis; (3) Active infection, skin disruption, or local tumor at the puncture site; (4) Allergy to ultrasound gel; (5) Refusal to provide informed consent or inability to cooperate. The study was approved by the ethics committee of Suining Central Hospital, and written informed consent was obtained from the patients' parents. All subjects gave written informed consent in accordance with the Declaration of Helsinki.

2.2 Study Methods

2.2.1 Ultrasound-Guided Femoral Vein Puncture Combined with Intravascular Manometry (Group 1)

All procedures were performed in the interventional catheterization laboratory. Patients were placed in a supine position. Those aged > 12 years received local anesthesia with 2% lidocaine, while those aged $\leq$

12 years or those unable to cooperate underwent general anesthesia. The right groin region was preferentially selected.

Femoral vein puncture was performed under real-time color Doppler ultrasound guidance. Using an ultrasound probe, the relative anatomical positions of the femoral artery and vein were identified 1–2 cm below the midpoint of the inguinal ligament, and the needle trajectory was monitored in real time. A puncture needle was inserted at a 30°–45° angle to the skin. Upon negative pressure aspiration yielding blood return, a guidewire was introduced, followed by insertion of a 5 Fr short sheath. A pressure measurement device was connected to the side port of the sheath to record femoral vein pressure. The 5 Fr short sheath was then slowly withdrawn over the guidewire, with continuous pressure monitoring. If the pressure reading increased sharply to the level of peripheral arterial pressure, indicating possible inadvertent arterial puncture, the sheath and guidewire were immediately removed, and manual compression was applied before reattempting puncture. If the pressure remained significantly lower than arterial pressure, the guidewire was retained and the 5 Fr sheath was exchanged for a 6 Fr short sheath.

2.2.2 Conventional Femoral Vein Puncture Group (Group 2)

Conventional femoral vein puncture was performed using the Seldinger technique. The puncture site was selected approximately 4 cm below the midpoint of the inguinal ligament. The left index finger was used to palpate the point of strongest femoral arterial pulsation, and the puncture needle was inserted at a 30°–45° angle approximately 0.5–1.0 cm medial to the femoral artery. Upon observation of dark red blood return, a guidewire was introduced, followed by insertion of a 6 Fr short sheath.

2.3 Postoperative Management.

After the procedure, manual compression was applied to the groin puncture site for 10 minutes in all patients, followed by figure-of-eight elastic bandage compression. Blood circulation of the right lower limb, dorsalis pedis pulse, and groin compression status were assessed every 1–2 hours. Patients were permitted to ambulate 8 hours after the procedure. The bandage was removed 12 hours postoperatively and replaced with a sterile adhesive dressing.

2.4 Outcome Measures

The two groups were compared in terms of overall puncture success rate, first-attempt puncture success rate, puncture time, and puncture-related complications, including bleeding, pseudoaneurysm, arteriovenous fistula, accidental femoral artery puncture, and postoperative neurological complications.

2.5 Statistical Analysis

Data were analyzed using SPSS version 26.0 (IBM Corp, Armonk, NY, USA). Normality of continuous variables was assessed using the Kolmogorov–Smirnov test. Continuous data with a normal distribution are presented as mean $\pm$ standard deviation (SD) and were compared using the independent-samples t-test; those with a non-normal distribution are presented as median (interquartile range) and were

compared using the Mann–Whitney U test. Categorical variables are presented as frequencies (percentages) and were compared using the chi-square test or Fisher’s exact test, as appropriate. A two-sided P value < 0.05 was considered statistically significant.

3.Results

3.1 Baseline Characteristics

No statistically significant differences were observed between the two groups in baseline characteristics such as sex, age, and body mass index (all $P < 0.05$), indicating good comparability (Table 1).

3.2 Puncture Success Rate

The overall puncture success rate was 100% (50/50) in Group 1, which was significantly higher than the 87.3% (48/55) in tGroup 2 ($P < 0.05$). The seven patients in the Group 2 who experienced puncture failure subsequently achieved successful puncture with the assistance of ultrasound guidance combined with intravascular pressure measurement.

The first-attempt puncture success rate was 98.0% (49/50) in the experimental group, also significantly higher than the 81.8% (45/55) in the control group ($P < 0.05$) (Table 2).

3.3 Puncture Time

Puncture time was significantly shorter in Group 1 (median [IQR], 103.00 [87.25, 113.25] seconds) than in the Group 2(112.00 [93.00, 123.00] seconds) ($P < 0.05$) (Table 2).

3.4 Complications

The overall incidence of vascular complications was significantly lower in the experimental group than in Group 2($P < 0.05$). Subgroup analysis revealed that the incidence rates of puncture site bleeding, pseudoaneurysm, and accidental femoral artery puncture were significantly lower in the experimental group (all $P < 0.05$). No statistically significant differences were observed between the two groups in arteriovenous fistula or puncture-related neurological complications (both $P > 0.05$) (Table 2).

4.Discussion

This study provides a preliminary investigation into the clinical utility of combining color Doppler ultrasound with intravascular manometry to optimize femoral vein puncture. Our findings indicate that, relative to the conventional anatomical landmark-based approach, this combined strategy significantly enhanced procedural precision. Specifically, it was associated with a superior first-attempt success rate, a marked reduction in the incidence of inadvertent arterial punctures, and a substantial shortening of total puncture time. Furthermore, real-time manometry served as an objective functional confirmation of the catheter’s intravascular position, effectively eliminating the risk of undetected arterial misplacement.

Collectively, these results support the adoption of this dual-modality approach as a valuable optimization of standard femoral vein puncture, particularly in scenarios demanding high procedural safety.

4.1 The Superiority of Ultrasound Guidance in Vascular Access

The efficacy of ultrasound guidance in mitigating mechanical complications during femoral vein cannulation is well established. Our results align with those of large-scale prospective studies, such as the ULTRA-FAST trial. This multicenter randomized study involving 320 patients demonstrated that ultrasound-guided femoral venipuncture significantly reduced median puncture time (288 vs. 369 seconds, $P < 0.001$), markedly improved first-pass success rates (74% vs. 20%, $P < 0.001$), and resulted in fewer overall complications compared to the landmark-based method[6]. The ultrasound-guided component of our study is also consistent with the findings reported by Lazaar et al. [7] and a recent meta-analysis published in The Ultrasound Journal [12]. These works collectively affirm that ultrasound guidance provides a critical advantage by enabling direct, real-time visualization of the underlying vascular anatomy, thereby minimizing the risk of collateral injury.

A distinct advantage of our methodology lies in the utilization of color Doppler, which provides dynamic assessment of blood flow. This is particularly crucial for differentiating arteries from veins, especially in anatomically complex regions. For instance, the external pudendal artery, a small branch coursing anterior to the femoral vein, represents a significant "blind spot" in landmark-based approaches. Unintentional puncture of such branches can lead to bleeding or hematoma formation that is not easily compressible. By visualizing flow direction and character, color Doppler allows the operator to avoid these small but consequential vessels—a capability that traditional methods lack[11, 13–15].

4.2. The Functional Confirmation of Manometry: Addressing the Limitations of Imaging Alone

Despite the established benefits of ultrasound guidance, it is essential to recognize that this modality provides primarily structural guidance [16]. It excels at visualizing anatomy and needle trajectory but cannot definitively confirm the functional status of a catheter tip after placement. Distinguishing between a vein and an artery based solely on the color or pulsatility of back-bleeding can be ambiguous, particularly in hypotensive patients, those with low cardiac output, or in cases of anatomical anomalies. Manometry addresses this critical gap by providing objective functional confirmation, allowing for definitive differentiation between venous and arterial systems based on characteristic pressure waveforms and quantitative values [17]. This study innovatively demonstrates that combining ultrasound guidance with vascular manometry can overcome the limitations of either technique alone, particularly in conditions of low perfusion or anatomical variation [18]. The necessity for such functional confirmation is underscored by Davies et al. [19], who cautioned that "the possibility of arterial injury should be considered in all patients, including those undergoing venous puncture." Reliance on visual cues alone can be subjective and, in rare instances, misleading. By connecting a pressure transducer, the operator

can observe a characteristic right atrial pressure waveform (typically exhibiting a, c, and v waves with a mean pressure of 2–8 mmHg), which serves as the gold standard for confirming catheter placement within the central venous system.

4.3 Synergistic Advantages of the “Structure + Function” Strategy

The combination of ultrasound and manometry embodies a "structure + function" paradigm that offers synergistic advantages. During the initial puncture phase, ultrasound provides real-time visualization, enabling the operator to avoid adjacent structures such as the femoral artery and nerve. This dynamic guidance reduces the number of needle passes, a critical factor in complication risk. Literature indicates that the risk of access-site complications increases exponentially—by a factor of 3.62—when the number of puncture attempts is three or more [20]. Following successful cannulation, manometry provides the final safety verification. This dual-safeguard approach is particularly valuable in high-risk clinical contexts, such as emergency situations requiring rapid central access, in critically ill patients with coagulopathies, or in patients undergoing periprocedural anticoagulation, where even minor bleeding or inadvertent arterial puncture can precipitate severe complications [21].

5. Limitations

While the results of this preliminary study are promising, several limitations must be acknowledged.

Limited Sample Size: As a preliminary application study, the sample size was modest. While sufficient to demonstrate improvements in primary endpoints such as first-attempt success rate and puncture time, a larger cohort would be required to comprehensively evaluate the incidence of rare but clinically significant complications.

Operator Dependence: The quality and success of ultrasound-guided procedures are inherently dependent on operator experience. Although all operators underwent a standardized training protocol, a learning curve effect may still exist, potentially influencing outcomes.

Single-Center Design: This was a single-center, non-randomized study, which may introduce selection bias. The results may not be fully generalizable to other healthcare settings with different patient demographics or resources.

Invasiveness and Cost-Effectiveness: The manometry procedure adds an additional procedural step, including the cost of the pressure transducer and setup time. A comprehensive health economic analysis is necessary to evaluate whether the incremental safety benefits justify the added costs.

6. Conclusion and Future Directions

In conclusion, color Doppler ultrasound combined with intravascular manometry for femoral vein puncture represents a significant advancement over conventional methods. This approach not only

enables real-time visualization of the puncture process but also provides objective functional confirmation of successful and safe catheter placement. The dual "structure + function" validation demonstrates high clinical applicability, particularly in improving procedural efficiency and reducing immediate access-related complications.

To substantiate these findings, future large-scale, multicenter, randomized controlled trials are essential. Such studies should aim to assess the efficacy of this approach in reducing long-term complications, including deep vein thrombosis and iatrogenic arteriovenous fistulae, as well as its cost-effectiveness and impact on patient-reported outcomes.

Abbreviations

ASD
Atrial septal defect
BMI
Body mass index
IQR
Interquartile range
PFO
Patent foramen ovale
RHC
Right heart catheterization
SD
Standard deviation

Declarations

Ethics approval and consent to participate

Written informed consent was obtained from all participants.

Consent for publication

All authors have consented to publication.

Competing Interests

The authors declare that they have no competing interests.

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Author Contribution

Yiwei He who is the Corresponding author was the intervencionist who performed all of the operations. Xia kong and Pan Xiong was responsible for writing the paper, Qiang Zhang was responsible for data collection, and He Yiwei was responsible for revising the paper. All authors have intellectually supported the study. All authors read and approved the final manuscript.

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Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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Tables

Table 1 Demographics of the studied groups

	Group 1 (n=50)	Group 2 (n=55)	χ^2/t -value	P-value
Gender, n(%)			1.367 ^c	0.242
Male	32 (64.0)	29 (52.7)		
Female	18 (36.0)	26 (47.3)		
Age (years)	48.00 (41.00-54.00)	46.00 (41.00-51.00)	-0.684 ^b	0.494
BMI (kg/m ²)	20.76±1.93	20.92±2.26	-0.378 ^a	0.706

Note: a indicates the use of the two independent samples t-test, b indicates the use of the Mann-Whitney U test, and c indicates the use of the chi-square test.

Table 2 Procedure results

	Group 1 (n=50)	Group 2 (n=55)	χ^2/t -value	P-value
Overall puncture success rate, n(%)	50 (100.0)	48 (87.3)	.c	0.013
First-attempt puncture success rate, n(%)	49 (98.0)	45 (81.8)	7.312 ^b	0.007
Puncture time, (s)	103.00 (87.25, 113.25)	112.00 (93.00, 123.00)	-2.387 ^a	0.017
Complications, n(%)				
Overall incidence	1 (2.0)	26 (47.3)	28.102 ^b	<0.001
Puncture site bleeding	1 (2.0)	8 (14.5)	.c	0.033
Pseudoaneurysm	0 (0)	7 (12.7)	.c	0.013
Arteriovenous fistula	0 (0)	3 (5.5)	.c	0.245
Accidental femoral artery puncture	0 (0)	6 (10.9)	.c	0.028
Puncture-related neurological complications	0 (0)	2 (3.6)	.c	0.496

Note: a indicates the use of the Mann-Whitney U test, b indicates the use of the chi-square test, and c indicates the use of Fisher's exact test.