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Analysis of Factors Influencing Peripheral Arterial Catheter Dysfunction in ICU Patients

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Abstract

Objective: To investigate the prevalence of peripheral arterial catheter dysfunction in ICU patients and analyze its influencing factors, providing a basis for early precise identification and intervention. **Methods:** Adult patients in the ICU of a tertiary hospital in Jingzhou, Hubei Province, from February to August 2025, were selected as the study subjects. Patients were divided into a dysfunction group and a non-dysfunction group. Univariate analysis and binary logistic regression analysis were employed to assess the influencing factors of peripheral arterial catheter dysfunction. **Results:** A total of 240 patients were included, with a dysfunction incidence rate of 29.2%. Eight indicators, including catheter dwell time, maintenance frequency, total number of blood draws, incidence of agitation, and ultrasound utilization rate, showed statistically significant differences between groups ($P < 0.05$). Six key influencing factors were identified ($P < 0.05$): Protective factors include normal skin at the puncture site, ultrasound-guided puncture, prolonged dwell time, and increased maintenance frequency; risk factors include the presence of blood residuals within the catheter and an increased total number of arterial blood sampling occurrences. **Conclusion:** The incidence of dysfunction during arterial catheterization in ICU patients is relatively high, necessitating the development of personalized prevention strategies and early precise identification to reduce the occurrence of catheter dysfunction.

Keywords

Intensive Care Unit, Peripheral Arterial Catheter, Catheter Function, Influencing Factors

1. Introduction

At the forefront of the medical field, the Intensive Care Unit (ICU) plays a crucial

role as the last line of defense for preserving life [1] [2]. Peripheral Arterial Catheters (PAC) are essential monitoring tools in the ICU and anesthesiology, widely utilized for continuous hemodynamic monitoring, blood sampling, and arterial blood gas analysis, with over 10 million catheters placed each year globally [3] [4], underscoring their indispensable clinical value. However, the widespread application of PACs is accompanied by certain risks and challenges [5]. During the retention of PACs, the occurrence of Peripheral Arterial Catheter Failure (PACF) is common, defined as the inability of the catheter to achieve the expected monitoring and therapeutic functions due to complications such as kinking, absence of blood return, abnormal waveforms, catheter-related bloodstream infections, occlusion, or dislodgment [6]. Currently, the incidence of PACF remains high both domestically and internationally, ranging from 4% to 25% worldwide [7]. A secondary analysis by Jessica A. *et al.* [8] on 664 patients indicated a PACF incidence of 26%, with 8% attributed to catheter occlusion; additionally, a study by Yuan Cui *et al.* [9] confirmed a PACF incidence of 25.1% among ICU patients in China. Despite the significant impact of PACF on clinical diagnosis and treatment, research on risk prediction tools for PACF is exceedingly scarce, resulting in challenges for clinicians in early and accurate identification of high-risk patients and the formulation of personalized preventive interventions, thereby scientifically guiding PAC maintenance practices. Based on this, the present study aims to analyze the influencing factors to provide a basis for the early prevention and control of PACF in clinical settings.

1. Objects and Methods

1.1. Study Subjects

The study subjects were adult patients with indwelling peripheral arterial catheters (such as radial artery, brachial artery, etc.) in the ICU of a tertiary hospital in Jingzhou, Hubei Province. Inclusion criteria: 1) Age ≥ 18 years; 2) Indwelling peripheral arterial catheter for ≥24 hours, with complete clinical data available; 3) The patient or their family members provided informed consent to participate in this study (if the patient was unconscious, informed consent was obtained from family members). Exclusion criteria: Short-term catheter removal (indwelling time < 24 hours) with incomplete monitoring data; presence of severe infectious diseases (such as sepsis), coagulation disorders (such as hemophilia), or terminal malignant tumors that may interfere with the assessment of catheter dysfunction; refusal of family members to cooperate in data collection or inability to continue follow-up after patient transfer. Based on the incidence of PACF and variable dimensions in previous studies [10], the expected incidence of PACF was 30%. It was anticipated that 5 variables would be included in the logistic regression model. According to empirical methods, the number of outcome events should exceed 10 times the number of variables, resulting in an estimated sample size of 167. Ultimately, this study included 240 patients. This research was approved by the hospital's ethics committee (Approval No.: KY2024-094-01).

1.2. Research Methods

1.2.1. Survey Tool

The researchers designed the "Survey on Risk Factors for Dysfunction of Peripheral Arterial Catheters in Adult ICU Patients" based on a comprehensive review of extensive literature, expert consensus, and relevant guidelines, tailored to clinical needs and data quality control objectives [11]. We developed a customized "ICU Adult Patient Peripheral Artery Catheter Dysfunction Risk Factors Survey Form", which comprises 20 core indicators across four key dimensions, detailed as follows: 1) Operator Factors: including years of experience in the ICU (<5 years/5 - 10 years/>10 years) and whether ultrasound guidance was used during the puncture (yes/no); 2) Patient Factors: covering age (18 - 59 years/60 - 74 years/75 years+), APACHE II score (10 - 19 points/20 - 29 points/30 - 49 points), presence of diabetes mellitus (yes/no), and existence of peripheral vascular disease (e.g., atherosclerosis, yes/no); 3) Catheterization Factors: including puncture site (radial artery/femoral artery/other sites), number of punctures (successful on first attempt/2 or more attempts successful), and whether collateral blood flow was assessed prior to catheter placement (yes/no); 4) Maintenance Factors: comprising pressure of the pressure bag (<300 mmHg/300 - 350 mmHg/>350 mmHg), presence of blood residual in the tubing (yes/no), method of catheter fixation (transparent dressing/elastoplast/other), and flushing frequency (once every 4 hours/once every 6 hours/other).

1.2.2. Data Collection

Specialized training for research nurses was conducted, with case demonstrations to clarify the evaluation standards for subjective indicators such as "bleeding grading" and "catheter blockage judgment criteria". Only those who passed the assessment were permitted to participate in data collection. Daily, "peripheral artery catheterization patients" were screened through the electronic medical record system, which was equipped with an automatic reminder function to prevent omissions. Research nurses verified patient information on-site and confirmed compliance with inclusion criteria before completing the survey forms. Concurrently, daily checks were conducted on catheter maintenance records, vital sign monitoring data, and laboratory test results to supplement and complete the information. For patients transferred to other departments, communication was established in advance with the receiving department's nurses to continuously track catheter status until removal or the occurrence of PACF, ensuring the integrity of follow-up data. After daily data collection, two researchers cross-verified the completeness of the questionnaires. In cases of missing or contradictory data, timely communication with the research nurses or clinical departments was initiated for corrections, ensuring that the accuracy rate of the data was maintained at ≥95%. A dual-person dual-entry mode was employed, where paper questionnaire data were entered into an electronic database, followed by independent verification of the entry results by two researchers. Additionally, logic validation rules were established to reduce entry errors.

1.2.3. Definition of Outcome Indicators

Peripheral Arterial Catheter Dysfunction (PACF): According to clinical diagnostic and therapeutic guidelines, it is defined as the occurrence of any of the following situations during the catheter indwelling period: 1) Catheter occlusion (no blood return, disappearance or attenuation of pressure monitoring waveform); 2) Puncture site bleeding/hematoma (bleeding extending beyond the edges of the dressing or hematoma diameter > 2 cm); 3) Local infection (redness and swelling at the puncture site, accompanied by discharge or body temperature > 38.5˚C, excluding other sources of infection); 4) Catheter dislodgement (partial or complete dislodgement from the vessel), determined by two senior ICU nurses, with discrepancies resolved through departmental case discussions.

1.3. Statistical Methods

All valid questionnaire data were double-entered using EpiData 3.1 software. After data entry, logical verification and data cleaning were performed to ensure data accuracy. The statistical analysis in this study was conducted using SPSS 25.0 software. The Shapiro-Wilk test was employed to assess whether quantitative data followed a normal distribution, and inter-group differences were analyzed using the independent samples Mann-Whitney U test. For qualitative data comparisons, the Chi-square test or Fisher's exact test was utilized. A binary Logistic regression analysis was conducted, incorporating factors with $P < 0.2$ from univariate analysis into the multivariate Logistic regression. A bidirectional stepwise regression method was applied to explore the independent effects of different factors. All tests were two-tailed, with $P < 0.05$ indicating statistical significance.

2. Results

2.1. Basic Physiological Indicators of ICU Patients

Six basic physiological indicators were assessed, including age, sex, BMI, heart rate, systolic blood pressure, and diastolic blood pressure. The P values for all indicators were greater than 0.05 (ranging from 0.199 to 0.679), indicating that there were no statistically significant variables. The differences in basic physiological indicators between the two groups of patients were not statistically significant. For specific details, refer to Table 1.

Table 1. Comparison of basic physiological indicators between the two groups of patients.

Variable	Total (n = 240)	No PACF (n = 170)	With PACF (n = 70)	Z/χ^2	P
Age	67.00 (57.00, 72.00)	67.00 (59.25, 72.75)	63.00 (54.00, 71.00)	−1.28	0.199
Gender				1.33	0.249
Male	169 (70.42)	116 (68.24)	53 (75.71)		
Female	71 (29.58)	54 (31.76)	17 (24.29)		
BMI	22.05 (19.50, 24.83)	21.65 (19.42, 24.80)	22.70 (19.65, 25.10)	−0.91	0.364
Heart Rate	96.00 (82.00, 115.50)	95.00 (82.00, 112.75)	101.00 (84.00, 119.25)	−1.11	0.266
Systolic Blood Pressure	126.13 ± 26.97	127.51 ± 28.35	122.77 ± 23.14	1.24	0.217
Diastolic Blood Pressure	70.00 (61.00, 80.00)	69.50 (60.00, 80.00)	70.50 (62.00, 79.00)	−0.41	0.679

2.2. Univariate Analysis of Factors Affecting Poor Peripheral Arterial Duct Function in ICU Patients

The results revealed significant differences in factors affecting peripheral arterial catheter function in ICU patients across multiple dimensions: platelet count, ICU length of stay, catheter retention duration, catheter maintenance frequency, total arterial blood draw volume, agitation levels, ultrasound application, procedure duration, catheter placement site, collateral blood flow assessment, total puncture attempts, puncture site bleeding, and arterial needle count ($P < 0.05$), as detailed in Table 2.

Table 2. Univariate analysis of factors affecting peripheral arterial catheter dysfunction in ICU patients.

Variable	Total (n = 240)	No PACF (n = 170)	With PACF (n = 70)	Z/χ^2	P
Platelet count	139.50 (95.75, 208.50)	129.50 (88.25, 201.75)	158.00 (110.00, 236.75)	−2.24	0.025
ICU length of stay	5.00 (4.00, 8.00)	5.00 (3.25, 7.00)	6.00 (5.00, 10.00)	−3.47	<0.001
Indwelling time (days)	3.00 (3.00, 5.00)	4.00 (3.00, 6.00)	2.00 (1.00, 3.00)	−8.07	<0.001
Catheter maintenance frequency (days/instance)	3.00 (2.00, 4.00)	3.00 (2.00, 4.00)	1.00 (1.00, 2.00)	−6.48	<0.001
Total number of arterial blood draws	9.00 (5.00, 14.00)	10.00 (6.00, 16.00)	6.00 (3.00, 9.00)	−4.96	<0.001
Restlessness				12.83	<0.001
No	184 (76.67)	141 (82.94)	43 (61.43)		
Yes	56 (23.33)	29 (17.06)	27 (38.57)		
Ultrasound				5.13	0.024
No	127 (52.92)	82 (48.24)	45 (64.29)		
Yes	113 (47.08)	88 (51.76)	25 (35.71)		
Operation time				6.13	0.047
<5 min	106 (44.17)	83 (48.82)	23 (32.86)		
>10 min	47 (19.58)	28 (16.47)	19 (27.14)		
5 - 10 min	87 (36.25)	59 (34.71)	28 (40.00)		
Catheter placement				10.76	0.013
Brachial artery	79 (32.92)	63 (37.06)	16 (22.86)		
Radial artery distance from the wrist joint < 4 cm	110 (45.83)	67 (39.41)	43 (61.43)		
Radial artery at a distance of 4 - 10 cm from the wrist joint	40 (16.67)	30 (17.65)	10 (14.29)		
Dorsalis pedis artery	11 (4.58)	10 (5.88)	1 (1.43)		
Collateral blood flow assessment				3.80	0.051
No	145 (60.42)	96 (56.47)	49 (70.00)		
Yes	95 (39.58)	74 (43.53)	21 (30.00)		

Continued

Total number of punctures				12.26	0.002
≥3 times	36 (15.00)	18 (10.59)	18 (25.71)		
1 time	143 (59.58)	112 (65.88)	31 (44.29)		
2 times	61 (25.42)	40 (23.53)	21 (30.00)		
Bleeding at the puncture site				8.35	0.004
No	172 (71.67)	131 (77.06)	41 (58.57)		
Yes	68 (28.33)	39 (22.94)	29 (41.43)		
Number of arterial punctures				–	0.006
1	192 (80.00)	145 (85.29)	47 (67.14)		
2	34 (14.17)	17 (10.00)	17 (24.29)		
3	13 (5.42)	7 (4.12)	6 (8.57)		
7	1 (0.42)	1 (0.59)	0 (0.00)		

2.3. Multivariate Logistic Regression Analysis of Peripheral Arterial Duct Dysfunction in ICU Patients

Using statistically significant variables from univariate analysis as independent variables, we performed logistic regression analysis. The results indicated that the following factors influenced poor peripheral arterial catheter function: normal skin at the puncture site, ultrasound application, catheter retention duration, and total arterial blood draw frequency (see Table 3). The multivariate logistic regression forest plot is shown in Figure 1.

Table 3. Multivariate logistic regression analysis of peripheral arterial catheter dysfunction in ICU patients.

Variable	β Value	S. E. Value	Z Value	P Value	OR	95% CI
The skin at the puncture site is normal	−1.84	0.66	−2.77	0.006	0.16	0.04 - 0.58
Ultrasound	−2.15	0.68	−3.16	0.002	0.12	0.03 - 0.44
Collateral blood flow assessment	1.05	0.67	1.57	0.117	2.84	0.77 - 10.50
Residual blood in the tubing	1.23	0.43	2.84	0.005	3.40	1.46 - 7.94
Platelet count ($\times 10^9$/L)	0.00	0.00	1.74	0.081	1.00	1.00 - 1.01
Indwelling time (days)	−1.49	0.27	−5.55	<0.001	0.23	0.13 - 0.38
Catheter maintenance frequency (days/time)	−0.50	0.23	−2.15	0.031	0.60	0.38 - 0.96
Total number of arterial blood draws	0.16	0.05	3.03	0.002	1.17	1.06 - 1.30

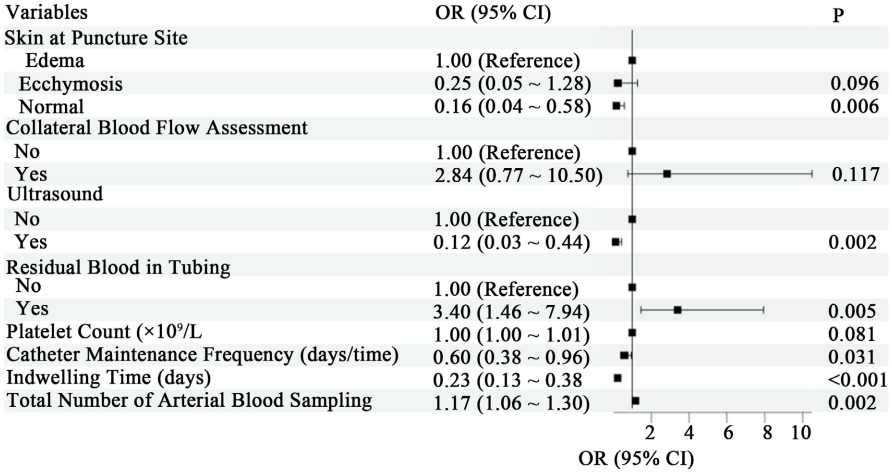

Figure 1. Forest plot of multivariate logistic regression analysis for peripheral arterial catheter dysfunction in ICU patients.

3. Discussion

The global incidence of PACF ranges from 4% to 25% [7], whereas in this study, the incidence of PACF among 240 ICU patients was 29.2%, which is slightly higher than the aforementioned studies. This discrepancy may be attributed to the median APACHE II score of 21 in the enrolled patients, indicating a higher severity of illness, as well as the presence of peripheral vascular diseases in some patients [12]. This also underscores the urgency of PACF prevention and control in critically ill patients and further validates the significant value of developing a PACF risk prediction model for clinical practice.

This study, employing a prospective cohort design, systematically analyzed the influencing factors of PACF in adult patients in the ICU of a tertiary hospital in Jingzhou for the first time. The results exhibit both consistency with existing domestic and international research and specific clinical characteristics. In terms of laboratory indicators, this study found that the median platelet count in the PACF group (158.00×10^9/L) was significantly higher than that in the non-PACF group (129.50×10^9/L, $P = 0.025$). Although platelet count did not enter the final model in the multivariate analysis ($P = 0.081$), this trend suggests that elevated platelet counts may increase the risk of blood coagulation. Platelet activation is a crucial early step in thrombosis formation. Clinically, for patients with significantly elevated platelet counts [13], it is essential to enhance the frequency of catheter flushing and monitor thrombotic risks, providing potential laboratory warning cues for the prevention of PACF. In terms of clinical outcomes, the median ICU length of stay in the PACF group (6.00 days) was significantly longer than that in the non-PACF group (5.00 days, $P < 0.001$). The catheter replacements and management of complications caused by PACF not only consume medical resources but may also delay clinical judgment due to monitoring interruptions, thereby prolonging patients' ICU stay. This underscores the direct significance of reducing the incidence of PACF in shortening hospitalization periods and improving pa-

tient prognosis [14].

Skin edema and bruising may compromise the integrity of the puncture site barrier, increasing the risk of bleeding and infection. Elli *et al.* [15] emphasized in their study on residual blood flow in radial artery catheters that the integrity of the puncture site skin is fundamental to maintaining catheter function. Abnormal skin conditions can elevate the probability of bleeding around the catheter and thrombosis; therefore, clinicians should prioritize puncturing areas with good skin conditions. The strong protective effect of ultrasound-guided puncture directly validates the recommendation by Imbriaco *et al.* based on the guidelines from the French Society of Anesthesia and Intensive Care (SFAR) that "patients with shock, obesity, and edema require ultrasound-assisted puncture". Furthermore, this study corroborates that even in ordinary ICU patients, ultrasound guidance can reduce the risk of PACF by 68%. This conclusion is highly consistent with the findings of Elli *et al.* [15], who assessed the radial artery catheter/artery ratio via ultrasound (recommended ≥ 45%) and found that ultrasound guidance could reduce vascular injury and decrease the rate of catheter occlusion. It is hypothesized that this protective effect is achieved by improving puncture accuracy and reducing the frequency of repeated punctures (in this study, the incidence of PACF in patients requiring ≥ 3 punctures was 25.71%, significantly higher than the 44.29% in those with a single successful attempt). Therefore, it is recommended to promote standardized ultrasound-guided puncture procedures in clinical practice.

With each additional day of catheter indwelling time, the risk of PACF significantly decreases. This finding appears to contradict the traditional perception that "longer indwelling time leads to higher risk". However, in this study, patients categorized as having "long indwelling time" were primarily those with standardized catheter maintenance (e.g., maintenance frequency ≥ 3 times/day) and relatively stable conditions, rather than those with "long-term indwelling but poor management". This discrepancy may be attributed to the standardized maintenance protocols implemented for patients with prolonged indwelling durations. This aligns with the conclusions of Watts *et al.* [16], who found that under the premise of standardized maintenance (such as daily flushing of the catheter ≥ 3 times and regular assessment of catheter patency), there was no significant positive correlation between the duration of radial artery catheter indwelling and the incidence of complications. This suggests that "reasonable indwelling under standardized maintenance" is more effective in reducing PACF risk than "blindly shortening indwelling time".

The study results directly emphasize the importance of regular flushing and monitoring the patency of catheters. Giani *et al.* [17] also pointed out in their research on the use of midline catheters for blood gas monitoring in critically ill patients that maintenance frequency (such as the number of flushes and line checks) is a core factor affecting catheter function. The findings of this study further address the gap in domestic research, which has largely focused on catheter infec-

tions and thrombosis while paying insufficient attention to the critical aspect of "maintenance frequency". The presence of blood residuals within the catheter is a risk factor for PACF, as blood residuals can easily lead to thrombus formation within the catheter. This is consistent with the conclusions of Ying *et al*. [18], whose literature review analyzed 57 cases of severe ischemia related to radial artery catheters and found that 82% of catheter blockages were due to thrombi within the lumen, with blood residuals being the primary cause of thrombus formation. Therefore, it is essential for clinical practice to strictly adhere to the operational protocols of "thoroughly flushing the catheter after blood sampling" and "timely addressing any residuals detected". The results indicate that frequent blood sampling may increase the likelihood of blood stasis within the catheter and endothelial irritation, suggesting a need for clinical optimization of blood sampling protocols. The research by Giani *et al*. [17] also supports this strategy, finding that midline catheters can accurately monitor blood gas parameters, achieving an 89.2% consistency with arterial catheters, indicating that midline catheters can partially replace arterial blood sampling, thereby reducing unnecessary arterial catheter use and lowering the risk of PACF.

4. Conclusion

In conclusion, this study systematically identified and clarified the key influencing factors of peripheral arterial catheter-related complications (PACF) in ICU patients, thereby laying a solid theoretical and data foundation for the subsequent construction of a high-precision and generalizable PACF risk prediction model. However, this study employed a convenience sampling method and was conducted in a single hospital, which may introduce certain sample bias. Additionally, this research did not include some variables, such as the experience of the operators or specific maintenance protocols, which may also affect the study outcomes. Future investigations could expand the sample size through multicenter studies and incorporate a more comprehensive range of variables, providing a basis for reducing PACF incidence and improving treatment outcomes and long-term prognosis for critically ill patients.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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