Research Square

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Forearm insertion site and arterial catheter performance in critically ill patients

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Abstract

Purpose

Arterial catheter (AC) function may deteriorate during indwelling even in the absence of overt failure. However, factors associated with sustained catheter performance remain incompletely understood. We investigated whether forearm insertion site influenced AC performance in critically ill patients.

Methods

This study included indwelling forearm ACs inserted under real-time ultrasound guidance in adult intensive care unit patients between May 2024 and June 2025. Forearm ACs were categorized as proximal, middle, or distal according to the insertion site. The primary outcome was optimal AC performance, defined as adequate monitoring without adjustment throughout the indwelling period. Associations with optimal AC performance were evaluated using logistic regression. AC failure was analyzed using cumulative incidence functions and Fine–Gray models. Multinomial propensity score weighting was conducted as a sensitivity analysis.

Results

Overall, 230 ACs were included: 66 proximal, 54 middle, and 110 distal. Proximal placement was associated with lower odds of optimal AC performance compared with middle placement, whereas distal placement was not significantly associated with optimal performance. In the Fine–Gray analysis, proximal placement was associated with a higher cumulative incidence of AC failure compared with middle placement; distal placement was not significantly associated with AC failure. Weighted sensitivity analyses were broadly consistent, although distal placement was associated with higher failure incidence only after weighting.

Conclusions

Middle forearm AC placement was associated with better performance and lower failure risk compared with proximal placement, with no clear difference relative to distal placement. Forearm insertion site may influence sustained AC function in critically ill patients.

1. Introduction

Circulatory shock is common among critically ill patients and remains associated with substantial mortality [1]. Because hemodynamic resuscitation and other bedside treatment decisions usually rely on arterial pressure targets, continuous blood pressure monitoring plays as a fundamental component of

intensive care unit (ICU) shock care [2]. In this regard, arterial catheters (ACs) are frequently placed to enable real-time blood pressure assessment and repeated arterial blood sampling [3, 4].

However, AC function is not always maintained throughout indwelling. As invasive devices, ACs may cause local complications or infection requiring replacement [5]. Reported failure rates range from 4% to 25% [6]. In addition to overt failure, functional deterioration, manifesting as poor blood return or unreliable waveform quality, is common but often underrecognized [7, 8]. Even when immediate replacement is not required, repeated assessment and troubleshooting to maintain adequate function may increase patient discomfort. Subsequent catheter-related care, such as dressing changes and wound management, further heightens the nursing burden in the ICU [9].

With the broader adoption of ultrasound guidance, clinicians have greater flexibility in selecting arterial access sites [10, 11]. Although more proximal sites have been reported to offer potential advantages compared to the wrist approach, most previous studies have focused on procedural outcomes, such as first-pass success, or immediate complications [8]. However, these outcomes do not necessarily translate into sustained catheter performance.

Evidence on factors associated with longitudinal AC performance remains limited. Therefore, in this study, we compared AC performance across different forearm insertion sites in ICU patients and examined factors associated with optimal AC performance and AC failure.

2. Patients and Methods

2.1. Study design and population

The study protocol was approved by the Institutional Review Board of Mackay Memorial Hospital on December 18, 2025 (IRB No. 25MMHIS505e), with a waiver of informed consent because of the retrospective design and use of deidentified data. This study was conducted and reported in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) reporting guideline [12].

We included all eligible forearm ACs inserted in adult patients admitted to the ICU of Mackay Memorial Hospital, Taipei, Taiwan, between May 1, 2024, and June 30, 2025. Eligible ACs were those inserted under real-time ultrasound guidance in patients aged 18 years or older. All cannulas were 20 gauge, 1.1 × 45 mm, and were inserted by attending critical care anesthesiologists using the catheter-over-needle technique under maximal barrier precautions. Ultrasound guidance was performed in B-mode using the LOGIQ™ e ultrasound system (GE HealthCare, Chicago, IL, USA) equipped with a 13–4 MHz linear transducer.

The exclusion criteria were as follows: 1) pregnancy; 2) inherited bleeding disorders, such as hemophilia or von Willebrand disease; 3) conditions associated with impaired vascular integrity or marked hemodynamic instability, including disseminated intravascular coagulation, extracorporeal membrane

oxygenation support, peripheral vascular disease, or hemorrhagic shock; 4) brachial or femoral arterial catheterization; 5) forearm deformity; and 6) incomplete AC performance documentation.

2.2. Data collection

Data were obtained from the electronic medical records and ICU research database. Baseline data, including age, sex, body mass index (BMI), comorbidities, and coagulation profiles, were obtained from the electronic medical records. AC-specific and ICU care-related data were retrieved from the ICU research database and included distance from the wrist crease, distance from the antecubital fossa, catheter-related complications, and shift-based AC performance assessments recorded by bedside nurses (day, 08:00–16:00; evening, 16:00–00:00; night, 00:00–08:00). AC performance assessments are routinely collected as part of a long-standing ICU quality assurance protocol and were not introduced specifically for this study. Patient status at the time of catheter insertion was also abstracted from the ICU research database, including Glasgow Coma Scale score, Richmond Agitation–Sedation Scale (RASS) score, respiratory status, and use of sedative or neuromuscular blocking agents.

Forearm insertion sites were categorized according to their measured distances from anatomical landmarks: proximal, within 5 cm distal to the antecubital fossa; distal, within 5 cm proximal to the wrist crease; and middle, between these two regions.

2.3. Outcome measures

2.3.1. Primary outcome

AC performance was assessed once per nursing shift and classified into one of the following four categories: (1) adequate monitoring without adjustment; (2) adequate monitoring only after adjustment; (3) unable to provide reliable monitoring but still usable for blood sampling; or (4) unable to provide either monitoring or blood sampling.

The primary outcome was optimal AC performance, defined as maintenance of category 1 performance throughout the entire indwelling course. In other words, only ACs that provided adequate monitoring without adjustment at every nursing shift were classified as having optimal performance.

2.3.2 Secondary outcome

The secondary outcome was AC failure. At catheter removal, each AC was classified as success or failure. Success was defined as catheter removal without catheter dysfunction or catheter-related complications, including removal at ICU discharge or when the AC was no longer indicated. Failure was defined as catheter removal because of loss of function or catheter-related complications. Loss of function was defined as inability to provide arterial pressure monitoring or blood withdrawal. Catheter-related complications included dislodgement, catheter-related bloodstream infection, and extravasation.

The secondary analyses compared AC failure rates across insertion sites and examined associated factors.

2.4. Statistical analysis

The unit of analysis was the individual catheter. Continuous variables were summarized as medians with interquartile ranges (IQRs) and compared using the Kruskal–Wallis test. When the overall test was significant, pairwise comparisons were performed using Dunn's test with Holm's correction. Categorical variables were summarized as counts with percentages and compared using the χ^2 test or Fisher exact test, as appropriate. When the overall comparison was significant for binary categorical variables, pairwise post hoc comparisons were performed with Holm's correction.

The primary outcome, optimal AC performance, was analyzed as a binary outcome. Univariable logistic regression was used to estimate odds ratios (ORs) and 95% confidence intervals (CIs). Variables with an overall p-value less than 0.10 in the univariable analysis were entered into the multivariable model. For the secondary outcome, AC failure, cumulative incidence functions were estimated using the number of nursing shifts as the time scale, with AC failure as the event of interest and AC success as the competing event. Group differences were assessed using Gray's test, followed by pairwise Gray's tests with Holm's correction. Fine–Gray subdistribution hazard models were used to estimate subdistribution hazard ratios (sHRs) and 95% CIs. Univariable Fine–Gray analyses were first performed for each covariate, and variables with an overall p-value less than 0.10 were entered into the multivariable model.

As a sensitivity analysis, multinomial propensity score weighting was performed to address baseline differences among the three insertion site groups. Propensity scores were estimated using generalized boosted models with the twang package in R. The models included prespecified baseline covariates: age, BMI, sex, operator experience, comorbidities, and coagulation profile [13]. Balance was assessed using standardized mean differences, with values greater than 0.10 indicating residual imbalance. Covariates not adjusted in the propensity score model were evaluated using weighted univariable analyses. Variables with an overall p-value less than 0.10 in these analyses, together with covariates that remained imbalanced after weighting, were entered into the weighted multivariable models along with the insertion site. Weighted logistic regression and weighted Fine–Gray models were used to estimate adjusted associations.

All tests were two-sided, and p-values less than 0.05 were considered to indicate statistical significance. Analyses were performed using R Studio, version 2024.12.0 (Posit PBC, Boston, MA, USA).

3. Results

3.1. Baseline characteristics and procedural details

During the 14-month study period, 230 eligible forearm ACs were inserted: 66 (28.7%) proximal, 54 (23.5%) middle, and 110 (47.8%) distal. Baseline characteristics are shown in **Table 1**. Age, BMI, sex, and coagulation profile were similar across the three groups. The proportion of patients with congestive

heart failure and chronic kidney disease differed significantly according to AC insertion site (p = 0.002 and p = 0.004, respectively).

Procedural details are summarized in **Table 2**. Operator experience differed significantly across groups (p < 0.001). Post hoc analyses showed a significant difference between the middle and distal groups (adjusted p < 0.001), whereas no significant differences were found between the middle and proximal or between the proximal and distal placement groups. Laterality, motor function, airway status, sedative use, and RASS scores were similar across groups.

3.2. Factors associated with optimal AC performance

In the univariable analysis, proximal placement was associated with lower odds of optimal AC performance compared with middle placement (OR, 0.39; 95% CI, 0.18–0.82; p = 0.014), whereas distal placement showed no significant association (OR, 0.70; 95% CI, 0.35–1.36; p = 0.296) **(Table 3)**. BMI and airway status met the prespecified threshold for entry into the multivariable model.

In the multivariable analysis, proximal placement remained associated with lower odds of optimal AC performance compared with middle placement (OR, 0.45; 95% CI, 0.21–0.94; p = 0.037). Distal placement was not significantly associated with the outcome (OR, 0.72; 95% CI, 0.35–1.42; p = 0.345). Higher BMI was also independently associated with lower odds of optimal AC performance (OR, 0.94; 95% CI, 0.88–0.99; p = 0.041), whereas airway status was not significant after adjustment.

3.3. AC removal and failure patterns

Reasons for catheter removal are summarized in **Table 4**. The overall median indwelling duration was 8 shifts (IQR, 5–14). Most ACs were removed after transfer from the ICU (161/230, 70.1%), while 13 ACs (5.7%) were removed without a clear medical indication. Among failure events, erroneous or unstable pressure readings were the most common reason for removal (35/230, 15.2%), followed by inability to withdraw blood (9/230, 3.9%), extravasation (7/230, 3%), catheter dislodgement (4/230, 1.7%), and catheter-related bloodstream infection (1/230, 0.4%). Erroneous or unstable pressure readings were the leading cause of AC failure in all three groups.

3.4. Factors associated with AC failure

The overall cumulative incidence of AC failure was 18.7% (95% CI, 13.7–23.7) at 15 shifts, 21.3% (95% CI, 16.1–26.6) at 30 shifts, 22.6% (95% CI, 17.2–28.0) at 45 shifts, and 23.5% (95% CI, 18.0–28.9) at 60 shifts. At 60 shifts, the cumulative incidence was 11.1% (95% CI, 2.6–19.6) in the middle, 30.3% (95% CI, 19.0–41.6) in the proximal, and 25.5% (95% CI, 17.3–33.7) in the distal placement group.

The cumulative incidence of AC failure differed according to insertion site (Gray's test, p = 0.034; **Fig. 1**). In the pairwise comparisons with Holm's correction, AC failure was more frequent in the proximal than in the middle placement group (adjusted p = 0.030). Differences between the middle and distal groups and between the proximal and distal groups were not significant (adjusted p = 0.064 and 0.609, respectively).

In the univariable Fine–Gray analysis, proximal placement was associated with a higher subdistribution hazard of AC failure compared with middle placement (sHR, 2.65; 95% CI, 1.14–6.13; p = 0.023) (Table 5). Distal placement showed an association with a similar direction, but did not reach statistical significance (sHR, 2.17; 95% CI, 0.95–4.94; p = 0.065). Airway status and RASS score met the prespecified threshold for entry into the multivariable model.

In the multivariable analysis, proximal placement remained associated with a higher cumulative incidence of AC failure compared with middle placement (sHR, 2.39; 95% CI, 1.04–5.50; p = 0.040). Distal placement was not significantly associated with AC failure (sHR, 2.13; 95% CI, 0.94–4.83; p = 0.069). Neither ventilator support nor RASS score was significantly associated with AC failure after adjustment.

3.5. Sensitivity analysis

After propensity score weighting, covariate balance improved across insertion site groups **(Online Resource 1 Table A)**. Most standardized mean differences were reduced to below 0.1, although residual imbalance remained for BMI, congestive heart failure, and chronic kidney disease.

For the primary outcome, the results of the weighted analysis were consistent with those of the main analysis **(Online Resource 1 Table B)**. In the weighted multivariable model, proximal placement remained associated with lower odds of optimal AC performance compared with middle placement (OR, 0.40; 95% CI, 0.17–0.93; p = 0.033), whereas distal placement was not significantly associated with the outcome (OR, 0.61; 95% CI, 0.28–1.32; p = 0.212). For AC failure **(Online Resource 1 Table C)**, the results of the weighted Fine–Gray analysis were broadly consistent in direction with those of the primary analysis. In the weighted multivariable model, proximal placement remained associated with a higher cumulative incidence of AC failure compared with middle placement (sHR, 2.84; 95% CI, 1.09–7.41; p = 0.033). Unlike in the primary analysis, distal placement was also significantly associated with a higher cumulative incidence of AC failure after weighting (sHR, 2.68; 95% CI, 1.11–6.46; p = 0.028).

4. Discussion

The main finding of this study was that middle forearm placement was associated with better AC performance compared with proximal placement, with both higher odds of optimal catheter performance and lower cumulative incidence of AC failure. These associations remained directionally consistent after propensity score weighting. Although no clear difference between middle and distal placement was observed in the primary analysis, distal placement was associated with a significantly higher cumulative incidence of AC failure in the weighted analysis. The cumulative incidence of AC failure in our cohort reached 23.5% at 60 shifts, which was close to the pooled noninfectious failure rate of 19.8% reported in a recent meta-analysis [14]. Most failures in our cohort were likewise noninfectious, suggesting that mechanical and functional deterioration were the predominant contributors to failure.

AC dysfunction is likely multifactorial and progressive rather than the result of a single discrete event. Poor waveform quality, partial obstruction, and progressive lumen compromise may coexist before

catheter failure becomes clinically apparent [14]. Therefore, AC performance should not be judged solely by occlusion or clinically evident failure [15]. In routine ICU practice, inappropriate damping appears to be common and may distort waveform transmission and pressure readings [16]. Prior studies have shown that underdamping or resonance may substantially overestimate systolic pressure and create clinically relevant discrepancies between displayed and actual blood pressure values [17]. Furthermore, when an AC no longer transduces reliably or allows blood withdrawal, bedside troubleshooting is often required, adding burden to routine monitoring and catheter care [18].

The more favorable outcomes with middle than with proximal forearm placement observed in this study may be explained by the better mechanical conditions for catheter placement and maintenance. Because the proximal radial artery is partially covered by the brachioradialis muscle belly, a more proximal target may be deeper and require a steeper insertion angle [19, 20]. These features could impair needle control, increase the distance to the vessel, and shorten the effective intraluminal catheter length, which may in turn reduce catheter stability and increase the risk of dislodgement or extravasation [8, 21, 22]. Middle forearm placement may also be theoretically preferable to distal placement because catheters placed closer to the wrist joint may be exposed to greater motion-related mechanical stress and less favorable securement conditions [10, 23]. However, we observed no clear difference in overall catheter performance between middle and distal placement in the main analysis, although distal placement was associated with a higher cumulative incidence of AC failure after weighting.

Although previous studies have suggested that the forearm may be a preferable site for AC insertion compared with the conventional wrist approach, the optimal forearm location remains uncertain [8]. Mid-forearm cannulation has been associated with a higher first-attempt success rate, shorter catheterization time, and fewer catheter-related infections [20, 24]. In contrast, other studies have found that distal forearm placement is associated with a higher success rate compared with mid-forearm placement [25]. However, direct comparison across studies is limited by the heterogeneity in the study design, insertion techniques, and definitions of forearm segments. Moreover, even when catheter dysfunction or failure was evaluated, these outcomes were generally treated as discrete events, providing limited insight into how catheter performance changed before removal [14, 23, 24]. By combining time-to-failure analysis with repeated assessment of AC performance, our study provides a more clinically informative characterization of catheter function throughout the indwelling period.

Despite the procedural risks of AC placement, invasive arterial pressure monitoring is more accurate than noninvasive cuff-based measurement and continues to be standard practice for hemodynamic monitoring in critically ill patients [26]. Several strategies have been proposed to improve AC performance, including heparinized saline flushing [27], optimization of catheter-to-vessel ratio [28], and appropriate dressing and securement practices [6, 18]. Our findings suggest that AC performance may also be influenced by a simpler and earlier step: insertion site selection at the time of placement. In our cohort, middle forearm placement was associated with both better catheter performance and a lower cumulative incidence of AC failure compared with proximal placement, suggesting that insertion site

choice may affect not only catheter survival but also the day-to-day reliability of invasive hemodynamic monitoring.

This study has certain limitations inherent to its single-center retrospective design. The limited sample size restricted the number of variables that could be included in the weighting model and may have left residual confounding. However, additional multivariable adjustment incorporating variables that were not included in the propensity score model yielded directionally consistent results. Second, AC insertions were performed by multiple anesthesiologists, and differences in site preference and procedural experience may have influenced the results [29, 30]. Although operator experience was included in the balancing model, individual clinician preferences are difficult to fully capture and may still have affected catheter performance. Third, catheter dwell time and failure timing were analyzed by nursing shift rather than by exact hours, which may have reduced the temporal precision of the time-to-event analyses.

5. Conclusion

In this study, middle forearm AC placement was associated with better catheter performance and a lower cumulative incidence of AC failure compared with proximal placement, whereas no clear difference was observed between middle and distal placement. These findings suggest that insertion site selection may be an important consideration for sustaining catheter function and monitoring reliability.

Abbreviations

AC, arterial catheter; BMI, body mass index; CI, confidence interval; ICU, intensive care unit; IQR, interquartile range; OR, odds ratio; RASS, Richmond Agitation–Sedation Scale; sHR, subdistribution hazard ratio.

Declarations

Human and animal rights

The authors affirm that the study was conducted in accordance with the principles of the Declaration of Helsinki and relevant institutional guidelines. The Institutional Review Board of Mackay Memorial Hospital approved the study on December 18, 2025 (IRB No. 25MMHIS505e). No animal experiments were performed.

Informed consent and patient details

The Institutional Review Board of Mackay Memorial Hospital waived the requirement for informed consent because of the retrospective design and use of deidentified data. The authors declare that this report contains no personal information that could lead to the identification of any patient. All personal details were removed to ensure anonymity.

Declaration of conflicting interest

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

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Data availability

The data underlying this article cannot be shared publicly because of institutional privacy regulations and the retrospective use of clinical data. Deidentified data may be available from the corresponding author upon reasonable request and with institutional approval.

Author Contributions

Ting-Chia Young: Conceptualization, Methodology, Formal analysis, Visualization, Writing - Original Draft; **Kuang-Hua Cheng:** Methodology, Validation, Writing - Review & Editing; **Hui-Fang Hsieh:** Investigation, Data Curation; **Ying-Hung Tang:** Methodology, Validation, Writing - Review & Editing; **Tzu-Chun Wang:** Methodology, Validation, Writing - Review & Editing; **Kuan-Pen Yu:** Conceptualization, Investigation, Formal analysis, Validation, Project administration, Supervision, Writing - Review & Editing.

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Tables

Tables 1 to 5 are available in the Supplementary Files section.

Figures

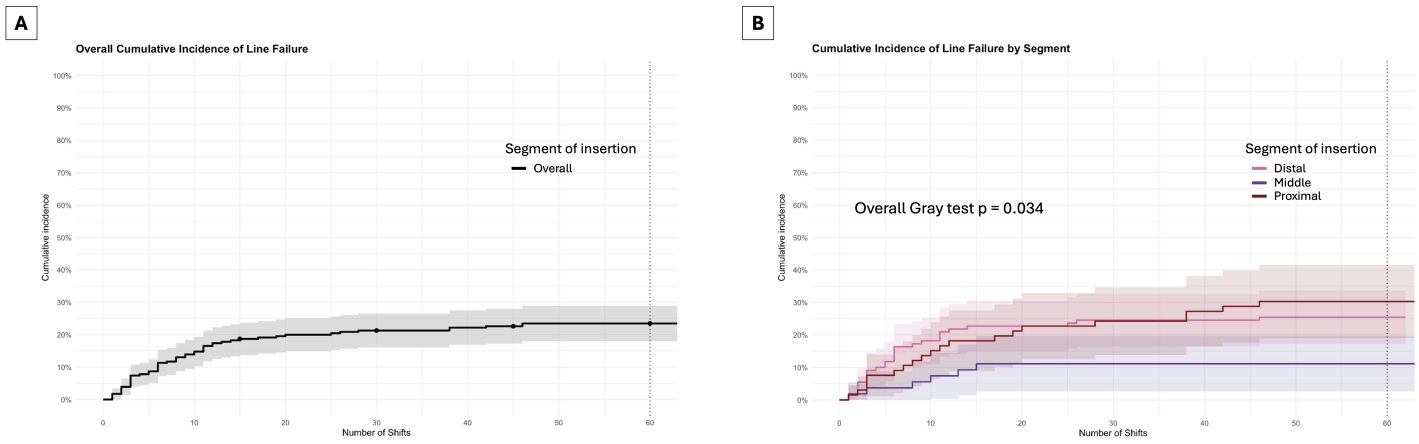


Figure 1

Cumulative incidence of arterial catheter failure with catheter success treated as the competing event. (A) Overall cumulative incidence; (B) Cumulative incidence according to forearm insertion site.

Supplementary Files

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- Tables.docx