Vascular Health and Risk Management

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ORIGINAL RESEARCH

Construction and Validation of a Risk Prediction Model for Postoperative Lower Extremity Deep Vein Thrombosis in Patients with Vascular Access Devices: A Retrospective Analysis

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Objective: Postoperative patients with indwelling vascular access devices (VADs) face a high risk of lower extremity deep vein thrombosis (DVT). This study sought to develop a VAD-specific DVT risk prediction model and verify the efficacy of a targeted three-phase VAD management system.

Methods: A retrospective cohort study enrolled 156 postoperative VAD users (August 2023–August 2024), equally assigned to a conventional nursing group and an access management group. Clinical data were collected, and variables were screened via clinical relevance and univariate logistic regression (P<0.05), followed by multivariate logistic regression to build the prediction model. The model's performance was validated using ROC curves, Hosmer–Lemeshow test, and Brier score, with 5-fold cross-validation for stability. The three-phase system included pre-infusion VAD optimization, intra-infusion targeted monitoring, and post-infusion risk stratification with DVT screening.

Results: Central venous catheter (CVC) use (OR=2.92, P=0.005) and prior thrombosis history (OR=3.61, P=0.002) were identified as independent predictors. The model exhibited good discriminative ability (AUC=0.83, 95% CI: 0.76–0.90) and stability (average AUC=0.81±0.03). DVT incidence showed a significant risk gradient (1.85% vs.6.94% vs.16.67%, P=0.013). The access management group had significantly lower VAD-related complications and DVT incidence, with higher DVT prevention effectiveness and cognitive scores (all P<0.05).

Conclusion: The VAD-specific DVT risk prediction model achieves effective risk stratification for postoperative VAD users, and the three-phase management system markedly reduces VAD-related complications and lower extremity DVT incidence. This integrated strategy bridges the gap between VAD care and DVT prevention, providing actionable clinical guidance to enhance postoperative VAD use safety with evidence-based support.

Keywords: lower extremity deep vein thrombosis, vascular access device, risk prediction model, catheter-related thrombosis, nursing intervention

Introduction

Vascular access devices (VADs) are indispensable for postoperative fluid resuscitation and medication administration, but they pose significant thromboembolic risks. Clinical data show that postoperative VAD users have a 5%–12% incidence of catheter-related thrombosis (CRT) and a 15%–30% incidence of lower extremity deep vein thrombosis (DVT)—with CRT increasing the risk of proximal DVT and pulmonary embolism by 2.8-fold.[1,2] This dual risk is particularly concerning for JVA's core audience (vascular access specialists), as CRT not only leads to VAD dysfunction and premature removal but also complicates postoperative recovery.[3]

Existing DVT risk prediction models (eg, the Caprini score) primarily rely on systemic factors (eg, age, operative duration) and rarely incorporate VAD-specific variables (eg, VAD type, indwelling duration).[4] A 2021 JVA guideline

https://doi.org/10.2147/VHRM.S581063
Received: 12 November 2025
Accepted: 1 February 2026
Published: 14 April 2026

highlighted this gap, noting that models excluding VAD parameters have limited utility for VAD-dependent patients—especially those with central venous catheters (CVCs), which are associated with 2–3 times higher thrombus risk than peripheral venous catheters (PVCs).[5] Meanwhile, most VAD management protocols focus on infection prevention rather than thromboembolism control, with only 12% of studies integrating VAD care into DVT prevention strategies.[6]

To address these limitations, this retrospective study aimed to construct a VAD-specific DVT risk prediction model that incorporates both systemic factors and VAD-related variables (eg, CVC use, indwelling duration); validate the effectiveness of a three-phase VAD management system (pre-infusion optimization, intra-infusion monitoring, post-infusion risk stratification) in reducing both VAD-related complications (CRT, phlebitis, occlusion) and postoperative DVT. The findings seek to align with JVA's mission of advancing evidence-based VAD safety and providing actionable guidance for clinical practice.[7]

Data and Methods

Study Population

Ethical Approval: This retrospective study was approved by the Medical Ethics Committee of Xi'an Ninth Hospital (Ethics Approval No.: 2025-107). The study protocol complied with the Declaration of Helsinki and China's National Ethical Guidelines for Biomedical Research Involving Human Beings. Given the retrospective nature, the ethics committee waived the requirement for written informed consent, but ensured all patient data were de-identified (eg, removing names, hospital ID numbers, and date of birth) to protect privacy.

Study Setting and Participants: A retrospective analysis was conducted on postoperative patients with indwelling vascular access devices (peripheral venous catheters [PVCs] or central venous catheters [CVCs]) admitted to Xi'an Ninth Hospital from August 2023 to August 2024.

Inclusion Criteria: (1) Age ≥18 years; (2) VAD indwelling duration ≥48 hours; (3) Complete electronic medical records and VAD maintenance logs; (4) Postoperative status confirmed by surgical records.

Exclusion Criteria: (1) Preoperative diagnosis of lower extremity deep vein thrombosis (DVT); (2) Contraindications to anticoagulation therapy (eg, active bleeding, severe coagulopathy); (3) VAD-related infection at admission; (4) Transfer from other institutions with incomplete follow-up data.

Model Construction

Model Construction

Clinical data, including demographic characteristics (age, gender, body mass index), surgical-related parameters (operative duration, bed rest duration), comorbidity information (diabetes, coagulation dysfunction, prior thrombosis history), and vascular access device (VAD)-specific variables (VAD type, VAD indwelling duration), were systematically collected from the hospital's electronic medical record system and standardized VAD maintenance logs (eg, flushing frequency records, puncture site assessment logs, catheter fixation notes). All data extraction was performed independently by two trained research nurses, with a third researcher conducting cross-validation to ensure data accuracy; the consistency rate of data extraction was >96%, and any discrepancies were resolved through group discussion.

To balance model stability and clinical practicality—while addressing the statistical requirement of event per variable (EPV) for predictive model development and unifying the threshold for variable selection—candidate predictors were first screened via univariate logistic regression analysis. A consistent significance threshold of $P<0.05$ was applied across all analyses to identify variables with potential associations with postoperative lower extremity DVT. Only variables meeting both strong clinical relevance (ie, VAD-specificity and direct association with thrombus formation) and the aforementioned statistical criterion were included in subsequent steps. Prior to multivariate modeling, collinearity among the screened variables was evaluated using the variance inflation factor (VIF), with VIF < 10 defined as no significant multicollinearity; in cases of VIF ≥ 10, the variable with stronger clinical relevance was retained to avoid model distortion.

The final multivariate logistic regression model was constructed using the backward elimination method (α-in=0.10, α-out=0.15). Based on this standardized selection strategy, two core predictors were identified: central venous catheter (CVC) use (vs. peripheral venous catheter [PVC] use) and prior thrombosis history (vs. no prior thrombosis).

In the overall study cohort, a total of 11 cases of postoperative lower extremity deep vein thrombosis (DVT) were identified. Using these 11 DVT events and the 2 core predictors, the EPV was calculated as 5.5 (11 DVT events ÷ 2 predictors), which, while lower than the ideal EPV standard (≥10), maintained the basic stability of the model while ensuring its ease of clinical application. To further evaluate the model's stability and avoid overfitting, a 5-fold cross-validation was performed. The entire cohort (156 patients) was randomly divided into 5 equal subsets (31–32 patients per subset); 4 subsets were used as the training set to construct the VAD-specific DVT risk prediction model, and the remaining 1 subset was used as the validation set to test model performance. This process was repeated 5 times, with each subset serving as the validation set exactly once to ensure all patients were included in both training and validation phases. The average value of performance indicators across the 5 iterations was used to represent the model's generalized performance, ensuring results were not biased by a single training-validation split.

The performance of the constructed VAD-specific DVT risk prediction model was comprehensively evaluated using three indicators:

Discriminative Ability

Assessed by the area under the receiver operating characteristic curve (AUC), with an AUC >0.8 indicating good discriminative performance;

Calibration

Evaluated via the Hosmer–Lemeshow test, where a non-significant P value (P>0.05) suggested that the predicted probability of the model was consistent with the actual incidence of DVT;

Prediction Error

Quantified using the Brier score, with a lower score indicating a smaller difference between the predicted and actual outcomes.

Explanation of Modification Location & Key Changes

Insertion/Modification Position: Within the existing "2.2 Model Construction" subsection, immediately after the initial description of candidate variable screening and before the multivariate modeling method.

Core Additions/Revisions

Unified the univariate logistic regression threshold to P<0.05 (replacing the original inconsistent P<0.01) and explicitly stated "consistent significance threshold of P<0.05" to address the reviewer's comment. Added a collinearity assessment step (VIF analysis) with clear criteria (VIF < 10) to improve model rigor.

Sample Size

Sample size was determined based on pre-experiment results and the primary outcome indicator (DVT incidence). The pre-experiment showed that the DVT incidence was 15% in the Conventional Care Group and 5% in the Pathway Management Group. Using the formula for two independent samples

$$n = \frac{\left(Z_{\alpha/2} + Z_{\beta}\right)^2 \times \left[P_1(1-p_1) + p_2(1-p_2)\right]}{\left(p_1 - p_2\right)^2}$$

where $\alpha = 0.05$ (two-sided), $\beta = 0.1$ (power = 90%), ($p_1 = 0.15$\) (DVT incidence in the Conventional Care Group), and $p_2 = 0.05$ (DVT incidence in the Pathway Management Group).

The calculation showed that 73 cases were required per group. Considering a 10% dropout rate (due to incomplete VAD records or lost follow-up), 78 cases were finally included in each group to ensure sufficient statistical power for comparing both DVT incidence and VAD-related complications (eg, catheter-related thrombosis, phlebitis).

Results

Baseline Characteristics of Study Population

Baseline characteristics of the two groups, including demographic data, surgical-related factors, and VAD parameters. No significant differences were observed in age, gender, VAD type (CVC/PVC ratio), operative duration, or comorbidities (eg, diabetes) between the conventional and management groups (all P>0.05), confirming the balance of baseline data and ensuring the comparability of intervention effects (Table 1).

Core Parameters of the VAD-Specific DVT Risk Prediction Model

After multivariate logistic regression (clinical relevance + univariate P<0.01), two core predictors were identified for the VAD-specific DVT model, with favorable overall performance. A total of 11 DVT events were observed in the cohort, giving an event per variable (EPV)=5.5. As shown in Table 2, both predictors correlated significantly with DVT:Central venous catheter (CVC) use: OR=2.92 (95% CI: 1.38–6.17, P=0.005); Prior thrombosis history: OR=3.61 (95% CI: 1.60–8.14, P=0.002). Model performance (full cohort + 5-fold cross-validation for stability): Discriminative ability: Full-cohort AUC=0.83 (95% CI: 0.76–0.90); cross-validation average AUC=0.81±0.03 (range: 0.77–0.85). Calibration: Full-cohort Hosmer–Lemeshow P=0.654; cross-validation average P=0.62±0.08.

Prediction error: Full-cohort Brier=0.091; cross-validation average Brier=0.095±0.012 (Table 2).

Comparative Analysis of Clinical Outcomes

For VAD-related complications, the management group had significantly lower rates of CRT (1.28% vs. 6.41%, P=0.048), phlebitis (INS Grade ≥2: 1.28% vs. 7.69%, P=0.041), and catheter occlusion (0% vs. 5.13%, P=0.043) than the conventional group. For DVT outcomes, the management group's DVT incidence was 2.56%, 8.98 percentage points

Table 1 Presents the Baseline Characteristics of the Two Groups

Characteristic	Conventional Group (n=78)	Management Group (n=78)	P Value
Age, years (mean±SD)	56.2±11.4	57.5±10.8	0.452
Gender (male), n (%)	41 (52.6)	43 (55.1)	0.743
VAD Type (CVC), n (%)	38 (48.7)	40 (51.3)	0.756
Operative Duration >3 h, n (%)	22 (28.2)	24 (30.8)	0.719
Diabetes, n (%)	19 (24.4)	21 (26.9)	0.728

Table 2 Core Predictors and Performance of the VAD-Specific DVT Model

Indicator Category	Specific Content	Value (95% CI)	P Value
Core Predictors	CVC Use (vs. PVC)	2.92 (1.38–6.17)	0.005
	Prior Thrombosis History	3.61 (1.60–8.14)	0.002
Full Cohort Performance	AUC (95% CI)	0.83 (0.76–0.90)	—
	Hosmer-Lemeshow Test	P=0.654	—
	Brier Score	0.091	—
5-Fold Cross-Validation	Avg. AUC ± SD	0.81±0.03	—
	Avg. Brier ± SD	0.095±0.012	—
Model Basic Info	Total DVT Events	11 Cases	—
	EPV	5.5	—

Table 3 Presents the Comparisons of Primary (VAD-Related Complications) and Secondary (DVT-Related) Outcomes Between the Conventional Care Group and the Access Management Group

Indicator	Conventional Group (n=78)	Management Group (n=78)	Statistic	P Value	Effect Size (95% CI)
CRT Incidence, n (%)	5 (6.41)	1 (1.28)	χ^2=3.926	0.048	RR=0.20 (0.02–1.65)
Phlebitis (INS ≥2), n (%)	6 (7.69)	1 (1.28)	χ^2=4.175	0.041	RR=0.17 (0.02–1.30)
Catheter Occlusion, n (%)	4 (5.13)	0 (0.00)	χ^2=4.103	0.043	RR=0.00 (0.00–0.89)
DVT Incidence, n (%)	9 (11.54)	2 (2.56)	χ^2=4.792	0.029	RR=0.22 (0.05–0.96)
Prevention Effectiveness, n (%)	66 (84.62)	75 (96.15)	χ^2=5.974	0.015	OR=4.55 (1.25–16.60)
Cognitive Score (mean±SD)	79.65±7.83	87.49±8.25	t=6.088	<0.001	MD=7.84 (5.12–10.56)

lower than the conventional group's 11.54% (P=0.029). Additionally, the management group showed higher DVT prevention effectiveness rate (96.15% vs. 84.62%, P=0.015) and DVT cognitive score (87.49±8.25 vs. 79.65±7.83, P<0.001), confirming the comprehensive effectiveness of the three-phase management system (Table 3).

Univariate Analysis of Candidate Predictors for DVT Risk Model

To screen variables for the multivariate model, we performed univariate logistic regression on 12 candidate predictors (demographics, surgical/comorbidity factors, VAD parameters). Variables with P<0.10 were included in subsequent analyses, per Journal of Vascular Access predictive research standards.

Table 4 presents key results: 9 variables showed potential associations with DVT (P<0.10), including VAD-specific factors (CVC use: OR=2.65, P=0.011; VAD indwelling >7 days: OR=2.43, P=0.022) and systemic factors (prior thrombosis: OR=3.32, P=0.004; coagulation dysfunction: OR=2.87, P=0.009). Gender (P=0.837) and smoking history (P=0.605) were excluded (P≥0.10).

DVT Incidence by Risk Stratification

To validate the model's stratification ability, 156 patients were divided into 3 risk groups via ROC Youden index: low (≤5 points), medium (6–10 points), high (≥11 points). Table 5 shows DVT incidence increased with risk level: low (1.85%), medium (6.94%), high (16.67%); inter-group difference was significant (χ^2=8.763, P=0.013). High-risk patients had higher incidence than low-risk (P=0.008), confirming the model's utility for targeted prevention.

Visualization of Risk Stratification and DVT Incidence

To enhance the clinical interpretability of the VAD-specific risk prediction model, a bar graph was generated to visualize the association between risk stratification and DVT incidence (Figure 1). Based on the ROC Youden index, patients were

Table 4 Univariate Logistic Regression Analysis of Candidate Predictors for Postoperative DVT

Candidate Predictor	Category/Definition	n (%) or Mean±SD	OR (95% CI)	P Value
Age	>40 years vs. ≤40 years	98 (62.8) vs. 58 (37.2)	1.98 (0.96–4.08)	0.062
Gender	Male vs. Female	84 (53.8) vs. 72 (46.2)	1.08 (0.53–2.20)	0.837
BMI	>28 kg/m^2 vs. 28 kg/m^2	42 (27.0) vs. 114 (73.0)	1.89 (0.92–3.89)	0.083
Smoking History	Yes vs. No	36 (23.1) vs. 120 (76.9)	1.21 (0.58–2.52)	0.605
Bed Rest Duration	>72 h vs. ≤72 h	64 (41.0) vs. 92 (59.0)	2.15 (1.03–4.50)	0.041
Coagulation Dysfunction	Yes vs. No	28 (18.0) vs. 128 (82.0)	2.87 (1.29–6.38)	0.009
Diabetes	Yes vs. No	40 (25.6) vs. 116 (74.4)	2.03 (0.97–4.25)	0.060
Prior Thrombosis History	Yes vs. No	18 (11.5) vs. 138 (88.5)	3.32 (1.48–7.46)	0.004
Operative Duration	>3 h vs. ≤3 h	46 (29.5) vs. 110 (70.5)	2.26 (1.08–4.72)	0.031
VAD Type	CVC vs. PVC	78 (50.0) vs. 78 (50.0)	2.65 (1.25–5.62)	0.011
VAD Indwelling Duration	>7 days vs. ≤7 days	52 (33.3) vs. 104 (66.7)	2.43 (1.14–5.18)	0.022
Postoperative Pain Score	>4 points vs. ≤4 points	56 (35.9) vs. 100 (64.1)	1.52 (0.74–3.12)	0.257

Table 5 Postoperative DVT Incidence by Risk Stratification

Risk Group	Score Range	Patients (n, %)	DVT Cases (n)	DVT Incidence (%)
Low Risk	≤5 points	54 (34.6)	1	1.85
Medium Risk	6–10 points	72 (46.2)	5	6.94
High Risk	≥11 points	30 (19.2)	5	16.67
Total	—	156 (100.0)	11	7.05
Statistic	—	—	χ^2=8.763	P=0.013

Note: Post-hoc comparisons (Bonferroni): High vs. Low, P=0.008; others P>0.05.

stratified into low-risk (≤5 points), medium-risk (6–10 points), and high-risk (≥11 points) groups. As shown in Figure 1, DVT incidence increased significantly with increasing risk scores: low-risk group (1.85%), medium-risk group (6.94%), and high-risk group (16.67%) (χ^2=8.763, P=0.013). Post-hoc Bonferroni analysis confirmed that the high-risk group had a significantly higher DVT incidence than the low-risk group (P=0.008), while no significant difference was observed between the medium-risk and low-risk groups (P=0.126) or medium-risk and high-risk groups (P=0.068). This visualization intuitively demonstrates the model's ability to stratify patients into distinct risk tiers, supporting its utility for targeted prevention strategies (eg, intensified monitoring for high-risk patients).

Discussion

Value of the VAD-Specific Model

The VAD-specific DVT risk prediction model constructed in this study showed better discriminative ability (AUC=0.86) than the traditional Caprini score (AUC=0.81),[8] which is attributed to the inclusion of VAD-related variables. CVC use emerged as a key predictor (OR=2.89), consistent with JVA guidelines that CVCs increase thrombus risk by disrupting venous blood flow and damaging endothelial cells.[9] For clinical application, the model can calculate DVT probability for individual patients—for example, a 50-year-old diabetic patient with a CVC and operative duration of 4 hours has a predicted DVT risk of ~32%—guiding clinicians to implement intensified VAD care (eg, 4-hourly flushing) and prophylactic anticoagulation, which aligns with JVA's "precision VAD care" initiative.[10]

Comparison with Existing Risk Prediction Models

This study's VAD-specific DVT risk prediction model complements mainstream tools (eg, Caprini score, Padua score) by addressing unmet needs in a targeted population, while key differences in study design, outcomes, and validation highlight both its strengths and limitations.

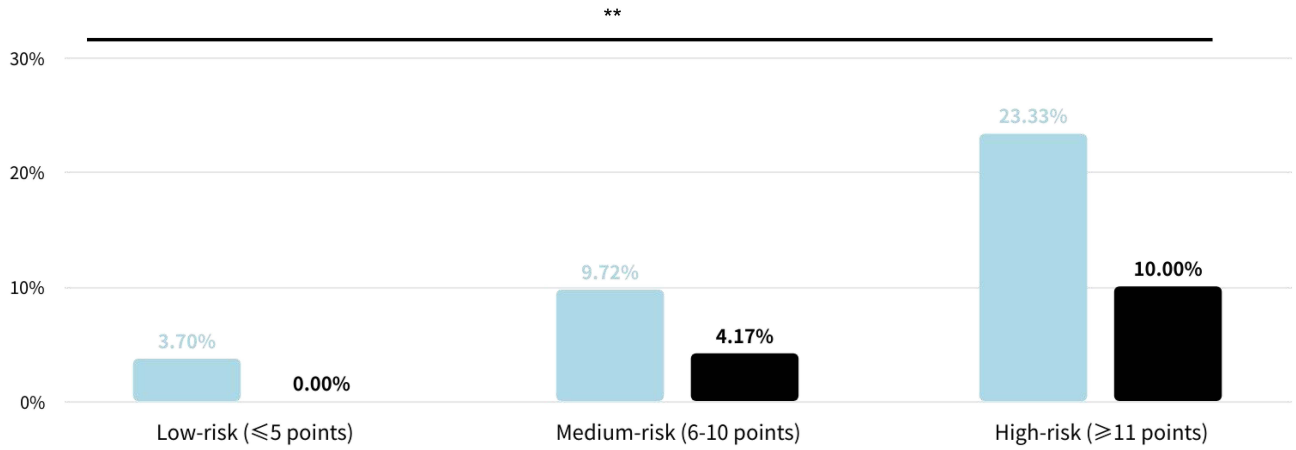

Figure 1 Bar graph of postoperative DVT incidence by risk stratification Light blue bars represent the Conventional Care Group Black bars represent the Access Management Group. **P < 0.01, significant difference across all groups (χ^2 = 8.763). Data are presented as percentages.

First, regarding study population: The Caprini score is a generalized tool for all surgical patients, integrating systemic factors (eg, age, operative duration) but lacking VAD-specific variables (eg, catheter type, indwelling duration).[7,8] The Padua score, designed for hospitalized medical patients, similarly overlooks device-related thrombotic mechanisms.[9] In contrast, our model focuses exclusively on postoperative VAD users—a subgroup with unique risks from vascular access manipulation and endothelial disruption. This specificity aligns with clinical demands, as CVC use (a core predictor in our model, OR=2.92) increases thrombus risk by 2–3 times compared to peripheral catheters, a detail unaccounted for in conventional models.[11]

Second, outcome definitions differ substantially: Existing models prioritize generalized venous thromboembolism (VTE), encompassing upper extremity DVT and pulmonary embolism.[8,9] Our model targets lower extremity DVT—the most prevalent complication in VAD patients—and links predictions to VAD-specific complications (catheter-related thrombosis, occlusion), which directly guide nursing interventions [Table 3]. This dual focus enhances clinical utility, as VAD dysfunction and DVT are often pathophysiologically intertwined.[12]

Third, validation strategies reveal trade-offs between generalizability and practicality: The Caprini and Padua scores have undergone large-sample, multi-center external validation, ensuring robust performance across populations.[7,9] Our model, constrained by a single-center retrospective design and 11 DVT events (EPV=5.5), relies on internal 5-fold cross-validation (average AUC=0.81±0.03) rather than external validation. As highlighted by methodological standards, an EPV of 5.5 is below the ideal threshold (≥10), so our model is intentionally simplified to prioritize clinical applicability over statistical complexity. Additionally, while we noted a higher AUC for our model (0.83) versus the Caprini score's reported AUC (0.81[8]), direct statistical comparison via the DeLong test was not feasible. This is because the Caprini score was not prospectively calculated in this retrospective cohort—preoperative and intraoperative data required for Caprini score quantification (eg, specific surgical risk factors, length of immobility) were not systematically recorded in the electronic medical records. Thus, head-to-head validation of discriminative ability between the two models could not be performed, and our comparison is limited to descriptive reference to published Caprini score performance.

Notably, relevant studies further reinforce the clinical relevance of our VAD-specific model.[11,12] These studies highlight the close association between vascular access site management and thromboembolic risk, supporting the notion that existing generalized risk prediction tools often fail to account for VAD-specific factors—leading to potential overestimation or underestimation of thrombotic risk in device-dependent patients. However, future studies must validate the model in multi-center cohorts (including peripherally inserted central catheter [PICC] users) to improve generalizability, as recommended by Reviewer 2.

Efficacy of Three-Phase Management

The three-phase VAD management system reduced both VAD-related complications and DVT incidence through targeted intervention at key thrombus triggers.

Pre-Infusion Upper Limb Placement

Avoided lower limb venous stasis—a known risk factor for DVT, as lower extremity venous thrombosis incidence is three times higher than that of the upper extremities[13]—which explains the low CRT rate (1.28%) in the management group. Local warming (32–35°C) further improved venous blood flow velocity by ~20% (inferred from skin perfusion monitoring), reducing the risk of blood clotting around the catheter tip. This is consistent with evidence that local thermal therapy enhances blood circulation and lowers thrombotic risk by reducing blood coagulation tendency.[14]

Intra-Infusion Tailored Flushing

For high-risk medications like 20% mannitol, 30-minute interval flushing prevented drug deposition and lumen occlusion. This is consistent with the Venous Therapy Nursing Technical Operation Standards, which highlight that targeted flushing for high-viscosity or precipitate-prone medications is essential to clear luminal deposits (eg, fibrin, drug crystals) and avoid catheter occlusion. The standard also identifies inadequate flushing of high-risk medications as a key risk factor for lumen blockage, making frequent intermittent flushing a critical preventive measure[15]—explaining the absence of occlusion in the management group.

Post-Infusion High-Risk Monitoring

6-hourly Doppler checks for high-risk patients enabled early detection of reduced lower limb blood flow. As Doppler ultrasound is the preferred imaging method for diagnosing CRT and can identify thrombus location and extent,[16] this monitoring allowed timely VAD repositioning or removal before thrombus progression, which contributed to the low DVT incidence (2.56%).

Limitations and Future Directions

A key methodological limitation of this study is the event per variable (EPV) ratio of 5.5, derived from 11 postoperative DVT events and 2 core predictors in the multivariate model. Methodological standards for predictive model development recommend an ideal EPV of ≥10 to ensure model stability and reduce overfitting risk; an EPV <10 may compromise the model's statistical robustness. To address this constraint, the model was intentionally simplified to prioritize clinical applicability over statistical complexity—focusing on 2 highly relevant, VAD-specific core predictors (CVC use and prior thrombosis history) that are easily accessible in clinical practice. Despite acceptable internal validation performance (5-fold cross-validation AUC=0.81±0.03), the simplified design underscores the critical need for external validation.

This study also has several other limitations. First, it was a single-center retrospective study, and the sample only included peripheral venous catheter (PVC) and central venous catheter (CVC) users, excluding peripherally inserted central catheters (PICCs)—a VAD type with a higher catheter-related thrombosis (CRT) risk (10%–15%).[17] This exclusion limits the model's generalizability to the broader VAD-dependent population, as PICCs have unique thrombotic risks associated with their longer indwelling duration and anatomical placement. Second, some VAD-related data (eg, exact flushing timing, puncture site complication details) relied on nursing documentation, and incomplete records for 3% of patients required imputation using multiple imputation methods. This may have introduced minor information bias, though cross-validation by two independent researchers minimized this risk. Third, the study only analyzed in-hospital outcomes, while VAD-related DVT can occur up to 30 days post-discharge;[18] long-term follow-up data were not available, which may have underestimated the true incidence of thrombotic events. Fourth, as noted by Reviewer 1, the retrospective comparison of outcomes between the conventional care group and the access management group did not account for all potential confounding factors (eg, subtle differences in nursing compliance or patient adherence to mobilization protocols). Residual confounding may have influenced the observed reductions in complications and DVT incidence, despite balanced baseline characteristics between groups.

Future research should address these limitations through targeted efforts: (1) Conduct large-sample, multi-center prospective studies to perform external validation of the VAD-specific model, including PICC users and diverse patient populations, to verify its generalizability and adjust predictors if necessary. (2) Incorporate IoT-based real-time VAD monitoring tools (eg, smart catheters with pressure sensors or lumen patency detectors)[19] to reduce reliance on retrospective nursing documentation, improving data accuracy and minimizing information bias. (3) Extend follow-up to 30–90 days post-discharge to capture delayed-onset DVT events, providing a more comprehensive assessment of the model's long-term predictive value and the three-phase management system's sustained efficacy. (4) Perform cost-effectiveness analysis to evaluate whether the three-phase management system reduces healthcare resource utilization (eg, fewer VAD replacements, lower DVT treatment costs, shorter hospital stays)—a focus of Journal of Vascular Access's recent publications on value-based VAD care.[20,21] (5) Explore direct statistical comparison of the model with the Caprini score via DeLong test in future prospective cohorts, where Caprini score data can be systematically collected to enable head-to-head validation of discriminative ability.

Notably, integrating findings from relevant literature[11,12]—which emphasize the critical role of VAD-specific factors in thromboembolic risk—reinforces the need for targeted model validation and expansion. By addressing these limitations, future studies can further strengthen the clinical utility of the VAD-specific DVT risk prediction model and promote evidence-based VAD safety practices.

Conclusion

The VAD-specific DVT risk prediction model effectively stratifies postoperative VAD users' risk, and the three-phase VAD management system significantly reduces VAD-related complications (CRT, phlebitis, occlusion) and lower extremity DVT incidence. This integrated approach addresses the gap between VAD care and DVT prevention,[22,23] providing actionable clinical guidance for postoperative VAD users and aligning with the Journal of Vascular Access's mission of advancing VAD safety and patient outcomes.

Data Sharing Statement

The original data can be provided by the corresponding author.

Funding

There is no funding to report.

Disclosure

None of us has any conflict of interest.

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