Nursing-Related Risk Characteristics and Identification of High-Risk Patients With In-Hospital Lower-Extremity Deep Vein Thrombosis After Lower-Limb Fracture Surgery: A Single-Center Retrospective Study

Ann. Ital. Chir., 2026 97, 11: 2035–2049
https://doi.org/10.62713/aic.4967

Meilan Ding[1], Hongfa Zhong[1], Li Huang[1]

[1]Department of Trauma Emergency Center, Ganzhou Hospital-Nanfang Hospital, Southern Medical University, 341000 Ganzhou, Jiangxi, China

AIM: Lower-limb fractures already contribute ≥5 Caprini points for venous thromboembolism (VTE) risk, limiting the ability of the conventional >5 cutoff to discriminate individual risk within this population. We evaluated whether an admission Caprini score ≥9, preoperative immobilization ≥72 h and severe postoperative day 1 (POD1) activity dependence are associated with in-hospital lower-extremity deep vein thrombosis (DVT), and whether POD1 activity provides additional within-group risk stratification beyond Caprini scoring.

METHODS: We conducted a single-center, retrospective, 1:3 matched case-control study of adults undergoing surgery for lower-limb fractures at Ganzhou Hospital-Nanfang Hospital, Southern Medical University between January 2022 and July 2024. Of 783 patients screened, 71 were excluded, leaving 712 in the source cohort (61 DVT cases and 651 ultrasound-negative, matchable controls). Cases and controls were matched 1:3 without replacement by age (±5 years), sex, and fracture site, yielding 61 matched sets (244 patients). After matching, non-matching variables were singly imputed using a random forest algorithm for the primary analysis. To assess uncertainty associated with this approach, a separate sensitivity analysis generated 20 completed datasets from the pre-imputation matched records using a stochastic chained-equation multiple-imputation procedure. Regression estimates across the 20 datasets were combined using Rubin's rules. Associations were estimated using conditional logistic regression stratified by matched set and reported as odds ratios (ORs) with 95% confidence intervals (CIs). Incremental within-set concordance was corrected using 2000 cluster bootstrap resamples. The primary analysis, complete-case analyses and multiple-imputation sensitivity analysis were conducted separately.

RESULTS: Matching variables were well balanced after matching, with standardized mean differences (SMD) of 0.02 for age and 0 for sex and fracture site, although several non-matching characteristics remained imbalanced. Three factors were positively associated with in-hospital DVT: admission Caprini ≥9 (OR 2.43, 95% CI 1.28–4.61), severe POD1 activity dependence (OR 3.89, 95% CI 1.38–10.94), and preoperative immobilization ≥72 h (OR 2.55, 95% CI 1.14–5.67). Compared with patients without any core risk features, the OR increased to 2.81 (95% CI 1.46–5.38) among those with one feature and to 6.28 (95% CI 1.57–25.03) among those with two features. Adding severe POD1 activity dependence to Caprini ≥9 was associated with a modest increase in corrected within-set concordance from 0.589 to 0.633, corresponding to a difference of 0.044 (bootstrap SE 0.022, 95% CI 0.003–0.088). Sensitivity analyses generally preserved the direction of the main associations, although the Caprini estimate was attenuated after additional adjustment for trauma-related variables and D-dimer.

CONCLUSIONS: Admission Caprini ≥9, preoperative immobilization ≥72 h, and severe POD1 activity dependence were each associated with in-hospital lower-extremity DVT. POD1 activity assessment was associated with a modest improvement in within-set risk ranking beyond Caprini stratification. This finding should not be interpreted as evidence of established clinical utility or improved patient outcomes; however, it may help guide nursing attention toward prophylaxis delivery, activity support, and symptom surveillance. Prospective multicenter studies are needed to determine its clinical relevance.

Keywords: fracture; venous thrombosis; case-control studies; risk assessment; early ambulation

Introduction

Fractures are a major contributor to the global trauma burden; the Global Burden of Disease study estimated approximately 178 million incident fractures worldwide in 2019, representing a marked increase from 1990 [1]. Patients with lower-limb fractures typically undergo surgery, immobilization and staged weight-bearing, during which the risk of venous thromboembolism (VTE)-principally deep vein thrombosis (DVT) and pulmonary embolism (PE)-persists throughout hospitalization [2]. In the PREVENT CLOT (Prevention of Clot in Orthopaedic Trauma) trial, which enrolled 12,211 patients treated for fractures, DVT events were still observed despite pharmacologic prophylaxis [3]. Moreover, the proportion of detected events varies accord-

Submitted: 25 August 2026 Revised: 9 September 2026 Accepted: 28 September 2026 Published: 10 November 2026
Correspondence to: Li Huang, Department of Trauma Emergency Center, Ganzhou Hospital-Nanfang Hospital, Southern Medical University, 341000 Ganzhou, Jiangxi, China (e-mail: 15970088107@163.com).
Editor: Roberto Cirocchi

ing to fracture site, ultrasound screening strategy, and the approach to prophylaxis delivery [4,5].

Thrombus formation after lower limb fracture follows the classic Virchow triad: trauma and surgery damage the vascular endothelium; delayed surgery and reduced postoperative activity aggravate venous stasis; and trauma-induced inflammation promotes coagulation activation, contributing to a hypercoagulable state [6]. Clinical pathways generally include VTE risk assessment, bleeding-risk evaluation, mechanical or pharmacologic prophylaxis, ankle pump exercises, pain control, and early mobilization [7]. However, a patient's risk varies according to the changing duration and pace of functional recovery, and identifying patients who require close monitoring and confirmation of prophylaxis delivery from routine nursing records remains a practical challenge in trauma care.

The Caprini risk assessment model integrates age, body mass index (BMI), previous VTE, malignancy, immobilization, and trauma into a single framework and is widely used for surgical risk stratification [8,9,10]. However, in the 2013 version, a hip, pelvic or lower-extremity fracture alone carries 5 points; therefore, a single >5-point threshold has limited ability to distinguish risk among patients who have already sustained a fracture. The duration of preoperative immobilization and activity level on postoperative day 1 (POD1) can both be routinely recorded by specialist nurses and reflect, respectively, activity restriction during the preoperative waiting period and functional status during the early postoperative phase. Transfer and mobility items from the Barthel index can quantify early functional dependence [11,12], but whether they provide additional value for DVT risk identification after lower-limb fracture surgery requires further evaluation.

We therefore undertook a single-center, 1:3 matched case-control study and, before analysis, prespecified a Caprini score ≥9 as the investigational high-risk threshold. We aimed to evaluate the associations of preoperative immobilization ≥72 h and severe POD1 activity dependence with in-hospital DVT, and to determine whether POD1 activity information provides incremental risk ranking beyond Caprini stratification. The study aimed to identify a set of high-risk features obtainable from routine nursing indicators for clinical reference, rather than to develop a model that estimates an individual's absolute risk.

Methods

Study Design and Participants

This single-center, retrospective, 1:3 matched case-control study was reported in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement [13]. We enrolled adults with lower-limb fractures who were admitted to the trauma emergency center/department of orthopaedics at the Ganzhou Hospital-Nanfang Hospital, Southern Medical University and underwent surgery between January 2022 and July 2024.

Eligibility criteria: (1) age ≥18 years; (2) imaging-confirmed fracture of the hip/femur, tibia/fibula or ankle/-foot; and (3) surgical treatment.

Exclusion criteria were: (1) DVT or PE present on admission; (2) pathological fracture, including metastatic fracture; (3) previous lower-limb DVT requiring therapeutic-dose anticoagulation, or long-term therapeutic anticoagulation for another indication; (4) failure to complete in-hospital lower-extremity venous ultrasonography because of a short hospital stay, early transfer/discharge, or other reasons; (5) pregnancy or within 6 weeks postpartum; (6) severe coagulopathy or hematologic disease; (7) severe craniocerebral or spinal cord injury, or severe cognitive impairment precluding postoperative functional assessment; and (8) severe vital organ dysfunction -such as end-stage heart failure, decompensated cirrhosis, or dialysis dependence-associated with a clinical course markedly different from that of typical trauma-surgery patients.

During the study period, 783 patients were screened, and 71 were excluded, yielding a source cohort of 712 eligible patients. Of these, 61 were DVT cases, and the remaining 651 ultrasound-negative patients constituted the matching pool (Fig. 1). The study protocol was approved by Ganzhou Hospital-Nanfang Hospital, Southern Medical University ethics committee (ethics number: TYZKY2024-095-01). Since this retrospective study involved no patient-identifiable information and ensured complete anonymization, the ethics committee waived the requirement for informed consent.

Cases, Controls and Matching

A case was defined as a new DVT first confirmed by lower-extremity venous compression ultrasonography or color Doppler ultrasonography between the index operation and discharge. Controls were selected from the same source cohort and had negative in-hospital ultrasound results. Matching was performed independently by investigators not involved in outcome assessment: each case was matched with 3 controls by age (±5 years), identical sex and identical fracture site. Age, sex and fracture site were selected as matching variables because they represent core demographic and injury characteristics that are reliably available before surgery. In contrast, D-dimer, time to surgery, and surgery-related indices may reflect subsequent clinical status or lie on the exposure-outcome pathway; therefore, they were not used for matching. Ultimately, all 61 cases were successfully matched to 3 controls, resulting in 61 complete 1:3 matched sets (244 patients) with no incomplete sets. No matching variables had missing data, and all missing data handling was performed only after matching and applied exclusively to non-matching variables.

DVT Screening and Outcome Ascertainment

The departmental protocol scheduled one routine bilateral lower-extremity venous duplex ultrasonographic ex-

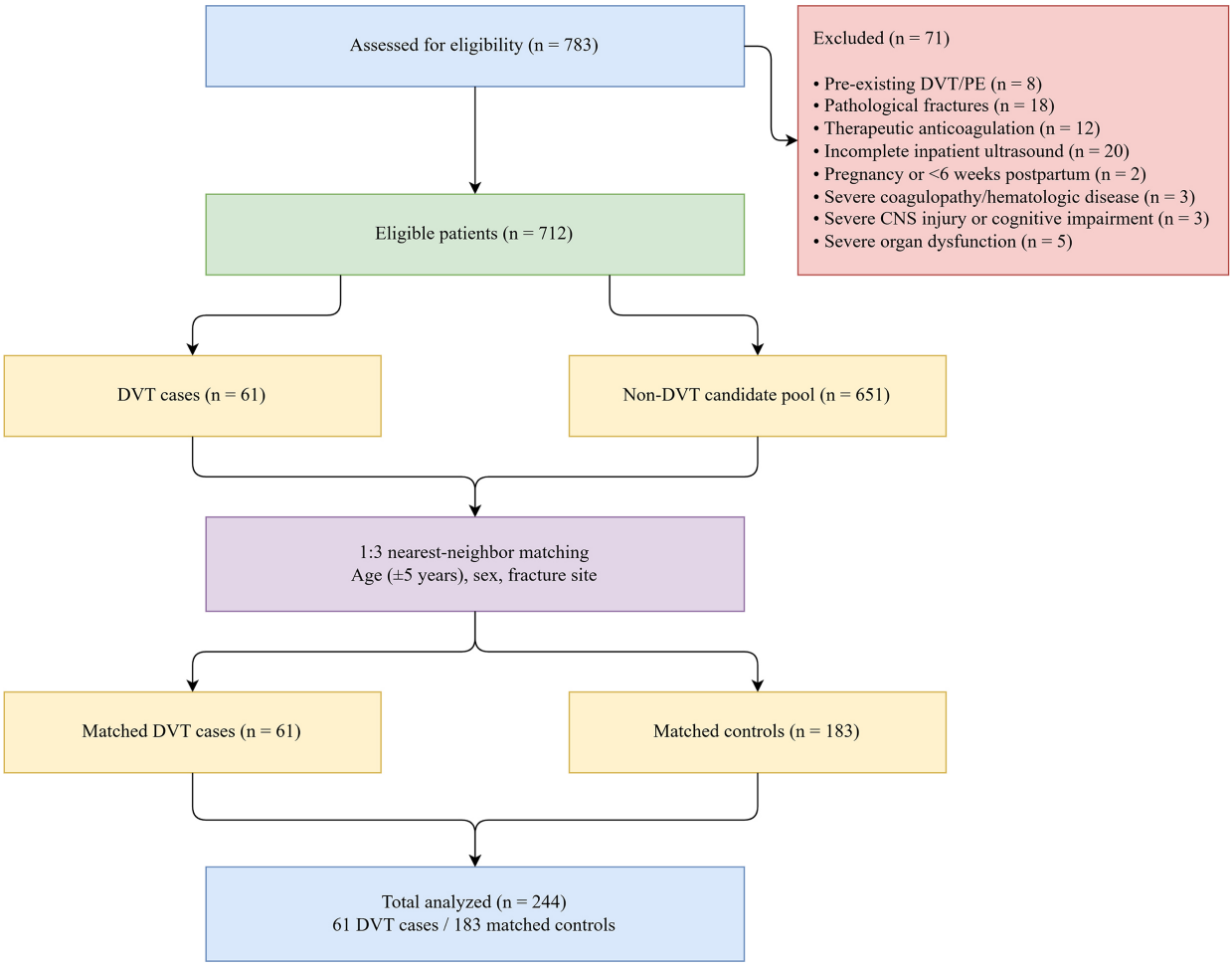


Fig. 1. Study selection, 1:3 matching and post-match analysis flow. DVT, deep vein thrombosis; PE, pulmonary embolism; CNS, central nervous system.

amination during POD1–5. The examination could be deferred to POD6–7 because of scheduling constraints, clinical instability or patient-related reasons, whereas additional or earlier examination could be requested for progressive swelling, pain or other suspected manifestations of DVT. All examinations were performed and reported by physicians from the Department of Ultrasonography who held relevant professional qualifications and had completed standardized departmental training in vascular ultrasonography. Using B-mode compression combined with color and spectral Doppler, both lower extremities were examined from the common femoral vein through the femoral and popliteal veins to the posterior tibial, peroneal and calf muscular veins. DVT was considered present when any deep venous segment was partially or completely noncompressible; direct visualization of intraluminal thrombus, a color-flow filling defect, or reduced color flow was considered supporting evidence. Thrombus involving the popliteal vein or any more proximal venous segment was classified as proximal DVT, whereas thrombosis confined to veins below the popliteal vein was classified as distal DVT. For each participant, we extracted the postoperative day and clinical indication of the first documented examination used for outcome ascertainment. All included patients completed at least one in-hospital examination; repeat examinations beyond the first were not systematically captured and were therefore excluded from timing comparisons. Because examinations were performed as part of routine clinical care, operators and reporting physicians were aware of the clinical indication and available medical record information and were not formally blinded. However, the study-specific Caprini score and POD1 activity variables were generated retrospectively and were not provided to the ultrasound team as research variables. DVT status and anatomical classification were abstracted from finalized ultrasound reports without independent reinterpretation of source images by the study investigators. Symptomatic DVT required both documented symptoms and imaging evidence, and suspected PE was further evaluated using computed tomography pulmonary angiography (CTPA). Diagnosis and treatment followed relevant guidelines and departmental protocols [14,15]. The primary outcome was new lower-extremity DVT first confirmed between the index operation and discharge.

Exposures, Nursing Variables and Covariates

For Caprini scoring, we included only items present at admission or before surgery: lower-limb fracture, age, BMI, limb swelling, varicose veins, previous VTE, family history of VTE, active malignancy, preoperative immobilization, central venous access and multiple major trauma. Each item was traceable to the case records, and the total score was recalculated after imputation. Because lower-extremity fracture contributes 5 points and age contributes up to 3 points in the scoring system used in this study, we prespecified Caprini ≥9 as the research stratification threshold. A score of ≥9 requires at least one additional risk point beyond the fracture- and age-related components. This threshold was used to identify patients with accumulated risk factors and to support nursing prioritization; it was not an official risk category or a trigger for anticoagulation or ultrasonography. Preoperative immobilization ≥72 h was defined as an inability to leave bed, walk, or effectively bear weight for at least 72 consecutive hours due to fracture-related factors, traction, medical orders or clinical status. This definition was cross-checked against emergency records, activity orders and nursing notes. The POD1 Barthel activity subscore used in this study was abstracted from the first routine nursing functional assessment documented on POD1 and calculated as the sum of the Barthel transfer (0–15) and mobility (0–15) items, yielding a total score ranging from 0 to 30. Severe POD1 activity dependence was defined as a POD1 Barthel activity subscore ≤5, indicating that transfer and mobility were almost entirely dependent on assistance.

Delivery of mechanical prophylaxis, pharmacologic prophylaxis and ankle-pump exercises was ascertained from nursing execution sheets, medication administration records and training logs. In this study, mechanical and pharmacologic prophylaxis were coded only as binary indicators of documented delivery. The database lacked sufficiently complete and standardized longitudinal information regarding pharmacologic agents, prophylactic doses, initiation and discontinuation times, duration, and adherence, as well as mechanical prophylaxis device type, daily application durations and adherence; therefore, these details were not analyzed. Admission D-dimer was defined as the first result obtained before prophylactic anticoagulation initiation and was reported in mg/L fibrinogen equivalent units (FEU). Both investigators received standardized training in data-extraction procedures before data collection. All medical and nursing record data were independently extracted by two investigators using a standardized data-extraction form and predefined variable definitions. The second investigator performed complete verification of all extracted data against the source records. Discrepancies were resolved through discussion, and unresolved disagreements were adjudicated by a third senior investigator.

Missing Data

The primary outcome, the matching identifier, and all matching factors were complete. Variables prespecified as acceptably missing and eligible for imputation were BMI, admission D-dimer, admission albumin, estimated blood loss, preoperative immobilization ≥72 h, the POD1 Barthel activity subscore, severe POD1 activity dependence, and records of pharmacologic prophylaxis and ankle-pump exercises; candidate variables with >20% missingness were excluded from the main models. On review, the actual proportion of missing data ranged from 2.0% to 8.6%, with all variables below this limit (**Supplementary Table 1**). After the 61 matched sets were formed, we imputed these nonmatching variables once using random forest (RF). Continuous and binary variables were initialized with the median and mode, respectively. For each target variable, we drew a bootstrap sample, selected a random predictor subspace, and grew 100 classification and regression trees (CART) over 4 iterations. The same candidate predictor pool was used for all eight incomplete target variables: BMI, admission D-dimer, admission albumin, estimated blood loss, preoperative immobilization ≥72 h, POD1 Barthel mobility subscore, pharmacologic prophylaxis documentation, and ankle-pump exercise documentation. For each imputation target, the target variable itself was removed from the available predictor set. We then used the forest's predicted mean for continuous variables and drew a single Bernoulli value from the mean predicted probability for binary variables [16,17].

As a separate sensitivity analysis, the pre-imputation matched dataset was used to generate 20 completed datasets using a stochastic chained-equation multiple-imputation procedure. Eight updating cycles were applied to each completed dataset. The outcome, matching identifier, age, sex and fracture site were kept fixed and were not imputed. Continuous variables were imputed using regression-based predictions with stochastic residual draws; admission D-dimer and estimated blood loss were logarithmically transformed before imputation. Binary variables were imputed using logistic regression followed by Bernoulli draws. After BMI and preoperative immobilization had been imputed, the corresponding Caprini component points, total Caprini score, Caprini ≥9, Caprini ≥10 and core-feature count were recalculated within each completed dataset. Each completed dataset retained the same 244 patients in 61 matched sets. Conditional logistic regression models were fitted separately in the 20 completed datasets, and the regression coefficients and variances were combined using Rubin's rules. This analysis was prespecified to assess the stability of the principal findings under an alternative approach to handling missing data and did not replace the primary single-RF-imputation analysis.

Sample Size

Sample-size feasibility was assessed using events per variable (EPV) [18]. The prespecified exploratory model 3 contains 5 regression coefficients; therefore, under the conservative EPV ≥10 rule, at least 50 DVT events are required [19]. With 1:3 matching, this corresponds to approximately 50 cases and 150 controls (200 patients in total). We included 61 DVT cases and 183 controls (244 patients), yielding an EPV of 61/5 = 12.2 for model 3, which meets this requirement. Nonetheless, EPV reflects only the basic stability of estimation and substitutes for neither external validation nor the estimation of individual absolute risk.

Statistical Analysis

All analyses were performed using R 4.5.1. Continuous variables are summarized as median [interquartile range (IQR)] and categorical variables as n (%). Formal tests of normality were not performed, as continuous variables were summarized descriptively using medians and IQRs, and conditional logistic regression does not require predictors to be normally distributed. Post-matching balance was judged primarily by the standardized mean difference (SMD), with an absolute SMD <0.10 considered to indicate negligible imbalance [20]. Because age, sex and fracture site were already controlled through matching and the conditional likelihood with matched-set stratification, they were not re-entered into any regression model. Conditional logistic regression was stratified by match_id, and odds ratios (ORs), 95% confidence intervals (CIs), and *p* values from two-sided Wald tests were reported. Nested conditional logistic regression models were compared using likelihood-ratio tests. The timing of the first postoperative ultrasonographic examination was summarized by outcome group as median [IQR] and counts for each postoperative day. Differences in timing were examined using conditional logistic regression stratified by match_id, first per 1-day delay in examination and then by comparing delayed examination on POD6–7 versus POD3–5. The per-day comparison was repeated after restricting the analysis to matched sets containing routinely screened DVT cases.

The models were specified as follows. Model 1 included only Caprini ≥9, whereas model 2 additionally included severe POD1 activity dependence. Model 3 was an exploratory actionable nursing and trauma association model containing preoperative immobilization ≥72 h, severe POD1 activity dependence, multiple trauma, open fracture, and admission D-dimer. Because preoperative immobilization and multiple trauma overlap with components of the Caprini score, the total Caprini score was deliberately omitted from this model to avoid duplicate representation of related information. Model 3 was intended to estimate mutually adjusted associations of individual nursing- and trauma-related features within a component-based model; it was not designed to estimate effects in addition to the Caprini total or to develop a validated individual-level prediction model. Model 4 compared patients with 1 or 2 core features (Caprini ≥9 and severe POD1 activity dependence) against those with 0; model 5 estimated the association per additional core feature; model 6 tested the multiplicative interaction between the two core features; and model 7 assessed the trend per 2-point increase in Caprini score. Models 1–7 were prespecified association analyses. Their odds ratios describe conditional associations within the matched sample and should not be interpreted as causal effects or as estimates from a validated clinical prediction model. The concordance analysis was limited to within-set ranking and did not constitute external validation of the prediction model.

Models 1 and 2 were compared using the Akaike information criterion (AIC), the likelihood-ratio test for nested models, and the concordance statistic (C statistic). The cluster bootstrap was applied specifically to correct the within-set C statistics and their difference for apparent optimism and to quantify uncertainty in the concordance difference; it was not used to correct the AIC or likelihood-ratio test. In each of 2000 iterations, 61 matched sets were sampled with replacement, using match_id as the resampling unit, and both models were refitted. Concordance was evaluated in both the bootstrap sample and the original matched sample, and the estimated optimism was subtracted from the apparent concordance. The bootstrap standard error and percentile-based 95% confidence interval were reported for the optimism-corrected difference in concordance. The C statistic was treated as a descriptive measure of relative ranking within the matched sample rather than as evidence of a validated individual-level prediction model or clinical utility.

Prespecified sensitivity analyses comprised a complete-case model-3 analysis and a Caprini-plus-POD1 analysis restricted to records complete for both variables using pre-imputation data; an alternative Caprini ≥10 threshold; additional adjustment for prophylaxis documentation; further adjustment for D-dimer, multiple trauma and open fracture; and restriction to routinely screened DVT cases. The first two analyses used pre-imputation records, whereas the subsequent analyses used the matched single-random-forest-imputed dataset. A separate sensitivity analysis generated 20 completed datasets from the pre-imputation matched records, with conditional logistic regression estimates pooled using Rubin's rules. Caprini thresholds from 6 to 12 were evaluated separately without POD1 adjustment. Exploratory analyses were also conducted for proximal and symptomatic DVT and for subgroups defined by fracture site, age (<65 vs ≥65 years), and operative duration (below vs at or above the median). Within each subgroup, conditional logistic regression stratified by match_id was used to estimate the associations of Caprini ≥9, severe POD1 activity dependence, and preoperative immobilization ≥72 h with DVT. These subgroup analyses were descriptive, were not powered for formal interaction testing,

and were not interpreted as confirmatory evidence of effect heterogeneity. To examine potential information overlap in the S5 specification, we calculated descriptive VIF-like diagnostics from auxiliary regressions and pairwise correlations among total Caprini score, multiple trauma, open fracture and admission D-dimer. These diagnostics were used to describe numerical overlap among covariates and were not interpreted as tests of causality or mediation. Because proximal and symptomatic DVT comprised only 17 and 11 cases, respectively, each subtype analysis was limited to separate single-exposure conditional logistic regression models for the three main exposures: Caprini score ≥9, severe POD1 activity dependence, and preoperative immobilization ≥72 h—were selected a priori because they represented the admission risk-stratification feature and the two nursing-related mobility features evaluated in the primary analysis. All models were stratified by match_id to retain the matched structure. Multivariable subtype models were not fitted because the small numbers of subtype events would have produced unstable estimates. Given the fixed-ratio matched case-control design, incidence, absolute risk, positive predictive value, and individual risk probabilities were not estimated.

Results

Study Flow and Post-Matching Balance

After 1:3 matching without replacement, all 61 cases were matched to 3 controls (100% completion), yielding 61 complete matched sets (244 patients). RF imputation was then applied only to missing values in non-matching variables. Every control's age fell within ±5 years of that of its matched case, and sex and fracture site matched exactly within each set. After matching, the SMD for age was 0.02, and the SMDs for sex and for hip/femur, tibia/fibula and ankle/foot fractures were all 0, meeting the prespecified balance criterion.

Baseline, Trauma and Nursing Characteristics

Post-matching baseline, trauma, and nursing characteristics are shown in Table 1. The overall cohort had a median age of 53 (41, 64) years, and 124 patients (50.8%) were men; hip/femur, tibia/fibula and ankle/foot fractures accounted for 37.7%, 44.3% and 18.0%, respectively. Among the non-matching variables, multiple trauma was more frequent in cases than in controls (26.2% vs 12.0%; SMD = 0.37). Admission D-dimer was 2.34 [2.03, 3.04] versus 1.81 [1.32, 2.24] mg/L FEU (SMD = 0.76), time from injury to surgery was 62 [47, 85] versus 45 [33, 60] h (SMD = 0.68), and estimated blood loss was 305 [187, 453] versus 235 [134, 379] mL (SMD = 0.36).

The Caprini score was 8 (7, 11) in cases and 7 (6, 9) in controls, with scores ≥9 in 45.9% and 27.9%, respectively. Preoperative immobilization ≥72 h occurred in 31.1% and 11.5%, respectively; the POD1 Barthel activity subscore was 15 (10, 20) vs 20 (15, 25), and severe POD1 activity dependence occurred in 16.4% vs 4.4%. Documentation of pharmacologic prophylaxis and ankle-pump exercises was similar between cases and controls (SMDs, 0.07 and 0.02, respectively), whereas documented mechanical prophylaxis showed a non-negligible descriptive imbalance (93.4% vs 87.4%; SMD = 0.21). Because these variables captured only whether delivery was documented, rather than the specific regimen, timing, duration, adherence or intensity, they were interpreted descriptively and not as estimates of prophylactic effectiveness.

DVT Outcome, Anatomical Phenotype and Screening Timing

Of the 61 DVT cases, 44 (72.1%) were distal and 17 (27.9%) were proximal; 11 (18.0%) were symptomatic, and one (1.6%) was accompanied by pulmonary embolism. All 11 symptomatic cases underwent symptom-triggered examination, comprising 3 distal and 8 proximal DVTs; the remaining 50 cases (82.0%) were detected through routine screening. The first postoperative examination occurred on POD3, 4, 5, 6 and 7 in 4, 4, 47, 5 and 1 cases, respectively, and in 0, 0, 167, 12 and 4 controls, respectively. The median examination day was POD5 [5,5] in both groups. No DVT was confirmed on POD1 or POD2; the earliest documented confirmation occurred on POD3. Thus, the POD1 activity assessment preceded documented DVT confirmation in all cases, although the biological onset of thrombosis could not be determined retrospectively. In the full matched sample, examination one day later was inversely associated with case status (OR = 0.40, 95% CI 0.19–0.83; p = 0.014), reflecting earlier examinations among symptom-triggered cases. After restriction to the 50 matched sets containing routinely screened cases, no clear timing difference remained (OR per 1-day later examination = 1.22, 95% CI 0.57–2.58; p = 0.610). Delayed examination on POD6–7 occurred in 6 cases and 16 controls and was not associated with case status (OR = 1.13, 95% CI 0.43–2.99; p = 0.800). Length of stay was 15 [13,18] days in cases and 11 [9,13] days in controls, although the case-control sampling and temporal relationship preclude a causal interpretation of this difference (Fig. 2; **Supplementary Table 2**).

Distribution of Risk Features

The 2 × 2 cross-count of Caprini ≥9 and severe POD1 activity dependence showed, among cases, 28 with neither, 5 with POD1 dependence only, 23 with Caprini ≥9 only and 5 with both; the corresponding control counts were 128, 4, 47 and 4. After collapsing to the number of core features, cases had 0, 1 and 2 features in 28 (45.9%), 28 (45.9%) and 5 (8.2%), and controls in 128 (69.9%), 51 (27.9%) and 4 (2.2%) (Fig. 3). This distribution agrees with the marginal counts in Table 1; the full cross-tabulation is in **Supplementary Table 3**.

Table 1. Post-matching baseline characteristics and standardized mean differences.

Variable	Overall	DVT cases	Controls	SMD	Raw missing, n
Age, years (matching factor; caliper +/–5 years)	53 [41, 64]	53 [42, 64]	53 [41, 64]	0.02	0
Male sex (exact matching factor)	124 (50.8%)	31 (50.8%)	93 (50.8%)	0	0
Fracture site: Hip/Femur (matching factor)	92 (37.7%)	23 (37.7%)	69 (37.7%)	0	0
Fracture site: Tibia/Fibula (matching factor)	108 (44.3%)	27 (44.3%)	81 (44.3%)	0	0
Fracture site: Ankle/Foot (matching factor)	44 (18.0%)	11 (18.0%)	33 (18.0%)	0	0
BMI, kg/m^2	23.7 [21.9, 25.5]	23.8 [21.8, 25.9]	23.7 [22.2, 25.4]	0.09	10
Open fracture	17 (7.0%)	7 (11.5%)	10 (5.5%)	0.22	0
Multiple trauma	38 (15.6%)	16 (26.2%)	22 (12.0%)	0.37	0
Diabetes	8 (3.3%)	2 (3.3%)	6 (3.3%)	0	0
Previous VTE	6 (2.5%)	2 (3.3%)	4 (2.2%)	0.07	0
Admission D-dimer, mg/L FEU	1.94 [1.44, 2.40]	2.34 [2.03, 3.04]	1.81 [1.32, 2.24]	0.76	21
Admission albumin, g/L	39.9 [37.8, 41.4]	39.3 [37.7, 40.8]	40.2 [37.9, 41.5]	0.2	16
Injury-to-surgery time, h	48 [37, 66]	62 [47, 85]	45 [33, 60]	0.68	0
Surgical duration, min	98 [84, 112]	102 [91, 116]	97 [83, 108]	0.19	0
Estimated blood loss, mL	240 [147, 389]	305 [187, 453]	235 [134, 379]	0.36	9
Transfusion within 48 h	46 (18.9%)	16 (26.2%)	30 (16.4%)	0.24	0
Admission Caprini score	7 [6, 9]	8 [7, 11]	7 [6, 9]	0.48	15
Caprini score ≥9	79 (32.4%)	28 (45.9%)	51 (27.9%)	0.38	15
Preoperative immobilization ≥72 h	40 (16.4%)	19 (31.1%)	21 (11.5%)	0.49	5
POD1 Barthel activity subscore (0–30)	20 [15, 25]	15 [10, 20]	20 [15, 25]	0.77	7
Severe POD1 activity dependence (subscore ≤5)	18 (7.4%)	10 (16.4%)	8 (4.4%)	0.4	7
Mechanical prophylaxis documented	217 (88.9%)	57 (93.4%)	160 (87.4%)	0.21	0
Pharmacologic prophylaxis documented	203 (83.2%)	52 (85.2%)	151 (82.5%)	0.07	6
Ankle-pump exercise documented	207 (84.8%)	52 (85.2%)	155 (84.7%)	0.02	9

Note: Continuous variables are presented as median [IQR] and categorical variables as n (%). Post-matching covariate balance was assessed using the absolute standardized mean difference (SMD); an absolute SMD <0.10 was considered negligible imbalance. *p* values were not reported because Table 1 was intended for descriptive balance assessment rather than hypothesis testing. SMD, standardized mean differences; BMI, body mass index; VTE, venous thromboembolism; FEU, fibrinogen equivalent units; POD1, postoperative day 1.

Conditional Logistic Regression and High-Risk Identification

In model 1, Caprini ≥9 was significantly associated with in-hospital DVT (OR = 2.43, 95% CI 1.28–4.61, $p = 0.007$; all conditional logistic regression stratified by matched set). In model 2, the associations of Caprini ≥9 (OR = 2.26, 95% CI 1.16–4.38, $p = 0.016$) and severe POD1 activity dependence (OR = 3.89, 95% CI 1.38–10.94, $p = 0.010$) were both retained. When Caprini was analysed on a continuous per-2-point scale (model 7), the OR was 1.51 (95% CI 1.19–1.92, $p < 0.001$).

In exploratory model 3, preoperative immobilization ≥72 h (OR = 2.55, 95% CI 1.14–5.67, $p = 0.022$), severe POD1 activity dependence (OR = 4.44, 95% CI 1.32–14.89, $p = 0.016$) and each 1 mg/L FEU rise in admission D-dimer (OR = 2.17, 95% CI 1.43–3.29, $p < 0.001$) were associated with DVT, whereas the confidence intervals for multiple trauma and open fracture crossed 1. These estimates represent mutually adjusted associations within a component-based exploratory model. Because the model omitted the total Caprini score to avoid overlapping information, its coefficients should not be interpreted as effects independent of, or additive to, the Caprini score, nor as evidence of a validated prediction model.

Against patients with no core feature, model 4 gave an OR of 2.81 (95% CI 1.46–5.38, $p = 0.002$) for one feature and 6.28 (95% CI 1.57–25.03, $p = 0.009$) for two; in model 5 each additional core feature carried an OR of 2.66 (95% CI 1.56–4.56, $p < 0.001$). The multiplicative interaction fitted in model 6 showed no statistical evidence (OR = 0.39, 95% CI 0.05–2.90, $p = 0.361$), so the findings are better read as an accumulation of risk information than as a biological synergy (Table 2, Fig. 4).

Incremental Information From POD1 Activity

The AIC of the Caprini base model was 163.77 and fell to 158.93 after the addition of severe POD1 activity dependence; the nested-model likelihood-ratio chi-square was 6.84 ($p = 0.009$). After optimism correction using cluster bootstrap resampling of the 61 matched sets, the within-set concordance increased from 0.589 for the base model to 0.633 for the augmented model, corresponding to a modest difference of 0.044. The bootstrap standard error (SE) of this gain was 0.022, with a percentile 95% CI of 0.003–

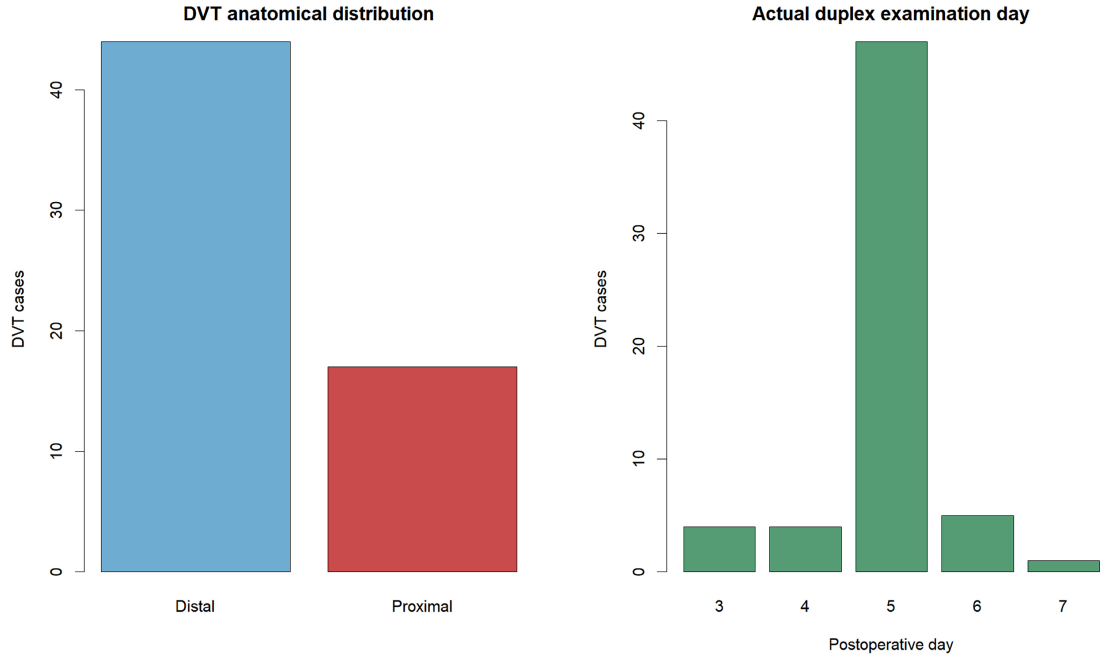


Fig. 2. DVT anatomical phenotype, symptom status and postoperative duplex ultrasonography timing. Panels display the anatomical and symptomatic composition of the 61 DVT cases and the postoperative day of the first documented ultrasonographic examination among the 61 DVT cases.

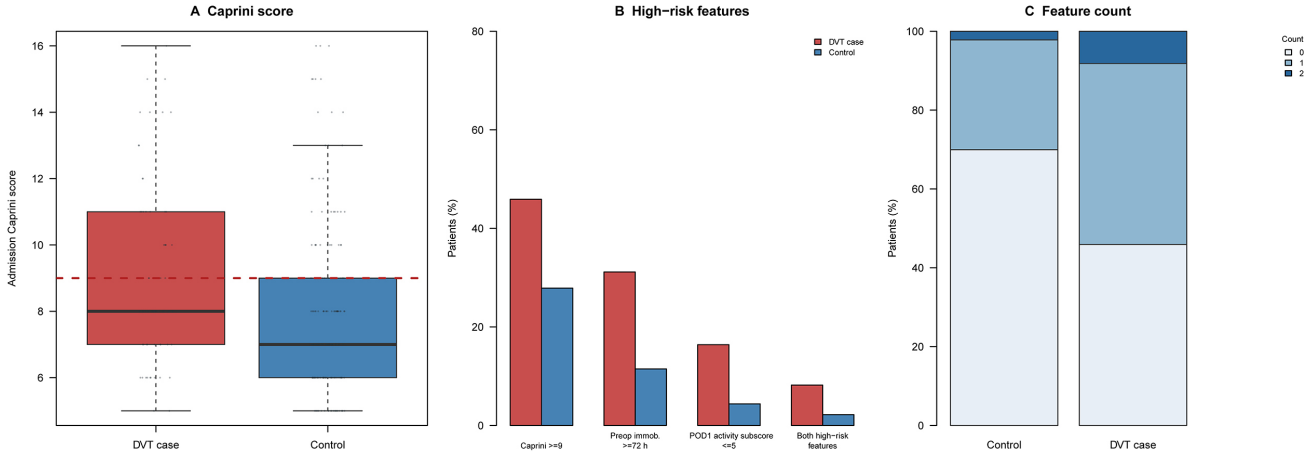


Fig. 3. Admission Caprini distribution, nursing-related features and cumulative core-risk profile.

0.088, and all 2000 resamples yielded valid estimates (Table 3). The resampling distribution is shown in **Supplementary Fig. 1**. The interval reflects sampling uncertainty at the matched-set level. Because within-set concordance measures relative ranking in this matched sample, the observed difference should not be interpreted as evidence of validated individual-level prediction, clinical net benefit or improved patient outcomes.

Sensitivity and DVT-Subtype Exploratory Analyses

Table 4 summarizes the sensitivity analyses. S1 used pre-imputation complete records for model 3. Of the 204 candidate records in 61 nominal sets, 51 informative sets remained after excluding 10 sets without a case, comprising 178 patients (4 two-person, 18 three-person and 29 four-person sets). The ORs were 2.06 (95% CI 0.76–5.53; p = 0.153) for preoperative immobilization ≥72 h and 6.37 (95% CI 1.55–26.11; p = 0.010) for severe POD1 activity dependence. S2 included 225 records complete for Caprini and POD1 variables from 61 nominal sets; after excluding 6 sets without a case, 55 informative sets comprising 207 patients remained (1 two-person, 11 three-person and 43 four-person sets). The ORs were 2.13 (95% CI 1.06–4.31; p = 0.035) for Caprini ≥9 and 3.78 (95% CI 1.35–10.61; p = 0.011) for severe POD1 activity dependence.

S3–S8 used the single-random-forest-imputed dataset. Replacing Caprini ≥9 with ≥10 in model 2 yielded an OR of 2.64 (95% CI 1.31–5.34; p = 0.007). After adjustment

Table 2. Main conditional logistic regression results.

Model	Model description	Variable	OR	95% CI	*p* value
Model 1	Caprini primary model	Caprini score ≥9	2.43	1.28–4.61	0.007
Model 2	Caprini plus POD1 activity dependence	Caprini score ≥9	2.26	1.16–4.38	0.016
Model 2	Caprini plus POD1 activity dependence	Severe POD1 activity dependence (subscore ≤5)	3.89	1.38–10.94	0.010
Model 3	Actionable nursing model	Preoperative immobilization ≥72 h	2.55	1.14–5.67	0.022
Model 3	Actionable nursing model	Severe POD1 activity dependence (subscore ≤5)	4.44	1.32–14.89	0.016
Model 3	Actionable nursing model	Multiple trauma	1.61	0.67–3.84	0.284
Model 3	Actionable nursing model	Open fracture	1.3	0.38–4.45	0.674
Model 3	Actionable nursing model	Admission D-dimer per 1 mg/L FEU	2.17	1.43–3.29	<0.001
Model 4	Core-feature categories	One core feature vs zero	2.81	1.46–5.38	0.002
Model 4	Core-feature categories	Two core features vs zero	6.28	1.57–25.03	0.009
Model 5	Core-feature trend	Per additional core feature	2.66	1.56–4.56	<0.001
Model 6	Multiplicative interaction	Interaction between Caprini ≥9 and severe POD1 activity dependence (subscore ≤5)	0.39	0.05–2.9	0.361
Model 7	Continuous Caprini	Per 2-point increase in Caprini score	1.51	1.19–1.92	<0.001

Note: All models were fitted using conditional logistic regression with the matched set as the stratum. Age, sex, and fracture site were not re-entered because they were matching factors. Model 3 intentionally omitted the total Caprini score because selected nursing and trauma variables overlap with or are closely related to Caprini components. It was an exploratory association model rather than a predictive model. Severe POD1 activity dependence was defined as a POD1 Barthel activity subscore ≤5.

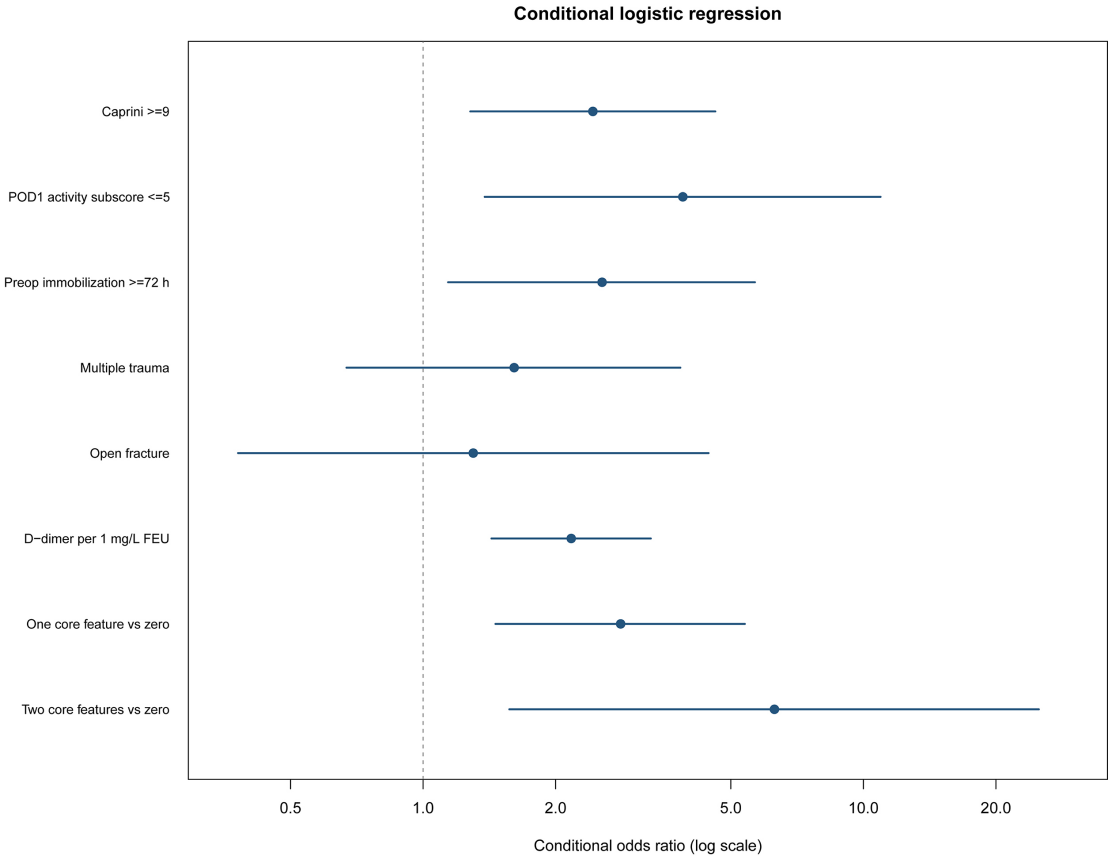


Fig. 4. Conditional logistic regression estimates for Caprini and nursing-related risk characteristics.

for prophylaxis documentation (S4), the ORs for Caprini ≥9 and severe POD1 activity dependence were 2.22 and 3.79, respectively. With further adjustment for multiple trauma, open fracture and admission D-dimer (S5), the OR for Caprini ≥9 attenuated to 1.31 (95% CI 0.51–3.36; $p = 0.572$), whereas severe POD1 activity dependence remained associated with DVT (OR = 4.40, 95% CI 1.34–14.49; $p = 0.015$). Descriptive VIF-like values were 1.68 for Caprini ≥9, 1.03 for severe POD1 activity dependence, 1.66 for multiple trauma, 1.03 for open fracture and 1.05

Table 3. Incremental information and matched-set bootstrap results.

Analysis	Estimate	Lower 95% CI	Upper 95% CI	*p* value
Base model AIC	163.767	-	-	-
Augmented model AIC	158.926	-	-	-
Likelihood-ratio chi-square	6.841	-	-	0.009
Apparent within-set concordance: base	0.590	-	-	-
Apparent within-set concordance: augmented	0.637	-	-	-
Optimism-corrected concordance: base	0.589	-	-	-
Optimism-corrected concordance: augmented	0.633	-	-	-
Optimism-corrected concordance improvement	0.044	0.003	0.088	-
Cluster-bootstrap standard error: concordance improvement	0.022	-	-	-
Valid matched-set bootstrap replicates	2000.000	-	-	-

Note: Concordance was calculated as a within-matched-set ranking measure. The reported difference was estimated using 2000 cluster bootstrap resamples of the 61 matched sets. This analysis was exploratory and does not represent external validation of a clinical prediction model or an estimate of clinical utility. AIC, Akaike information criterion.

Table 4. Sensitivity analyses.

Analysis	Model	Variable	OR	95% CI	*p* value	Records / sets
S1	Complete-case actionable nursing model	Preoperative immobilization ≥72 h	2.06	0.76–5.53	0.153	178 / 51
S1	Complete-case actionable nursing model	Severe POD1 activity dependence (subscore ≤5)	6.37	1.55–26.11	0.010	178 / 51
S2	POD1-record-complete model	Caprini score ≥9	2.13	1.06–4.31	0.035	207 / 55
S2	POD1-record-complete model	Severe POD1 activity dependence (subscore ≤5)	3.78	1.35–10.61	0.011	207 / 55
S3	Alternative-threshold model: Caprini ≥10 plus severe POD1 activity dependence	caprini_ge10	2.64	1.31–5.34	0.007	244 / 61
S4	Prevention-adjusted model	Caprini score ≥9	2.22	1.14–4.34	0.019	244 / 61
S4	Prevention-adjusted model	Severe POD1 activity dependence (subscore ≤5)	3.79	1.34–10.73	0.012	244 / 61
S5	Trauma-severity and D-dimer-adjusted model	Caprini score ≥9	1.31	0.51–3.36	0.572	244 / 61
S5	Trauma-severity and D-dimer-adjusted model	Severe POD1 activity dependence (subscore ≤5)	4.4	1.34–14.49	0.015	244 / 61
S6	Routine-screening cases only	Caprini score ≥9	2.48	1.17–5.25	0.018	200 / 50
S6	Routine-screening cases only	Severe POD1 activity dependence (subscore ≤5)	5.04	1.47–17.22	0.010	200 / 50
S7	Proximal DVT: separate single-exposure model	Caprini score ≥9	1.51	0.43–5.23	0.518	68 / 17
S7	Proximal DVT: separate single-exposure model	Severe POD1 activity dependence	4.37	0.37–51.24	0.240	68 / 17
S7	Proximal DVT: separate single-exposure model	Preoperative immobilization ≥72 h	2.00	0.48–8.40	0.344	68 / 17
S8	Symptomatic DVT: separate single-exposure model	Caprini score ≥9	1.84	0.46–7.30	0.388	44 / 11
S8	Symptomatic DVT: separate single-exposure model	Severe POD1 activity dependence	2.30	0.31–17.24	0.417	44 / 11
S8	Symptomatic DVT: separate single-exposure model	Preoperative immobilization ≥72 h	2.35	0.60–9.17	0.220	44 / 11

Severe POD1 activity dependence was defined as a POD1 Barthel activity subscore ≤5. For S7 and S8, each exposure was examined in a separate conditional logistic regression model stratified by matched set. These subtype analyses were exploratory, and no multivariable subtype model was fitted because of the limited number of events.

for admission D-dimer. The total Caprini score was correlated with multiple trauma (r = 0.74), whereas correlations with admission D-dimer and the other trauma variable were weaker. Thus, the attenuation observed in S5 was compatible with information overlap and possible over-adjustment rather than evidence of severe numerical collinearity or a

proven mediation pathway (**Supplementary Tables 4,5**). Restriction to routinely screened cases (S6) included 200 patients in 50 matched sets; Caprini ≥9 and severe POD1 activity dependence remained associated with DVT, with ORs of 2.48 (95% CI 1.17–5.25; $p = 0.018$) and 5.04 (95% CI 1.47–17.22; $p = 0.010$), respectively.

In separate threshold-only analyses, the ORs for Caprini cutoffs of ≥6, ≥7, ≥8, ≥9, ≥10, ≥11 and ≥12 were 4.94, 3.35, 3.41, 2.43, 2.70, 2.78 and 2.21, respectively; the corresponding apparent within-set concordance values were 0.544, 0.590, 0.623, 0.590, 0.590, 0.579 and 0.544 (**Supplementary Table 6**). Although concordance was highest at ≥8, no cutoff was uniformly superior. The prespecified ≥9 cutoff was therefore retained as a clinically interpretable research stratum rather than as an empirically optimal or official clinical threshold.

The additional multiple-imputation analysis included 244 patients in 61 matched sets across 20 completed datasets. Pooled results were comparable with those of the primary analysis: Caprini ≥9, OR 2.43 (95% CI 1.28–4.61; $p = 0.007$); Caprini ≥9 in the Caprini-plus-POD1 model, OR 2.25 (95% CI 1.16–4.37; $p = 0.017$); severe POD1 activity dependence, OR 4.00 (95% CI 1.42–11.25; $p = 0.009$); preoperative immobilization ≥72 h, OR 2.80 (95% CI 1.22–6.43; $p = 0.015$); and admission D-dimer, OR 2.13 (95% CI 1.41–3.22; $p < 0.001$). The alternative Caprini ≥10 model yielded an OR of 2.62 (95% CI 1.30–5.32; $p = 0.007$). Multiple trauma and open fracture remained non-significant. The fraction of missing information ranged from approximately 0% to 7.9% (**Supplementary Table 7**).

Exploratory analyses by fracture site, age group and operative duration are shown in **Supplementary Table 8**. The direction of associations for Caprini ≥9, severe POD1 activity dependence and preoperative immobilization was generally consistent with the primary analysis, although several subgroup estimates were imprecise and one POD1 model in the ankle/foot stratum was not estimable. These analyses were descriptive and were not powered for formal interaction testing. Exploratory subtype analyses included 17 proximal-DVT matched sets and 11 symptomatic-DVT matched sets. In separate single-exposure conditional logistic regression models, the ORs for proximal DVT were 1.51 (95% CI 0.43–5.23) for Caprini score ≥9, 4.37 (95% CI 0.37–51.24) for severe POD1 activity dependence and 2.00 (95% CI 0.48–8.40) for preoperative immobilization ≥72 h. The corresponding ORs for symptomatic DVT were 1.84 (95% CI 0.46–7.30), 2.30 (95% CI 0.31–17.24) and 2.35 (95% CI 0.60–9.17), respectively. All confidence intervals were wide and crossed 1; therefore, these exploratory estimates do not support definitive conclusions regarding subtype-specific associations. Complete subtype results are provided in Table 4 and **Supplementary Table 9**.

Discussion

In 61 case-control sets matched on age, sex and fracture site, we systematically assessed the admission Caprini score and nursing-related activity measures. Caprini ≥9, preoperative immobilization ≥72 h and severe POD1 activity dependence were each positively associated with in-hospital DVT, and the OR increased stepwise as the number of core features rose from 0 to 1 to 2. Adding POD1 activity information improved within-set concordance, although the improvement was modest. Taken together, these findings support POD1 activity assessment as a supplement to, rather than a replacement for, admission risk stratification.

Applicability of the Caprini Score in Lower-Limb Fracture

The Caprini model has shown risk-stratification value across many surgical populations, yet its performance is inevitably shaped by case mix, outcome definition and the prophylaxis pathway [21,22]. When Wu and Cheng [23] developed a nomogram for femoral fracture, they reported a Caprini AUC of only 0.571 and found that DVT incidence did not increase monotonically with the score, concluding that this generic tool was unsuitable for orthopaedic-trauma patients. This accords with our own observation: because a lower-limb fracture itself contributes 5 points, the conventional >5-point cutoff has limited discriminative power in this population. We therefore prespecified ≥9 as a research-oriented nursing stratification threshold. Because lower-extremity fracture contributes 5 points and age contributes up to 3 points, a score of at least 9 ensures at least one additional risk point beyond the maximum combined contribution of these two components, thereby identifying a stratum with further accumulated risk information. In our matched sample, Caprini ≥9 was associated with an OR of 2.43 for DVT, and each 2-point increase with an OR of 1.51; the ≥10 sensitivity analysis showed a similar direction of association, indicating that the score still carries meaningful ranking information in this population. Across the exploratory cutoffs, apparent within-set concordance was numerically highest at ≥8. We nevertheless retained ≥9 because it was prespecified and reflected the intended accumulated-risk definition; we do not interpret it as either the statistically optimal or an official clinical cutoff. In 953 patients with lower-limb fracture, Wang et al. [24] attempted to refine the Caprini score using fasting glucose and D-dimer and found that its stand-alone discrimination was limited, whereas adding these readily available variables increased the receiver operating characteristic (ROC) value to 0.784, providing further evidence that supplementing Caprini with accessible variables may improve risk ordering.

After further adjustment for multiple trauma, open fracture and admission D-dimer in S5, the OR for Caprini ≥9 attenuated to 1.31, with a confidence interval crossing 1. The descriptive VIF-like diagnostics did not suggest severe numerical collinearity, with values ranging from 1.03 to

1.68; however, the total Caprini score was correlated with multiple trauma (r = 0.74), indicating substantial information overlap. Multiple trauma is itself represented within the Caprini score, whereas admission D-dimer may capture post-traumatic coagulation activation and open fracture may provide additional information about injury severity. Thus, the attenuation is compatible with overlapping information among the Caprini score, trauma burden and post-traumatic coagulation activation and may also reflect over-adjustment relative to the broader admission-risk estimand. It should not be interpreted as evidence that Caprini ≥9 is not associated with DVT or as proof of a mediation pathway, because the retrospective case-control design does not establish the temporal ordering or causal role of these variables. Model 3, which omitted the total Caprini score, should therefore be interpreted as a component-based exploratory association model for examining the joint pattern of nursing and trauma-related features rather than as a second score that can be added directly to Caprini. The retrospective design does not allow the relative contributions of these overlapping components to be separated reliably.

Clinical Interpretation of Preoperative Immobilization and POD1 Activity Dependence

The clinical meaning of preoperative immobilization and POD1 activity dependence can be understood within a framework in which venous stasis, inflammation and coagulation activation jointly contribute to thrombosis [25]. The most direct effect of prolonged immobilization is to weaken the calf muscle pump and slow venous return, thereby promoting stasis-a pathway that Alsuwaylihi and colleagues [26] place at the forefront of the Virchow triad. They noted that, without prophylaxis, the incidence of DVT after major orthopaedic surgery can reach 40–60%; their ICU findings regarding immobility and proximal DVT provide additional background but may not be directly generalizable to patients hospitalized after lower-limb fracture surgery.

Waiting for surgery, traction, pain and restricted weight-bearing can all weaken the calf muscle pump, whereas the need for near-complete assistance on POD1 may reflect several factors simultaneously, including trauma burden, pain control, surgical constraints, and slow functional recovery. In our data, both preoperative immobilization ≥72 h and severe POD1 activity dependence were associated with DVT. Pearse et al. [27] reported a reduction in DVT from 27.6% to 1.0% with early mobilization after knee replacement; however, these findings may not be directly generalizable to patients undergoing surgery for lower-limb fractures. These observations are consistent with an association between limited early activity and DVT, but they do not establish that reduced activity caused thrombosis. Although no DVT was confirmed before POD3 and the association with severe POD1 activity dependence remained in the routine-screening-only analysis, undetected thrombosis or early symptoms preceding imaging may themselves have restricted activity. Residual confounding by surgical technique, anesthesia, pain severity, prescribed weight-bearing restrictions, and other aspects of postoperative recovery therefore cannot be excluded.

From the standpoint of nursing-record availability, the duration of preoperative immobilization can be documented during handover, and the POD1 Barthel transfer and mobility subscores can be obtained during routine functional assessment. Neither requires additional laboratory testing nor complex time-series modelling, making both readily collectable. It should be clear, however, that POD1 activity dependence is not a directly modifiable causal factor; it is better regarded as a risk signal that may prompt closer assessment of pain, activity restriction, prophylaxis delivery and limb symptoms.

Incremental Information and Nursing Risk Stratification

Adding severe POD1 activity dependence to Caprini ≥9 lowered the AIC, and the corrected within-set concordance increased from 0.589 to 0.633, corresponding to a difference of 0.044. The cluster-bootstrap SE of 0.022 and 95% CI of 0.003–0.088 reflect sampling uncertainty at the level of the 61 matched sets. Although the point estimate was positive, the magnitude was modest, and the lower confidence limit was close to zero. The result therefore provides, at most, limited support for additional within-set ranking information from POD1 activity assessment. It does not establish improved individual-level prediction, clinical net benefit, or better patient outcomes. Because this study did not assess calibration, decision-curve net benefit, or whether the activity assessment changed nursing management, the clinical significance of this difference requires prospective evaluation.

The core value of nursing risk stratification lies not in replacing anticoagulation decisions but in helping prioritize the work. In a prospective multicentre observational study, Chua et al. [28] found that the timing of first mobilization after total hip or knee arthroplasty was driven more by treatment-related than patient-related factors, suggesting that early mobilization depends substantially on provider-related practices. For patients with Caprini ≥9, prolonged preoperative immobilization, or severe POD1 activity dependence, one may prioritize checking the continuity of mechanical prophylaxis, pharmacologic prophylaxis orders in relation to bleeding contraindications, the actual completion of ankle-pump exercises, pain control, limb symptoms and the ultrasound handoff. Current orthopaedic and in-hospital VTE guidelines emphasize an individualized balance between thrombotic and bleeding risk [29]; therefore, the feature combination identified here can serve, at most, as a cue for nursing attention and cannot independently direct treatment.

Prophylaxis Records and the DVT Phenotype

Mechanical prophylaxis was documented in 93.4% of cases and 87.4% of controls (SMD = 0.21), indicating a non-negligible descriptive imbalance. This may reflect a greater clinical inclination to use mechanical prophylaxis in higher-risk patients, its use as an alternative when pharmacologic prophylaxis is a concern, or simply more complete nursing documentation in higher-risk patients. Because the prophylaxis variables capture only whether a measure was recorded-not the actual dose, duration or quality of delivery-such descriptive differences are more likely to reflect confounding by indication and cannot be used to estimate a protective or harmful effect of mechanical prophylaxis.

The PREVENT CLOT trial has shown that, even against a background of routine pharmacologic prophylaxis, patients with fractures can still develop symptomatic VTE. It should be clear, however, that our study was not a comparative study of pharmacologic prophylaxis and therefore cannot adjudicate between aspirin and low-molecular-weight heparin (LMWH). In our study, distal DVT accounted for 72.1% of all DVT cases, whereas 50 of the 61 cases (82.0%) were detected through routine screening. These are separate descriptors of outcome composition: the latter percentage refers to all DVT cases rather than specifically to distal DVT. In the full sample, cases underwent ultrasonography earlier overall because the 11 symptomatic cases received symptom-triggered examinations. No clear difference in examination timing was observed after restriction to matched sets containing routinely screened cases, and POD6–7 delays were similarly distributed between cases and controls. These findings reduce concern that the observed associations were explained solely by unequal examination timing, but they cannot eliminate detection bias. Routine ultrasonography preferentially identifies clinically silent distal thrombosis; consequently, our findings apply primarily to in-hospital, ultrasound-detected DVT and should not be directly extrapolated to symptomatic proximal DVT, pulmonary embolism or post-discharge venous thromboembolism. Nor can these data determine the net clinical benefit of routine screening or establish that DVT prolonged hospitalization.

Limitations

Several limitations deserve mention. First, the single-center retrospective design may introduce selection bias, information bias, and residual confounding, and matching on age, sex and fracture site cannot control for all unmeasured factors. Surgical approach, anesthesia regimen, standardized pain intensity, and the precise timing of early symptoms were not consistently available for adjustment. Because systematic preoperative ultrasonographic screening was not performed in all patients, pre-existing asymptomatic DVT could not be completely excluded, which may have led to misclassification of some cases as newly detected postoperative DVT. Moreover, although the POD1 assessment preceded documented DVT confirmation, it could not be established that it preceded the biological onset of thrombosis. In addition, the fully adjusted S5 specification included variables that may overlap with Caprini components or reflect the post-traumatic coagulation response; its attenuated Caprini estimate should therefore be interpreted as a sensitivity result rather than as an estimate of a distinct causal effect.

Second, outcome ascertainment was limited to the hospital stay and was dominated by routinely detected, asymptomatic distal DVT. Although examination timing was similar after restriction to matched sets containing routinely screened cases, detection and ascertainment bias related to the screening strategy and the absence of formal blinding to clinical information cannot be excluded; post-discharge events were not captured. The fixed 1:3 case-control sampling also means that this matched sample cannot be used to estimate incidence, absolute risk, calibration or positive predictive value.

Third, the primary analysis used single random-forest imputation and therefore did not fully propagate imputation uncertainty. In the additional 20-dataset multiple-imputation sensitivity analysis, the pooled estimates were generally similar in direction and magnitude to those of the primary analysis, reducing concern that the principal findings were driven by a particular single imputation. Nevertheless, this sensitivity analysis was conducted within the same single-center matched sample and cannot substitute for validation in an independent cohort.

Fourth, the numbers of events for proximal DVT, symptomatic DVT, and the doubly positive core-feature group were small, limiting the precision of these estimates. The exploratory subgroup estimates also did not provide a reliable basis for concluding that nursing-related associations differed by fracture site, age or operative duration. The wider intervals in several strata mainly reflect the limited number of informative matched sets, particularly among older patients and those with ankle/foot fractures.

Finally, prophylaxis was available only as binary indicators of documented delivery. We could not reliably reconstruct the pharmacologic agent and dose, start and stop times, duration, administration adherence, or the type, daily application duration, and adherence of mechanical prophylaxis. Because pharmacologic and mechanical prophylaxis are important determinants of DVT risk, the lack of detailed information on their timing, intensity, duration, and adherence may have led to misclassification of prophylaxis exposure before DVT confirmation and residual confounding by differences in clinical management and indication for prophylaxis. The findings therefore cannot determine the effectiveness of any specific pharmacologic or mechanical prophylaxis strategy. We also did not perform temporal or external validation or formally evaluate clinical utility.

Conclusions

In this 1:3 matched sample of adults undergoing lower-limb fracture surgery, admission Caprini ≥9, preoperative immobilization ≥72 h, and severe POD1 activity dependence were each associated with in-hospital DVT and together formed a set of cumulative high-risk features readily identifiable from routine records. Linking the admission risk score with a quantified POD1 activity assessment may provide a practical way to organize nursing attention toward prophylaxis delivery, activity support, symptom observation, and coordination of ultrasonography; however, the modest increase in within-set concordance should not be interpreted as evidence of improved clinical prediction or patient outcomes. Future work should use prospective multicentre cohorts that uniformly record the start and end of immobilization, the POD1 Barthel activity subscore, and the dose and quality of prophylaxis, and should further evaluate incidence, calibration, clinical net benefit, nursing-resource use and cost.

Availability of Data and Materials

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

Author Contributions

MLD and LH designed the research study. MLD, HFZ and LH performed the research. MLD and HFZ analyzed the data. MLD participated in drafting the manuscript. All authors contributed to important editorial changes in the manuscript. All authors read and approved the final manuscript. All authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

Ethics Approval and Consent to Participate

The study protocol was approved by Ganzhou Hospital-Nanfang Hospital, Southern Medical University ethics committee (ethics number: TY-ZKY2024-095-01). This study complies with the relevant requirements of the Declaration of Helsinki. Since this retrospective study involved no patient-identifiable information and ensured complete anonymization, the ethics committee waived the requirement for informed consent.

Acknowledgment

Not applicable.

Funding

This research received no external funding.

Conflict of Interest

The authors declare no conflict of interest.

Supplementary Material

Supplementary material associated with this article can be found, in the online version, at https://doi.org/10.62713/aic.4967.

References

[1] GBD 2019 Fracture Collaborators. Global, regional, and national burden of bone fractures in 204 countries and territories, 1990-2019: a systematic analysis from the Global Burden of Disease Study 2019. The Lancet. Healthy Longevity. 2021; 2: e580–e592. https://doi.org/10.1016/S2666-7568(21)00172-0

[2] Douillet D, Chapelle C, Ollier E, Mismetti P, Roy PM, Laporte S. Prevention of venous thromboembolic events in patients with lower leg immobilization after trauma: Systematic review and network meta-analysis with meta-epsidemiological approach. PLoS Medicine. 2022; 19: e1004059. https://doi.org/10.1371/journal.pmed.1004059

[3] Major Extremity Trauma Research Consortium (METRC), O'Toole RV, Stein DM, O'Hara NN, Frey KP, Taylor TJ, et al. Aspirin or Low-Molecular-Weight Heparin for Thromboprophylaxis after a Fracture. The New England Journal of Medicine. 2023; 388: 203–213. https://doi.org/10.1056/NEJMoa2205973

[4] Rappold JF, Sheppard FR, Carmichael Ii SP, Cuschieri J, Ley E, Rangel E, et al. Venous thromboembolism prophylaxis in the trauma intensive care unit: an American Association for the Surgery of Trauma Critical Care Committee Clinical Consensus Document. Trauma Surgery & Acute Care Open. 2021; 6: e000643. https://doi.org/10.1136/tsaco-2020-000643

[5] Ley EJ, Brown CVR, Moore EE, Sava JA, Peck K, Ciesla DJ, et al. Updated guidelines to reduce venous thromboembolism in trauma patients: A Western Trauma Association critical decisions algorithm. The Journal of Trauma and Acute Care Surgery. 2020; 89: 971–981. https://doi.org/10.1097/TA.0000000000002830

[6] Anderson DR, Morgano GP, Bennett C, Dentali F, Francis CW, Garcia DA, et al. American Society of Hematology 2019 guidelines for management of venous thromboembolism: prevention of venous thromboembolism in surgical hospitalized patients. Blood Advances. 2019; 3: 3898–3944. https://doi.org/10.1182/bloodadvances.2019000975

[7] Stevens SM, Woller SC, Kreuziger LB, Bounameaux H, Doerschug K, Geersing GJ, et al. Antithrombotic Therapy for VTE Disease: Second Update of the CHEST Guideline and Expert Panel Report. Chest. 2021; 160: e545–e608. https://doi.org/10.1016/j.chest.2021.07.055

[8] Caprini JA. Thrombosis risk assessment as a guide to quality patient care. Disease-a-month: DM. 2005; 51: 70–78. https://doi.org/10.1016/j.disamonth.2005.02.003

[9] Pannucci CJ, Swistun L, MacDonald JK, Henke PK, Brooke BS. Individualized Venous Thromboembolism Risk Stratification Using the 2005 Caprini Score to Identify the Benefits and Harms of Chemoprophylaxis in Surgical Patients: A Meta-analysis. Annals of Surgery. 2017; 265: 1094–1103. https://doi.org/10.1097/SLA.0000000000002126

[10] Bahl V, Hu HM, Henke PK, Wakefield TW, Campbell DA, Jr, Caprini JA. A validation study of a retrospective venous thromboembolism risk scoring method. Annals of Surgery. 2010; 251: 344–350. https://doi.org/10.1097/SLA.0b013e3181b7fca6

[11] MAHONEY FI, BARTHEL DW. FUNCTIONAL EVALUATION: THE BARTHEL INDEX. Maryland State Medical Journal. 1965; 14: 61–65.

[12] Collin C, Wade DT, Davies S, Horne V. The Barthel ADL Index: a reliability study. International Disability Studies. 1988; 10: 61–63. https://doi.org/10.3109/09638288809164103

[13] von Elm E, Altman DG, Egger M, Pocock SJ, Gøtzsche PC, Vanden-

broucke JP, et al. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: guidelines for reporting observational studies. Lancet (London, England). 2007; 370: 1453–1457. https://doi.org/10.1016/S0140-6736(07)61602-X

[14] National Institute for Health and Care Excellence: Clinical Guidelines. In Venous thromboembolic diseases: diagnosis, management and thrombophilia testing. National Institute for Health and Care Excellence (NICE) Copyright © NICE: London. 2023.

[15] Ortel TL, Neumann I, Ageno W, Beyth R, Clark NP, Cuker A, et al. American Society of Hematology 2020 guidelines for management of venous thromboembolism: treatment of deep vein thrombosis and pulmonary embolism. Blood Advances. 2020; 4: 4693–4738. https://doi.org/10.1182/bloodadvances.2020001830

[16] Stekhoven DJ, Bühlmann P. MissForest–non-parametric missing value imputation for mixed-type data. Bioinformatics (Oxford, England). 2012; 28: 112–118. https://doi.org/10.1093/bioinformatics/btr597

[17] Waljee AK, Mukherjee A, Singal AG, Zhang Y, Warren J, Balis U, et al. Comparison of imputation methods for missing laboratory data in medicine. BMJ Open. 2013; 3: e002847. https://doi.org/10.1136/bmjopen-2013-002847

[18] Peduzzi P, Concato J, Kemper E, Holford TR, Feinstein AR. A simulation study of the number of events per variable in logistic regression analysis. Journal of Clinical Epidemiology. 1996; 49: 1373–1379. https://doi.org/10.1016/s0895-4356(96)00236-3

[19] Vittinghoff E, McCulloch CE. Relaxing the rule of ten events per variable in logistic and Cox regression. American Journal of Epidemiology. 2007; 165: 710–718. https://doi.org/10.1093/aje/kwk052

[20] Austin PC. Balance diagnostics for comparing the distribution of baseline covariates between treatment groups in propensity-score matched samples. Statistics in Medicine. 2009; 28: 3083–3107. https://doi.org/10.1002/sim.3697

[21] Cronin M, Dengler N, Krauss ES, Segal A, Wei N, Daly M, et al. Completion of the Updated Caprini Risk Assessment Model (2013 Version). Clinical and Applied Thrombosis/hemostasis: Official Journal of the International Academy of Clinical and Applied Thrombosis/Hemostasis. 2019; 25: 1076029619838052. https://doi.org/10.1177/1076029619838052

[22] Swanson E. Venous Thromboembolism Risk Stratification and Chemoprophylaxis: A Meta-Analysis Finds No Benefit, More Risk. Plastic and Reconstructive Surgery. Global Open. 2017; 5: e1356. https://doi.org/10.1097/GOX.0000000000001356

[23] Wu L, Cheng B. A nomogram to predict postoperative deep vein thrombosis in patients with femoral fracture: a retrospective study. Journal of Orthopaedic Surgery and Research. 2023; 18: 463. https://doi.org/10.1186/s13018-023-03931-1

[24] Wang P, Yang Y, Zheng L, Qi X, Yan S, Dong H. The predicted value for venous thromboembolism based on a modified model of caprini combined with fasting blood glucose and D-dimer: a retrospective study. BMC Musculoskeletal Disorders. 2025; 26: 130. https://doi.org/10.1186/s12891-024-08133-2

[25] Wolberg AS, Rosendaal FR, Weitz JI, Jaffer IH, Agnelli G, Baglin T, et al. Venous thrombosis. Nature Reviews. Disease Primers. 2015; 1: 15006. https://doi.org/10.1038/nrdp.2015.6

[26] Alsuwaylihi A, O'Connor D, Joshi GP, Kehlet H, Lobo DN. Importance of early postoperative mobilization: comprehensive review. BJS Open. 2025; 10: zrag016. https://doi.org/10.1093/bjsopen/zrag016

[27] Pearse EO, Caldwell BF, Lockwood RJ, Hollard J. Early mobilisation after conventional knee replacement may reduce the risk of postoperative venous thromboembolism. The Journal of Bone and Joint Surgery. British Volume. 2007; 89: 316–322. https://doi.org/10.1302/0301-620X.89B3.18196

[28] Chua MJ, Hart AJ, Mittal R, Harris IA, Xuan W, Naylor JM. Early mobilisation after total hip or knee arthroplasty: A multicentre prospective observational study. PloS One. 2017; 12: e0179820. https://doi.org/10.1371/journal.pone.0179820

[29] Switzer JA, O'Connor MI. AAOS Management of Hip Fractures in Older Adults Evidence-based Clinical Practice Guideline. The Journal of the American Academy of Orthopaedic Surgeons. 2022; 30: e1297–e1301. https://doi.org/10.5435/JAAOS-D-22-00273

© 2026 The Author(s).

