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ORIGINAL RESEARCH

# Prevalence, Related Factors and Outcomes of Pre-Operative Anemia in Patients Undergoing Hip Arthroplasty: A Retrospective Observational Study from Vietnam

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**Background:** Managing pre-operative anemia is an essential element of the Enhanced Recovery After Surgery program. In developing nations, a high prevalence of pre-operative anemia and worse outcomes are predicted for patients undergoing hip arthroplasty. However, this area remains a significant research gap in these healthcare settings.

**Purpose:** The study aims to determine the prevalence, related factors, and outcomes of pre-operative anemia in hip arthroplasty patients.

**Methods:** This retrospective observational study used descriptive statistics to determine the prevalence of pre-operative anemia and employed multivariable logistic regression to identify its associated factors. Propensity score matching (PSM) was applied to reduce confounding before outcome comparisons, with inverse probability of treatment weighting (IPTW) used as a sensitivity analysis. The primary outcome was post-operative complications, with secondary and tertiary outcomes focusing on infection conditions, length of stay, clinical symptoms, and care demands.

**Results:** The study involved 769 patients, with a pre-operative anemia prevalence of 41.1%. Pre-operative factors related independently to anemia included aging, body mass index, creatinine levels, hip fractures, hyponatremia, and atrial fibrillation. After PSM, those with pre-operative anemia had significantly higher rates of post-operative composite complications (37.6% and 25.9%, p=0.017), infection complications (22.8% and 11.2%, p=0.003), urinary tract infections (10.2% and 3.6%, p=0.017), and sepsis (14.2% and 6.1%, p=0.012). Additionally, these patients experienced post-operative anemia (89.8% vs 74.6%, p<0.001), a higher need for blood transfusions (44.7% vs 10.7%, p<0.001), and a longer post-operative length of stay (7.2 vs 6.8 days, p<0.001). These findings remained consistent after IPTW adjustment.

**Conclusion:** In our setting, pre-operative anemia is highly prevalent among patients undergoing hip arthroplasty and is associated with adverse post-operative outcomes. Therefore, this study emphasizes the need to identify these patients as high risk for post-operative complications.

**Keywords:** anemia, arthroplasty, replacement, hip, post-operative complications

## Introduction

Hip arthroplasty is an effective procedure for end-stage hip disease and hip fractures, and its demand is rising globally due to population ageing and expanding surgical indications.[1,2] However, this increasing demand places a growing burden on

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healthcare systems, particularly in the management of post-operative outcomes and adverse events.[3] The incidence of hip fractures and subsequent hip arthroplasty is increasing rapidly in developing countries, driven by population ageing and a high burden of comorbidities, often resulting in prolonged hospitalisation and increased post-operative complications.[4,5] Hip arthroplasty performed for hip fractures is associated with a higher burden of comorbidities, particularly infectious, cardiovascular, and respiratory conditions, and increased mortality compared with elective procedures.[6,7]

Pre-operative anemia is a prevalent and modifiable risk factor for adverse outcomes in patients undergoing hip arthroplasty.[7–9] This condition can worsen outcomes after hip arthroplasty by creating a peri-operative oxygen supply-demand mismatch, reducing arterial oxygen content and tissue oxygen delivery, and forcing compensatory increases in cardiac workload.[10] Additionally, anemia also functions as a marker for systemic inflammation, malnutrition, chronic kidney disease, and occult bleeding, thereby compounding immune dysfunction and impairing wound healing in hip arthroplasty cohorts.[11–13] These risks are particularly pronounced in elderly patients, who constitute the majority of the hip arthroplasty population and often have reduced cardiopulmonary reserve.[14] Therefore, managing pre-operative anemia is an essential element of the Enhanced Recovery After Surgery (ERAS) program for patients scheduled for hip and knee arthroplasty.[15]

A recent meta-analysis reported a global pre-operative anemia prevalence of approximately 22% in patients awaiting arthroplasty, with marked regional variation. However, most data were derived from developed countries, where advanced healthcare systems may attenuate the associated risks.[8] In contrast, studies conducted in developing countries have reported higher prevalence rates, ranging from nearly one-fourth to one-half of patients.[7,11,16,17] Notably, in the setting of hip fracture surgery, pre-operative anemia is even more prevalent, with reported rates exceeding one-half of patients in China.[7] Within developing countries, factors like racial characteristics, nutritional deficiencies, inadequate health screenings, and substandard medical facilities likely increase the prevalence and severity of pre-operative anemia.[18,19] Pre-operative anemia is associated with increased post-operative morbidity and mortality, with a greater impact in low- and middle-income countries (LMICs).[9] Concurrently, LMICs are experiencing a growing burden of hip fractures, which further strains resource-limited healthcare systems where post-operative infection remains a common and challenging complication following hip arthroplasty.[4,19]

Population-based data on the characteristics of pre-operative anemia among patients undergoing hip arthroplasty in developing or LMICs remain scarce. Although several studies have examined the association between anemia and clinical outcomes, evidence specifically focusing on hip arthroplasty performed for hip fracture is limited.[11,16,17,20] Furthermore, data on anemia risk factors and post-operative outcomes, particularly in infections, transfusion requirements, and length of hospital stay (LOS), in resource-limited settings remain insufficient. Therefore, we conducted this study to determine the prevalence of pre-operative anemia among patients undergoing hip arthroplasty in a developing country. We also examined associated factors and assessed their impact on post-operative outcomes. The findings may inform the development of context-specific peri-operative management strategies in similar settings.

# Methods

## Study Settings

This retrospective observational study was conducted at the University Medical Center Ho Chi Minh City and included patients who underwent hip arthroplasty between 2022 and 2024. Patients were categorized into two groups based on the presence or absence pre-operative anemia. The study was reported in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines.[21] This study used the same institutional hip arthroplasty cohort previously reported for a different primary objective (ERAS effectiveness),[22] but represents a pre-specified secondary analysis addressing an independent research question on pre-operative anemia with distinct aims and analytic models.

## Patients

Eligible patients were adults aged eighteen years or older who underwent elective hip arthroplasty during the study period. Patients with American Society of Anesthesiologists (ASA) physical status classification of IV or higher were excluded because severe systemic disease confers a high baseline risk of complications and transfusion independent of anemia. Emergency procedures, multiple concurrent traumatic injuries or operations, bilateral arthroplasty, and complex hip conditions, including severe deformity or instability such as Crowe type IV dysplasia and prior spinal surgery, were excluded to minimise heterogeneity in surgical complexity and peri-operative management. Finally, patients with missing essential peri-operative variables were excluded to avoid outcome misclassification and to preserve the integrity of multivariable analyses.

## Anemia Management

At our institution, peri-operative care for hip arthroplasty was partially aligned with ERAS guidelines. During the study period, anemia assessment, particularly evaluation of underlying causes, and management were not fully standardized according to international recommendations, partly due to the lack of national consensus and the limited availability of intravenous iron.[23] Pre-operatively, hemoglobin was measured as part of routine assessment, and nutritional status was formally evaluated by multidisciplinary specialists to guide peri-operative optimization. Nutritional risk was screened at admission using the Nutritional Risk Screening 2002 (NRS-2002) tool to identify patients at nutritional risk, who may benefit from peri-operative nutritional support.[24] Transfusions were administered according to hemoglobin thresholds, with adjustments based on patient-specific factors such as age and pre-existing cardiovascular disease. Laboratory markers for potential etiologies of anemia, including iron indices, vitamin B12 and folate levels, and inflammatory markers, were not routinely measured in all patients. Oral iron supplementation and erythropoietin were not routinely administered within the study protocol.

## Peri-Operative Care and Data Collection

Data were extracted from electronic medical records using a predefined case-report form. During the pre-operative phase, collected variables included demographics, surgical diagnosis, smoking status, comorbidities, physical and nutritional status, and baseline parameters. Optimization of existing comorbidities was undertaken when feasible and clinically indicated before surgery. ERAS participation was recorded as a binary variable based on the ERAS checklist, consistent with the prior study, as element-level adherence could not be reliably quantified in this cohort.[22] Information regarding pre-operative anemia treatments was abstracted when available.

Intra-operatively, data were collected from anesthesia records and operative notes. Hemodynamic management followed predefined target ranges, and administration of intravenous fluids, vasopressors, or antihypertensive agents was recorded. Surgical characteristics, including type of hip arthroplasty, laterality, and surgical indication, as well as anesthesia-related variables, were documented. Medication use, including vasoactive agents, analgesics, tranexamic acid, neuromuscular blocking agents, reversal strategies, and fluid balance, was systematically collected. Active temperature management strategies were employed to maintain normothermia throughout the procedure. Intra-operative fluid balance was defined as the difference between total measured fluid input (crystalloids, colloids, and blood products) and measured outputs (urine output and estimated blood loss), normalized to body weight.

Post-operative management followed a multimodal analgesic strategy, and the use of non-opioid and opioid analgesics was recorded. Antithrombotic therapy and antiplatelet agents were also documented. Prophylactic antibiotics were administered according to institutional protocols, and therapeutic antibiotics were initiated when infection was clinically suspected. The earliest available post-operative laboratory results, if any, were also recorded. Patients were discharged upon meeting standardized criteria, including removal of surgical drains, absence of clinical signs of infection, adequate pain control with oral medications, independent basic mobility, tolerance of oral intake, and no requirement for supplemental oxygen.

## Prevalences

All available complete blood count results were reviewed to minimize underdiagnosis of anemia, as testing was frequently repeated during hospitalization. The lowest recorded hemoglobin levels in the pre-operative and post-operative periods were used to identify anemia. Pre-operative anemia was defined as anemia occurring at any time in the pre-operative stage. According to World Health Organization criteria, anemia is diagnosed at hemoglobin levels below 12 $g.dL^{-1}$ in non-pregnant women and below 13 $g.dL^{-1}$ in men. Among patients with anemia, severe anemia is defined as hemoglobin below 8 $g.dL^{-1}$, moderate anemia is 8 to 11 $g.dL^{-1}$, and mild anemia is above 11 $g.dL^{-1}$.[25] Changes in anemia severity were also evaluated between the pre-operative and post-operative stages. Concurrent etiologies of anemia were classified using a standard mechanistic framework, including hemorrhage, inflammation or chronic disease, decreased red blood cell production, and others. Red blood cell morphology was classified using mean corpuscular volume (MCV) and mean corpuscular hemoglobin concentration (MCHC).[26]

## Related Factors

Factors associated with pre-operative anemia were evaluated using baseline patient characteristics, including age, sex, body mass index, and surgical indication, categorized as fracture-related or elective hip arthroplasty. Comorbidity burden was quantified using the Charlson Comorbidity Index, while nutritional and physical status were assessed using the NRS-2002 and the ASA classification, respectively. Pre-operative hemoglobin levels and anemia prevalence were further compared between fracture-related procedures, primarily femoral neck and intertrochanteric fractures, and elective arthroplasty for avascular necrosis and osteoarthritis to elucidate the association between surgical indication and pre-operative anemia.

## Outcomes

The primary outcomes concentrate on post-operative clinical complications affecting major organ systems. These complications included infections, cardiovascular, respiratory, urinary, gastrointestinal, and neurological disorders, as well as their composite outcomes.

Secondary outcomes of the study focused on organ-specific and systemic infections, including urinary tract infections, surgical site infections, cutaneous ulcers, pneumonia, sepsis, and septic shock. The diagnosis of sepsis and septic shock was determined based on the SEPSIS-3 criteria, ensuring standardized and accurate identification of these conditions.[27]

Tertiary outcomes of the study included a range of clinical care needs and post-operative symptoms experienced by patients. These outcomes encompassed intensive care unit (ICU) admissions, re-operations, LOS, and the necessity for therapeutic antibiotics and invasive mechanical ventilation. Additionally, peri-operative transfusions were monitored. Clinical symptoms reported included nausea and vomiting, constipation, urinary retention, insomnia, severe pain that required rescue opioids, and the presence of post-operative anemia. The earliest post-operative laboratory results were analysed separately in patients for whom such data were available.

## Propensity Score Matching

Propensity score matching (PSM) was used to balance covariates between patients with and without pre-operative anemia, accounting for baseline characteristics such as age, BMI, and comorbidities, as well as intervention factors including surgical details and ERAS program involvement. Covariates showing clinical or statistical differences between groups before matching were considered potential confounders and included in the propensity score model. Propensity score estimation and adjustment were performed on a complete-case sample, including only patients with complete data for all covariates in the propensity score model. Propensity scores were estimated via logistic regression, and patients were matched by nearest-neighbor matching with a caliper of 0.1. Post-matching balance was verified using absolute standardized mean differences (aSMDs), with values $< 0.1$ indicating acceptable balance.[28] Variables not included in the matching process were subsequently compared between groups using conventional statistical tests to identify residual differences.

## Sample Size Estimation

To determine the prevalence of pre-operative anemia, we referenced a study from a neighboring developing country, China, which reported a prevalence of 33.6%. Using an alpha error of 0.01 and a margin of error of 5%, the required sample size for estimating a proportion with absolute precision was 593 patients.[20] We assessed differences in post-operative composite complications as the primary outcome for outcome comparisons. A two-sided Chi-square test was conducted at the 5% significance level with 80% power. We based on a reported in-hospital complication rate of 28.9% in a study in the United States.[29] Assuming a 15% higher complication rate in the pre-operative anemia group, at least 161 patients per group were required to achieve sufficient statistical power. Considering a 1:1 ratio for PSM and an expected 50% post-matching attrition, a minimum of 644 patients was necessary to ensure statistical validity.

## Statistical Analysis

Statistical analyses were performed using R software (version 4.3.2; R Foundation for Statistical Computing, Austria) within the RStudio environment (version 2023.06.2 + 561).

The distribution of continuous variables was assessed using formal normality tests, including Shapiro–Wilk or Kolmogorov–Smirnov as appropriate. Categorical variables were summarized as counts and percentages; continuous variables with normal distributions were presented as means with standard deviations; and non-normally distributed variables were presented as medians with interquartile ranges. Group comparisons for categorical variables were performed using the Chi-square or Fisher's exact test; continuous variables were compared using the two-sample *t*-test or the Wilcoxon rank-sum test, as appropriate. Between-group comparisons were conducted using a complete-case approach, including only patients with non-missing values for the variable being analyzed.

Multivariable logistic regression analysis was performed to identify factors independently associated with pre-operative anemia. Candidate variables were selected based on clinical relevance, and those with a p-value < 0.20 in univariable analyses were included in the multivariable model. Adjusted odds ratios (aORs) with 95% confidence intervals (CIs) were reported. All tests were two-sided, and p-values < 0.05 were considered statistically significant.

## Sensitivity Analysis

To assess the robustness of the association between pre-operative anemia and post-operative outcomes, inverse probability of treatment weighting (IPTW) was performed using the same propensity score specification as in the primary PSM. Stabilized weights were applied and truncated at the 1st and 99th percentiles to reduce the influence of extreme weights. Similar to PSM, covariate balance after weighting was evaluated using aSMD, and all variables were examined descriptively between groups after weighting to assess residual imbalance. Post-operative outcomes were then analyzed in the weighted sample using regression models with robust (sandwich) standard errors to account for weighting.

# Results

## Patients

A total of 769 patients were included in the study, of whom 316 had pre-operative anemia, and 453 did not (Figure 1). These patients were analyzed to determine prevalence and related factors. A PSM was performed, yielding two matched groups of 197 patients each, for a total of 394 patients included in the outcome comparison.

Pre-operative baseline characteristics and interventions are summarized in Tables 1 and 2. Compared with non-anemic patients, those with anemia were older (median: 75.0 vs 61.0 years) and had a lower BMI (mean: 21.6 vs 23.0 kg.m$^{-2}$, both p<0.001). Hip fractures accounted for 47.6% (366/769) of arthroplasty indications and were more frequent in patients with anemia. Pre-operative hemoglobin was lower (11.0 vs 13.8 g.dL$^{-1}$) and C-reactive protein (CRP) higher (24.3 vs 9.3 mg.L$^{-1}$) in the anemic group. The median estimated intra-operative blood loss was 200 mL, and the median net fluid balance exceeded 10.0 mL.kg$^{-1}$ in both groups.

## Prevalences

In the pre-operative stage, 31.1% of patients had mild anemia, 7.9% had moderate anemia, and 2.1% had severe anemia (Figure 2). The prevalence of anemia was 41.1% pre-operatively and increased to 79.1% post-operatively. There was a marked increase in the proportions of moderate (7.9% to 32.9%) and severe anemia (2.1% to 15.6%) among patients undergoing hip arthroplasty. Among patients who were non-anemic pre-operatively (58.9%), 48.4% developed mild anemia, 21.9% moderate anemia, and 3.9% severe anemia post-operatively.

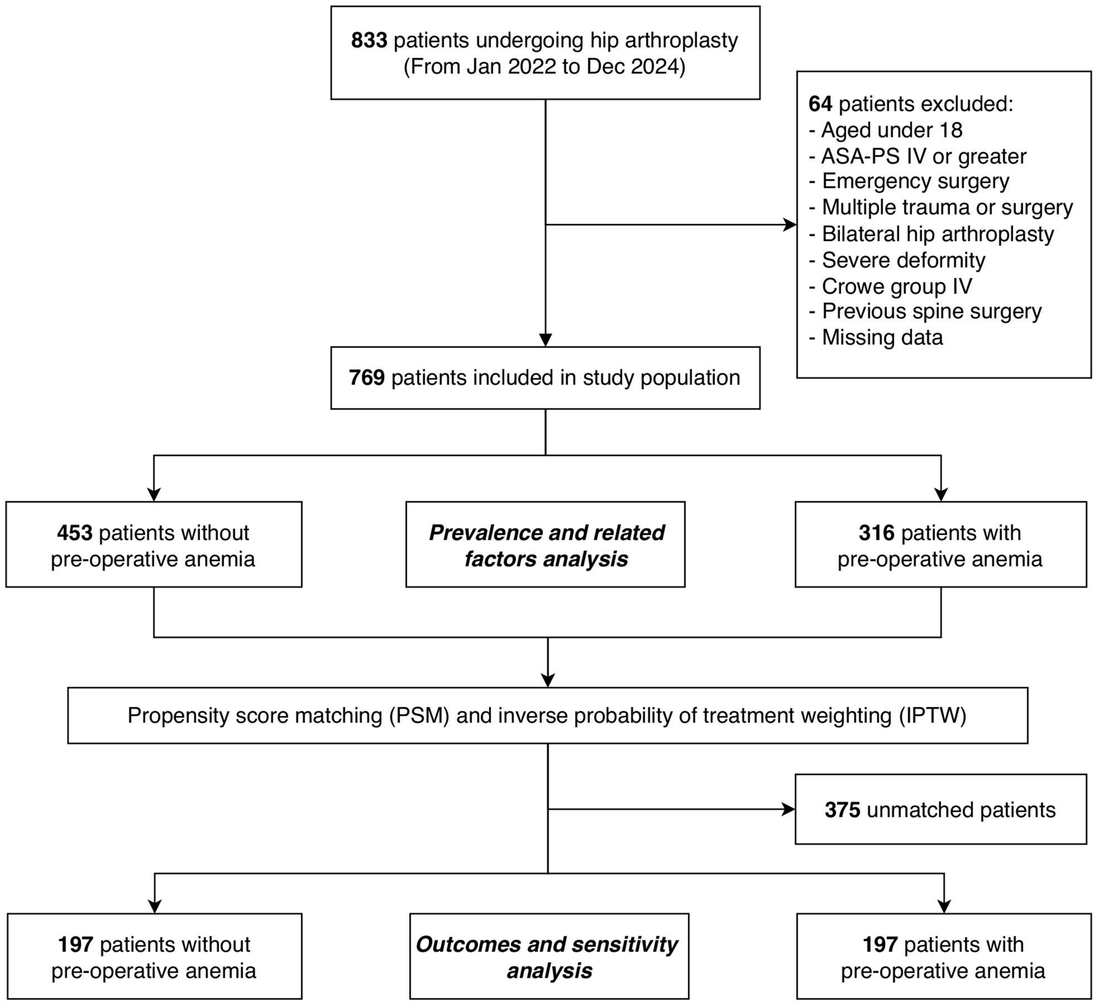



**Figure 1** Flow chart of this study.
**Notes**: Bold values indicate the number of participants included in the analysis for each study objective.
**Abbreviation**: ASA-PS, American Society of Anesthesiologists physical status.

## Characteristics

Among patients with pre-operative anemia (Table 3), the anemia was predominantly normocytic (81.3%) and normochromic (78.2%). Fracture-related indications were frequent, including femoral neck (36.7%) and intertrochanteric fractures (31.6%). Commonly observed conditions included hypoalbuminemia (22.2%), chronic kidney disease (20.6%), and avascular necrosis (25.6%). Pre-operative management showed limited use of oral iron supplementation (0.6%) and erythropoiesis-stimulating agents (1.9%).

## Related Factors

Pre-operative anemia was more prevalent in fracture-related hip arthroplasty than in elective procedures (59.0% vs 24.8%; Figure 3), with mean hemoglobin levels of 11.8 and 13.5 g.dL$^{-1}$, respectively. Intertrochanteric fractures showed the highest anemia prevalence (78.7%), with a mean hemoglobin level of 11.0 g.dL$^{-1}$.

After multivariable analysis (Figure 4), advanced age was associated with pre-operative anemia (aOR 1.033 per year, p=0.007), whereas higher BMI was protective (aOR 0.896 per kg.m$^{-2}$, p<0.001). Hip fracture (aOR 1.782), elevated creatinine (aOR 4.022 per mg.dL$^{-1}$), hyponatremia (aOR 2.530), and atrial fibrillation (aOR 6.171) were independently associated with higher odds of anemia (all p<0.05).

**Table 1** Baseline Features of the Study Population (n=769)

| Variables | Pre-Operative Anemia Absence (n=453) | Pre-Operative Anemia Presence (n=316) | p-value |
|---|---|---|---|
| **Demographics** | | | |
| Age, years | 61.0 (49.0–72.0) | 75.0 (63.8–84.0) | <0.001 |
| Male, n (%) | 228 (50.3) | 104 (32.9) | <0.001 |
| BMI, $kg.m^{-2}$ | 23.0 ± 3.4 | 21.6 ± 3.6 | <0.001 |
| Surgical diagnosis, n (%) | | | <0.001 |
| • Avascular necrosis | 259 (57.2) | 81 (25.6) | |
| • Femoral neck fracture | 123 (27.2) | 116 (36.7) | |
| • Intertrochanteric fracture | 27 (6.0) | 100 (31.6) | |
| • Osteoarthritis | 44 (9.7) | 19 (6.0) | |
| **Comorbidities** | | | |
| Smoking, n (%) | 54 (11.9) | 14 (4.4) | <0.001 |
| Alcohol use, n (%) | 38 (8.4) | 10 (3.2) | 0.005 |
| Hypertension, n (%) | 277 (61.1) | 248 (78.5) | <0.001 |
| CVD, n (%) | 86 (19.0) | 110 (34.8) | <0.001 |
| CKD, n (%) | 16 (3.5) | 65 (20.6) | <0.001 |
| Pulmonary TB, n (%) | 18 (4.0) | 21 (6.6) | 0.135 |
| COPD, n (%) | 5 (1.1) | 11 (3.5) | 0.044 |
| Asthma, n (%) | 9 (2.0) | 15 (4.7) | 0.051 |
| Diabetes, n (%) | 112 (24.7) | 115 (36.4) | <0.001 |
| Dyslipidemia, n (%) | 146 (32.2) | 99 (31.3) | 0.853 |
| Heart failure, n (%) | 15 (3.3) | 26 (8.2) | 0.005 |
| Cushing syndrome, n (%) | 48 (10.6) | 35 (11.1) | 0.926 |
| Stroke sequelae, n (%) | 34 (7.5) | 30 (9.5) | 0.396 |
| Atrial fibrillation, n (%) | 2 (0.4) | 13 (4.1) | <0.001 |
| Hepatitis, n (%) | 27 (6.0) | 18 (5.7) | 1.000 |
| Thyroid disease, n (%) | 15 (3.3) | 19 (6.0) | 0.106 |
| Cancer, n (%) | 18 (4.0) | 21 (6.6) | 0.135 |
| Peptic ulcer, n (%) | 17 (3.8) | 18 (5.7) | 0.273 |
| Dementia, n (%) | 6 (1.3) | 18 (5.7) | 0.001 |
| Cirrhosis, n (%) | 5 (1.1) | 8 (2.5) | 0.220 |
| Osteoporosis, n (%) | 20 (4.4) | 24 (7.6) | 0.087 |
| CTD, n (%) | 9 (2.0) | 8 (2.5) | 0.798 |
| Charlson comorbidity index | 2.0 (1.0–4.0) | 4.0 (3.0–5.0) | <0.001 |
| Physical status, n (%) | | | <0.001 |
| • ASA-I | 117 (25.8) | 47 (14.9) | |
| • ASA-II | 238 (52.5) | 137 (43.4) | |
| • ASA-III | 98 (21.6) | 132 (41.8) | |
| **Laboratory features** | | | |
| WBC, $G.L^{-1}$ | 8.9 (7.1–10.8) | 9.0 (7.0–11.4) | 0.615 |
| RBC, $T.L^{-1}$ | 4.6 (4.3–5.0) | 3.8 (3.4–4.1) | <0.001 |
| Hb, $g.dL^{-1}$ | 13.8 (13.0–14.6) | 11.0 (10.1–11.7) | <0.001 |
| PLT, $G.L^{-1}$ | 269 (225–320) | 264 (201–362) | 0.791 |
| Glucose, $mmol.L^{-1}$ | 5.5 (4.8–6.8) | 6.1 (5.1–8.3) | <0.001 |
| CRP, $mg.L^{-1}$ | 9.3 (3.4–36.7) | 24.3 (8.6–56.6) | <0.001 |
| Ejection fraction, % | 67.4 ± 8.4 | 67.1 ± 8.8 | 0.706 |
| INR, ratio | 1 (0.9–1.0) | 1 (1.0–1.1) | <0.001 |
| Fibrinogen, $g.L^{-1}$ | 4.0 (3.3–4.7) | 4.5 (3.5–5.6) | <0.001 |
| Urea, $mmol.L^{-1}$ | 4.7 (3.7–5.9) | 5.5 (4.1–6.9) | <0.001 |
| Creatinine, $mg.dL^{-1}$ | 0.8 (0.6–0.9) | 0.8 (0.6–0.9) | 0.309 |
| eGFR, $mL.min^{-1}$ | 93.5 ± 21.1 | 81.1 ± 26.9 | <0.001 |

(*Continued*)

**Table 1** (Continued).

| Variables | Pre-Operative Anemia Absence (n=453) | Pre-Operative Anemia Presence (n=316) | p-value |
|---|---|---|---|
| AST, $IU.L^{-1}$ | 27 (21.0–34.5) | 26 (20.0–34.0) | 0.305 |
| ALT, $IU.L^{-1}$ | 24 (16.0–37.0) | 17.7 (12.0–26.0) | <0.001 |
| HbA1c, % | 6.8 (6.0–8.7) | 6.8 (5.9–8.6) | 0.656 |
| Sodium, $mmol.L^{-1}$ | 140 (138–142) | 138 (136–141) | <0.001 |
| Potassium, $mmol.L^{-1}$ | 3.8 (3.5–4.0) | 3.8 (3.5–4.2) | 0.062 |
| Chloride, $mmol.L^{-1}$ | 104 (102–106) | 104 (101–107) | 0.141 |

**Abbreviations**: ASA, American Society of Anesthesiologists; AST, aspartate aminotransferase; BMI, body mass index; CKD, chronic kidney disease; COPD, chronic obstructive pulmonary disease; CRP, C-reactive protein; CVD, cardiovascular disease; CTD, Connective tissue disease; eGFR, estimated glomerular filtration rate; Hb, hemoglobin; HbA1c, hemoglobin A1C; Hct, hematocrit; INR, international normalized ratio; NRS, Nutritional Risk Screening; PLT, platelet count; RBC, red blood cell count; TB, tuberculosis; WBC, white blood cell count.

**Table 2** Intervention and Treatment Comparisons in Unadjusted Cohort (n=769)

| Variables | Pre-Operative Anemia Absence (n=453) | Pre-Operative Anemia Presence (n=316) | p-value |
|---|---|---|---|
| **Pre-operative stage** | | | |
| ERAS intervention, n (%) | 235 (51.9) | 121 (38.3) | <0.001 |
| Prophylactic antibiotics, n (%) | 450 (99.3) | 303 (95.9) | 0.001 |
| Pre-operative LOS, days | 1.2 (1.0–1.4) | 1.4 (1.1–2.8) | <0.001 |
| **Intra-operative stage** | | | |
| Surgery time, minutes | 80 (65–90) | 75 (60–90) | 0.097 |
| Right hip arthroplasty, n (%) | 219 (48.3) | 145 (45.9) | 0.550 |
| Total hip arthroplasty, n (%) | 356 (78.6) | 171 (54.1) | <0.001 |
| Primary hip arthroplasty, n (%) | 427 (94.3) | 297 (94.0) | 0.998 |
| Anesthesia time, minutes | 130 (110–145) | 127 (110–149) | 0.812 |
| General anesthesia, n (%) | 392 (86.5) | 291 (92.1) | 0.022 |
| Regional analgesia, n (%) | 210 (46.4) | 137 (43.4) | 0.453 |
| Ephedrine use, n (%) | 139 (30.7) | 132 (41.8) | 0.002 |
| Epinephrine use, n (%) | 2 (0.4) | 1 (0.3) | 1.000 |
| Phenylephrine use, n (%) | 34 (7.5) | 46 (14.6) | 0.002 |
| Noradrenalin use, n (%) | 10 (2.2) | 26 (8.2) | <0.001 |
| Nicardipine use, n (%) | 26 (5.7) | 21 (6.6) | 0.717 |
| Tranexamic acid use, n (%) | 159 (35.1) | 90 (28.5) | 0.064 |
| Acetaminophen use, n (%) | 371 (81.9) | 277 (87.7) | 0.040 |
| NSAID use, n (%) | 84 (18.5) | 24 (7.6) | <0.001 |
| Nefopam use, n (%) | 274 (60.5) | 201 (63.6) | 0.423 |
| Tramadol use, n (%) | 176 (38.9) | 131 (41.5) | 0.515 |
| Morphine use, n (%) | 13 (2.9) | 13 (4.1) | 0.461 |
| Fluid balance, $mL.kg^{-1}$ | 10.8 ± 7.6 | 10.5 ± 9.4 | 0.610 |
| Estimated blood loss, mL | 200 (150–400) | 200 (100–350) | 0.428 |
| NMBA use, n (%) | | | <0.001 |
| • None | 92 (20.3) | 48 (15.2) | |
| • Neostigmine | 199 (43.9) | 83 (26.3) | |
| • Sugammadex | 162 (35.8) | 185 (58.5) | |

(*Continued*)

**Table 2** (Continued).

| Variables | Pre-Operative Anemia Absence (n=453) | Pre-Operative Anemia Presence (n=316) | p-value |
|---|---|---|---|
| **Post-operative stage** | | | |
| Acetaminophen use, n (%) | 451 (99.6) | 313 (99.1) | 0.406 |
| Nefopam use, n (%) | 310 (68.4) | 224 (70.9) | 0.518 |
| NSAID use, n (%) | 310 (68.4) | 268 (84.8) | <0.001 |
| Pregabalin use, n (%) | 267 (58.9) | 192 (60.8) | 0.666 |
| Tramadol use, n (%) | 271 (59.8) | 174 (55.1) | 0.215 |
| Morphine use, n (%) | 106 (23.4) | 62 (19.6) | 0.246 |
| Enoxaparin use, n (%) | 450 (99.3) | 305 (96.5) | 0.005 |
| NOACs use, n (%) | 436 (96.2) | 289 (91.5) | 0.008 |
| Heparin use, n (%) | 3 (0.7) | 12 (3.8) | 0.003 |
| Aspirin use, n (%) | 34 (7.5) | 26 (8.2) | 0.817 |
| P2Y12 inhibitors use, n (%) | 35 (7.7) | 35 (11.1) | 0.144 |

**Abbreviations**: Intra-op, intra-operative; ERAS, enhanced recovery after surgery; LOS: length of stay; NOACs, novel oral anticoagulants; NSAID, non-steroidal anti-inflammatory drugs; NMBA, neuromuscular blocking agent; Post-op, Post-operative; Pre-op, pre-operative.

## Outcomes

Figure 5 shows a substantial reduction in baseline imbalance after adjustment, with most covariates included in the adjusted models achieving adequate balance between groups following PSM and IPTW (aSMD < 0.1). Detailed distributions of baseline characteristics and peri-operative variables before adjustment, after PSM, and IPTW are provided in Supplementary Tables S1 and S2.

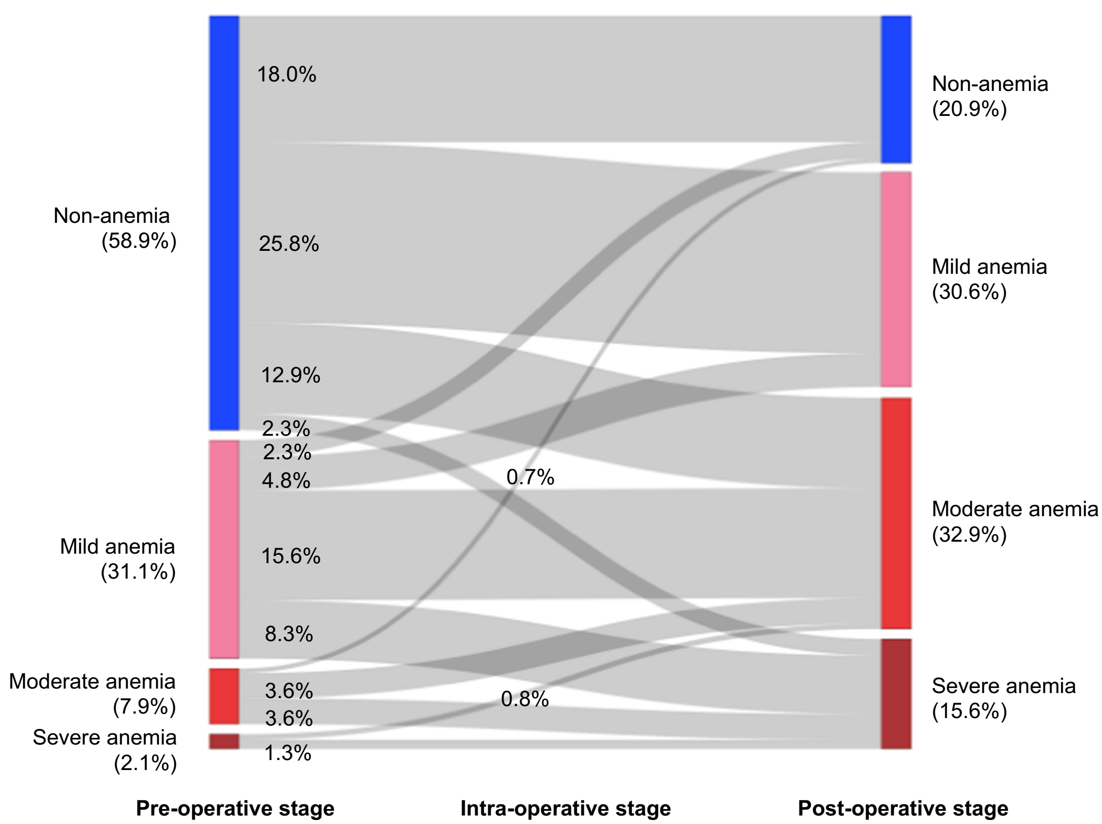



**Figure 2** The prevalence of pre-operative anemia severities and their progression to the post-operative stage.

**Table 3** Characteristics of Pre-Operative Anemia: Severities, Etiologies, Morphologies and Treatments (n = 316)

| Characteristics | Count | Percent |
|---|---|---|
| **Severities** | | |
| • Mild anemia | 239 | 75.6 |
| • Moderate anemia | 61 | 19.3 |
| • Severe anemia | 16 | 5.1 |
| **Etiologies (concurrent)** | | |
| Hemorrhagic anemia | | |
| • Femoral neck fracture | 116 | 36.7 |
| • Intertrochanteric fracture | 100 | 31.6 |
| • Major gastrointestinal bleeding | 5 | 1.6 |
| • Gastritis | 15 | 4.7 |
| • Gastric ulcer | 3 | 0.9 |
| • Duodenal ulcer | 3 | 0.9 |
| • Esophagitis | 2 | 0.6 |
| • Hemorrhoids | 3 | 0.9 |
| • Hematuria | 2 | 0.6 |
| • Epistaxis | 1 | 0.3 |
| Anemia of inflammation or chronic disease | | |
| • Avascular necrosis | 81 | 25.6 |
| • Tuberculosis | 21 | 6.6 |
| • Chronic pneumonia | 9 | 2.8 |
| • Recurrent urinary tract infections | 3 | 0.9 |
| • Systemic lupus erythematosus | 3 | 0.9 |
| • Rheumatoid arthritis | 5 | 1.6 |
| Decreased red blood cell production | | |
| • Chronic kidney disease | 65 | 20.6 |
| • Hypoalbuminemia | 70 | 22.2 |
| • Iron deficiency | 2 | 0.6 |
| • Vitamin B12 or folate deficiency | 0 | 0.0 |
| Other secondary causes of anemia | | |
| • Malignancy-related anemia | 21 | 6.6 |
| • Cirrhosis | 8 | 2.5 |
| • Chronic viral hepatitis | 18 | 5.7 |
| • Hemolytic anemia (Thalassemia) | 1 | 0.3 |
| • Corticosteroid use (Cushing's syndrome) | 35 | 11.1 |
| **Morphologies (red blood cells)** | | |
| According to MCV | | |
| • Microcytic anemia | 46 | 14.6 |
| • Normocytic anemia | 257 | 81.3 |
| • Macrocytic anemia | 13 | 4.1 |
| According to MCHC | | |
| • Hypochromic anemia | 64 | 20.3 |
| • Normochromic anemia | 247 | 78.2 |
| • Hyperchromic anemia | 5 | 1.6 |
| Combined MCV–MCHC categories | | |
| • Microcytic hypochromic anemia | 19 | 6.0 |
| • Microcytic normochromic anemia | 27 | 8.5 |
| • Normocytic hypochromic anemia | 43 | 13.6 |
| • Normocytic normochromic anemia | 210 | 66.5 |
| • Macrocytic normochromic anemia | 10 | 3.2 |
| • Others | 7 | 2.2 |

(*Continued*)

**Table 3** (Continued).

| Characteristics | Count | Percent |
|---|---|---|
| **Treatments** | | |
| • Oral Iron supplementation | 2 | 0.6 |
| • Erythropoiesis-stimulating agents | 6 | 1.9 |
| • Blood transfusion | 33 | 10.4 |
| • Nutritional support | 55 | 17.4 |

**Notes**: Etiologies were classified according to underlying pathophysiological mechanisms and were not mutually exclusive; patients could have more than one concurrent cause of anemia. Definitions: Microcytic anemia was defined as MCV < 80 fL, normocytic anemia as MCV 80–100 fL, and macrocytic anemia as MCV > 100 fL. Hypochromic anemia was defined as MCHC < 32 g/dL. Others included uncommon or mixed red blood cell indices that did not fit standard categories.
**Abbreviations**: MCV, mean corpuscular volume; MCHC, mean corpuscular hemoglobin concentration.

Regarding the primary outcomes, pre-operative anemia was associated with higher rates of composite complications (37.6% vs 25.9%, p=0.017) and infectious complications (22.8% vs 11.2%, p=0.003) (Figure 6). Secondary outcomes showed increased rates of urinary tract infection (10.2% and 3.6%, p=0.017) and sepsis (14.2% and 6.1%, p=0.012) among patients with anemia (Figure 7). For tertiary outcomes, patients with anemia had higher rates of post-operative anemia (89.8% vs 74.6%), peri-operative transfusion (44.7% vs 10.7%), longer post-operative LOS (median 7.2 vs 6.8 days), and more frequent use of therapeutic antibiotics (23.9% vs 15.2%, all p <0.05) (Table 4). These associations remained statistically significant in IPTW-adjusted analyses.

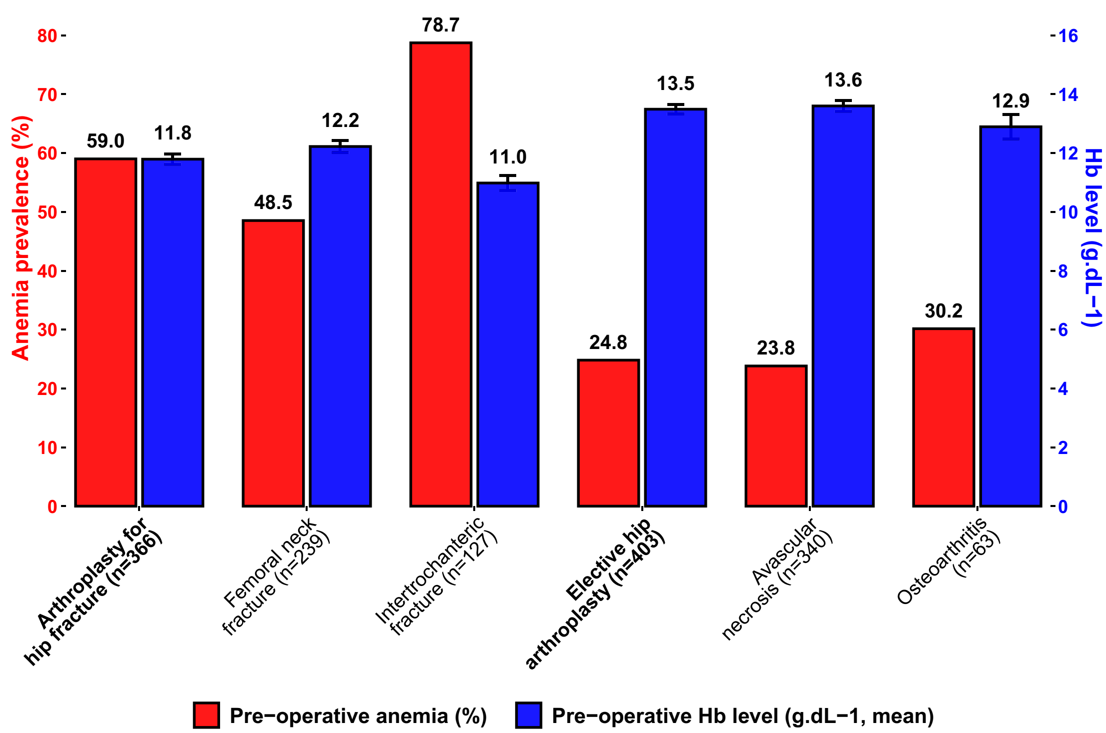
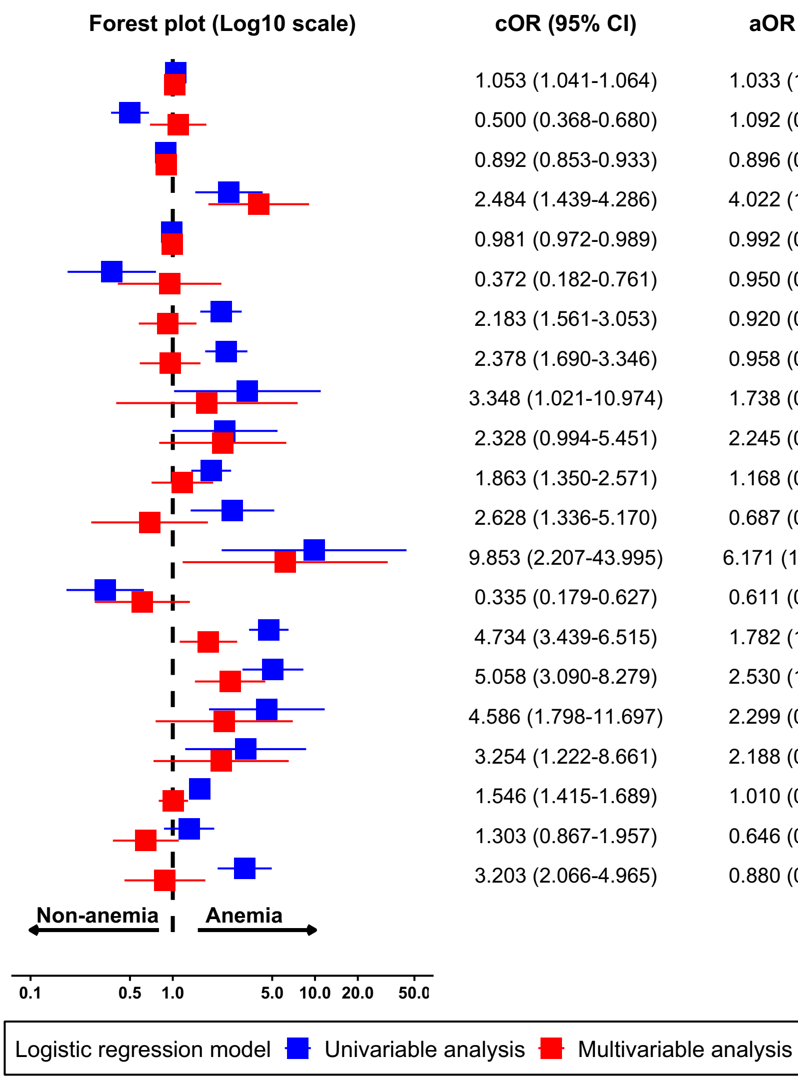



**Figure 3** Distribution of pre-operative anemia and hemoglobin levels by indication for Hip arthroplasty.
**Abbreviation**: Hb, hemoglobin.




| Covariates | cOR (95% CI) | aOR (95% CI) | P-value |
|---|---|---|---|
| Age (+1 years) | 1.053 (1.041-1.064) | 1.033 (1.009-1.057) | 0.007 |
| Male | 0.500 (0.368-0.680) | 1.092 (0.692-1.723) | 0.706 |
| BMI (+1 kg.m-2) | 0.892 (0.853-0.933) | 0.896 (0.850-0.946) | <0.001 |
| Creatinine (+1 mg.dl-1) | 2.484 (1.439-4.286) | 4.022 (1.780-9.090) | <0.001 |
| ALT (+1 IU.L-1) | 0.981 (0.972-0.989) | 0.992 (0.983-1.002) | 0.103 |
| Alcohol use | 0.372 (0.182-0.761) | 0.950 (0.411-2.196) | 0.904 |
| Hypertension | 2.183 (1.561-3.053) | 0.920 (0.577-1.467) | 0.726 |
| CVD | 2.378 (1.690-3.346) | 0.958 (0.586-1.566) | 0.864 |
| COPD | 3.348 (1.021-10.974) | 1.738 (0.400-7.548) | 0.461 |
| Asthma | 2.328 (0.994-5.451) | 2.245 (0.802-6.284) | 0.123 |
| Diabetes | 1.863 (1.350-2.571) | 1.168 (0.710-1.923) | 0.541 |
| Heart failure | 2.628 (1.336-5.170) | 0.687 (0.267-1.766) | 0.435 |
| Atrial fibrillation | 9.853 (2.207-43.995) | 6.171 (1.173-32.464) | 0.032 |
| Dyslipidemia | 0.335 (0.179-0.627) | 0.611 (0.283-1.319) | 0.209 |
| Hip fracture | 4.734 (3.439-6.515) | 1.782 (1.119-2.838) | 0.015 |
| Hyponatremia | 5.058 (3.090-8.279) | 2.530 (1.432-4.472) | 0.001 |
| Dementia | 4.586 (1.798-11.697) | 2.299 (0.758-6.979) | 0.142 |
| Parkinson | 3.254 (1.222-8.661) | 2.188 (0.732-6.538) | 0.161 |
| CCI (+1 score) | 1.546 (1.415-1.689) | 1.010 (0.797-1.280) | 0.936 |
| ASA-PS II | 1.303 (0.867-1.957) | 0.646 (0.379-1.102) | 0.109 |
| ASA-PS III | 3.203 (2.066-4.965) | 0.880 (0.457-1.694) | 0.703 |

**Figure 4** Logistic regression model to determine related factors to pre-operative anemia.

**Notes**: Multivariable logistic regression model: AIC: 823.588, BIC: 924.545, Pseudo $R^2$: Cox & Snell = 0.244, Nagelkerke = 0.329, McFadden = 0.207, accuracy = 0.719, sensitivity = 0.819, specificity = 0.574, AUC = 0.790, 95% CI = 0.757–0.823.

**Abbreviations**: AIC, Akaike information criterion; ALT, alanine aminotransferase; ASA-PS, American Society of Anesthesiologists physical status; aOR, adjusted odds ratio; AUC, area under the curve; BIC, Bayesian information criterion; BMI, body mass index; CI, confidence interval; cOR, crude odds ratio; CCI, Charlson comorbidity index; COPD, chronic obstructive pulmonary disease; CVD, cardiovascular disease; $R^2$, R-squared.

## Discussions

To our knowledge, this is one of the first studies to comprehensively assess the prevalence, risk factors, and outcomes of pre-operative anemia in patients undergoing hip arthroplasty in Vietnam. Compared with developed countries, pre-operative anemia is theoretically more prevalent in developing settings and may be associated with poorer peri-operative and post-operative outcomes, particularly in the context of hip fracture surgery. Our findings indicate a notably high prevalence of pre-operative anemia, primarily associated with non-modifiable baseline characteristics. Pre-operative anemia was also significantly associated with multiple adverse post-operative outcomes. Therefore, this study highlights the need for improved peri-operative anemia management, particularly pre-operative identification and post-operative surveillance for anemia-related complications.

We observed a pre-operative anemia prevalence of 41.1%, which lies within the intermediate range reported in other developing or LMICs, including Ethiopia (24.1%), Colombia (24.5%), Brazil (30.7%), and China (55.4%).[7,11,16,17] This variation likely reflects differences in patient populations and surgical indications. Studies dominated by elective

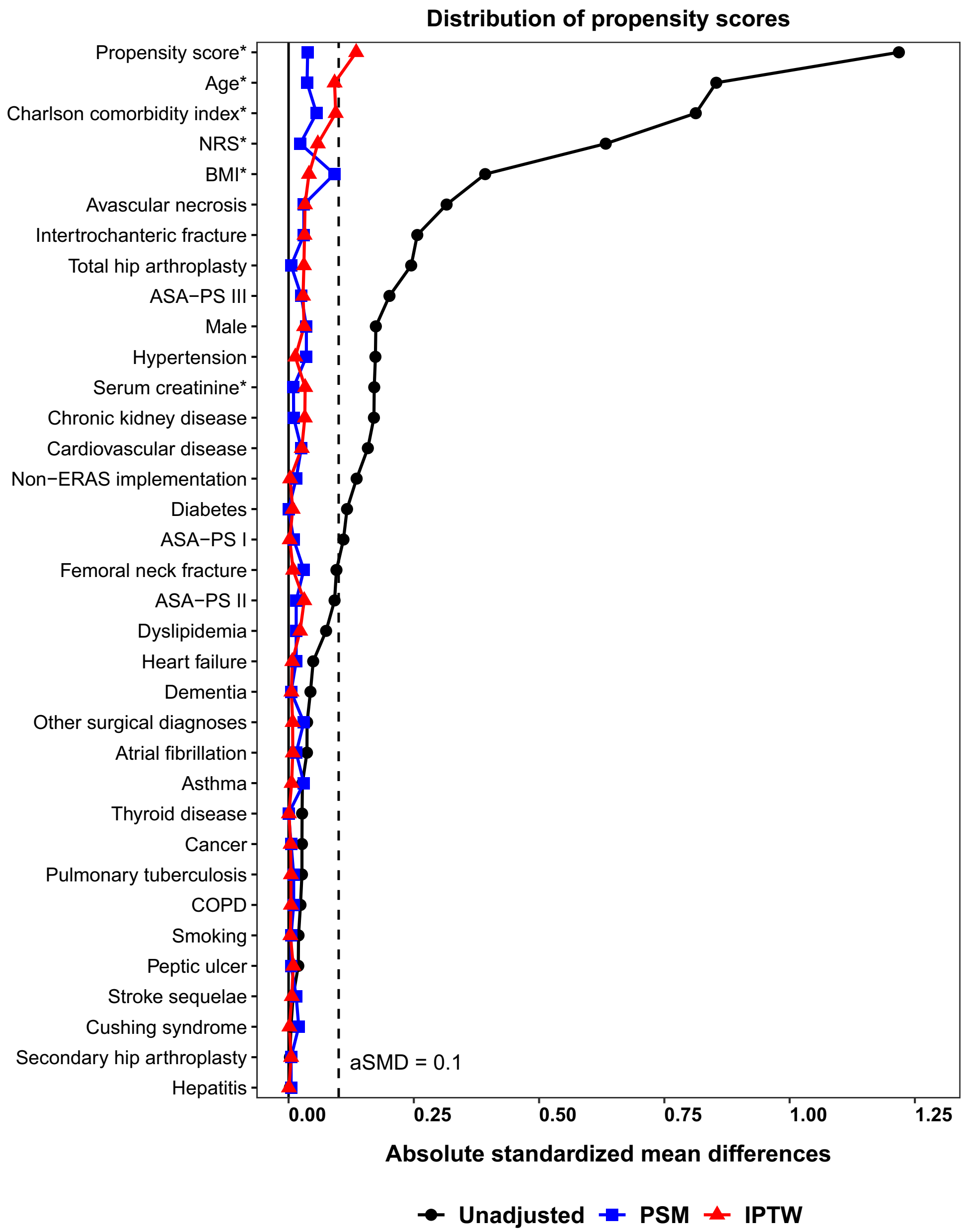



**Figure 5** Absolute standardized mean differences of baseline covariates before adjustment, after propensity score matching, and inverse probability of treatment weighting.
**Note**: * indicates a continuous variable.
**Abbreviations**: ASA-PS, American Society of Anesthesiologists physical status; aSMD, absolute standardized mean difference; BMI, body mass index; COPD, chronic obstructive pulmonary disease; ERAS, enhanced recovery after surgery; IPTW, inverse probability of treatment weighting; NRS, Nutritional Risk Screening; PSM, propensity score matching.

orthopedic procedures, such as those from Ethiopia, report substantially lower anemia rates, whereas cohorts focused on hip fracture surgery, as in China, demonstrate markedly higher prevalence.[7,17] Our cohort comprised a mixed population, with approximately half undergoing hip arthroplasty for fractures (anemia prevalence 59.0%) and the other half undergoing elective hip arthroplasty (24.8%), mirroring these contrasts. Notably, anemia was particularly prevalent in intertrochanteric fractures, reaching 78.7% in our study and 72.0% in the Chinese cohort.[7] As extracapsular injuries with extensive cancellous bone exposure and medullary cavity disruption, intertrochanteric fractures lack the tamponade effect of the joint capsule, promoting occult blood loss and resulting in greater peri-operative blood loss than intracapsular femoral neck fractures or non-fracture conditions.[30]

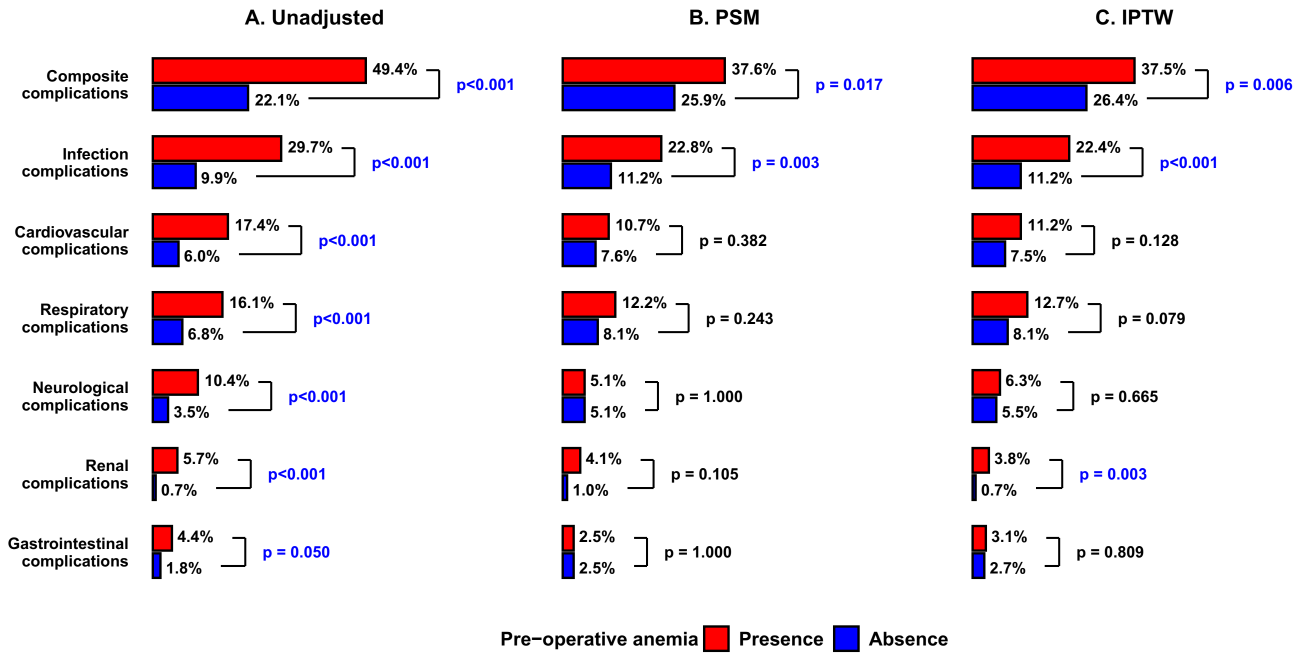



**Figure 6** Post-operative primary outcomes before adjustment (**A**), after propensity score matching (**B**), and after inverse probability of treatment weighting (**C**).
**Note**: Blue p-values indicate statistical significance.
**Abbreviations**: PSM, propensity score matching; IPTW, inverse probability of treatment weighting.

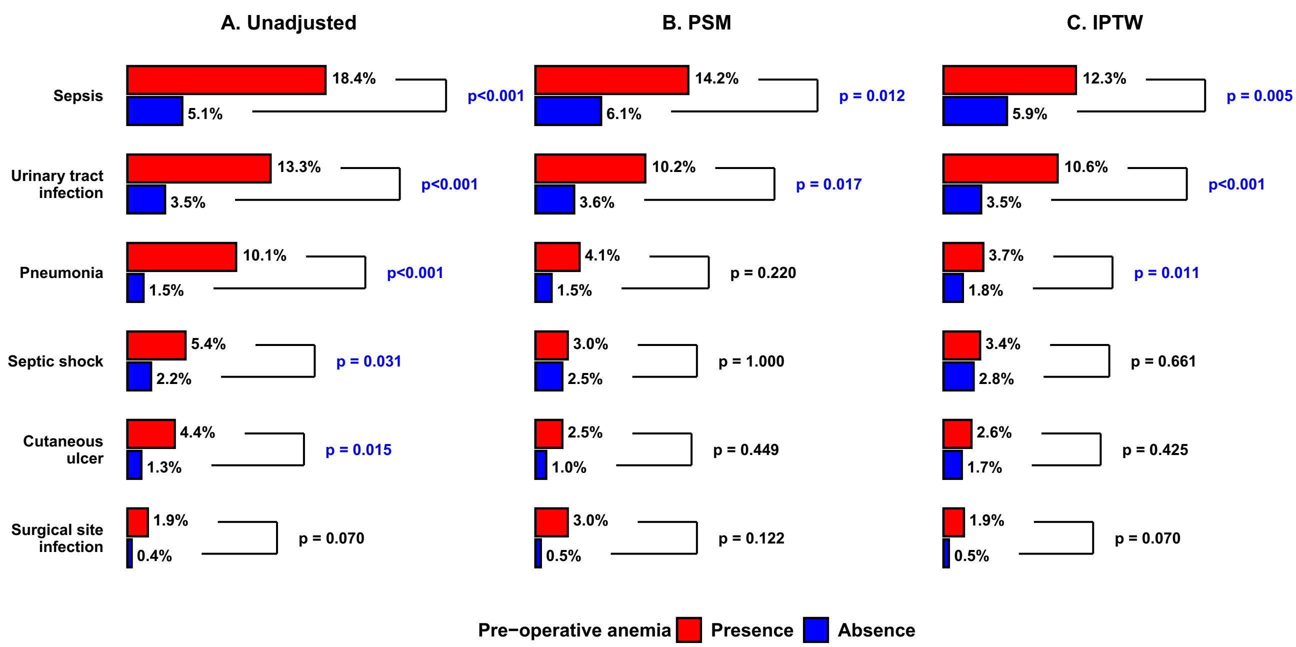



**Figure 7** Post-operative secondary outcomes before adjustment (**A**), after propensity score matching (**B**), and after inverse probability of treatment weighting (**C**).
**Note**: Blue p-values indicate statistical significance.
**Abbreviations**: PSM, propensity score matching; IPTW, inverse probability of treatment weighting.

Although iron deficiency is the predominant global cause of anemia, pre-operative anemia in our cohort was largely normocytic (81.3%) and normochromic (78.2%).[31] This morphology is more consistent with acute blood loss, chronic disease, or impaired erythropoiesis in frail, comorbid patients rather than iron deficiency.[26,32] A substantial hemorrhagic component is evident in our study, driven mainly by femoral neck (36.7%) and intertrochanteric fractures (31.6%).

**Table 4** Post-Operative Tertiary Outcomes Before Adjustment, After Propensity Score Matching, and After Inverse Probability of Treatment Weighting

| Variables | Unadjusted | | | PSM | | | IPTW | | |
|---|---|---|---|---|---|---|---|---|---|
| | Pre-Operative Anemia | | P-value | Pre-Operative Anemia | | P-value | Pre-Operative Anemia | | P-value |
| | Absence (n=453) | Presence (n=316) | | Absence (n=197) | Presence (n=197) | | Absence (n=453) | Presence (n=316) | |
| **Clinical care demands** | | | | | | | | | |
| ICU admission, n (%) | 2 (0.4) | 6 (1.9) | 0.070 | 2 (1.0) | 2 (1.0) | 1.000 | 6 (1.4) | 3 (1.0) | 0.725 |
| Re-operation, n (%) | 12 (2.6) | 7 (2.2) | 0.885 | 8 (4.1) | 6 (3.0) | 0.786 | 11 (2.6) | 7 (2.3) | 0.831 |
| Post-op LOS, days | 6.1 (5.1–7.1) | 8.7 (6.5–11.7) | <0.001 | 6.8 (5.2–7.9) | 7.2 (6.0–10.1) | <0.001 | 6.6 (5.2–7.9) | 7.1 (5.9–9.9) | 0.002 |
| Therapeutic antibiotics, n (%) | 65 (14.3) | 88 (27.8) | <0.001 | 30 (15.2) | 47 (23.9) | 0.042 | 70 (16.4) | 72 (23.2) | 0.049 |
| IMV need, n (%) | 20 (4.4) | 19 (6.0) | 0.409 | 8 (4.1) | 14 (7.1) | 0.273 | 17 (4.1) | 19 (6.2) | 0.217 |
| Peri-op transfusion, n (%) | 39 (8.6) | 175 (55.4) | <0.001 | 21 (10.7) | 88 (44.7) | <0.001 | 45 (10.5) | 137 (43.9) | <0.001 |
| **Clinical symptoms** | | | | | | | | | |
| Nausea and vomiting, n (%) | 17 (3.8) | 11 (3.5) | 0.998 | 4 (2.0) | 8 (4.1) | 0.380 | 14 (3.3) | 11 (3.4) | 0.937 |
| Constipation, n (%) | 133 (29.4) | 135 (42.7) | <0.001 | 63 (32.0) | 76 (38.6) | 0.206 | 139 (32.4) | 110 (35.3) | 0.478 |
| Urinary retention, n (%) | 21 (4.6) | 35 (11.1) | 0.001 | 10 (5.1) | 20 (10.2) | 0.087 | 26 (6.0) | 28 (8.9) | 0.221 |
| Insomnia, n (%) | 72 (15.9) | 55 (17.4) | 0.648 | 40 (20.3) | 24 (12.2) | 0.04 | 83 (19.3) | 40 (12.6) | 0.027 |
| Severe pain, n (%) | 42 (9.3) | 27 (8.5) | 0.827 | 17 (8.6) | 21 (10.7) | 0.609 | 37 (8.7) | 40 (12.8) | 0.155 |
| Post-op anemia, n (%) | 315 (69.5) | 293 (92.7) | <0.001 | 147 (74.6) | 177 (89.8) | <0.001 | 315 (73.5) | 276 (88.2) | <0.001 |
| **Laboratory features** | | | | | | | | | |
| WBC, G.L$^{-1}$ | 9.7 (8.0–12.2) | 9.0 (7.1–11.6) | 0.004 | 9.5 (8.0–11.5) | 8.8 (7.2–11.7) | 0.091 | 9.6 (7.8–12.0) | 9.1 (7.4–11.9) | 0.321 |
| RBC, T.L$^{-1}$ | 3.6 (3.3–4.0) | 3.2 (3.0–3.6) | <0.001 | 3.6 (3.2–3.9) | 3.3 (3.0–3.7) | <0.001 | 3.6 (3.3–4.0) | 3.3 (3.0–3.7) | <0.001 |
| Hb, g.dL$^{-1}$ | 11.0 (9.9–12.0) | 9.5 (8.8–10.1) | <0.001 | 10.6 (9.7–11.6) | 9.5 (8.8–10.2) | <0.001 | 10.9 (9.7–11.7) | 9.5 (8.8–10.2) | <0.001 |
| PLT, G.L$^{-1}$ | 242 (201–304) | 306 (238–414) | <0.001 | 256 (203–328) | 298 (222–403) | <0.001 | 247 (203–317) | 291 (218–390) | <0.001 |
| Sodium, mmol.L$^{-1}$ | 138 (136–140) | 137 (134–140) | <0.001 | 138 (136–140) | 138 (135–140) | 0.159 | 138 (136–141) | 138 (135–140) | 0.087 |
| Potassium, mmol.L$^{-1}$ | 3.8 (3.5–4.1) | 3.8 (3.5–4.1) | 0.270 | 3.8 (3.5–4.1) | 3.7 (3.5–4.0) | 0.444 | 3.8 (3.5–4.1) | 3.7 (3.5–4.0) | 0.390 |
| Chloride, mmol.L$^{-1}$ | 104 (102–106) | 103 (100–106) | 0.002 | 103 (102–106) | 104 (102–106) | 0.588 | 104 (101–106) | 104 (101–106) | 0.450 |
| CRP, mg.L$^{-1}$ | 107 (61–173) | 89 (47–144) | 0.026 | 108 (52–171) | 95 (50–139) | 0.360 | 106 (52–173) | 91 (47–153) | 0.309 |
| hs-TnT, ng.mL$^{-1}$ | 9.6 (6.7–14.4) | 13.4 (9.5–22.4) | 0.006 | 11.2 (7.6–15.4) | 12.0 (9.1–18.4) | 0.585 | 10.0 (7.0–15.6) | 12.1 (8.8–18.2) | 0.360 |
| Procalcitonin, ng.mL$^{-1}$ | 0.2 (0.1–0.4) | 0.2 (0.1–0.6) | 0.085 | 0.2 (0.1–0.4) | 0.2 (0.1–0.4) | 0.885 | 0.2 (0.1–0.4) | 0.2 (0.1–0.4) | 0.906 |
| NT-pro BNP, pg.mL$^{-1}$ | 191 (61–575) | 716 (286–1754) | <0.001 | 258 (58–916) | 591 (193–1082) | 0.181 | 318 (105–1349) | 604 (215–1240) | 0.453 |

**Abbreviations**: CRP, C-reactive protein; Hb, hemoglobin; hs-TnT, high-sensitivity troponin T; ICU, intensive care unit; IMV, invasive mechanical ventilation; IPTW, inverse probability of treatment weighting; LOS, length of stay; NT-proBNP, N-terminal pro-B-type natriuretic peptide; PLT, platelet count; PSM, propensity score matching; RBC, red blood cell count; WBC, white blood cell count.

Evidence from hip-fracture literature indicates that trauma-related blood loss can cause a pre-operative hemoglobin decline (~2 g.dL$^{-1}$), with substantial hidden blood loss (429 ± 223 mL).[33,34] Chronic diseases also likely contributed, as evidenced by a high prevalence of avascular necrosis (25.6%), inflammatory comorbidities, and higher pre-operative CRP levels in the anemic group. The presence of hypoalbuminemia (22.2%) and chronic kidney disease (20.6%) suggests impaired red blood cell production. Therefore, the etiologies of pre-operative anemia in our cohort suggest a mixed mechanism. We also observed a marked increase in post-operative anemia, reaching 79.1%, likely reflecting the combined effects of peri-operative blood loss, hemodilution, and inflammation. Intra-operative blood loss was substantial (median 200 mL), and peri-operative fluid administration resulted in a median net fluid balance exceeding +10 mL.kg$^{-1}$. Concurrently, inflammation-mediated iron restriction, reflected by peri-operative increases in CRP levels from approximately 10–20 to 90–100 mg.L$^{-1}$, may have exacerbated anemia and delayed hemoglobin recovery.

Pre-operative anemia in this study was found to be a multifactorial condition influenced by hip fractures, advanced age, low BMI, elevated serum creatinine levels, pre-operative hyponatremia, and atrial fibrillation. The relationships among aging, malnutrition, renal function, and anemia are widely accepted, making these factors expected contributors.[35] Patients with hip fractures experienced greater hemoglobin loss, likely due to occult blood loss around the fracture site, particularly in unstable cases, which may contribute to anemia.[36] Hyponatremia seemed to be associated with anemia in a bidirectional manner rather than through a direct causal relationship. Meanwhile, anemia may have facilitated the development of atrial fibrillation, rather than the other way around.[37] Clinically, no clearly modifiable intervention targets were identified. The associated factors may therefore serve as indicators for early risk stratification. Recognition of these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factors supports proactive and repeatable pre-operative anemia screening in high-risk patients, particularly when major changes in clinical status occur.

In our study, there was no clinically meaningful difference in pre-operative LOS between patients with and without anemia, with a median of approximately 1.3 days. However, pre-operative anemia was associated with worse post-operative outcomes, including higher infection rates, greater transfusion requirements, prolonged hospital stay, and increased antibiotic use, consistent with prior literature.[9,11] In our study, overall infections, as well as urinary tract infections and sepsis, were more frequent among patients with pre-operative anemia. This association was consistently observed both before and after adjustment, suggesting a relatively robust relationship between pre-operative anemia and infection risk. Anemia may impair immune function and tissue oxygen delivery, increasing susceptibility to surgical and systemic infections and the need for therapeutic antibiotics, particularly in elderly patients.[10–13] Prolonged hospitalization in anemic patients likely reflects delayed recovery, higher post-operative complications, and greater monitoring needs. Pre-operative transfusion occurred in 10.4% of patients, mainly those with moderate-to-severe anemia, and the increased need for peri-operative transfusion further adds to the clinical burden, particularly in resource-limited settings.[31]

Given the high prevalence of pre-operative anemia in patients undergoing hip arthroplasty in our setting, several important clinical implications can be drawn. Pre-operative anemia was strongly associated with adverse post-operative outcomes, particularly infectious complications and increased transfusion requirements, and prolonged LOS. These findings emphasize the importance of routine peri-operative hemoglobin monitoring. For elective procedures, timely identification of anemia may offer an opportunity for pre-operative optimization and reduction of post-operative morbidity, particularly among patients at increased risk of infection.[23] In this study, the underlying etiologies of anemia were not fully characterized, reflecting prevailing peri-operative practices in which systematic etiologic evaluation and anemia optimization before surgery are not routinely prioritized, as indicated by the limited use of iron supplementation and erythropoiesis-stimulating agents. Therefore, these findings highlight the importance of increasing clinical awareness of peri-operative anemia and of integrating structured anemia screening, etiologic assessment, and targeted management into peri-operative care pathways. Such efforts may ultimately improve patient outcomes and support the development of context-appropriate, consensus-based strategies for peri-operative anemia management.

This study has several limitations. First, the retrospective observational design precludes causal inference regarding the relationship between pre-operative anemia and post-operative outcomes. Second, although PSM and IPTW were employed, residual confounding from unmeasured variables cannot be entirely ruled out. Third, the etiology of anemia was not routinely evaluated using assessments of hematopoietic substrates or detailed inflammatory markers; therefore, the underlying causes of anemia could not be definitively established. Finally, the study population was analyzed as an aggregated cohort, which may not adequately represent clinically distinct subgroups of patients with potentially correctable versus non-correctable anemia. Separate analyses of these subgroups would be necessary to delineate better differential risks, treatment responsiveness, and the clinical implications associated with specific anemia phenotypes. Future prospective studies, including randomized controlled trials and cost-effectiveness analyses, are warranted to validate these findings and to evaluate the feasibility and impact of pre-operative anemia optimization strategies in routine surgical practice.

## Conclusion

Pre-operative anemia is highly prevalent among patients undergoing hip arthroplasty in our cohort. In this healthcare setting, it is linked to significant adverse outcomes, including increased infection complications, peri-operative transfusion requirements, and prolonged length of stay. Factors associated with pre-operative anemia included advanced age, low body mass index, elevated creatinine levels, hip fractures, hyponatremia, and atrial fibrillation. These factors are largely non-modifiable and should be regarded primarily as predictors rather than direct targets for intervention. Our study mentioned the importance of routine hemoglobin monitoring peri-operatively in patients undergoing hip arthroplasty to detect pre-operative anemia and monitor its progression post-operatively. Patients with pre-operative anemia should receive proactive monitoring for adverse post-operative outcomes, particularly those at high risk of infectious complications. Further research is needed to assess the effectiveness of anemia treatment protocols and to explore cost-effective strategies for enhancing peri-operative care.

## Declaration of Generative AI and AI-Assisted Technologies in the Writing Process

During the preparation of this work, we used ChatGPT to correct spelling and typographical errors. After using this tool, we reviewed and edited the content as needed and take full responsibility for the publication's content.

## Data Statement

Data supporting the findings of this study are available within the article and its supplementary materials. Additional raw and processed datasets used during the study are available from the corresponding author on reasonable request.

## Ethical Statement

The authors take full responsibility for all aspects of the work and ensure that any questions related to the accuracy or integrity of any part of the study are appropriately investigated and addressed. This retrospective study did not affect the patients' diagnosis, treatment, or follow-up. Ethical approval for the study was granted by the Ethics Council in Biomedical Research at University Medical Center Ho Chi Minh City on January 24th, 2025 (Approval No. 07/GCN-HĐĐĐ). All patient information was anonymized and handled with strict confidentiality. The study was conducted in accordance with the ethical principles of the Declaration of Helsinki. Given the retrospective nature of the study and the use of de-identified data, the requirement for individual informed consent was waived.

## Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

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## Disclosure

All authors declare no conflicts of interest in this work.

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