Article

Effect of Restrictive Blood Transfusion Strategy on Perioperative Prognosis in Elderly Orthopedic Surgery Patients With Preoperative Anemia

Ann. Ital. Chir., 2025 96, 9: 1190–1197
https://doi.org/10.62713/aic.4234

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AIM: Preoperative anemia remains a common condition in elderly patients undergoing orthopedic surgery, and the choice of transfusion strategy may affect perioperative outcomes. Therefore, this study aims to investigate the effect of a restrictive transfusion strategy on perioperative outcomes in this population.

METHODS: A retrospective analysis was conducted on 782 preoperatively anemic patients (aged $\geq$60 years) who underwent hip replacement, knee replacement, or spine surgery at Xuanwu Hospital Capital Medical University, China, between January 2018 and June 2024. Patients were categorized into the restrictive (n = 380) and liberal (n = 402) transfusion strategy groups. Perioperative indicators included estimated blood loss, transfusion volume, length of hospital stay, as well as additional relevant variables. Primary outcomes were 30-day all-cause mortality, transfusion-related adverse reactions, and postoperative infection rates. Secondary outcomes included postoperative hemoglobin levels, readmission rates, reoperation rates, thrombosis, and cardiovascular events.

RESULTS: In hip replacement and spine surgery patients, the estimated blood loss was significantly lower in the restrictive transfusion group than in the liberal transfusion group ($p < 0.001$), while higher in knee replacement patients ($p < 0.001$). The restrictive transfusion strategy reduced transfusion requirements and shortened hospital stay across all surgical types ($p < 0.001$). No significant difference in 30-day all-cause mortality was observed between the groups ($p > 0.05$). However, the restrictive transfusion group had significantly lower rates of transfusion-related adverse reactions (1.3% vs. 5.0%, $p < 0.001$) and infections (2.6% vs. 6.5%, $p = 0.017$). Additionally, transfusion strategy was identified as an independent risk factor for transfusion-related adverse reactions [odds ratio (OR) = 3.96, 95% CI: 1.468–10.682, $p = 0.007$)].

CONCLUSIONS: A restrictive transfusion strategy reduces transfusion volume, minimizes the incidence of transfusion-related adverse reactions and infections. This study supports individualized perioperative anemia management to optimize outcomes in elderly patients.

Keywords: preoperative anemia; restrictive transfusion strategy; orthopedic surgery; elderly patients; prognosis

Introduction

The risk of anemia rises significantly with age, particularly among older adults with chronic illnesses or malnutrition [1,2]. Globally, about 30–40% of individuals over 60 years suffer from varying degrees of anemia, with women showing a higher incidence rate than men [3,4]. In China, an estimated 20–25% of the elderly population is affected by this disease [5]. Anemia in elderly patients not only compromises the quality of life but also increases the risk of perioperative and postoperative complications, especially during high-risk surgeries such as orthopedic procedures [6,7]. Moreover, elderly patients undergoing orthopedic surgery often present chronic comorbidities, such as cardiovascular disease and diabetes [8–10], which further elevate surgical risk and contribute to a higher incidence of postoperative complications.

Although perioperative anemia is commonly managed through blood transfusion [11,12], the body can often compensate for low hemoglobin levels by increasing cardiac output and enhancing tissue oxygen extraction, alleviating immediate reliance on transfusion. However, excessive transfusion introduces additional donor red blood cells, which can increase the risk of immune responses and infections, particularly during postoperative immunosuppression. Transfusion-related immunomodulation (TRIM) can suppress immune function by reducing natural killer (NK) cell activity and disrupting cytokine balance, thereby increasing susceptibility to infection [13]. Furthermore, storage-induced lesions in red blood cells release bioactive substances, such as cytokines, free hemoglobin, and microparticles, which can trigger inflammatory responses after transfusion [14]. Residual leukocytes and minor antigens in donor blood may also provoke alloimmune reactions, further compromising immune function [15]. These mechanisms are especially relevant in elderly patients, who are prone to age-related immune decline and postoperative immunosuppression. Additionally, transfusion may also lead to circulatory overload [16], increasing the likelihood of cardiovascular complications, along with risks of acute lung injury and hemolytic reactions [17,18].

Submitted: 26 June 2025 Revised: 7 August 2025 Accepted: 11 August 2025 Published: 10 September 2025
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A restrictive transfusion strategy sets a lower hemoglobin threshold, administering transfusions only when significant hypoxia or insufficient physiological compensation occurs. This approach minimizes transfusion volume, optimizes perioperative management, and may improve long-term outcomes [19]. However, perioperative transfusion requirements may vary based on the severity of anemia, and the prognostic effects of restrictive transfusion strategies in patients with different anemia levels have not been fully explored [20]. In particular, the effectiveness and applicability of restrictive transfusion strategies in patients with moderate to severe anemia require comprehensive investigation.

Previous randomized controlled trials have compared the effects of restrictive and liberal red blood cell transfusion strategies in elderly orthopedic patients. For example, Carson *et al*. [21] conducted the Functional Outcomes in Cardiovascular Patients Undergoing Surgical Hip Fracture Repair (FOCUS) trial in hip fracture patients with cardiovascular comorbidities and reported that, compared with a liberal transfusion approach (hemoglobin threshold of 10 g/dL), a restrictive transfusion strategy (transfusion at hemoglobin <8 g/dL or upon symptom onset) did not increase the risk of 60-day mortality or adversely affect functional outcomes. Similarly, a recent meta-analysis by Zhou *et al*. [22] analyzed data from 19 studies involving 7833 orthopedic patients, and suggested that restrictive transfusion reduces transfusion rates but may increase the risk of cardiovascular events in high-risk individuals. Notably, the effects of restrictive transfusion on infection rates, length of hospital stay, functional recovery, and long-term outcomes warrant further investigation. Particularly, evidence addressing its impact on elderly Chinese patients remains limited, and changes in baseline health status and perioperative risk profiles compared to Western populations underscore the urgent need for investigations tailored to local populations.

This retrospective study evaluates the clinical value of a restrictive blood transfusion strategy in elderly orthopedic surgery patients with preoperative anemia, focusing primarily on its effect on perioperative indicators and postoperative outcomes. By exploring the key factors that guide transfusion decisions and assessing the safety and efficacy of restrictive transfusion, this study aims to optimize perioperative anemia management, reduce unnecessary transfusions, and improve postoperative recovery and overall prognosis in elderly patients.

Materials and Methods

Recruitment of Study Participants

This retrospective analysis included 782 elderly patients aged ≥60 years who underwent hip arthroplasty, knee arthroplasty, or spinal surgery at Xuanwu Hospital Capital Medical University, Beijing, China, between January 2018 and June 2024. This study was approved by the Ethics Committee of Xuanwu Hospital Capital Medical University (approval no. 2024-446-003) and was conducted in accordance with the ethical principles outlined in the Declaration of Helsinki. Patients' confidentiality was rigorously maintained, with all data anonymized following relevant regulations.

The inclusion criteria for patient selection were as follows: (1) patient age ≥60 years; (2) a confirmed diagnosis of preoperative anemia, defined as hemoglobin <13 g/dL or red blood cell (RBC) count $<4.8 \times 10^6$/L for men, and hemoglobin <12 g/dL or RBC $<4.3 \times 10^6$/L) for women; (3) patient undergoing hip arthroplasty, knee arthroplasty, or spinal surgery. The exclusion criteria included: (1) history of severe cardiovascular disease, renal failure, or other severe complications; (2) history of acute hemorrhagic disease, hematologic disorders, or malignant tumors; and (3) patients with incomplete clinical data. A flowchart of the study design and patient selection process is illustrated in Fig. 1.

Transfusion Strategy and Patient Grouping

Two transfusion strategies were included in this study: the restrictive and liberal transfusion methods. In the restrictive approach, transfusion was considered when hemoglobin levels dropped below 8 g/dL. The final decision to transfuse was guided by clinical judgment based on signs of anemia-related hypoxia or inadequate physiological compensation, such as tachycardia, hypotension, dyspnea, chest pain, or electrocardiographic evidence of myocardial ischemia. However, the liberal transfusion is allowed when hemoglobin dropped <10 g/dL, aiming to maintain hemoglobin (Hb) levels ≥10 g/dL [21]. All patients were managed using a standardized transfusion management framework with leukocyte-depleted red blood cell concentrates. Within this framework, patients were managed according to either a restrictive or liberal transfusion strategy, as documented in their medical records. Therefore, patients were categorized into either the restrictive or liberal transfusion group. Furthermore, to assess prognostic differences across surgical types under the two transfusion strategies, a subgroup analysis was performed based on the type of surgery, such as hip replacement, knee replacement, and spinal surgery.

Data Collection and Outcomes

Patient data were obtained from the hospital's electronic medical records system. Baseline characteristics included age, sex, body mass index (BMI), American Society of Anesthesiologists (ASA) score, Charlson Comorbidity Index (CCI, a validated scoring system for quantifying comorbidity burden and predicting mortality risk), type of admission (elective or emergency), type of surgery, and major comorbidities such as congestive heart failure, chronic kidney disease, stroke, and diabetes.

Primary outcomes included 30-day all-cause mortality, transfusion-related adverse reactions (hemolysis, allergic reactions, and iron overload), and postoperative infection rates. Secondary outcomes included hemoglobin levels on postoperative days 7 and 30, readmission and reoperation

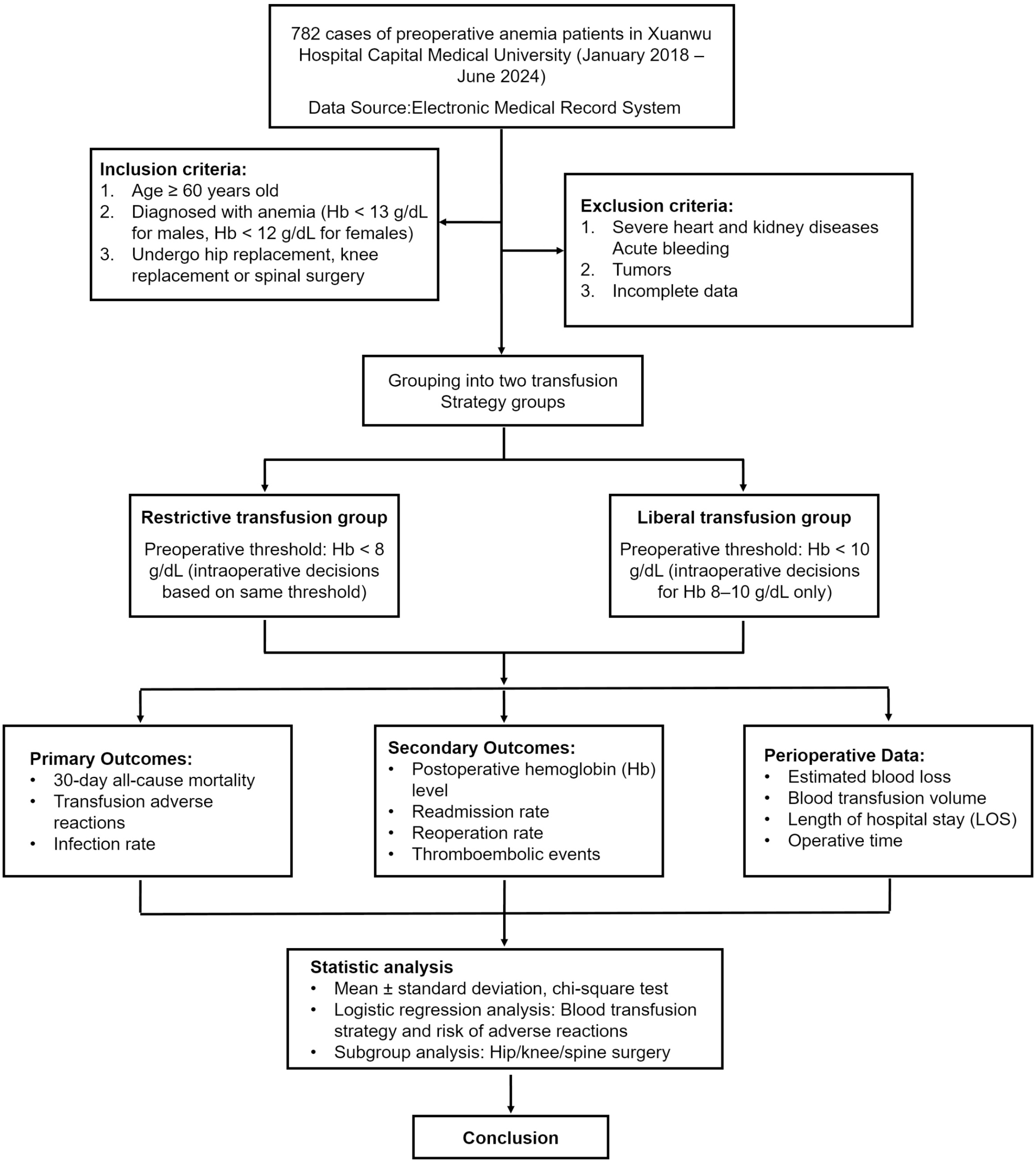

Fig. 1. A flowchart of patient selection and grouping.

rates, cardiovascular events (heart failure or myocardial infarction), and thrombotic events.

After extraction from the electronic medical records system, data were independently verified by two researchers. During data processing, missing values were identified, and logical checks were conducted to detect outliers, ensuring that variables such as age and anemia severity fell within clinically reasonable ranges.

Statistical Analysis

Statistical analysis was performed using IBM SPSS Statistics 23 (IBM Corp., Armonk, NY, USA). The normality of continuous variables was assessed using the Shapiro-Wilk test. Normally distributed continuous variables were presented as mean $\pm$ standard deviation and between-group comparison was performed using an independent sample *t*-test or one-way analysis of variance (ANOVA). However, non-normally distributed continuous variables were presented as median (inter-quartile range) and the Mann-

Table 1. Comparison of demographic and clinical characteristics between the two study groups.

Variable	Restrictive transfusion group (n = 380)	Liberal transfusion group (n = 402)	Statistic	*p*-value
Age, years (median, interquartile range)	75.0 (65.0,83.0)	74.0 (67.0,83.0)	1.878	0.061
Sex (male, n [%])	100 (26.3%)	105 (26.1%)	0.062	0.950
BMI (kg/m^2, mean $\pm$ SD)	24.5 $\pm$ 3.2	24.6 $\pm$ 3.1	–0.443	0.658
ASA score (n [%])			–0.072	0.943
-I	50 (13.2%)	52 (12.9%)		
-II	200 (52.6%)	210 (52.2%)		
-III	100 (26.3%)	110 (27.4%)		
-IV	30 (7.9%)	30 (7.5%)		
CCI (n [%])			0.110	0.913
-$\leq$3	200 (52.6%)	210 (52.2%)		
->3	180 (47.4%)	192 (47.8%)		
Admission type (n [%])			–0.093	0.926
-Urgent	150 (39.5%)	160 (39.8%)		
-Elective	230 (60.5%)	242 (60.2%)		
Surgical procedure (n [%])			0.098	0.922
-Hip replacement	180 (47.4%)	190 (47.3%)		
-Knee replacement	120 (31.6%)	130 (32.3%)		
-Spine surgery	80 (21.0%)	82 (20.4%)		
Congestive heart failure (n [%])	50 (13.2%)	55 (13.7%)	–0.215	0.830
Chronic kidney disease (n [%])	45 (11.8%)	50 (12.4%)	–0.255	0.799
Stroke (n [%])	50 (13.2%)	52 (12.9%)	0.092	0.927
Diabetes (n [%])	80 (21.1%)	85 (21.1%)	–0.031	0.975
Preoperative hemoglobin (g/dL, mean $\pm$ SD)	9.80 $\pm$ 1.2	9.84 $\pm$ 1.3	–0.447	0.655

Note: BMI, body mass index; ASA, American Society of Anesthesiologists; CCI, Charlson Comorbidity Index.

Whitney U test or Kruskal-Wallis H test was applied for non-parametric comparisons.

Moreover, categorical variables were expressed as frequencies and percentages and analyzed using the chi-square (χ^2) test or Fisher's exact test, as appropriate. Independent risk factors were evaluated using logistic regression analysis, with results presented as odds ratio (OR) and 95% CI. A *p*-value of $<$0.05 was considered statistically significant. To minimize potential bias, pairwise deletion was applied for descriptive analyses, while records with missing values for key variables were excluded from inferential analyses.

Results

Demographic and Clinical Characteristics of the Study Population

A comparison of baseline clinical characteristics between the two patient groups is summarized in Table 1. There were no significant differences between the two groups in terms of sex, age, BMI, ASA score, CCI, admission type (elective/emergency), surgical procedure (hip arthroplasty, knee arthroplasty, or spinal surgery), or major comorbidities (congestive heart failure, chronic kidney disease, stroke, and diabetes) (all $p > 0.05$). Furthermore, preoperative hemoglobin levels were comparable between the two groups (9.80 $\pm$ 1.20 g/dL vs. 9.84 $\pm$ 1.30 g/dL, p = 0.655).

Comparison of Perioperative Variables Between the Restrictive and Liberal Transfusion Groups

Analysis of perioperative indicators showed that the estimated blood loss was significantly lower in the restrictive transfusion group compared to the liberal transfusion group (505.3 $\pm$ 135.6 mL vs. 542.8 $\pm$ 142.4 mL, $p < 0.001$). Similarly, the proportion of patients receiving transfusion (34.2% vs. 54.7%, $p < 0.001$) and the total transfusion volume (250.8 $\pm$ 85.3 mL vs. 410.5 $\pm$ 120.4 mL, $p < 0.001$) were significantly decreased in the restrictive transfusion group. Furthermore, the length of hospital stay was significantly shorter in the restrictive transfusion group than in the liberal transfusion group (10.5 $\pm$ 3.1 days vs. 12.2 $\pm$ 3.6 days, $p < 0.001$), whereas no significant difference was observed in operative time (p = 0.072). In terms of transfusion unit distribution, the proportion of patients receiving $\geq$3 units of transfusion was significantly higher in the liberal transfusion group ($p < 0.001$) (Table 2).

Analysis of Postoperative Primary and Secondary Outcomes Across the Study Participants

In terms of primary outcomes, no significant difference was observed in 30-day all-cause mortality between the restrictive and liberal transfusion groups (8.7% vs. 9.2%, p = 0.799). However, the restrictive transfusion group demonstrated substantially lower rates of transfusion-related adverse reactions (1.3% vs. 5.0%, $p < 0.001$) and postoperative infections (2.6% vs. 6.5%, p = 0.017).

Table 2. Comparison of perioperative indicators between the two study groups.

Variable	Restrictive transfusion group (n = 380)	Liberal transfusion group (n = 402)	Statistic	*p*-value
Estimated blood loss (mL)	505.3 ± 135.6	542.8 ± 142.4	–4.315	<0.001
Number of patients transfused, n (%)	130 (34.2%)	220 (54.7%)	33.254	<0.001
Blood transfusion volume (mL)	250.8 ± 85.3	410.5 ± 120.4	–21.493	<0.001
Length of hospital stay (days)	10.5 ± 3.1	12.2 ± 3.6	–7.058	<0.001
Operation time (minutes)	123.5 ± 28.7	127.3 ± 30.2	–1.804	0.072
Red blood cell units transfused, n (%):				
0 units	230 (60.5%)	182 (45.3%)	18.231	<0.001
1 unit	80 (21.1%)	70 (17.4%)	3.473	0.196
2 units	40 (10.5%)	45 (11.2%)	0.090	0.764
3 units	20 (5.3%)	60 (14.9%)	19.858	<0.001
≥4 units	10 (2.6%)	45 (11.2%)	21.904	<0.001

Note: number of patients transfused: patients who received at least one unit of allogeneic red blood cells during the perioperative period.

Table 3. The incidence of postoperative primary and secondary outcomes between the two study groups.

Outcome	Restrictive transfusion group (n = 380)	Liberal transfusion group (n = 402)	Statistic	*p*-value
Primary outcomes				
30-day all-cause mortality, n (%)	33 (8.7%)	37 (9.2%)	–0.254	0.799
Transfusion-related adverse reactions, n (%)	5 (1.3%)	20 (5.0%)	–2.967	<0.001
Infection rate, n (%)	10 (2.6%)	26 (6.5%)	5.701	0.017
Secondary outcomes				
Hemoglobin level (g/dL)				
- Postoperative day 7	9.25 ± 6.1	9.78 ± 6.4	–11.857	<0.001
- Postoperative day 30	9.80 ± 6.7	9.95 ± 7.0	–3.062	0.002
Readmission rate, n (%)	21 (5.5%)	27 (6.7%)	–0.694	0.488
Reoperation rate, n (%)	9 (2.4%)	13 (3.2%)	–0.734	0.463
Cardiovascular events, n (%)			2.670	<0.001
- Heart failure	26 (6.8%)	15 (3.7%)		
- Myocardial infarction	12 (3.2%)	5 (1.2%)		
Thrombosis, n (%)	4 (1.1%)	26 (6.5%)	–4.055	<0.001

For secondary outcomes, postoperative hemoglobin levels on day 7 and day 30 were significantly lower in the restrictive transfusion group compared to the liberal transfusion group ($p < 0.01$). However, the groups showed no significant differences in readmission (5.5% vs. 6.7%, $p = 0.488$) or reoperation rates (2.4% vs. 3.2%, $p = 0.463$). Additionally, the incidence of thrombosis was substantially lower in the restrictive transfusion group (1.1% vs. 6.5%, $p < 0.001$) (Table 3).

Multivariate Analysis of Risk Factors for Adverse Transfusion Reactions

A multivariate logistic regression analysis was conducted to identify independent risk factors for adverse transfusion reactions. As shown in Table 4, both transfusion strategy (OR = 3.96, 95% CI: 1.468–10.682, $p = 0.007$) and sex (OR = 2.311, 95% CI: 1.026–5.207, $p = 0.043$) were independently associated with the occurrence of adverse transfusion reactions. However, age, BMI, and CCI showed no association with transfusion-related adverse events ($p > 0.05$).

Perioperative and Prognostic Outcomes of Transfusion Strategies in Surgical Subgroups

In the subgroup analysis of hip replacement, knee replacement, and spine surgery, perioperative indicators showed significant differences between the restrictive and liberal transfusion groups (Table 5). The restrictive transfusion group had significantly lower estimated blood loss in hip replacement and spine surgery patients compared to the liberal transfusion group ($p < 0.001$), whereas in knee replacement patients, the estimated blood loss was higher ($p < 0.001$). Moreover, transfusion volume and length of hospital stay were significantly reduced in the restrictive transfusion group across all surgical types ($p < 0.001$).
Regarding prognostic outcomes, 30-day all-cause mortality showed no significant difference between the two groups across all surgical types ($p > 0.05$). However, among hip replacement patients, the infection rate was significantly lower in the restrictive transfusion group compared to the liberal transfusion group ($p = 0.014$), while no significant differences were observed in knee replacement and spine surgery patients ($p > 0.05$).

Table 4. Logistic regression analysis of risk factors for adverse transfusion reactions.

	Univariate regression					Multivariate regression				
	B	Wald χ^2	*p*-value	OR	95% CI	B	Wald χ^2	*p*-value	OR	95% CI
Transfusion strategy	1.368	7.329	0.007	3.93	1.459–10.571	1.376	7.392	0.007	3.96	1.468–10.682
Age	0.010	0.061	0.805	1.01	0.933–1.094					
Sex	0.824	4.014	0.045	2.28	1.018–5.107	0.838	4.089	0.043	2.31	1.026–5.207
BMI	–0.020	0.094	0.759	0.98	0.864–1.113					
CCI	0.519	1.568	0.211	1.68	0.746–3.789					

Table 5. Perioperative subgroup analysis across three surgical types.

Variable	Group	Hip replacement (n = 310)	Knee replacement (n = 310)	Spine surgery (n = 162)	Statistics	*p*-value
Estimated blood loss (mL)	Restrictive	499.4 ± 141.5	527.8 ± 121.6	484.7 ± 138.8	77.782	<0.001
	Liberal	569.7 ± 53.2	391.6 ± 79.1	746.7 ± 59.1		
	Statistics	–6.257	10.411	–15.565		
	p-value	<0.001	<0.001	<0.001		
Blood transfusion volume (mL)	Restrictive	260.1 ± 33.1	157.1 ± 43.5	370.2 ± 40.0	355.453	<0.001
	Liberal	434.5 ± 42.7	275.2 ± 42.7	569.4 ± 55.6		
	Statistics	–44.057	–15.913	–26.199		
	p-value	<0.001	<0.001	<0.001		
Length of hospital stay (days)	Restrictive	10.9 ± 1.2	7.0 ± 1.6	14.7 ± 1.3	1142.870	<0.001
	Liberal	12.7 ± 1.3	8.3 ± 2.0	17.3 ± 1.6		
	Statistics	–13.270	–5.585	–11.129		
	p-value	<0.001	<0.001	<0.001		
30-day all-cause mortality, n (%)	Restrictive	8 (6.67)	9 (5.00)	16 (20)	16.615	<0.001
	Liberal	17 (8.95)	3 (2.31)	17 (20.73)	20.453	<0.001
	Statistics	0.254	1.470	0.013		
	p-value	0.614	0.225	0.908		
Infection rate, n (%)	Restrictive	0 (0.00)	4 (2.22)	6 (7.5)	10.761	0.005
	Liberal	9 (4.74)	3 (2.31)	14 (17.07)	19.906	<0.001
	Statistics	-	0.000	2.70		
	p-value	0.014	1.000	0.107		
Transfusion-related adverse reactions, n (%)	Restrictive	0 (0.00)	1 (0.56)	4 (0.50)	10.764	0.005
	Liberal	5 (2.63)	4 (3.08)	11 (13.40)	15.552	<0.001
	Statistics	-	-	2.485		
	p-value	0.161	0.165	0.115		

Overall, the restrictive transfusion strategy was associated with reduced transfusion volume and a shorter hospital stay, with a potential reduction in infection rates among spine surgery patients. However, it had no significant effect on 30-day all-cause mortality across any surgical type.

Discussion

Blood transfusion is a frequent practice in clinical settings, particularly among elderly patients [21]. Preoperative anemia is highly prevalent among elderly individuals undergoing orthopedic surgery, affecting perioperative management and potentially increasing the risk of postoperative complications [23]. Therefore, optimizing the management of perioperative anemia to improve patient outcomes has become a key clinical concern. Although blood transfusion is a standard intervention for managing anemia, the effect of different transfusion strategies on clinical outcomes remains controversial, necessitating further research and strategy optimization [24].

The restrictive transfusion strategy limits blood transfusion to cases where hemoglobin levels fall below a specific threshold (typically 7–8 g/dL), and is usually applied when the patient exhibits significant hypoxia or hemodynamic instability [25]. This approach aims to minimize unnecessary transfusions and help reduce associated adverse effects, such as immunosuppression, infection, iron overload, and hemolytic reactions [26]. However, excessive restriction may lead to severe anemia, compromising tissue oxygenation and potentially delaying postoperative recovery [27]. A systematic review and meta-analysis evaluating the efficacy and safety of restrictive versus liberal transfusion strategies in orthopedic surgical patients reported that, although a restrictive transfusion strategy reduced transfusion volume, it was associated with a 51%

increased risk of cardiovascular events, particularly in hip fracture patients, regardless of pre-existing cardiovascular disease. These findings emphasize the significance of individualized transfusion decisions, considering surgical type, comorbidities, and cardiovascular risk when determining hemoglobin thresholds [28].

In our retrospective analysis, patients were categorized into restrictive and liberal transfusion groups based on actual transfusion strategies, and their perioperative and prognostic outcomes were compared. The results showed that the restrictive transfusion strategy significantly reduced transfusion volume and length of hospital stay, while also decreasing the risk of transfusion-related adverse reactions and postoperative infections. Clinically, the reduction in transfusion volume is particularly important, as it minimizes patient exposure to donor blood, and potentially reduces risks of immune-mediated reactions, infections, and other transfusion-related complications. Similarly, the observed shorter hospital stay in the restrictive group (approximately 1–2 days) may enhance faster recovery, decrease healthcare costs, and improve hospital bed turnover, offering benefits for both patients and healthcare systems. Notably, there was no significant difference in 30-day all-cause mortality between the two groups, supporting the safety of the restrictive transfusion strategy in this population.

To explore potential variations across surgical types, a subgroup analysis was conducted for individuals undergoing hip replacement, knee replacement, and spine surgery. Among hip replacement patients, those managed with a restrictive transfusion strategy had a significantly lower infection rate. These findings align with a similar retrospective study [29] evaluating the effectiveness of a restrictive transfusion strategy in elderly patients with hip fractures, which revealed no significant increase in perioperative complications or adverse events, suggesting the safety of this strategy in this population. Moreover, our multivariate analysis identified transfusion strategy as an independent risk factor for transfusion-related adverse reactions, highlighting the crucial role of effective and individualized transfusion management.

Although this study provides preliminary evidence supporting individualized transfusion management in elderly orthopedic patients with preoperative anemia, several limitations should be acknowledged. First, this was a retrospective study; the lack of detailed stratification by specific surgical procedures may have introduced selection bias and limited the generalizability of the findings. Secondly, the study focused solely on short-term outcomes and did not include long-term follow-up data regarding functional recovery and quality of life, which are critical for comprehensive evaluation of the clinical impact of different transfusion strategies. Future research should include prospective, multicenter studies with larger cohorts and longer follow-up to validate these findings. Additionally, further studies are needed to assess the cost-effectiveness of transfusion thresholds and to elucidate the underlying physiological mechanisms, ultimately optimizing perioperative transfusion management.

Conclusions

The restrictive transfusion strategy reduces transfusion-related risks without increasing short-term mortality. This study provides evidence supporting individualized transfusion management in elderly patients undergoing orthopedic surgery, and serves as a reference for optimizing perioperative anemia management.

Availability of Data and Materials

The data analyzed are available from the corresponding author upon reasonable request.

Author Contributions

WR conceived and designed the study. WR conducted the study. JY contributed to data acquisition. JY analyzed the data. JY interpreted the data. WR wrote the manuscript draft. WR reviewed and contributed to editorial changes in the manuscript. Both authors have been involved in revising it critically for important intellectual content. Both authors gave final approval of the version to be published. Both authors have participated sufficiently in the work to take public responsibility for appropriate portions of the content and agreed to be accountable for all aspects of the work in ensuring that questions related to its accuracy or integrity.

Ethics Approval and Consent to Participate

This study was approved by the Ethics Committee of Xuanwu Hospital Capital Medical University (approval no. 2024-446-003), and was conducted in accordance with the ethical principles outlined in the Declaration of Helsinki. Informed consent was obtained from all participants included in the study.

Acknowledgment

Not applicable.

Funding

This research received no external funding.

Conflict of Interest

The authors declare no conflict of interest.

References

[1] Chen H, Yu J, Wei Q, Zhang Y, Ouyang X, Wang S. Intravenous iron and erythropoietin therapy for postoperative anemia among orthopedic surgery patients. Journal of Orthopaedic Surgery and Research. 2023; 18: 510. https://doi.org/10.1186/s13018-023-03926-y.

[2] Wan S, Sparring V, Cabrales DA, Jansson KÅ, Wikman A. Clinical and Budget Impact of Treating Preoperative Anemia in Major Orthopedic Surgery-A Retrospective Observational Study. The Journal of Arthroplasty. 2020; 35: 3084–3088. https://doi.org/10.1016/j.arth.2020.06.018.

[3] Safiri S, Kolahi AA, Noori M, Nejadghaderi SA, Karamzad N, Bragazzi NL, *et al*. Burden of anemia and its underlying causes in 204 countries and territories, 1990-2019: results from the Global Burden of Disease Study 2019. Journal of Hematology & Oncology. 2021; 14: 185. https://doi.org/10.1186/s13045-021-01202-2.

[4] Stevens GA, Paciorek CJ, Flores-Urrutia MC, Borghi E, Namaste S, Wirth JP, *et al*. National, regional, and global estimates of anaemia by severity in women and children for 2000-19: a pooled analysis of population-representative data. The Lancet. Global Health. 2022; 10: e627–e639. https://doi.org/10.1016/S2214-109X(22)00084-5.

[5] Liu Y, Zeng Y, Lu J, Zhang X, Zhang Z, Li H, *et al*. Correlation of hemoglobin with osteoporosis in elderly Chinese population: A cross-sectional study. Frontiers in Public Health. 2023; 11: 1073968. https://doi.org/10.3389/fpubh.2023.1073968.

[6] Warner MA, Shore-Lesserson L, Shander A, Patel SY, Perelman SI, Guinn NR. Perioperative Anemia: Prevention, Diagnosis, and Management Throughout the Spectrum of Perioperative Care. Anesthesia and Analgesia. 2020; 130: 1364–1380. https://doi.org/10.1213/ANE.0000000000004727.

[7] Shander A, Corwin HL, Meier J, Auerbach M, Bisbe E, Blitz J, *et al*. Recommendations From the International Consensus Conference on Anemia Management in Surgical Patients (ICCAMS). Annals of Surgery. 2023; 277: 581–590. https://doi.org/10.1097/SLA.0000000000005721.

[8] Meyer M, Leiss F, Greimel F, Renkawitz T, Grifka J, Maderbacher G, *et al*. Impact of malnutrition and vitamin deficiency in geriatric patients undergoing orthopedic surgery. Acta Orthopaedica. 2021; 92: 358–363. https://doi.org/10.1080/17453674.2021.1882092.

[9] Picca A, Mankowski RT, Burman JL, Donisi L, Kim JS, Marzetti E, *et al*. Mitochondrial quality control mechanisms as molecular targets in cardiac ageing. Nature Reviews. Cardiology. 2018; 15: 543–554. https://doi.org/10.1038/s41569-018-0059-z.

[10] Ton A, Shahrestani S, Saboori N, Ballatori AM, Chen XT, Wang JC, *et al*. The impact of frailty on postoperative complications in geriatric patients undergoing multi-level lumbar fusion surgery. European Spine Journal: Official Publication of the European Spine Society, the European Spinal Deformity Society, and the European Section of the Cervical Spine Research Society. 2022; 31: 1745–1753. https://doi.org/10.1007/s00586-022-07237-4.

[11] Peel JK, Trudeau J, Tano R, Jadunandan S, Callum J, Moussa F, *et al*. Determining Optimal Treatment to Correct Preoperative Anemia and Reduce Perioperative Allogeneic Blood Transfusions in Cardiac Surgery: A Retrospective Cohort Study. Journal of Cardiothoracic and Vascular Anesthesia. 2021; 35: 2631–2639. https://doi.org/10.1053/j.jvca.2020.12.044.

[12] Bharadwaj A, Khandelwal M, Bhargava SK. Perioperative neonatal and paediatric blood transfusion. Indian Journal of Anaesthesia. 2014; 58: 652–657. https://doi.org/10.4103/0019-5049.144679.

[13] Remy KE, Hall MW, Cholette J, Juffermans NP, Nicol K, Doctor A, *et al*. Mechanisms of red blood cell transfusion-related immunomodulation. Transfusion. 2018; 58: 804–815. https://doi.org/10.1111/trf.14488.

[14] Nelson KA, Warner P, Latchman Y, Slichter SJ. Immunomodulatory Effects of Transfusion. Blood. 2015; 126: 1144. https://doi.org/10.1182/blood.V126.23.1144.1144.

[15] Garraud O, Chiaroni J. An overview of red blood cell and platelet alloimmunisation in transfusion. Transfusion Clinique et Biologique: Journal De La Societe Francaise De Transfusion Sanguine. 2022; 29: 297–306. https://doi.org/10.1016/j.tracli.2022.08.140.

[16] Bulle EB, Klanderman RB, Pendergrast J, Cserti-Gazdewich C, Callum J, Vlaar APJ. The recipe for TACO: A narrative review on the pathophysiology and potential mitigation strategies of transfusion-associated circulatory overload. Blood Reviews. 2022; 52: 100891. https://doi.org/10.1016/j.blre.2021.100891.

[17] Ross A, Mohammed S, Vanburen G, Silberfein EJ, Artinyan A, Hodges SE, *et al*. An assessment of the necessity of transfusion during pancreatoduodenectomy. Surgery. 2013; 154: 504–511. https://doi.org/10.1016/j.surg.2013.06.012.

[18] Bateman RM, Sharpe MD, Jagger JE, Ellis CG, Solé-Violán J, López-Rodríguez M, *et al*. 36th International Symposium on Intensive Care and Emergency Medicine: Brussels, Belgium. 15-18 March 2016. Critical Care (London, England). 2016; 20: 94. https://doi.org/10.1186/s13054-016-1208-6.

[19] Schaap CM, Klanderman RB, Peters AL, Vlaar APJ, Müller MCA. Ultra-Restrictive Transfusion Thresholds in Critically Ill Adults: Are We Ready for the Next Step? Transfusion Medicine Reviews. 2025; 39: 150893. https://doi.org/10.1016/j.tmrv.2025.150893.

[20] Ducrocq G, Gonzalez-Juanatey JR, Puymirat E, Lemesle G, Cachanado M, Durand-Zaleski I, *et al*. Effect of a Restrictive vs Liberal Blood Transfusion Strategy on Major Cardiovascular Events Among Patients With Acute Myocardial Infarction and Anemia: The REALITY Randomized Clinical Trial. JAMA. 2021; 325: 552–560. https://doi.org/10.1001/jama.2021.0135.

[21] Carson JL, Terrin ML, Noveck H, Sanders DW, Chaitman BR, Rhoads GG, *et al*. Liberal or restrictive transfusion in high-risk patients after hip surgery. The New England Journal of Medicine. 2011; 365: 2453–2462. https://doi.org/10.1056/NEJMoa1012452.

[22] Zhou Z, Xiao Z, Luo Y, Nie T, Xiao X. Restrictive versus Liberal blood transfusion strategies for patients undergoing orthopedic surgery: a meta-analysis of randomised controlled trials with trial sequential analysis. Journal of Orthopaedic Surgery and Research. 2025; 20: 513. https://doi.org/10.1186/s13018-025-05883-0.

[23] Seicean A, Seicean S, Alan N, Schiltz NK, Rosenbaum BP, Jones PK, *et al*. Preoperative anemia and perioperative outcomes in patients who undergo elective spine surgery. Spine. 2013; 38: 1331–1341. https://doi.org/10.1097/BRS.0b013e3182912c6b.

[24] Desai N, Schofield N, Richards T. Perioperative Patient Blood Management to Improve Outcomes. Anesthesia and Analgesia. 2018; 127: 1211–1220. https://doi.org/10.1213/ANE.0000000000002549.

[25] Carson JL, Stanworth SJ, Guyatt G, Valentine S, Dennis J, Bakhtary S, *et al*. Red Blood Cell Transfusion: 2023 AABB International Guidelines. JAMA. 2023; 330: 1892–1902. https://doi.org/10.1001/jama.2023.12914.

[26] Odutayo A, Desborough MJR, Trivella M, Stanley AJ, Dorée C, Collins GS, *et al*. Restrictive versus liberal blood transfusion for gastrointestinal bleeding: a systematic review and meta-analysis of randomised controlled trials. The Lancet. Gastroenterology & Hepatology. 2017; 2: 354–360. https://doi.org/10.1016/S2468-1253(17)30054-7.

[27] Muñoz M, Acheson AG, Auerbach M, Besser M, Habler O, Kehlet H, *et al*. International consensus statement on the peri-operative management of anaemia and iron deficiency. Anaesthesia. 2017; 72: 233–247. https://doi.org/10.1111/anae.13773.

[28] Gu WJ, Gu XP, Wu XD, Chen H, Kwong JSW, Zhou LY, *et al*. Restrictive Versus Liberal Strategy for Red Blood-Cell Transfusion: A Systematic Review and Meta-Analysis in Orthopaedic Patients. The Journal of Bone and Joint Surgery. American Volume. 2018; 100: 686–695. https://doi.org/10.2106/JBJS.17.00375.

[29] Zerah L, Dourthe L, Cohen-Bittan J, Verny M, Raux M, Mézière A, *et al*. Retrospective Evaluation of a Restrictive Transfusion Strategy in Older Adults with Hip Fracture. Journal of the American Geriatrics Society. 2018; 66: 1151–1157. https://doi.org/10.1111/jgs.15371.