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Research Article

Evaluation of the Effect of Intraoperative Packed Cell Transfusion on Postoperative Hematologic and Coagulation Parameters, A Retrospective Case-Control Study in Patients Undergoing Lumbar Spinal Fusion

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ABSTRACT

Background: Lumbar spinal fusion surgery often involves significant intraoperative blood loss, necessitating packed red blood cell (PRBC) transfusions. While transfusions restore oxygen-carrying capacity, their immediate effects on postoperative hematologic and coagulation parameters remain unclear, potentially confounded by surgical and patient factors.

Methods: This retrospective case-control study analyzed 396 adult patients (aged 20–80 years, ASA I–III) undergoing lumbar spinal fusion at Al-Zahra Hospital, Isfahan University of Medical Sciences, from September 2019 to September 2022. Patients were grouped by intraoperative PRBC transfusion status (transfused: n=204; non-transfused: n=192). Primary outcomes were postoperative day-1 hemoglobin (Hb), hematocrit (Hct), international normalized ratio (INR), and prothrombin time (PT). Unadjusted comparisons used t-tests or Mann-Whitney U tests with Benjamini-Hochberg correction. Multivariable regression controlled for age, sex, surgical duration, fusion levels, blood loss, and comorbidities.

Results: The unadjusted analysis indicated that transfused patients exhibited significantly decreased hemoglobin (12.0 ± 2.1 vs. 13.5 ± 1.7 g/dL, $p < 0.001$) and hematocrit ($36.1 \pm 5.3\%$ vs. $39.7 \pm 4.3\%$, $p < 0.001$), as well as elevated INR and prolonged PT ($p < 0.05$). Nonetheless, following multivariable correction for surgery length, blood loss, and comorbidities, only the decrease in Hct retained statistical significance (\beta = -3.63, $p < 0.001$). The relationships between transfusion and Hb ($p = 0.063$), INR ($p = 0.312$), and PT ($p = 0.481$) were rendered non-significant after adjusting for clinical covariates.

Conclusion: Our findings suggest that intraoperative PRBC transfusion does not independently influence early postoperative hematologic or coagulation metrics when accounting for surgical complexity. A slight decrease in hematocrit was seen; however, its clinical significance is negligible. These findings support the safety of restricting transfusion operations, allowing physicians to minimize excessive blood exposure while maintaining hemodynamic stability in spinal fusion patients.

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Introduction

Lumbar spinal fusion is a common and effective surgical intervention for a range of degenerative spine diseases, but it is frequently complicated by substantial intraoperative blood loss [1]. The magnitude of surgical bleeding in these procedures can be significant, varying widely depending on factors such as the number of instrumented levels, the use of different surgical approaches (e.g., posterior vs. anterior), and whether the procedure is a primary or revision surgery [2]. Studies have documented average blood loss of over 800 mL for non-instrumented fusions, with figures rising to more than 1,500 mL for complex, instrumented cases and exceeding 3 liters in extensive reconstructive procedures [3]. This blood loss is a direct consequence of the extensive surgical exposure required, which involves stripping muscle from bone and navigating the highly vascularized spinal anatomy [4].

Risk factors for significant bleeding are well-established and include patient characteristics such as older age, higher body mass index, and pre-existing comorbidities, as well as procedural factors like increased fusion levels and longer operative times. The sheer volume and variability of hemorrhage make intraoperative blood transfusion a common and often necessary component of perioperative care [5]. The decision to transfuse packed red blood cells (PRBCs) is a critical component of intraoperative management, aimed at restoring a patient's oxygen-carrying capacity and mitigating the life-threatening consequences of severe hemorrhage, such as hemodynamic instability, end-organ ischemia, and death [6]. However, this clinical decision is fraught with a paradox. The administration of allogeneic blood products is associated with a spectrum of adverse events, ranging from acute complications like transfusion-associated circulatory overload (TACO) and transfusion-related acute lung injury (TRALI) to delayed effects such as increased rates of hospital-acquired infections, longer hospital stays, and elevated morbidity and mortality [6]. The recognition of these risks has driven a paradigm shift in transfusion medicine from a liberal transfusion strategy, transfusing at higher hemoglobin (Hb) thresholds, to a more restrictive approach, which is now supported by high-quality evidence in most patient populations [7]. Notwithstanding this conceptual transition, the choice to transfuse is a nuanced, patient-specific determination made by the anaesthesiologist, informed by a complex interplay of clinical indicators, comorbidities, and laboratory results [8]. Thus, any noted negative effects may be ascribed to the inherent severity of the patient's condition or surgical procedure rather than the transfusion itself. While the efficacy of packed red blood cells (PRBCs) in raising hemoglobin and hematocrit levels is well-documented, with a single unit expected to elevate Hb by about 1 g/dL and Hct by roughly 3%, the immediate effect of transfusion on a patient's coagulation status is unclear and remains a subject of significant debate [9]. Allogeneic PRBCs undergo several biochemical and morphological changes during storage, collectively termed “storage lesion” [10]. These changes, which include the shedding of prothrombotic microvesicles and alterations in erythrocyte function, can theoretically influence the recipient's hemostatic system. However, the clinical significance of these in vitro changes on postoperative coagulation parameters remains a point of contention [11]. The complex relationship between the consumptive coagulopathy that accompanies massive hemorrhage and any potential transfusion-induced alterations makes it difficult to isolate the true effect of the blood product [12]. This represents a significant gap in the current literature, as most studies focus on long-term clinical outcomes rather than the immediate physiological impact on the first postoperative day. This study was meant to fill the information gap by assessing the immediate impact of intraoperative PRBC transfusion on hemoglobin, hematocrit, and coagulation markers, notably INR and PT, on postoperative day one. Utilizing a retrospective case-control methodology, we aimed to ascertain if the correlation between transfusion and these laboratory markers, prone to confounding, would remain significant after correcting for essential patient and surgical variables. We hypothesized that while unadjusted analyses might show an association between transfusion and reduced hemoglobin and altered coagulation, these relationships would be significantly attenuated or eliminated once the underlying clinical factors that drove the decision to transfuse were statistically accounted for.

Methods

Study design and setting

This retrospective case-control study was conducted at Al-Zahra Hospital, Isfahan University of Medical Sciences. The target population comprised adult patients (age 20–80 years) who underwent lumbar spine fusion between September 2019 and September 2022. Patient records were identified and extracted from the hospital electronic medical record system.

Ethics

The study protocol was approved by the Research Ethics Committee of Isfahan University of Medical Sciences (IRB approval number: [IR.MUI.MED.REC.1404.090]). Given the retrospective chart-review design and use of de-identified clinical data, the requirement for written informed consent was waived in accordance with institutional policy. All data were handled in compliance with institutional confidentiality rules.

Participants- inclusion and exclusion criteria

Inclusion criteria were age 20–80 years, American Society of Anesthesiologists (ASA) physical status I–III, and having undergone lumbar fusion surgery at the study site during the study period with available postoperative day-1 laboratory testing. Exclusion criteria were perioperative factors or diagnoses likely to confound coagulation or hemoglobin independently of transfusion: death during surgery or in the immediate recovery period; receipt of blood transfusion within one week before the index operation; thalassemia, sickle cell disease, leukemia, and hemophilia; heart failure; and renal failure. Patients with incomplete records for core demographic fields (age, sex) or the laboratory tests required for an analysis were excluded from that variable's analysis (complete-case analysis).

Exposure and outcomes

The exposure of interest was intraoperative PRBC transfusion, recorded dichotomously (transfused vs not transfused). Transfusion status was determined from intraoperative anesthesia and blood bank records.

Primary outcomes were postoperative day-1 laboratory values: hemoglobin (Hb, g/dL), hematocrit (Hct, %), international normalized ratio (INR, unitless), and prothrombin time (PT, seconds). Secondary variables extracted for descriptive and adjusted analyses included platelet count, PTT, number of transfused PRBCs, number of FFP or platelet units, operative time (minutes), number of instrumented levels, estimated blood loss (when available), comorbidities, and emergence time from anesthesia.

Sample size

The sample size was calculated to detect a difference in the blood parameter with the largest variance between groups. Using the two-sample mean formula

$$n = \frac{(z_{\frac{\alpha}{2}} + z_{1-\beta})^2 + ({s_1}^2 + {s_2}^2)}{(\mu_1 - \mu_2)^2}$$

With $\alpha = 0.05$ and power $1-\beta = 0.80$, using prior-study estimates of SDs s1 = 2.48 and s2 = 1.94 and an anticipated mean difference ($\mu_1-\mu_2$) of 0.64, the required sample size was 200 per group. Accordingly, the planned sample consisted of 400 patients (200 cases and 200 controls). (The final available sample sizes for each outcome are reported in the results and tables because of variable missingness.)

Data extraction and quality control

Data were abstracted from electronic records into a standardized spreadsheet. All laboratory values and key clinical data were screened for implausible values. Extreme or implausible laboratory values were cross-checked against the source record and corrected if errors were identified; otherwise, extreme values were retained and addressed in sensitivity analyses. For each outcome, analyses were performed using complete cases (observations with non-missing values for that outcome and for transfusion status). The number of observations included per comparison is reported alongside the descriptive results.

Statistical analysis

Analyses were prespecified to follow distribution-appropriate methods and to account for multiple testing. All inferential tests were two-sided, and nominal statistical significance was set at $\alpha = 0.05$ after adjustment for multiple comparisons.

Continuous variables are summarized as mean ± standard deviation (SD) and median (interquartile range, IQR). Categorical variables are summarized as counts and percentages. Group sample sizes for each outcome are reported as n (no transfusion/transfusion) (Table 1).

For each continuous outcome, the distribution within each group (transfused vs. non-transfused) was assessed with the Shapiro–Wilk test for normality. Equality of variances was assessed with Levene's test. Based on these diagnostics:

- If both groups for a given variable did not show a significant departure from normality, an independent two-sample t-test was used to compare means. If Levene's test indicated unequal variances, Welch's t-test was applied.
- If one or both groups violated normality, the nonparametric Mann–Whitney U test (two-sided) was used to compare group distributions. For repeated (before-and-after) within-subject comparisons (if performed), paired t-tests or Wilcoxon signed-rank tests were planned depending on normality.

Effect sizes and multiple testing correction

Effect sizes were reported for each comparison. For t-tests. Cohen's d was calculated (mean difference divided by pooled SD).

For Mann–Whitney U tests, a rank-biserial effect estimate derived from the U statistic was reported. Because four primary laboratory outcomes were tested, raw P values were adjusted using the Benjamini–Hochberg procedure to control the false discovery rate (FDR). Significance was assessed at FDR-adjusted $\alpha = 0.05$.

Adjusted analyses and sensitivity analyses

To assess the association between intraoperative PRBC transfusion and postoperative laboratory values while accounting for potential confounders, multivariable regression models were prespecified.

Table 1- Postoperative Day 1 Laboratory Parameters by Intraoperative PRBC Transfusion Status

Variable	n (No transfusion)	n (Transfusion)	Mean ± SD (No transfusion)	Median (IQR)	Mean ± SD (Transfusion)	Median (IQR)
Hemoglobin (g/dL)	104	111	13.48 ± 1.67	13.6 (2.3)	12.00 ± 2.11	12.1 (2.4)
Hematocrit (%)	192	204	39.70 ± 4.31	39.8 (5.6)	36.11 ± 5.29	36.4 (6.1)
INR	187	203	1.12 ± 0.14	1.11 (0.15)	1.22 ± 0.68	1.13 (0.17)
PT (sec)	187	203	11.78 ± 1.55	11.5 (1.7)	12.73 ± 6.80	11.8 (2.1)

For approximately normally distributed outcomes, multivariable linear regression was used with the postoperative measurement as the dependent variable and adjustment covariates including the corresponding preoperative value (baseline); age; sex; estimated blood loss (or levels fused/surgery duration if EBL is unavailable); and key comorbidities. For skewed outcomes or where residuals violated modeling assumptions, quantile (median) regression or robust regression methods were employed; regression residuals and model diagnostics were inspected. Sensitivity analyses included:

(1) inspection and exclusion (or winsorization) of extreme outliers identified in INR and PT; (2) log-transformation of skewed outcomes followed by parametric testing; and (3) reanalysis using propensity score adjustment or covariate adjustment to reduce confounding by indication (transfusion vs. no transfusion). Missing data were handled with complete-case analysis for the primary comparisons; if the extent of missingness warranted, multiple imputation was considered for adjusted models (details provided if performed).

Software and reproducibility

All analyses reported here were executed in Python to allow scripted, fully reproducible workflows. The primary analysis used pandas for data management, SciPy for hypothesis tests (Shapiro–Wilk, Levene, t-tests, Mann–Whitney U), statsmodels for regression modeling and multiple testing correction, and matplotlib for figures. Analysis scripts and a reproducible summary of package versions are available from the authors upon reasonable request.

Results

Study Population

A total of 396 patients undergoing lumbar spinal fusion were included in the analysis. Of these, 204 patients (51.5%) received intraoperative PRBC transfusion, while 192 patients (48.5%) did not. Postoperative laboratory data were available for hemoglobin (Hb, n = 215), hematocrit (Hct, n = 396), international normalized ratio (INR, n = 390), and prothrombin time (PT, n = 390) (Figure 1).

Descriptive Analysis

On postoperative day 1, the mean Hb was 13.5 ± 1.7 g/dL in the non-transfused group compared with 12.0 ± 2.1 g/dL in the transfused group. The corresponding mean Hct values were 39.7 ± 4.3% and 36.1 ± 5.3%, respectively. For coagulation parameters, the mean INR was 1.12 ± 0.14 in the non-transfused group and 1.22 ± 0.68 in the transfused group. The mean PT was 11.8 ± 1.6 seconds versus 12.7 ± 6.8 seconds in the respective groups (Table 2).

Unadjusted Group Comparisons

Normality testing showed mixed results across parameters, and thus, parametric or nonparametric tests were applied accordingly.

- **Hemoglobin:** Patients receiving intraoperative PRBC transfusion had significantly lower Hb compared with non-transfused patients (mean difference: –1.48 g/dL, t = –5.69, p < 0.001, Cohen's d = –0.78).
- **Hematocrit:** A comparable trend was noted for Hct, which was markedly diminished in the transfused cohort (Mann–Whitney U = 11,341.5, p < 0.001, rank-biserial correlation = 0.42).
- **INR:** Median INR was slightly higher among transfused patients, and the difference reached statistical significance (Mann–Whitney U = 21,511.5, p = 0.023, rank-biserial correlation = –0.13).
- **PT:** Likewise, PT was longer in the transfused group (Mann–Whitney U = 21,676.0, p = 0.015, rank-biserial correlation = –0.14).

After controlling for multiple comparisons using the Benjamini–Hochberg false discovery rate adjustment, all four outcomes (Hb, Hct, INR, PT) remained statistically significant (q < 0.05).

Multivariable Regression Analysis

To account for potential confounding, multivariable models were constructed, including age, sex, surgery duration, number of fusion levels, intraoperative blood loss, and PMH (Table 3).

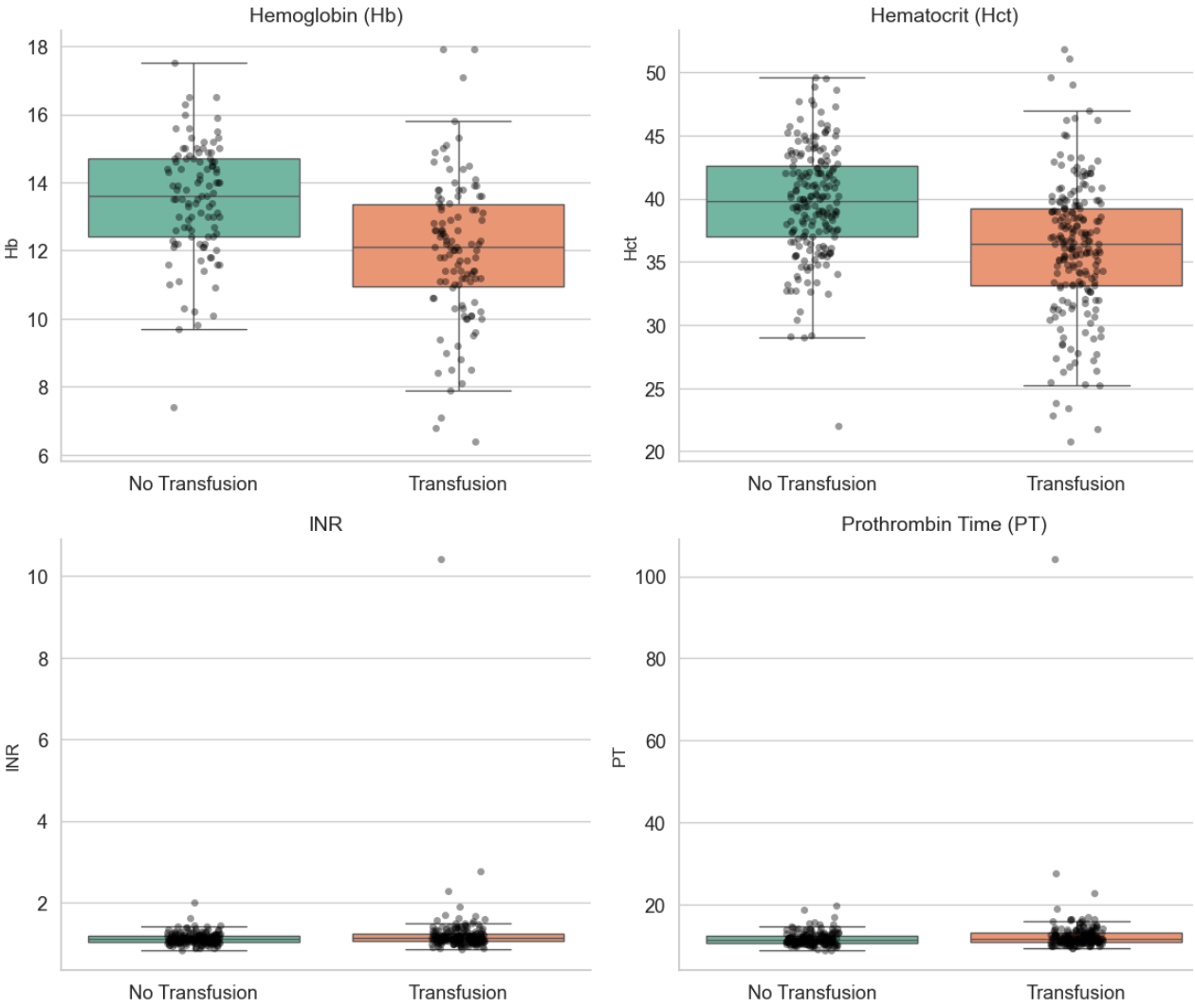

Figure 1- Distribution of postoperative hematologic and coagulation parameters by intraoperative packed red blood cell transfusion status. Boxplots with overlaid individual data points show comparisons between patients who did not receive a transfusion and those who received a transfusion during lumbar spinal fusion surgery. The figure demonstrates lower hemoglobin (Hb) and hematocrit (Hct) levels, and higher INR and prothrombin time (PT) values in the transfusion group compared with the non-transfusion group.

Table 2- Group Comparisons of Postoperative Day 1 Laboratory Parameters

Variable	Test	Statistic	P value (raw)	Effect size (Cohen's d or r)	FDR-adjusted p	Significant (FDR-BH)
Hemoglobin (g/dL)	*t*-test	-5.69	<0.0001	d = -0.78	<0.0001	Yes
Hematocrit (%)	Mann–Whitney U	11341.5	<0.0001	r = 0.42	<0.0001	Yes
INR	Mann–Whitney U	21511.5	0.023	r = -0.13	0.023	Yes
PT (sec)	Mann–Whitney U	21676.0	0.015	r = -0.14	0.020	Yes

Notes: Shapiro–Wilk indicated non-normality for Hct, INR, and PT in at least one group; Levene's test showed homogeneity of variances across groups. Effect size for t-test reported as Cohen's d; for Mann–Whitney U reported as effect size r. Multiple testing correction performed using the Benjamini–Hochberg false discovery rate (FDR-BH).

Table 3- Multivariable Regression Analysis of the Association Between Intraoperative PRBC Transfusion and Postoperative Laboratory Parameters

Outcome	Model	n	β (Transfusion)	95% CI	P value	Interpretation
Hemoglobin (g/dL)	OLS	215	–1.09	-2.23, 0.06	0.063	NS, trend toward lower Hb
Hematocrit (%)	OLS	396	–3.63	-5.64, -1.61	<0.001	Significant reduction
INR	Quantile (median)	390	+0.03	-0.03, 0.09	0.312	NS
PT (sec)	Quantile (median)	390	+0.22	-0.40, 0.84	0.481	NS

NS = not significant; β = regression coefficient for transfusion effect. All models adjusted for age, sex, surgery time, fusion levels, blood loss, and PMH. Robust SEs applied.

- **Hemoglobin:** In the adjusted OLS model, transfusion was associated with a decrease of –1.09 g/dL in Hb, though this effect did not reach statistical significance (β = –1.09, 95% CI –2.23 to 0.06, p = 0.063).
- **Hematocrit:** Transfusion remained an independent predictor of reduced Hct (β = –3.63, 95% CI –5.64 to –1.61, p < 0.001).
- **INR:** Median regression showed no significant association between transfusion and INR (β = 0.03, 95% CI –0.03 to 0.09, p = 0.312).
- **PT:** Similarly, transfusion was not significantly associated with PT prolongation after adjustment (β = 0.22, 95% CI –0.40 to 0.84, p = 0.481).

Unadjusted analyses indicated significant postoperative reductions in Hb and Hct and mild elevations in INR and PT among patients receiving intraoperative transfusion.

However, in adjusted models accounting for clinical and surgical covariates, only hematocrit remained significantly associated with transfusion, whereas the associations with Hb, INR, and PT were attenuated and no longer significant.

Discussion

The current investigation sought to clarify the acute impact of intraoperative PRBC transfusion on hematologic and coagulation stability in patients undergoing lumbar spinal fusion. Initial, unadjusted comparisons indicated that transfused patients exhibit a more significant decrease in Hb and Hct, accompanied by slight extensions in INR and PT; however, these relationships essentially dissipated after thorough multivariable adjustment.

After considering characteristics such as surgical difficulty, operative duration, and pre-existing comorbidities, the sole statistically significant independent predictor was a slight decrease in hematocrit. This pattern indicates that the majority of laboratory changes noted on the first postoperative day are chiefly the result of surgical trauma and the severity of hemorrhage, rather than direct negative impacts of the blood product itself. There are no significant differences, consistent with the overall trend of diminished effects following adjustment. Our findings are consistent with prior research demonstrating that intraoperative PRBC transfusion in spinal fusion surgery is often associated with alterations in postoperative hematologic and coagulation parameters, though these effects are frequently confounded by procedural and patient factors. Numerous studies have indicated reduced postoperative hemoglobin (Hb) and hematocrit (Hct) levels in transfused patients, ascribed to dilutional anemia resulting from volume expansion or undetected blood loss, with mean differences comparable to the unadjusted -1.48 g/dL in Hb and -3.59% in Hct noted in this analysis [13-14].

Concerning coagulation, studies on substantial transfusion during elective spinal and orthopedic surgeries reveal considerable intraoperative variations in international normalized ratio (INR) and prothrombin time (PT) attributable to transfusion ratios, such as 1:1 red blood cells to fresh frozen plasma; however, postoperative stabilization frequently restores these parameters to near-baseline levels, reflecting the attenuation observed in our adjusted analyses [15]. The storage lesion in PRBCs has been associated with impaired coagulation function, potentially prolonging PT and increasing INR due to mechanisms such as diminished clotting factor activity and microvesicle release; however, clinical effects differ and are less significant after covariate adjustment in controlled environments like ours [16].

Conversely, certain observational data from spine surgery cohorts indicate enduring mild coagulopathy following transfusion, especially in patients with preoperative anomalies or elevated transfusion volumes. However, these studies frequently lack rigorous adjustments for blood loss and surgical duration, potentially elucidating the discrepancies with our findings, where only hematocrit remained significantly impacted [17-18].

Our data underscores the transition to restrictive transfusion techniques in spine surgery, as corroborated by reviews highlighting reduced allogeneic exposure to alleviate potential detrimental effects on coagulation and hematology, while considering confounding by indication. [19-20]. Interpreting these data necessitates situating them within the broader pathophysiology of perioperative blood control in spinal surgery. Lumbar

spinal fusion is intrinsically linked to significant blood loss owing to the vascular characteristics of the paraspinal muscles, vertebral bone, and epidural venous plexus, frequently requiring transfusion to preserve hemodynamic stability and provide adequate oxygen delivery [21]. Our unadjusted results indicate a decrease in postoperative hemoglobin (mean difference: -1.48 g/dL) and hematocrit (-3.59%) in transfused patients, which seems contradictory as PRBC transfusion is anticipated to enhance these parameters. This paradox is clarified by the extent of intraoperative hemorrhage in the transfused group, which likely reduced red cell mass more substantially than could be sufficiently compensated by the transfused units. A meta-analysis by Yoshihara and Yoneoka (2014) on blood transfusion in spinal fusion indicates that transfused patients often exhibit diminished postoperative hemoglobin levels due to increased baseline losses, with average blood loss exceeding 1 liter in instrumented cases [22]. Our revised model for hemoglobin demonstrated a non-significant trend towards decline (β = -1.09 g/dL, p = 0.063), suggesting that while transfusion mitigates acute anemia, the residual effects of blood loss persist on postoperative day 1. The enduring substantial correlation with decreased Hct following adjustment (β = -3.63%, $p < 0.001$) necessitates further examination. Hematocrit, as a volumetric indicator of red blood cell concentration, may exhibit heightened sensitivity to dilutional effects from intravenous fluids or inadequate equilibration following transfusion. During storage, PRBCs experience rheological alterations, such as heightened fragility and diminished deformability, which may result in inadequate integration into the recipient's circulation shortly after surgery [23]. This aligns with research on storage lesions, indicating that older units (>21 days) are associated with transitory hemolysis and inflammatory responses that may reduce Hct more significantly than Hb in the near term [24]. A prospective study by Blankstein et al. (2018) including orthopedic surgery patients revealed that intraoperative transfusion was associated with a 2-4% reduction in Hct on day 1, irrespective of blood loss, which was ascribed to cytokine-mediated endothelial activation and fluid shifts [25]. Our findings apply to spinal fusion, emphasizing Hct as a possible indicator for assessing transfusion success; nonetheless, the clinical significance of a 3.6% variance is minimal and unlikely to independently precipitate adverse outcomes. The unadjusted increases in INR (median difference indicating rank-biserial r = -0.13) and PT (r = -0.14) in transfused patients imply a slight prothrombotic or consumptive alteration; however, these effects were completely mitigated in adjusted models (INR: β = 0.03, p = 0.312; PT: β = 0.22, p = 0.481). This attenuation highlights the influence of confounding variables, including extended surgical durations and increased tissue damage in transfused instances, which might precipitate disseminated intravascular coagulation (DIC)-like conditions via thrombin production and fibrinogen depletion. Transfusion may promote the release of procoagulant microparticles from erythrocytes due to storage, while clinical evidence is unclear. A randomized experiment conducted by Goobie et al. in juvenile scoliosis surgery revealed no significant alterations in INR or PT following transfusion when controlled for blood loss, corroborating our findings [26]. Conversely, some observational data from cardiac surgery. In our cohort, where the median transfused units were presumably low (though not detailed per patient), such effects appear negligible. The absence of correlation with platelet count reinforces this, as PRBCs possess few platelets, and any thrombocytopenia would more likely arise from surgical consumption rather than transfusion. These findings correspond with the emerging paradigm of restrictive transfusion strategies, supported by guidelines from the American Society of Anesthesiologists (ASA) and the Association of Anesthetists, which recommend hemoglobin thresholds of <7-8 g/dL in stable patients to reduce risks such as infection and thromboembolism [27-28]. Our research demonstrates that intraoperative PRBC transfusion following lumbar fusion does not independently impair early postoperative coagulation, perhaps offering confidence to physicians in high-bleeding scenarios. The ongoing reduction in hematocrit may indicate minor inefficiencies in red blood cell utilization, suggesting the potential use of adjuncts such as tranexamic acid (TXA) or cell salvage to decrease transfusion requirements. Cheriyan and colleagues conducted a systematic review of antifibrinolytics in spine surgery, indicating that TXA can reduce blood loss by up to 50%, thereby eliminating the need for transfusions and their related costs, estimated at $500-1000 per unit, along with indirect morbidity [29]. These findings have clinical implications for perioperative monitoring and resource allocation. In resource-constrained environments such as our Iranian hospital, where blood products are valuable, minimizing unnecessary transfusions based on liberal thresholds could conserve supplies. The lack of coagulation abnormalities following transfusion endorses early mobilization strategies, as extended PT/INR could otherwise exacerbate bleeding risks during physiotherapy. In patients with comorbidities, such as cardiovascular disease, the minor effects of hemoglobin and hematocrit indicate that transfusion continues to be advantageous for oxygen delivery without exacerbating thrombotic hazards; however, individualized evaluation is essential. Notwithstanding these insights, certain limits must be recognized. The retrospective approach introduces selection bias, as transfusion decisions were made based on clinician judgment rather than randomization, potentially leading to an underestimation of confounding despite multivariable adjustment.

Estimated blood loss (EBL), a critical covariate, is famously subjective and frequently underestimated, potentially leading to biased null findings in adjusted models. The absence of Hb data in 215 out of 396 patients necessitated a complete-case analysis, which may introduce bias if the missing data is non-random (e.g., if sicker patients lack laboratory results). The platelet count and partial thromboplastin time (PTT) were extracted but not thoroughly analyzed due to inconsistent availability, hindering a complete assessment of hemostasis; future research should emphasize these factors. We did not stratify by transfusion volume or storage duration, which could influence outcomes; older units are associated with poorer results in trauma literature. Moreover, our single-center emphasis at Al-Zahra Hospital may restrict the applicability to varied demographics or surgical methodologies (e.g., minimally invasive versus open methods).

The strengths of this study comprise a substantial sample size (n=396), surpassing the power calculation, and a meticulous statistical methodology that includes normality diagnostics, effect sizes, and false discovery rate adjustment to reduce type I errors. Employing Python for reproducible analysis improves transparency, mitigating reproducibility crises in medical research.

By concentrating on the immediate postoperative day 1, we identified acute effects frequently neglected in outcome-oriented investigations. Future investigations should utilize prospective designs with randomized transfusion triggers to delineate causative effects, integrating viscoelastic testing (e.g., thromboelastography) for dynamic coagulation evaluation beyond static INR/PT measurements. An extended follow-up may associate these laboratory alterations with clinical outcomes such as infection or readmission. Multicenter trials conducted in diverse settings, particularly resource-limited environments, would enhance generalizability. Investigating biomarkers of storage lesion (e.g., free hemoglobin) may clarify the mechanisms underlying the connection with hematocrit.

Conclusion

In conclusion, this study demonstrates that intraoperative PRBC transfusion in lumbar spinal fusion is not independently associated with significant alterations in postoperative Hb, INR, or PT after accounting for confounders, though a modest Hct reduction persists. These findings mitigate concerns over transfusion-induced coagulopathy in this context, advocating for evidence-based, restrictive strategies to optimize patient outcomes while minimizing risks. By addressing a gap in immediate physiological impacts, our work contributes to refined perioperative care in spinal surgery, ultimately supporting safer, more efficient blood management practices.

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