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Beyond the Visible: Quantifying Hidden Blood Loss in Open Posterior Thoracolumbar Fusion – A Prospective Analysis

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Article

Keywords: hidden blood loss, spinal fusion, thoracolumbar surgery, perioperative blood management, transfusion, intraoperative bleeding

Posted Date: June 5th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-8855564/v1

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Additional Declarations: No competing interests reported.

Abstract

Purpose:

Standard intraoperative estimates and postoperative drain outputs in major spine surgery often underestimate true perioperative blood loss because they do not capture hidden blood loss (HBL), which may be sequestered in tissues, lost through hemolysis, or obscured by fluid shifts. This study aimed to quantify HBL in open posterior thoracolumbar fusion and identify factors associated with its magnitude. 23 adults undergoing elective open posterior decompression and instrumented thoracolumbar fusion with expected blood loss > 1 L were enrolled. Primary outcomes were total blood loss (TBL), visible blood loss (VBL), and HBL.

Methods:

Patient blood volume was estimated using the Nadler formula. TBL was calculated from perioperative hematocrit changes using the Gross formula and adjusted for transfusion. VBL included intraoperative suction and sponge losses (gravimetric method) plus postoperative drain output. HBL was defined as TBL minus VBL. Correlations were analyzed nonparametrically.

Results:

Mean intraoperative blood loss was 1,718 ± 498 mL; VBL was 1,864 ± 461 mL. Mean TBL was 2,721 ± 671 mL. HBL accounted for 857 ± 259 mL (31.3 ± 4.3% of TBL). HBL correlated negatively with age (ρ = − 0.492; p = 0.017). VBL correlated negatively with age (ρ = − 0.430; p = 0.040) and positively with operative time (ρ = 0.503; p = 0.014).

Conclusions:

In open posterior thoracolumbar fusion, HBL represents roughly one-third of perioperative blood loss and is more pronounced in younger patients. Recognition of HBL may improve perioperative blood management and transfusion planning.

INTRODUCTION

Perioperative blood loss remains a significant challenge in spinal surgery, particularly during multilevel fusion procedures [1]. Excessive blood loss may necessitate transfusion, with all its inherent risks. Standard intraoperative measurements and postoperative drain outputs frequently underestimate true total blood loss because they fail to account for hidden blood loss (HBL)—blood that is lost into surrounding tissues, through hemolysis, or sequestered internally and therefore not captured by suction or drains.

Although HBL was first described in joint arthroplasty [2, 3], it is now increasingly recognized as a substantial and clinically relevant component of total blood loss in spinal surgery. Lei et al. [4] reported an average HBL of 449 mL, accounting for approximately 44% of total blood loss during posterior lumbar fusion. Similar proportions have been observed in other studies [5, 6], with HBL typically representing 40–45% of total blood loss across various spinal fusion procedures [7, 8]. High levels of HBL have been reported in pediatric patients undergoing complex spinal procedures, such as osteotomies and hemivertebra resections, as well as in minimally invasive techniques [9, 10].

In clinical practice, HBL in spinal surgery often exceeds surgeons' expectations. Despite growing recognition, it remains underestimated, underreported, and frequently unaddressed in perioperative management. A better understanding of its magnitude and associated risk factors is crucial—particularly for patients with limited physiologic reserve or those at increased surgical risk.

The aim of this study was twofold: (1) to quantify the magnitude of HBL in patients undergoing major spinal surgery, and (2) to identify demographic and surgical factors associated with it, with a focus on the proportion of HBL rather than solely visible losses (intraoperative measurements and postoperative drains).

PATIENTS AND METHODS

Study design and population

This was a prospective single-center observational cohort study. Between June 2024 and April 2025, patients undergoing elective major spinal surgery (open posterior decompression and instrumented thoracolumbar fusion) with an expected blood loss greater than 1 L were prospectively enrolled. All procedures were performed in accordance with the ethical standards of the institutional and national research committees and with the 1964 Declaration of Helsinki and its later amendments. Written informed consent was obtained from all individual participants included in the study. A total of 35 patients were initially enrolled, of whom 28 had a blood loss greater than 1 L. To minimize the effect of extreme hemodilution on the calculations, 5 patients with a blood loss exceeding 3 L were excluded from the analysis. Baseline demographic characteristics are presented in Table 1.

Table 1
Patient demographics and surgical characteristics

Parameter	Mean (SD)
Age (years)	63.87 (19.08)
Height (cm)	172.39 (7.98)
Weight (kg)	84.13 (19.74)
BMI (kg/m²)*	27.87 (5.17)
BMI < 25	8 persons (34.78%)
BMI ≥ 25	15 persons (65.22%)
ASA classification	2.52 (0.67)
ASA 1	1 person (4.35%)
ASA 2	10 persons (43.48%)
ASA 3	11 persons (47.83%)
ASA 4	1 person (4.35%)
No. of spinal segments	5.43 (2.43)
Type of surgery: Posterior column surgery	20 persons (86.96%)
Type of surgery: Two columns surgery	3 persons (13.04%)
Time of surgery (min)	201.04 (43.25)

*BMI, body mass index.

Exclusion criteria were: 1) spinal pathologies including tumor, tuberculosis, or fracture; 2) coagulation disorders or hypertensive disorders; 3) preoperative anemia, preoperative allogeneic blood transfusion, or use of antiplatelet agents; 4) age under 18 years at the time of surgery; 5) previously documented hematologic or bone marrow diseases; 6) history of splenectomy; 7) blood loss greater than 3 L.

Surgical procedures and perioperative management

Patients were placed prone on a radiolucent table, and general anesthesia was administered. All operations were performed via a posterior approach. Following a midline incision, the paravertebral muscles were systematically dissected. Perioperative CT navigation was used for transpedicular screw insertion and was repeated for each operated segment in multilevel procedures. Additional procedures were diagnosis-dependent: for spinal stenosis, laminectomy and decompression were performed; for scoliosis, arthrodesis and reduction; for double-column procedures, discectomy and interbody fusion with autogenous graft and cage were performed using either the PLIF or TLIF technique. Internal fixation

was completed, followed by intra-articular fusion and decortication of the transverse processes for posterolateral fusion. A Redon suction drain was placed, and the wound was closed in layers with standard fascial and skin closure. NPWT (negative-pressure wound therapy) was not used in any case to ensure maximal accuracy of blood loss measurement. All surgeries were performed by the same senior surgeon with more than 15 years of experience.

All patients received a loading dose of tranexamic acid (20 mg/kg, maximum 2 g IV) at skin incision. Low-molecular-weight heparin was routinely administered postoperatively to prevent deep vein thrombosis. Antibiotic prophylaxis was given intravenously for 24 hours. No patient received preoperative allogeneic blood or intraoperative cell-saver reinfusion. Intraoperative or postoperative allogeneic blood transfusion was administered in 18 patients (78%) when hemoglobin decreased below 80 g/L. Fluid management was standardized: a rehydration bolus of 20 mL/kg on admission, followed by intraoperative isotonic balanced crystalloid infusion.

Data collection

Collected variables included age, sex, height, weight, BMI, ASA classification, type of surgery (posterior vs. two columns surgery), number of operated spinal segments, and time of surgery. Hematocrit was measured preoperatively and on postoperative Days 1 and 2. Intraoperative visible blood loss was recorded by the anesthesiologist and included suction bottle contents (after deducting irrigation fluid) and the calculated volume of blood absorbed by surgical sponges. Postoperative visible blood loss was defined as the drainage volume collected until the morning of postoperative Day 1.

Calculation of Blood Loss

To calculate total blood loss (TBL), the patient's blood volume (PBV) was first estimated. Weight and height were recorded for all patients, and PBV (L) was calculated according to the formula described by Nadler et al. [11]:

$PBV\ (L) = k1 \times [height\ (m)]^3 + k2 \times weight\ (kg) + k3$

For males: k1 = 0.3669, k2 = 0.03219, k3 = 0.6041

For females: k1 = 0.3561, k2 = 0.03308, k3 = 0.1833

Total red cell volume was calculated by multiplying PBV by hematocrit, with changes derived from perioperative hematocrit variation [12]. During blood loss, intravascular volume is maintained by fluid administration and vascular refill, resulting in a logarithmic decline in hematocrit [13]. Gross proposed a simplified linear formula using mean perioperative hematocrit [14], which closely approximates the logarithmic model under non-massive hemorrhage. Because the linear method may overestimate blood loss in massive bleeding, cases exceeding 3 L were excluded from the analysis.

The Gross formula was applied as follows:

$$\text{Calculated TBL (L)} = \text{PBV} \times (\text{Hct_pre} - \text{Hct_post}) / \text{Hct_ave}$$

$$\text{Hct_ave} = (\text{Hct_pre} + \text{Hct_post}) / 2$$

where Hct_pre is the preoperative hematocrit, Hct_post is the hematocrit on postoperative Day 1, and Hct_ave is their average.

Intraoperative blood loss (IBL) was estimated using the gravimetric method [15]. Surgical sponges were weighed before and after use, with each gram of weight gain corresponding to 1 mL of blood. The anesthesiologist recorded IBL, including suction bottle contents (after subtracting irrigation fluid) and sponge blood volume.

Total visible blood loss (VBL) was calculated as:

$$\text{VBL} = \text{IBL} + \text{B_d}$$

where B_d is the total drainage volume collected until the first postoperative morning.

If a patient received allogeneic transfusion, TBL calculated from hematocrit was smaller than the actual value, so it was corrected by adding the transfused volume, as transfusion increases postoperative hematocrit. Hidden blood loss (HBL; Fig. 1) was then calculated as:

$$\text{HBL} = \text{Calculated TBL} + \text{transfused blood volume} - \text{VBL}$$

This approach follows the method originally described by Gross [14] and incorporates both calculated and measured losses to account for the unmeasured component of perioperative blood loss.

Packed red blood cell (RBC) transfusion units from our blood bank were converted to whole-blood equivalents by dividing the red cell volume in each unit (calculated as unit volume × unit hematocrit, based on blood bank labeling and validation data) by the patient's mean perioperative hematocrit. Thus:

Whole-blood equivalent = RBC volume ÷ mean hematocrit,

as described in transfusion standards [16].

Statistical Analysis

Descriptive statistics were used to summarize patient and surgical characteristics. Continuous variables are presented as mean ± SD or median (IQR), and categorical variables as counts and percentages. Normality and homogeneity of variance were assessed using the Shapiro–Wilk and Levene's tests. Given the small sample size (n = 23), non-parametric methods were applied. Associations between HBL, VBL, HBL/TBL, and demographic or surgical variables were evaluated using Spearman's rank correlation.

Group comparisons were performed with the Mann–Whitney U test. Results are reported with 95% confidence intervals and effect sizes where applicable. Statistical analyses were conducted using StatView 5.0, with $p < 0.05$ considered statistically significant.

RESULTS

A total of 23 patients (43.5% were male) undergoing elective major spinal surgery were included (Table 1). The mean age was 63.87 ± 19.08 years (range 19–83), and the mean BMI was 27.87 ± 5.17 kg/m²; 65.2% of patients had a BMI ≥ 25 kg/m². Additional characteristics are presented in Table 1.

The mean intraoperative blood loss was 1,718.06 ± 498.14 mL. On postoperative Day 1, the mean drain output was 146.26 ± 87.33 mL, resulting in a total visible blood loss of 1,864.32 ± 461.49 mL (Table 2). Mean total blood loss was 2,721.34 ± 670.53 mL, of which hidden blood loss accounted for 857.03 ± 259.39 mL, representing 31.35 ± 4.30% of total blood loss. Detailed descriptive statistics are provided in Supplementary Table S1. The distribution of intraoperative, postoperative drain, and hidden blood loss is shown in Fig. 2.

Table 2
Blood loss measurements summary

Parameter	Mean (SD)
Intraoperative Blood Loss (IBL, mL)	1718.06 (498.14)
Drain Output on Postoperative Day 1 (Bd, mL)	146.26 (87.33)
Visible Blood Loss on Postoperative Day 1 (VBL, mL)	1864.32 (461.49)
Patient's Blood Volume (PBV, mL)	4974.22 (988.42)
Total Blood Loss (TBL, mL)	2721.34 (670.53)
Hidden Blood Loss (HBL, mL)	857.03 (259.39)
Hidden Blood Loss as % of TBL	31.35 (4.30)

Supplementary Table S1

Detailed patient demographics, surgical characteristics, and blood loss measurements

Parameter	Median	Range	IQR
Patient Demographics and Surgical Characteristics			
Age (years)	70	19–83	17.5
Height (cm)	171	155–184	12.0
Weight (kg)	85	52–120	30.0
BMI (kg/m²)*	29.14	19.44–36.23	8.15
ASA classification	3	1–4	—
No. of operated spinal segments	5	3–12	4
Time of surgery (min)	198	140–288	67.50
Blood Loss Measurements			
Intraoperative blood loss (IBL, mL)	1788.53	1077.61–2675.77	715.87
Drain output on postoperative day 1 (Bd, mL)	136.00	12–280	154.00
Visible blood loss on postoperative day 1 (VBL, mL)	1902.14	1192.40–2723.77	662.73
Patient's blood volume PBV, (mL)	4894.44	3362.05–6678.78	1475.86
Total blood loss (TBL, mL)	2800.37	1644.99–4021.44	959.17
Hidden blood loss (HBL, mL)	843.23	452.60–1499.87	417.21
Hidden blood loss as % of TBL	30.16	25.07–41.85	6.48

*BMI, body mass index.

Hidden blood loss (HBL) demonstrated a statistically significant negative correlation with patient age (Spearman's ρ = − 0.492; p = 0.017; Supplementary Table S2; Fig. 3), indicating that older patients tended to have lower HBL. No other demographic or surgical variables were significantly correlated with HBL. Weak positive, non-significant trends were observed for height (ρ = 0.314; p = 0.145) and time of surgery (ρ = 0.252; p = 0.246), whereas ASA classification demonstrated a weak negative trend (ρ = − 0.281; p = 0.194).

Supplementary Table S2

Correlation coefficients between demographic/surgical variables and hidden blood loss (HBL), percentage of hidden blood loss from total blood loss (%HBL from TBL), and visible blood loss (VBL) (n = 23). Spearman's ρ are shown with corresponding *p*-values.

Variable	HBL (Spearman ρ, p)	%HBL from TBL (Spearman ρ, p)	VBL (Spearman ρ, p)
Age	−0.492, 0.017*	−0.142, 0.518	−0.430, 0.040*
Gender (M = 1, F = 0)	0.145, 0.508	0.185, 0.398	0.134, 0.548
Height (cm)	0.314, 0.145	0.247, 0.256	0.182, 0.405
Weight (kg)	0.216, 0.322	0.041, 0.853	0.172, 0.435
BMI	0.119, 0.590	0.006, 0.979	0.143, 0.515
ASA class	−0.281, 0.194	0.049, 0.823	−0.358, 0.094
No. of segments	−0.040, 0.855	−0.187, 0.393	−0.062, 0.786
Type of surgery (post.=1)	−0.175, 0.424	−0.122, 0.582	−0.172, 0.437
Time of surgery (min)	0.252, 0.246	−0.180, 0.412	0.503, 0.014*

*Statistically significant at $p < 0.05$.

Group comparisons confirmed the absence of statistically significant differences in HBL across sex, age group (≥ 65 vs. <65 years), BMI category (≥ 25 vs. <25 kg/m²), ASA classification (≥ 3 vs. <3), type of surgery (posterior vs. combined), or time of surgery (≥ 180 vs. <180 min) (all $p > 0.13$; Supplementary Table S3).

Supplementary Table S3

Group comparisons for hidden blood loss (HBL) according to selected categorical variables. Values are mean ± SD; differences are expressed with 95% confidence intervals (CI) and effect size (Cohen's *d*).

Variable	Group 1	Group 2	Mean HBL (mL) G1	Mean HBL (mL) G2	Mean diff (mL)	95% CI (low–high)	Cohen's d	p-value
Gender	Male	Female	942.3	879.5	62.8	–267.1–392.7	0.20	0.344
Age group	≥ 65 y	< 65 y	896.2	958.6	–62.4	–346.5–221.7	–0.18	0.284
BMI group	≥ 25	< 25	930.5	893.8	36.7	–251.2–324.6	0.12	0.565
ASA class	≥ 3	< 3	855.1	1011.4	–156.3	–370.9–58.3	–0.64	0.133
Type of surgery	Posterior	Combined	922.8	797.4	125.4	–56.1–306.9	0.48	0.175
Time of surgery	≥ 180 min	< 180 min	911.2	876.9	34.3	–238.6–307.2	0.11	0.544

Analysis of the percentage of HBL from total blood loss (%HBL from TBL) revealed no statistically significant associations with any demographic or surgical factor (Supplementary Table S2).

Visible blood loss (VBL) showed two significant correlations: a negative correlation with age ($\rho = -0.430$; $p = 0.040$; Supplementary Table S2, Fig. 4) and a positive correlation with time of surgery ($\rho = 0.503$; $p = 0.014$; Supplementary Table S2, Fig. 5). A non-significant trend toward lower VBL was observed in patients with higher ASA classification ($\rho = -0.358$; $p = 0.094$). Other tested factors, including sex, height, weight, BMI, number of operated segments, and type of surgery, were not significantly related to VBL.

Overall, age emerged as the only consistent factor significantly associated with both HBL and VBL in this cohort, whereas other demographic and surgical characteristics did not demonstrate statistically significant or clinically strong associations.

DISCUSSION

Spinal surgery is associated with considerable intraoperative and postoperative blood loss. In our cohort, hidden blood loss (HBL)—the fraction of total blood loss (TBL) not captured by intraoperative suction, surgical gauze, or postoperative drains—accounted for approximately 31% of TBL in open posterior thoracolumbar fusion, a proportion higher than many surgeons might expect.

Smorgick et al. [5] reported that hidden blood loss accounts for approximately 40% of total blood loss in posterior spinal fusion, which is consistent with our findings. Similar proportions have been reported across different surgical approaches, including MI-TLIF, O-TLIF, and PLIF, despite lower absolute blood loss with endoscopic techniques [4, 17].

We found a significant negative correlation between HBL and age, while no other demographic or surgical variables were significant. An inverse association between age and HBL has been reported in minimally invasive, endoscopic, and deformity surgery, but not consistently in open posterior lumbar fusion [4, 18, 19]. Younger patients may exhibit greater capillary density, vascular compliance, and more effective transcapillary refill, promoting tissue extravasation and plasma volume restoration, thereby increasing calculated HBL [20]. In contrast, stronger paraspinal musculature may predispose younger patients to bleeding, whereas a hypercoagulable state in older patients may limit HBL. Previously reported associations of HBL with BMI and operative time were not confirmed in our cohort, with only a weak correlation observed for operative time [4]. The HBL/TBL ratio showed no association with patient or surgical variables, suggesting a stable proportional contribution across surgical techniques.

In orthopedic surgery, HBL is mainly attributed to blood sequestration within tissues, hemolysis, residual blood in dead spaces, and underestimation of visible blood loss [3]. Volumetric studies suggest that tissue extravasation accounts for up to 60% of HBL, with most of the remainder explained by hemolysis [21]. Additional mechanisms include splenic clearance of damaged erythrocytes with reduced deformability due to oxidative injury, osmotic stress, or fat microemboli generated during instrumentation [22].

We propose that transcapillary refill represents an additional physiological contributor to HBL. Following blood loss, sympathetic vasoconstriction reduces capillary hydrostatic pressure and shifts Starling forces toward net absorption, restoring up to 500–1,500 mL of plasma within hours. Although essential for hemodynamic stabilization, this process induces hemodilution, lowers measured hemoglobin concentration, and inflates calculated HBL even without ongoing bleeding [20]. In extensive spinal surgery, both tissue extravasation and vascular refill likely contribute substantially to HBL. Despite being rarely acknowledged in the orthopedic HBL literature, this mechanism deserves consideration and confirmation in larger, preferably multicenter, studies.

The use of the Gross formula allows a more realistic estimation of blood loss by incorporating total blood volume and mean hematocrit, thereby correcting for fluid administration and residual hemodilution. Although crystalloids may transiently lower hematocrit, their rapid extravascular redistribution and comparable fluid volumes across patients likely minimized any net effect [23]. Methodological robustness was further strengthened by standardized perioperative conditions, uniform timing of hematologic measurements after equilibration, and conversion of transfused packed red blood cells into whole blood equivalents—an adjustment often omitted in prior studies and a potential source of bias.

Limitations

This study has several limitations. Its single-center design and relatively small sample size limit generalizability, and the findings should be considered exploratory, with a risk of incidental associations. Larger prospective multicenter studies are needed for confirmation. In addition, HBL was calculated using first postoperative day hematocrit values; incomplete fluid redistribution in some patients may have affected accuracy [24]. Alternative postoperative time points might yield different estimates but would also reduce comparability across studies. These limitations are unlikely to materially affect the primary conclusions.

CONCLUSION

Hidden blood loss accounts for a substantial proportion of total blood loss in open posterior thoracolumbar fusion, averaging nearly one-third of perioperative blood loss. Younger patients may be more susceptible, possibly due to physiological characteristics such as greater vascular reserve and more dynamic fluid shifts. Comprehensive perioperative blood loss assessment should include HBL to optimize transfusion strategies and reduce anemia-related complications in spinal surgery. Incorporating standardized HBL evaluation into perioperative care may contribute to improved outcomes in complex spine surgery.

ABBREVIATIONS

HBL
hidden blood loss
TBL
total blood loss
VBL
visible blood loss
IBL
intraoperative blood loss
PBV
patient blood volume
BMI
body mass index
ASA
American Society of Anesthesiologists classification
PLIF
posterior lumbar interbody fusion
TLIF
transforaminal lumbar interbody fusion
MI-TLIF

minimally invasive transforaminal lumbar interbody fusion
O-TLIF
open transforaminal lumbar interbody fusion
NPWT
negative-pressure wound therapy
RBC
red blood cell
SD
standard deviation
IQR
interquartile range.

DECLARATIONS

Ethical considerations

The study was approved by the institutional ethics committee, and all participants provided written informed consent.

Declaration of conflicting interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Data availability statement

Data supporting the findings of this study are available from the corresponding author upon reasonable request.

Funding Declaration

This research received no external funding.

Author Contribution

Conceptualization: P.K., J.J., and J.S.-R.; Methodology: P.K., J.J., T.K., and J.S.-R.; Formal analysis: T.K. and P.K.; Investigation: P.K., J.J., I.O., I.K.Z., and J.S.; Data curation: J.J. and T.K.; Resources: J.S.-R. and J.S.; Visualization: T.K. and J.J.; Writing—original draft: P.K. and J.J.; Writing—review and editing: all authors; Supervision: J.S.-R.; Project administration: P.K. and J.S.-R.

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Figures

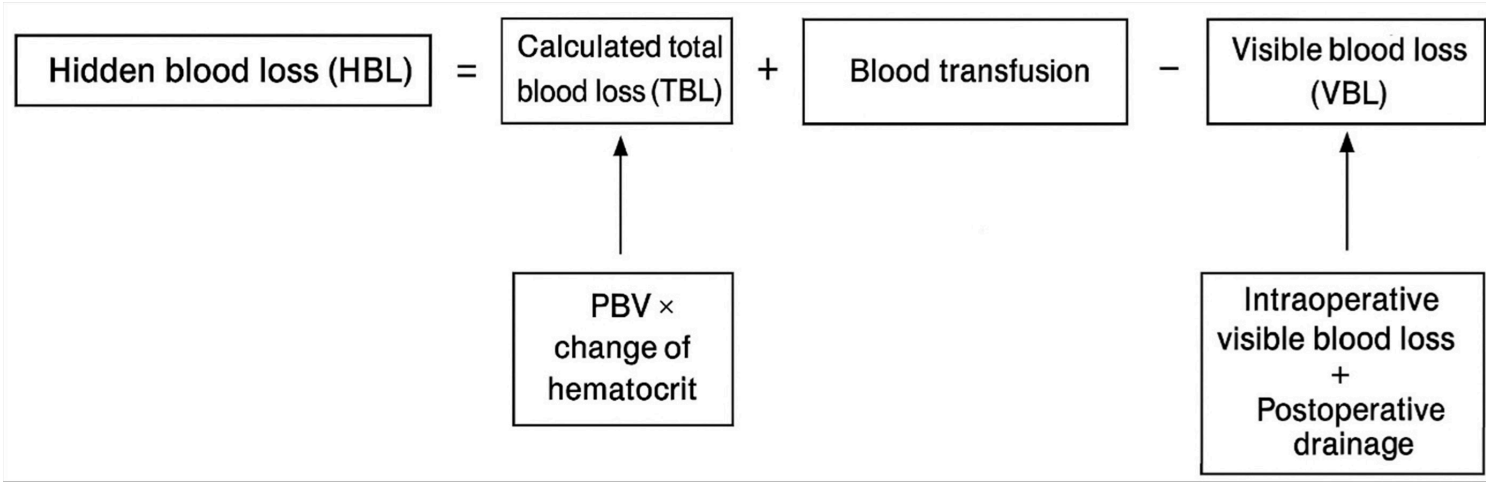


Figure 1

Flowchart illustrating the calculation of hidden blood loss (HBL).

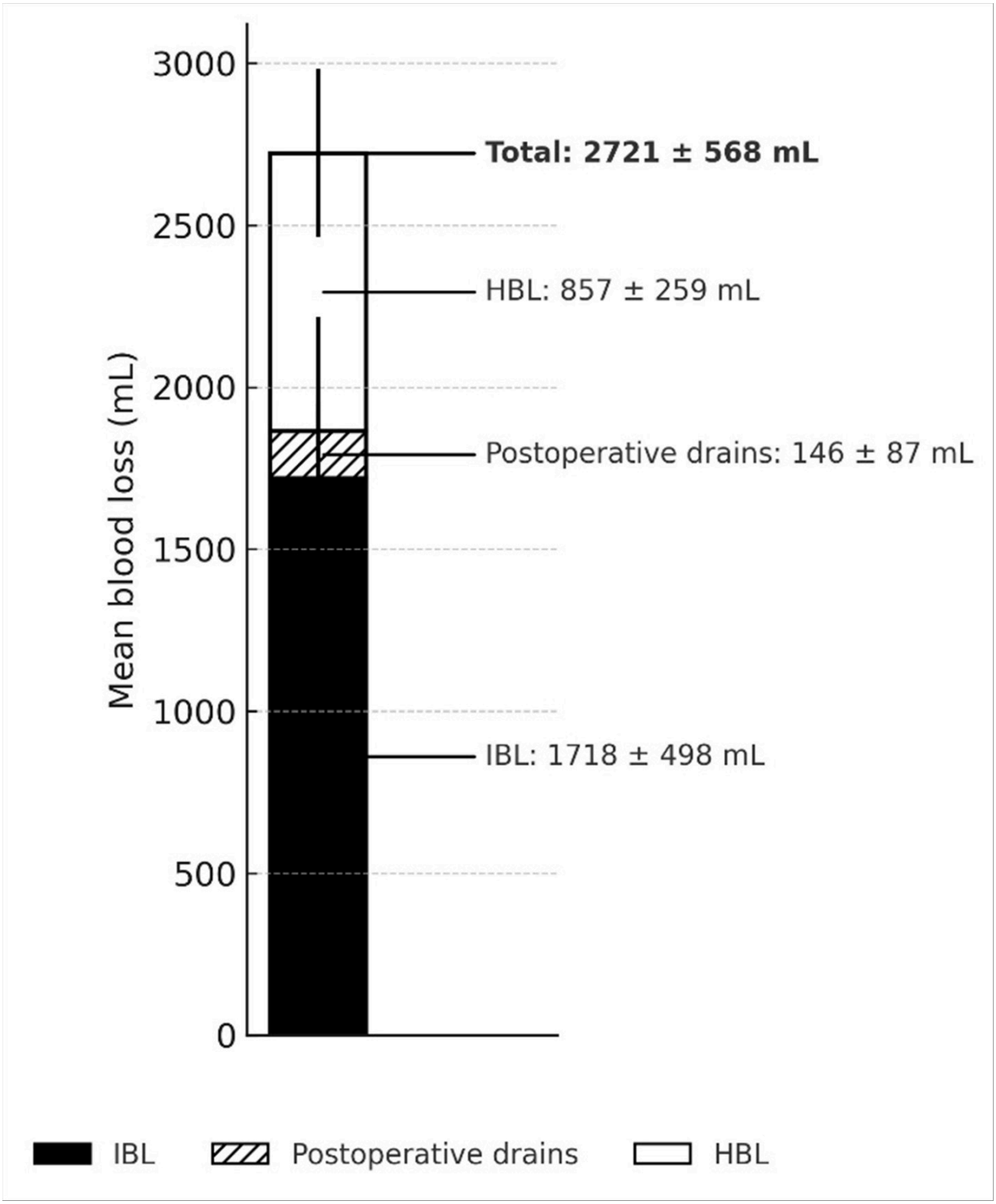


Figure 2

Mean intraoperative blood loss (IBL), postoperative drain output, and hidden blood loss (HBL) in patients undergoing elective major spinal surgery. Values are presented as mean ± standard deviation. Total blood loss (TBL) represents the sum of IBL, postoperative drain output, and HBL.

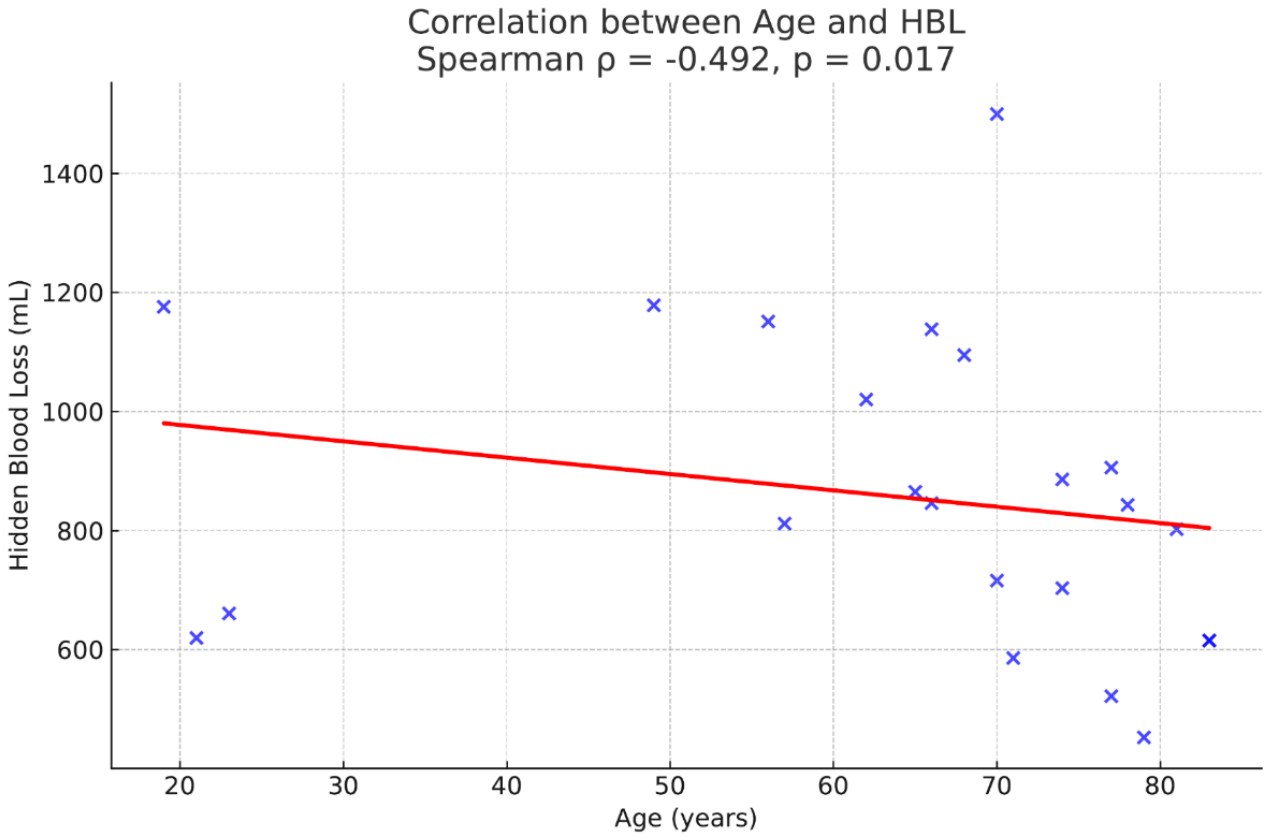


Figure 3

Correlation between age and hidden blood loss (HBL). Scatter plot illustrating the relationship between patient age and HBL in 23 patients undergoing spinal surgery. Each dot represents one patient. The red line indicates the line of best fit. The association was statistically significant (Spearman's ρ = −0.492; p = 0.017), indicating that older patients tended to have lower HBL.



Figure 4

Correlation between age and visible blood loss (VBL). Scatter plot illustrating the relationship between patient age and VBL. A statistically significant negative correlation was observed (Spearman's ρ = –0.430; p = 0.040), indicating that older patients tended to have lower visible blood loss.

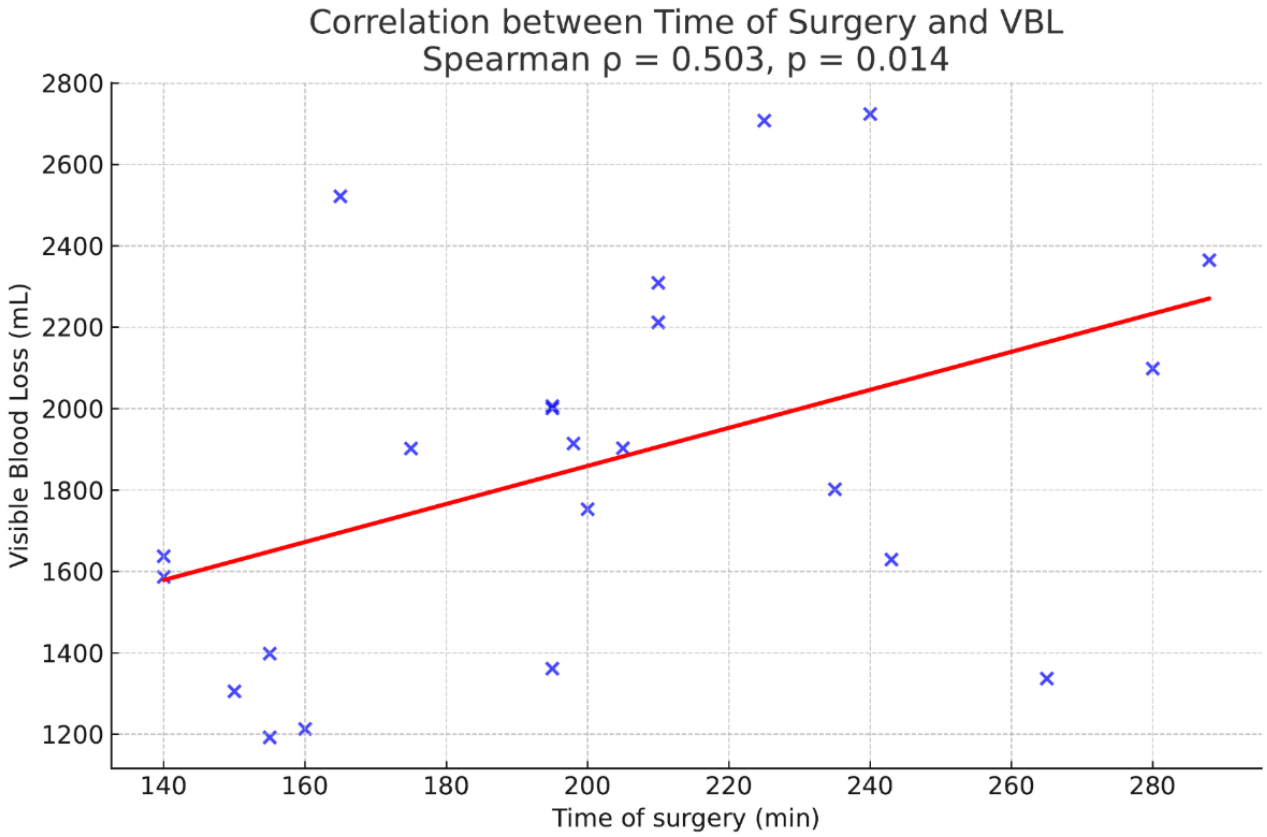


Figure 5

Correlation between time of surgery and visible blood loss (VBL). Scatter plot illustrating the relationship between time of surgery and VBL. A statistically significant positive correlation was observed (Spearman's ρ = 0.503; p = 0.014), indicating that longer surgeries were associated with higher visible blood loss.