Research Square

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Correlation Between Perioperative Total Blood Loss and Paraspinal Muscle Metrics in Patients Undergoing Single-Level Transforaminal Lumbar Interbody Fusion

Erfu Dong
Shandong First Medical University
Xiaoyu Zhou
Shandong First Medical University
Wenting Zha
Shandong First Medical University
Jingming Wang
The 960th Hospital of the People's Liberation Army
Lei Wang
The 960th Hospital of the People's Liberation Army
Weimin Huang
ever_23@163.com

The 960th Hospital of the People's Liberation Army

Research Article

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Abstract

Background

Research on blood loss after transforaminal lumbar interbody fusion (TLIF) is of great significance for peri-operative management and postoperative rehabilitation. Most previous studies primarily focused on hidden blood loss and conventional clinical risk factors, while only limited paraspinal muscle parameters have been adopted for bleeding risk evaluation. The present study aimed to assess the relationship between paraspinal muscle metrics and perioperative total blood loss (TBL) in patients who underwent single-level TLIF.

Methods

This retrospective single-center study included patients who underwent single-level TLIF between 2023 and 2025 in our institution. Demographic, perioperative, hematological, and coagulation data were collected. Preoperative lumbar magnetic resonance imaging (MRI) was used to evaluate paraspinal muscle parameters. These parameters included total cross-sectional area (TCSA), functional cross-sectional area (fCSA), fat infiltration (FI), and mean signal intensity. TBL was calculated using established formulas. Correlation analyses were performed to screen relevant indicators preliminarily, and multivariable linear regression analyses were further conducted to identify independent predictors of TBL.

Results

A total of 170 patients (69 males and 101 females) were included in this study. Correlation analyses showed significant relationships between several paraspinal muscle parameters and TBL ($P < 0.05$). TCSA and fCSA were positively correlated with TBL, while FI and mean signal intensity were negatively correlated. Multivariable regression identified L3 ES-TCSA, L3 MF-TCSA as independent positive predictors, and L4 MF-FI, L4 ES mean signal intensity as independent negative predictors of TBL (all $P < 0.05$). The regression model had a good predictive performance ($R^2 = 0.945$, $P < 0.05$).

Conclusion

Paraspinal muscle related parameters were significantly associated with TBL in patients who underwent single-level TLIF. Incorporating paraspinal muscle characteristics into routine preoperative assessment may enhance bleeding risk stratification and support individualized perioperative management.

1.Introduction

Transforaminal lumbar interbody fusion (TLIF) has been the prevalent technique used for the treatment of lumbar degenerative diseases (LDD), including lumbar disc herniation, lumbar spinal stenosis, and lumbar spondylolisthesis. This procedure offers the advantages of maintaining spinal stability and achieving reliable fusion[1]. Given its invasive nature, careful preoperative evaluation of blood loss and adequate blood preparation are essential. Effective control of perioperative total blood loss (TBL) may reduce postoperative complications and promote recovery. Excessive blood loss may result in anemia, delayed wound healing, postoperative infection, and an increased need for allogeneic transfusion. These complications may negatively affect surgical outcomes[2]. Therefore, identifying factors associated with TBL in TLIF is important for improving surgical safety and postoperative outcomes.

The paraspinal muscles include the erector spinae (ES), multifidus (MF), and psoas major (PS). The ES helps maintain posture and resist gravity. The MF mainly contributes to spinal stability and trunk rotation[3]. As key soft tissue targets in posterior lumbar surgery, their anatomical characteristics have attracted considerable attention in spine surgery and rehabilitation research due to their close relationship with surgical procedures[4]. During TLIF, manipulation of the paraspinal muscles including dissection, retraction, and repositioning is essential for surgical exposure and closure. Parameters such as muscle volume, morphology, and functional status may directly affect the extent of surgical trauma and, consequently, intraoperative and perioperative blood loss[5].

However, current literature on predictors of surgical blood loss has predominantly focused on traditional demographic and clinical variables, such as age, body mass index (BMI), number of operative levels, and hematological parameters[6]. Consequently, research investigating the association between paraspinal muscle metrics and TBL remains scant. Previous studies have suggested a link between muscle-related anatomical features and blood loss in orthopedic surgery. Paraspinal muscle thickness, for example, has been reported to correlate with hidden blood loss(HBL)[7].Despite the crucial role of these muscles in posterior lumbar surgery, the effect of paraspinal muscle parameters on TBL has not been investigated.

This study aimed to analyze the correlation of paraspinal muscle parameters and TBL in single-level TLIF, as well as the potential underlying mechanisms. The findings may help improve preoperative prediction of blood loss, guide perioperative interventions, and support individualized blood management strategies, thereby enhancing perioperative management in TLIF.

2. Methods and Results

2.1 Patient Population

This retrospective clinical study included patients with lumbar degenerative diseases who underwent TLIF at a single tertiary care hospital in China between March 2023 and January 2025.

Inclusion criteria were as follows: (1) age ≥ 18 years; (2) lumbar degenerative diseases diagonsed by clinical symptoms, physical examination, and imaging studies, including lumbar X-ray, computed tomography (CT), and magnetic resonance imaging (MRI); (3) primary TLIF performed by a single

surgical team to minimize operator variability; (4) complete preoperative and postoperative clinical, laboratory, and imaging data; and (5) single-level surgery.

Exclusion criteria were as follows: (1) age < 18 years; (2) lumbar infection, tumor, or acute fracture; (3) previous lumbar surgery; (4) intraoperative dural tear; (5) hematological diseases or coagulation disorders; (6) use of antiplatelet or anticoagulant drugs within 1 week before surgery; (7) perioperative blood transfusion; (8) preoperative MRI not performed at our institution, inaccessible via the Picture Archiving and Communication System (PACS), or of insufficient quality for paraspinal muscle measurement (Fig. 1).

This study was approved by the Ethics Committee of the 960 Hospital of the PLA (Approval No. 2026120). As a retrospective study, the requirement for informed consent was waived. All procedures followed the Declaration of Helsinki.

2.2 Data Extraction

Clinical and laboratory data were collected from the hospital electronic medical record system, and imaging data were retrieved from the Picture Archiving and Communication System (PACS).

Demographic and clinical characteristics included sex, age, height, weight, BMI, and length of hospital stay. To evaluate perioperative blood loss, hemoglobin (Hb) and hematocrit (Hct) levels were recorded preoperatively and on postoperative day 3 using an automated hematology analyzer. Additionally, the preoperative baseline coagulation profile was reviewed, which included platelet count (PLT), prothrombin time (PT), activated partial thromboplastin time (APTT), thrombin time (TT), international normalized ratio (INR), D-dimer, erythrocyte sedimentation rate (ESR), and fibrinogen.

Paraspinal muscle parameters were measured using preoperative lumbar MRI (1.5 T). Measurements were performed on sagittal and axial T2-weighted images at the inferior endplate levels of L3 and L4. These levels provide clear anatomical visualization for differentiating muscle, fat, and other soft tissues, with the erector spinae (ES) and multifidus (MF) selected as the target muscles for analysis.

Measurements were performed using ImageJ software (version 1.8.0, National Institutes of Health, USA). The following parameters were assessed: TCSA (mm^2), fCSA (mm^2), FI (%), and mean signal intensity. TCSA was defined as the total muscle area, including intramuscular fat. fCSA was defined as lean muscle area excluding fat infiltration using the Otsu thresholding method. FI was calculated as (TCSA − fCSA)/TCSA × 100%, representing intramuscular fat proportion. Mean signal intensity reflected muscle quality, with lower values indicating better muscle integrity.

To reduce interobserver variability, all measurements were independently performed three times by two experienced radiologists who were blinded to the patients' clinical and surgical information. The mean of six measurements (three per observer) was used for statistical analysis. Measurement reliability was assessed using the intraclass correlation coefficient (ICC), with an ICC > 0.8 indicating good reproducibility (Fig. 2).

Calculation of Total Blood Loss (TBL): Patient blood volume (PBV) was first calculated using the Nadler formula[8]:

PBV = k_1 × height $(m)^3$ + k_2 × weight (kg) + k_3.

For males: k_1 = 0.3669, k_2 = 0.03219, k_3 = 0.6041; for females: k_1 = 0.3561, k_2 = 0.03308, k_3 = 0.1833. TBL was then calculated using the Gross formula[9]:

TBL = PBV × (Hct-pre – Hct-post 3rd day) / Hct-ave

$$\text{TBL} = \text{PBV} \times \frac{\Delta\, Hct}{Hct_{mean}}$$

where $\Delta\, Hct$ is the difference between the preoperative hematocrit (Hct_{pre}) and the postoperative hematocrit on day 3(Hct_{post}), and Hct_{mean} is the average of $Hct_{pre}$and Hct_{post}.

2.3 Statistical Analysis

All statistical analyses were performed using SPSS software (version 27.0; IBM Corp., Armonk, NY, USA). The Shapiro–Wilk test was used to assess data normality. Continuous variables with a normal distribution were reported as mean ± standard deviation (SD). Non-normally distributed variables were reported as median (interquartile range, IQR). Categorical variables were reported as counts and percentages.

Preoperative and postoperative Hb and Hct levels were recorded and used for TBL calculation. Pearson correlation analysis assessed associations between normally distributed variables and TBL. Spearman correlation analysis was used for non-normally distributed variables. Multiple linear regression analysis (stepwise method) identified independent risk factors for TBL. Variables with P < 0.1 in univariate analysis were included in the multivariable model. This reduced the risk of excluding potential predictors. Multicollinearity was assessed using the variance inflation factor (VIF). VIF < 5 indicated no significant collinearity. To reduce multicollinearity, fCSA was excluded from the model, and FI was retained. A two-tailed P < 0.05 was considered statistically significant.

3. Results

3.1 Demographic and Clinical Baseline Characteristics

This retrospective study included 170 patients with lumbar degenerative diseases who underwent single-level TLIF. The cohort included 69 males and 101 females. The mean age was 60.23 ± 9.10 years. The mean BMI was 25.62 ± 3.18 kg/m^2. The mean hospitalization time/length of hospital stay was 13.71 ± 3.18 days. The mean TBL was 708.44 ± 323.10 ml.

Preoperative Hb and Hct were 136.13 ± 16.53 g/L and 40.64 ± 4.06%, respectively. Hb and Hct on the postoperative 3rd day were 116.18 ± 15.19 g/L and 34.34 ± 4.23%, respectively. ESR was 13.54 ± 10.34

mm/h. PT was 11.37 ± 0.85 s, and PT activity was 95.12 ± 12.39%. APTT was 27.26 ± 4.14 s, and TT was 16.85 ± 2.32 s. Fibrinogen was 2.80 ± 0.63 g/L. D-dimer was 0.45 ± 0.61 mg/L. PLT was 235.15 ± 60.17 $\times 10^9$/L.

At the L3 level, ES-CSA was 2895.74 ± 721.67 mm^2, ES-fCSA was 1433.01 ± 575.60 mm^2, ES-FI was 50.64 ± 11.22%, and ES mean signal intensity was 21.62 ± 5.68. MF-CSA was 850.91 ± 224.97 mm^2, MF-fCSA was 370.39 ± 151.84 mm^2, MF-FI was 56.91 ± 12.64%, and MF mean signal intensity was 24.55 ± 6.53.

At L4 level, ES-CSA was 2452.20 ± 648.08 mm^2, ES-fCSA was 1100.01 ± 447.23 mm^2, ES-FI was 55.83 ± 11.35%, and ES mean signal intensity was 22.24 ± 5.34. MF-CSA was 1213.99 ± 294.12 mm^2, MF-fCSA was 490.39 ± 196.39 mm^2, MF-FI was 59.90 ± 11.90%, and MF mean signal intensity was 23.66 ± 4.78 (Table 1).

Table 1
Demographic and clinical characteristics of the patients.

Parameter	Statistic
No.	170
Male	69
Female	101
Mean Age(yr)	60.23 ± 9.10
BMI(kg/m^2)	25.62 ± 3.18
Hospital stays (d)	13.71 ± 3.18
TBL(ml)	708.44 ± 323.10
Hb (Pre)(g/L)	136.13 ± 16.53
Hb (post 3rd day)(g/L)	116.18 ± 15.19
HCT(pre)(%)	40.64 ± 4.06
HCT(post 3rd day)(%)	34.34 ± 4.23
ESR (mm/h)	13.54 ± 10.34
PT (s)	11.37 ± 0.85
PT Activity	95.12 ± 12.39
APTT (s)	27.26 ± 4.14
TT (s)	16.85 ± 2.32
FIB (g/L)	2.80 ± 0.63
D-dimer(mg/L)	0.45 ± 0.61
PLT (10^9/L)	235.15 ± 60.17
L3 level	
ES-CSA(mm^2)	2895.74 ± 721.67
ES-fCSA(mm^2)	1433.01 ± 575.60
ES-FI(%)	50.64 ± 11.22
ES-mean	21.62 ± 5.68

BMI, body mass index; Hb, hemoglobin; Hct, hematocrit; PBV, patient blood volume; TBL, total blood loss; ESR, erythrocyte sedimentation rate; PT, prothrombin time; APTT, activated partial thromboplastin time; TT, thrombin time; FIB, fibrinogen; PLT, platelet; CSA, cross-sectional area; fCSA, functional cross-sectional area; FI, fat infiltration; ES, erector spinae; MF, multifidus.

Parameter	Statistic
MF-CSA(mm^2)	850.91 ± 224.97
MF-fCSA(mm^2)	370.39 ± 151.84
MF-FI(%)	56.91 ± 12.64
MF-mean	24.55 ± 6.53
L4 level	
ES-CSA(mm^2)	2452.20 ± 648.08
ES-fCSA(mm^2)	1100.01 ± 447.23
ES-FI(%)	55.83 ± 11.35
ES-mean	22.24 ± 5.34
MF-CSA(mm^2)	1213.99 ± 294.12
MF-fCSA(mm^2)	490.39 ± 196.39
MF-FI(%)	59.90 ± 11.90
MF-mean	23.66 ± 4.78

BMI, body mass index; Hb, hemoglobin; Hct, hematocrit; PBV, patient blood volume; TBL, total blood loss; ESR, erythrocyte sedimentation rate; PT, prothrombin time; APTT, activated partial thromboplastin time; TT, thrombin time; FIB, fibrinogen; PLT, platelet; CSA, cross-sectional area; fCSA, functional cross-sectional area; FI, fat infiltration; ES, erector spinae; MF, multifidus.

3.2 Reliability of Paraspinal Muscle Measurements

Paraspinal muscle parameters, including TCSA, fCSA, FI and mean signal intensity of ES and MF at the inferior endplate levels of L3 and L4, were measured by two independent radiologists. Measurement reliability was assessed using the intraclass correlation coefficient (ICC). All ICC values were > 0.8 (range, 0.805–0.96), indicating good interobserver reproducibility.

3.3 Correlation Analysis Between Paraspinal Muscle Parameters and Total Blood Loss

Pearson and Spearman correlation analyses showed significant associations between several paraspinal muscle parameters and TBL (all $P < 0.05$). At the L3 level, both ES and MF parameters were correlated with TBL. For ES, TCSA ($r = 0.227$, $P = 0.003$) and fCSA ($r = 0.237$, $P = 0.002$) showed positive correlations with TBL. FI ($r = -0.202$, $P = 0.008$) and mean signal intensity ($r = -0.156$, $P = 0.043$) showed negative correlations. For MF, TCSA ($r = 0.173$, $P = 0.024$) and fCSA ($r = 0.179$, $P = 0.010$) showed positive correlations with TBL. FI ($r = -0.157$, $P = 0.041$) and mean signal intensity ($r = -0.189$, $P = 0.014$) showed negative correlations.

At the L4 level, significant correlations were observed for ES fCSA ($r = 0.245$, $P = 0.001$), ES FI ($r = -0.260$, $P < 0.001$), ES mean signal intensity ($r = -0.165$, $P = 0.031$), as well as MF fCSA ($r = 0.237$, $P = 0.002$) and MF FI ($r = -0.330$, $P < 0.001$). In addition, several baseline and coagulation-related variables—including age, BMI, APTT, TT, and preoperative and postoperative day 3 Hct and Hb—were also significantly associated with TBL ($P < 0.05$ for all comparisons) (Table 2).

Table 2
Correlation coefficients (r) and P-values between total blood loss and clinical, laboratory, and imaging parameters.

Parameter	Correlation Coefficient (r)	P-value
Age(yr)	-0.169	0.028
BMI(kg/m^2)	0.160	0.037
Hospital stays (d)	0.149	0.052
Hb(pre)(g/L)	0.324	< 0.001
Hb(post 3day)(g/L)	-0.226	0.003
HCT(pre)(%)	0.296	< 0.001
HCT(post 3day)(%)	-0.315	< 0.001
ESR(mm/h)	-0.111	0.151
APTT(s)	-0.271	< 0.001
TT(s)	0.205	0.007
FIB(g/L)	-0.183	0.017
D-dimer(mg/L)	-0.107	0.164
L3 level		
ES-CSA(mm^2)	0.227	0.002
ES-fCSA(mm^2)	0.237	0.002
ES-FI(%)	-0.202	0.008
ES-mean	-0.156	0.043
MF-CSA(mm^2)	0.173	0.024
MF-fCSA(mm^2)	0.197	0.010
MF-FI(%)	-0.157	0.041
MF-mean	-0.189	0.014
L4 level		
ES-CSA(mm^2)	0.125	0.105

BMI, body mass index; Hb, hemoglobin; HCT, hematocrit; ESR, erythrocyte sedimentation rate; APTT, activated partial thromboplastin time; TT, thrombin time; FIB, fibrinogen; CSA, cross-sectional area; fCSA, functional cross-sectional area; FI, fat infiltration; ES, erector spinae; MF, multifidus; pre, preoperative; post 3 day, postoperative 3 days.

Parameter	Correlation Coefficient (r)	P-value
ES-fCSA(mm^2)	0.245	0.001
ES-FI(%)	-0.260	< 0.001
ES-mean	-0.165	0.031
MF-CSA(mm^2)	0.047	0.543
MF-fCSA(mm^2)	0.237	0.002
MF-FI(%)	-0.330	< 0.001
MF-mean	-0.078	0.314

BMI, body mass index; Hb, hemoglobin; HCT, hematocrit; ESR, erythrocyte sedimentation rate; APTT, activated partial thromboplastin time; TT, thrombin time; FIB, fibrinogen; CSA, cross-sectional area; fCSA, functional cross-sectional area; FI, fat infiltration; ES, erector spinae; MF, multifidus; pre, preoperative; post 3 day, postoperative 3 days.

3.4 Multivariable Linear Regression Analysis of Risk Factors for Total Blood Loss

To avoid excluding potential predictors, variables with $P < 0.1$ in the correlation analysis were included in the multivariable linear regression model. Multicollinearity was also assessed. All variables showed variance inflation factor (VIF) values < 5, indicating no significant collinearity. To further reduce multicollinearity, fCSA was excluded from the final model, and FI was retained.

After adjustment for potential confounders, MF FI at L4 ($\beta = -2.65$, standard error [SE] = 0.523, standardized $\beta = -0.098$, $P < 0.001$), ES TCSA at L3 ($\beta = 0.047$, SE = 0.012, standardized $\beta = 0.104$, $P < 0.001$), MF TCSA at L3 ($\beta = 0.095$, SE = 0.031, standardized $\beta = 0.066$, $P = 0.002$), and ES mean signal intensity at L4 ($\beta = 3.087$, SE = 1.306, standardized $\beta = 0.051$, $P = 0.019$) were identified as independent risk factors for TBL in patients undergoing single-level TLIF. The model showed good fit ($R^2 = 0.945$, $F = 397.7$, $P < 0.001$). The model explained 94.5% of the variance in TBL (Table 3, Fig. 3).

Table 3
Results of multivariate regression analysis.

Coefficients[a]					
	Unstandardized Coefficients		**Standardized Coefficients**		
Model	B	SD	Beta	t	Sig.
BMI	8.109	1.999	0.080	4.057	< 0.001
HCT(pre)(%)	107.379	2.612	1.351	41.116	< 0.001
HCT(post3rd day)(%)	-114.254	2.360	-1.496	-48.418	< 0.001
L3 level					
ES-CSA(mm2)	0.047	0.012	0.104	4.029	< 0.001
MF-CSA(mm2)	0.080	0.032	0.055	2.516	0.013
L4 level					
MF-FI(%)	-2.408	0.546	-0.089	-4.407	< 0.001
ES-mean	3.265	1.359	0.054	2.402	0.017
a. Dependent Variable: Total Blood Loss (TBL).					

4. Discussion

Our study revealed that ES and MF TCSA at the inferior endplate level of L3 and MF FI at L4 were identified as independent factors associated with TBL. ES and MF TCSA showed positive correlations with TBL, whereas MF FI showed a negative correlation.

Several studies have explored the association between paraspinal muscle characteristics and blood loss in spine surgery[10]. Zhou et al.[7] analyzed hidden blood loss in 137 patients with lumbar degenerative diseases who underwent minimally invasive transforaminal lumbar interbody fusion (MIS-TLIF). They found that sagittal paraspinal muscle thickness, subcutaneous fat, and hematological parameters were significantly associated with hidden blood loss. Similarly, Jin et al.[11] reported a significant positive correlation between paraspinal muscle thickness and hidden blood loss in 100 patients who underwent unilateral biportal endoscopic lumbar interbody fusion. However, studies investigating the relationship between paraspinal muscle characteristics and total blood loss remain limited. Although HBL accounts for a substantial proportion of perioperative bleeding in lumbar fusion surgery, it represents only one component of TBL. As a more comprehensive measure of perioperative blood loss, TBL reflects both visible and hidden bleeding and may better characterize the overall surgical burden. Furthermore, clinical decision-making, including transfusion strategies and postoperative management, is more closely

related to TBL than to HBL alone. Therefore, identifying factors associated with TBL may provide greater clinical value for preoperative risk stratification and individualized perioperative management.

From a mechanistic perspective, muscle tissue has a richer blood supply than intermuscular fat[12]. Therefore, larger paraspinal muscle TCSA may reflect a denser intramuscular vascular network[13]. Greater muscle mass requires more extensive dissection to achieve adequate exposure, leading to increased vascular injury and blood loss during and after surgery[14]. Conversely, MF FI showed a negative association with TBL in the present study. Fatty infiltration is a hallmark of paraspinal muscle degeneration and reflects the replacement of contractile muscle fibers by adipose tissue[15]. Furthermore, fatty infiltration is often accompanied by muscle atrophy and loss of functional muscle mass, which may lessen the extent of muscle dissection required to achieve adequate exposure[16]. Together, these changes may contribute to reduced perioperative blood loss, thereby explaining the inverse relationship between MF FI and TBL observed in the present study. In the present study, traditional indicators such as subcutaneous fat and muscle thickness were further refined into more comprehensive paraspinal muscle parameters, including bilateral ES and MF TCSA and FI. This may improve the reliability of the findings.

Therefore, selecting an appropriate vertebral level for paraspinal muscle assessment is particularly important. Hu et al.[17] evaluated the reliability of paraspinal muscle measurements in patients with chronic low back pain. They found that the L3-L4 level showed clearer muscle boundaries and more stable anatomical landmarks than the L4-L5 and L5-S1 levels. The L3-L4 level also showed higher ICC values and lower measurement error. Therefore, this level is considered suitable for assessing paraspinal muscle cross-sectional area and fat infiltration. In addition, L3 represented the apex of lumbar lordosis and is an important biomechanical region for lumbar load transmission[18]. Paraspinal muscles at this level have broader attachment areas and larger volumes. Adequate exposure of the lamina, facet joints, and intervertebral disc space requires wider muscle dissection at this level[19]. Therefore, ES and MF TCSA at L3 may reflect the amount of muscle involved during surgery and may show a stronger association with TBL. In contrast, the L4 level is located near the lumbosacral junction, where anatomical structures are more compact. Paraspinal muscle attachment and adhesion to bony structures are less extensive than at L3. Surgical exposure at this level can often be achieved through the natural anatomical space of the lumbosacral junction, without extensive muscle dissection into adjacent levels[20, 21]. As a result, the influence of muscle TCSA at L4 on TBL may be reduced.

The present study also identified MF FI at the inferior endplate level of L4 as an independent factor associated with TBL. Higher FI was associated with lower perioperative blood loss. Normally, the MF consists of well-vascularized skeletal muscle. Surgical procedures such as dissection and retraction may therefore cause considerable bleeding[22]. However, as fat gradually accumulates, it replaces well-perfused muscle fibers, leading to an overall reduction in muscle blood supply[23]. During surgical exposure, the loose texture of intramuscular fat can be visually distinguished from muscle fibers[24]. This may help limit muscle dissection and reduce injury to muscle-derived vessels, thereby decreasing bleeding. In addition, adipose tissue has relatively sparse vascularity. Bipolar coagulation may therefore

achieve hemostasis more effectively by rapidly sealing small vessels, which may further reduce blood loss[25].

Although Chen et al. [26] reported increased intraoperative blood loss with greater paraspinal muscle fat infiltration in unilateral biportal endoscopic transforaminal lumbar interbody fusion (UBE-TLIF), differences in surgical techniques may limit direct comparison with the present study. In contrast, the present study focused on open posterior fusion, where muscle dissection was relatively consistent. In this setting, greater preoperative fat infiltration may reflect replacement of muscle fibers by adipose tissue, resulting in lower muscle vascularity and consequently reduced muscle-derived bleeding under comparable surgical trauma.

Under a similar degree of surgical trauma, muscle-derived bleeding may therefore be reduced. Kulkarni et al. [27] also reported that greater paraspinal muscle fat infiltration was associated with poorer muscle integrity and lower vascular supply. These findings support the results of the present study.

In addition, the present study found that the mean signal intensity of the ES at the L4 level was significantly negatively correlated with TBL. No such association was observed at other levels or in other muscles. This finding may reflect the segment-specific pattern of lumbar degeneration and the influence of preoperative muscle pathology on TBL. The L4/L5 segment is a common site of lumbar degenerative changes[13, 28]. At this level, the ES is exposed to chronic compensatory stress and inflammation, which may lead to fibrosis and edema. On T2-weighted MRI, these changes usually appear as high signal intensity and lower grayscale values[29]. Compared with normal muscle, this pathological tissue may show greater vascularity, higher stiffness, and lower elasticity[30]. As a result, this type of muscle may be more prone to diffuse bleeding and more difficult to control during surgery, which may increase TBL.

The present study is the first to highlight the association between paraspinal muscle parameters, particularly MF TCSA and FI, and TBL in TLIF. These findings provide a theoretical basis for preoperative imaging-based assessment of bleeding risk. Incorporating paraspinal muscle parameters, such as TCSA, FI, and mean signal intensity, into preoperative evaluation may improve prediction of TBL and help identify patients at high risk of bleeding. This may also assist perioperative planning, including transfusion and fluid management. Previous studies have shown that paraspinal muscle morphology and function significantly affect postoperative outcomes after lumbar spine surgery. Increased FI of the MF and ES has been identified as a risk factor for postoperative low back pain, poor functional recovery, and adjacent segment degeneration (ASD). Reduced TCSA has also been associated with lower fusion rates and postoperative dysfunction[31–35].

Therefore, in patients with poor paraspinal muscle quality, attention should be given not only to bleeding risk but also to the effect of muscle dysfunction on postoperative recovery. In elective cases with high bleeding risk, targeted preoperative training may help improve muscle quality and reduce intraoperative blood loss and postoperative complications.

This study has several limitations. First, it included only patients undergoing single-level TLIF, without multilevel fusion, revision surgery, or other complex cases. While ensuring the consistency of the study data, this may limit the generalizability of the findings. Second, paraspinal muscle assessment was limited to L3 and L4. The entire lumbar spine was not analyzed, so global muscle status may not be fully represented. Third, this was a single-center retrospective study with a relatively small sample size. Fourth, all patients were from a Chinese population, which may limit external validity.

Future studies should involve larger and more diverse patient populations to further confirm the present findings and improve their generalizability across different clinical settings.

5. Conclusion

The present findings suggest that paraspinal muscle–related parameters are valuable in predicting TBL in patients undergoing single-level TLIF. Independent factors include TT, BMI, preoperative and postoperative Hct, ES, and MF TCSA at L3, ES mean signal intensity at L4, and MF FI at L4. Preoperative imaging-based assessment of paraspinal muscle parameters may help identify patients at high risk of bleeding and support individualized perioperative management, including blood preparation and postoperative rehabilitation. This may reduce hospitalization time and postoperative complications and improve patient outcomes and quality of life.

Declarations

Ethics approval

The study was conducted in accordance with the guidelines of the Declaration of Helsinki stated in 1964. This is a single-center retrospective cohort study approved by the Ethics Committee of the 960th Hospital of the People's Liberation Army (Approval NO. 2026120).

Consent to participate

In accordance with the ethical requirements for retrospective studies, the Ethics Committee of the 960th Hospital of the People's Liberation Army granted a waiver of patient informed consent. Clinical trial number: not applicable.

Consent for publication

Not applicable.

Availability of data and materials

The datasets analysed during the present study are not publicly available due to hospital patient-privacy restrictions, but are available from the corresponding author on reasonable request.

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Competing interest

The authors declare that they have no competing interests.

Authors' contributions

Each author made substantial contributions to this work. Erfu Dong conceived and designed the research, collected imaging and clinical data, completed statistical analysis, and drafted the original manuscript. Jingming Wang took charge of critical revision of the manuscript and assisted with patient data collection. Wenting Zha, Lei Wang and Xiaoyu Zhou performed case screening, clinical data extraction and MRI paraspinal muscle measurement. Weimin Huang supervised the whole research project, participated in study design, and conducted substantial revision of the manuscript. All authors read and approved the final submitted version.

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Figures

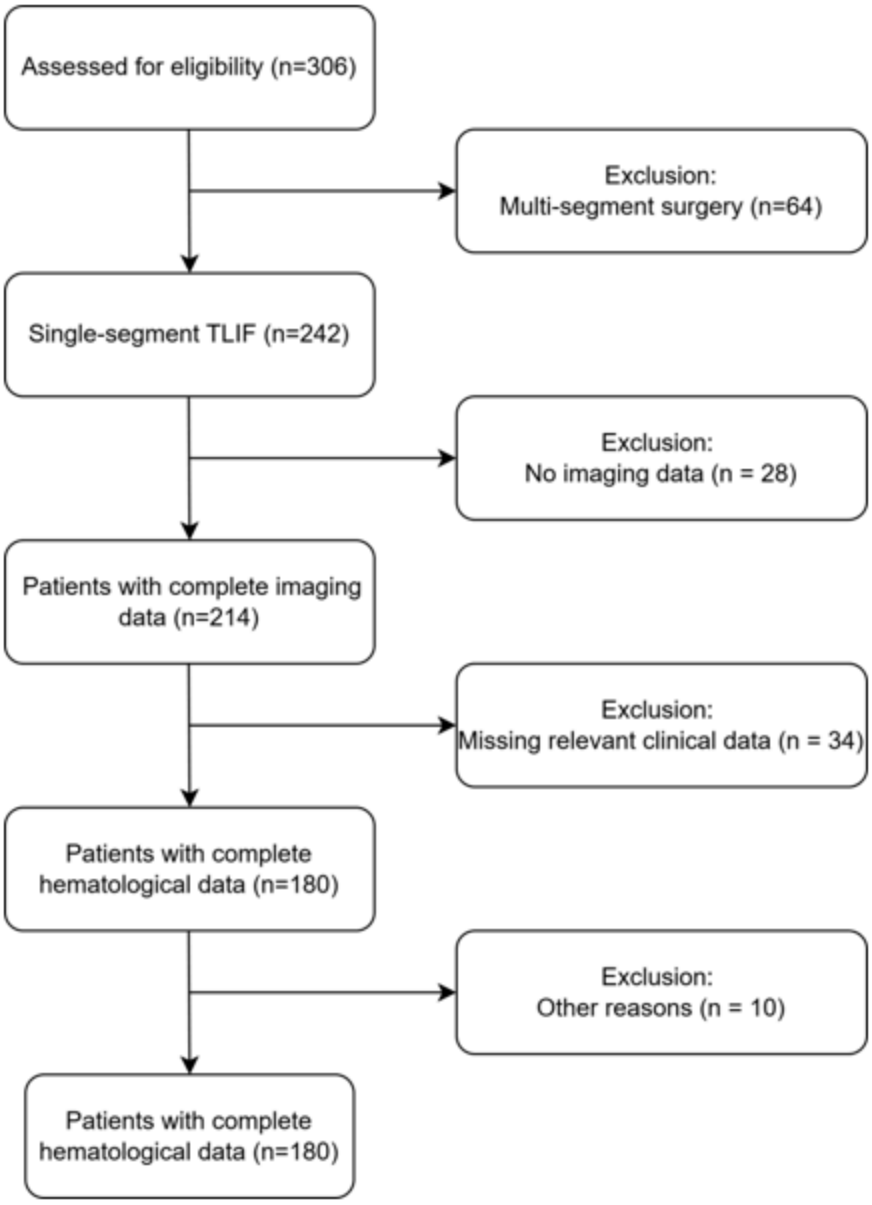


Figure 1

Patient selection flow chart. Note: TLIF, transforaminal lumbar interbody fusion.

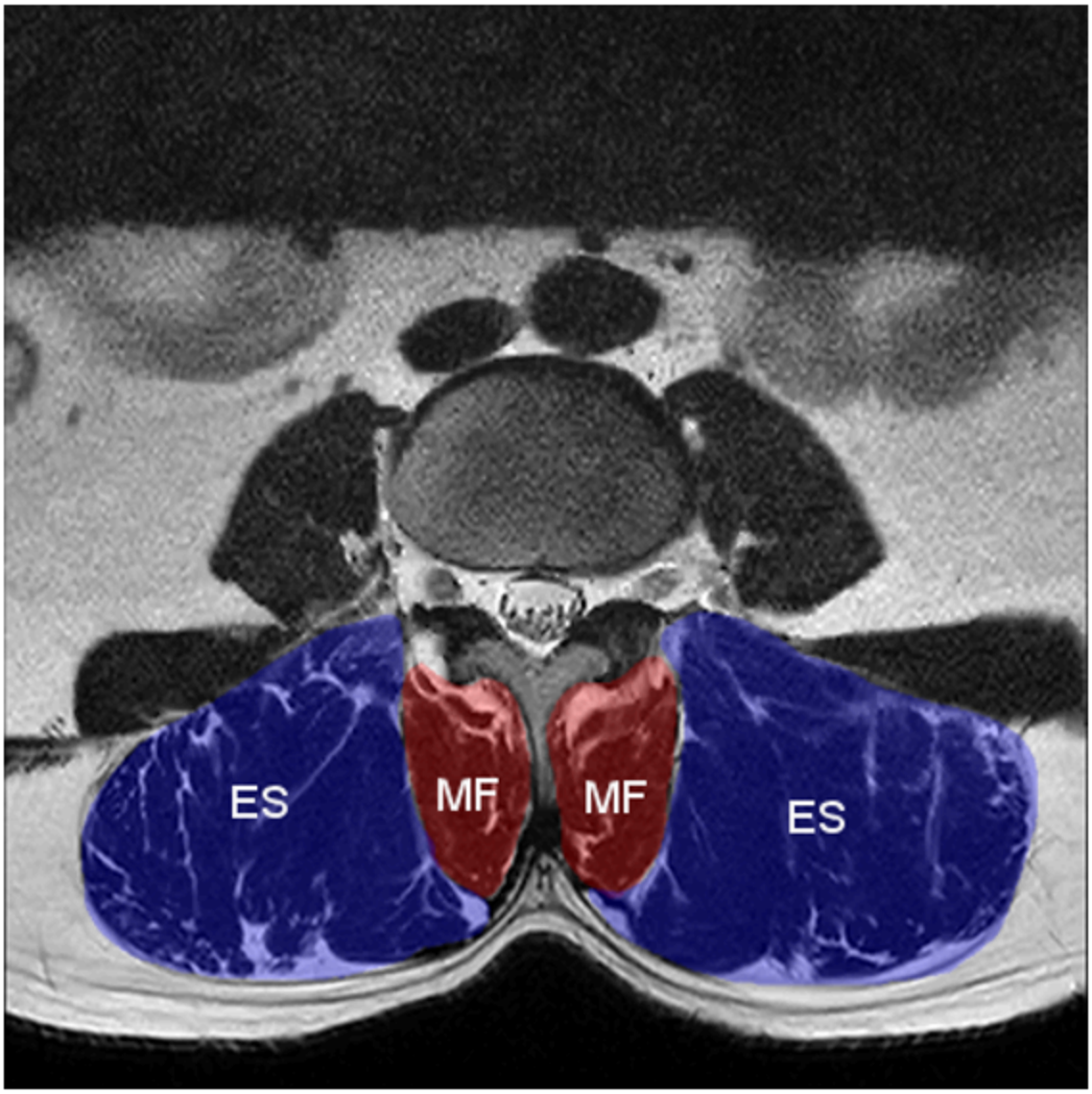


Figure 2

Bilateral segmentation of paraspinal muscle (erector spinae (ES) and multifidus (MF)) on axial T2-weighted MRI. For each muscle group, the total cross-sectional area was calculated as the sum of both sides.

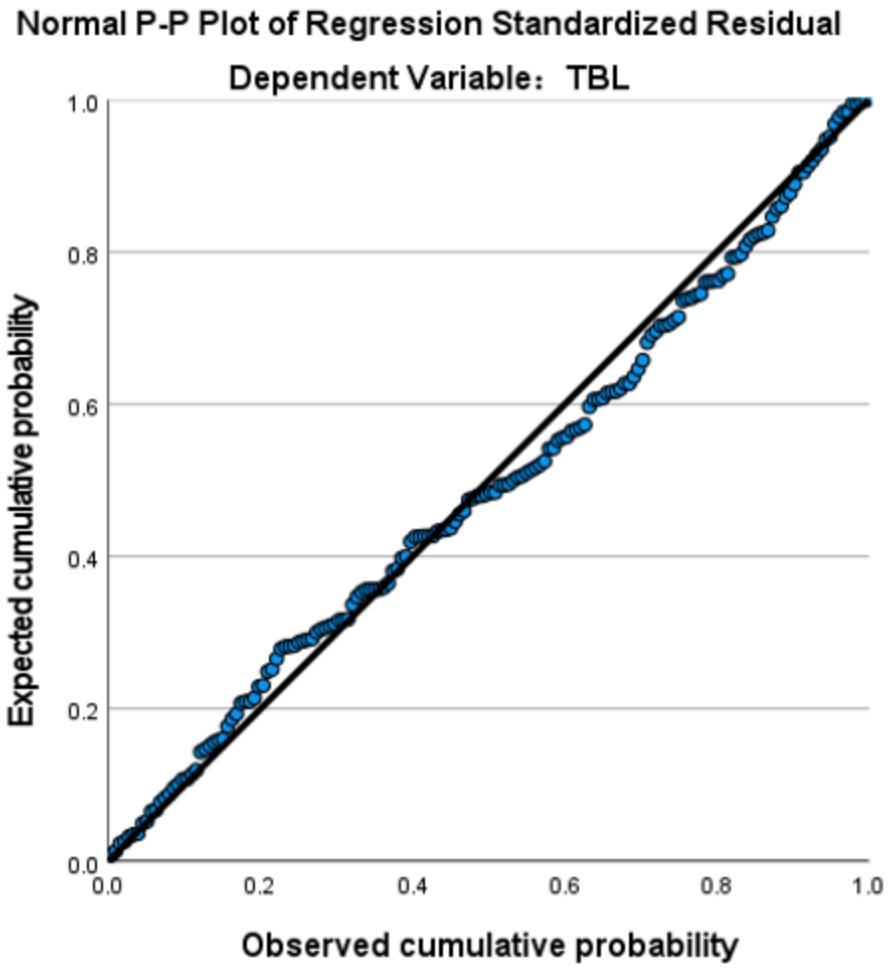


Figure 3

Normal P-P Plot of standardized residuals for multiple linear regression model. The standardized residuals are approximately normally distributed, as indicated by the close alignment of data points along the diagonal line. Note: Dependent variable = total blood loss (TBL).

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Table1.docx
- Table2.docx
- Table3.docx