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RESEARCH

Validated intraoperative bleeding severity scale (VIBe) for hemostasis assessment in lumbar spinal fusion: a prospective, randomized controlled trial

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Abstract

Purpose Intraoperative bleeding remains a major challenge in lumbar spine surgery, with conventional assessment methods lacking standardization. The Validated Intraoperative Bleeding Severity Scale (VIBe) is a structured five-grade tool developed to objectively assess bleeding severity across surgical fields. This study evaluated the clinical utility of VIBe in lumbar spinal fusion by comparing it with conventional bleeding metrics across various hemostatic strategies, including hypotensive anesthesia and local hemostatic agent use.

Methods In this prospective, randomized controlled trial, 70 patients undergoing elective posterior lumbar decompression and fusion were randomized to normotensive or hypotensive anesthesia. Each group was further divided by hemostatic strategy: active agents alone or a combination of active and passive agents. VIBe grades were independently recorded by the surgeon and assistant for each bleeding site. Conventional bleeding metrics—including estimated blood loss (EBL), transfusion volume, and drain output—were also collected. Between group comparisons and inter-rater agreement were assessed, and correlation analysis was performed to evaluate the association between the VIBe and conventional bleeding metrics.

Results VIBe grades improved significantly after hemostasis in all patients ($p<0.001$). Although intraoperative blood pressures were significantly lower in the hypotensive group, there were no significant differences in transfusion volume, EBL, drain output, or VIBe-based assessments. Outcomes were also comparable between patients receiving combined versus active-only hemostatic agents. Inter-rater agreement for VIBe scores before hemostasis, after hemostasis, and for score changes was near-perfect ($\kappa=0.934$, 0.834, and 0.856 respectively, all $p<0.001$). Operator-assigned VIBe scores significantly correlated with EBL ($\rho=0.305$, $p=0.010$) and transfusion volume ($\rho=0.264$, $p=0.027$); assistant correlated with EBL ($\rho=0.284$, $p=0.017$).

Conclusion VIBe is a reliable and reproducible tool for intraoperative bleeding assessment in lumbar spine fusion. Active hemostatic agents were effective, and the addition of passive agents offered no measurable advantage.

Keywords Lumbar spine · Spinal fusion · Intraoperative bleeding · Hemostasis · Validated intraoperative bleeding severity scale · Randomized controlled trial

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Introduction

Lumbar spinal fusion is an effective surgical intervention for degenerative lumbar spine disorders, including spinal stenosis, spondylolisthesis, degenerative kyphoscoliosis, and adjacent segment pathology. Despite advances in surgical techniques and anesthetic care, the procedure still carries a notable complication rate of approximately 5%, contributing to increased healthcare costs and poorer outcomes [1, 2].

Among these complications, perioperative bleeding and transfusion remain clinically significant due to their association with morbidity and mortality [3, 4]. To minimize intraoperative blood loss, several established methods are routinely employed, including induced hypotensive anesthesia and the application of local hemostatic agents—both of which have demonstrated efficacy in spinal surgery [3, 5–7].

The Validated Intraoperative Bleeding Severity Scale (VIBe), introduced by Lewis et al.., is a five-grade scale developed to standardize bleeding assessments and evaluate hemostatic agents in clinical trials [8]. Although originally validated in general surgery, its applicability in spine surgery has recently gained attention. A validation study conducted by spine surgeons confirmed the reliability of VIBe for quantifying intraoperative blood loss, establishing its utility in both clinical practice and research [9]. Furthermore, VIBe scores have shown significant associations with perioperative blood loss and transfusion rates in thoracolumbar spine surgeries [10].

To date, however, no study has applied VIBe to assess the effectiveness of intraoperative bleeding control strategies in lumbar spinal fusion. Notably, although VIBe was originally developed to evaluate hemostatic agents, there remains limited clinical guidance on the optimal use and sequencing of such agents in spinal surgery. Therefore, this study aimed to (1) evaluate the utility of VIBe for assessing bleeding control achieved through induced hypotensive anesthesia and local hemostatic agents, and (2) compare the effectiveness of active hemostatic agents alone versus combined active and passive agents in standard surgical practice.

Materials and methods

Study design

Patients aged 50–80 years with symptomatic degenerative lumbar pathology confirmed by MRI were eligible. Exclusion criteria included inability to provide written consent (e.g., illiteracy or cognitive impairment); surgery for trauma, infection, tumor, or metastasis; staged or revision procedures; fusion extending beyond the lumbar spine; known coagulopathy or bleeding disorders; inability to discontinue antiplatelet or anticoagulant; or contraindications to induced hypotensive anesthesia (e.g., ischemic heart disease, renal insufficiency, or cerebrovascular disease).

Patients were randomized into normotensive or induced hypotensive anesthesia groups. Each group was further randomized into two subgroups based on intraoperative hemostatic strategy: combined use of active and passive agents, or active agents alone (Fig. 1). This hemostatic comparison was designed to reflect common surgical practice, where passive agents are frequently added to active agents despite limited evidence. To enable a controlled evaluation, all patients first received a flowable active agent, allowing the additional effect of passive agent use to be assessed in isolation.

Randomization was performed one month before surgery using a computer-generated permuted block randomization method with a block size of four. The allocation process was conducted by a researcher not involved in the surgical procedures to ensure allocation concealment.

The study protocol was approved by the Institutional Review Board, and all participants provided written informed consent.

Surgical procedure

All patients underwent posterior lumbar decompression, including laminectomy, facetectomy, and instrumented fusion with pedicle screw fixation using the conventional open approach. Muscle and soft tissue bleeding was controlled using electrocautery, and bone bleeding with bone wax. Epidural venous bleeding, typically encountered near the facetectomy sites, was addressed with local hemostatic agents.

All patients received a flowable active hemostatic agent (Floseal, Baxter International, Deerfield, IL, USA) as the first-line treatment. In the combined group, a mechanical passive agent (Avitene, Davol, Warwick, RI, USA) was additionally applied to evaluate whether this sequence offers further benefit in bleeding control.

Validated intraoperative bleeding severity scale (VIBe)

Epidural bleeding severity at each facetectomy site was graded by the lead surgeon and two orthopedic spine fellows using VIBe, which ranges from 0 (no bleeding) to 4 (life-threatening bleeding) (Table 1, Supplementary Videos) [8]. Following hemostasis, the VIBe was reassessed at each site.

Assessments were performed in real time within the surgical field, with all observers blinded to one another's

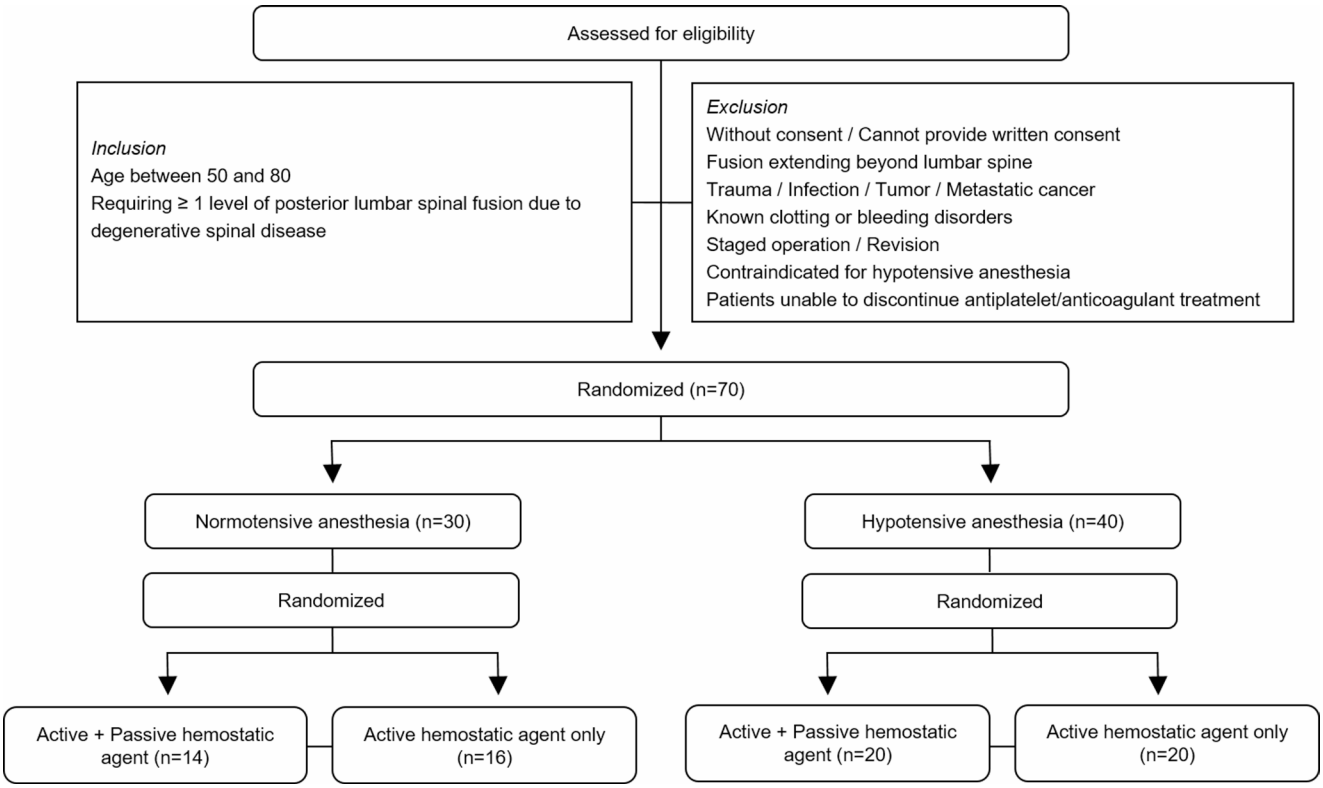

Fig. 1 The CONSORT flow diagram of this research

Table 1 Validated intraoperative bleeding severity scale (VIBe)

Grade	Visual presentation	Anatomic appearance	Qualitative description	Visually estimated rate of blood loss (mL/min)
0	No bleeding	No bleeding	No bleeding	≤ 1.0
1	Ooze or intermittent flow	Capillary-like bleeding	Mild	>1.0-5.0
2	Continuous flow	Venule and arteriolar-like bleeding	Moderate	>5.0-10.0
3	Controllable spurting and/or overwhelming flow	Noncentral venous- and arterial-like bleeding	Severe	>10.0-50.0
4	Unidentified or inaccessible spurting or gush	Central arterial- or venous-like bleeding	Life threatening	>50.0

ratings. Scores were documented independently prior to any discussion or data entry. Inter-rater agreement between the two assistant observers was assessed using Cohen's kappa. Given the high agreement, the average of their two scores was used as a composite assistant rating for subsequent comparisons.

All raters reviewed standardized training materials, including instructional videos and practice simulations, provided by Baxter International prior to study initiation.

Data collection

Baseline patient data included age, sex, body mass index (BMI), American Society of Anesthesiologists (ASA) classification and Charlson Comorbidity Index (CCI) as a baseline comorbidity burden measure, preoperative hemoglobin (Hb), osteoporosis status, and preoperative systolic and diastolic blood pressure (SBP and DBP, respectively).

Intraoperative data included SBP, DBP, mean arterial blood pressure (MBP), number of fusion levels, number of epidural bleeders, hemostasis success rate, operation duration, estimated blood loss (EBL), and dural tear incidence.

Perioperative data included postoperative Hb, transfusion volume, number of packed red blood cell (pRBC) and/or fresh frozen plasma (FFP) units transfused, length of hospital stay, total drain output, and duration of drain usage.

Outcomes

The primary outcome was to evaluate the utility of VIBe for assessing intraoperative bleeding control achieved through established bleeding reduction strategies, including induced

hypotensive anesthesia and local hemostatic agent use. To this end, we compared VIBe scores with conventional bleeding metrics including estimated blood loss, transfusion volume, and postoperative drain output. These strategies were selected for their known effects on bleeding control, allowing evaluation of how well VIBe reflects intraoperative bleeding relative to conventional metrics.

Secondary outcomes included a comparison of bleeding control between the use of active hemostatic agents alone versus combined active and passive agents, as well as assessment of inter-observer reliability of VIBe between the surgeon and assistants.

Statistical analysis

Continuous variables are presented as means ± standard deviations; categorical variables as frequencies and percentages. Normality was assessed using the Shapiro–Wilk test. Group comparisons were made using independent t-tests or Chi-square tests, as appropriate. McNemar's test was used to evaluate changes in VIBe before and after hemostasis. To evaluate the clinical responsiveness of the VIBe scale, Spearman's rank correlation was used to assess the association between each patient's maximum VIBe score and conventional bleeding metrics including EBL, transfusion volume, and drain output. Inter-rater reliability between surgeon and assistant assessments was analyzed using Cohen's kappa coefficient. Analyses were conducted using SAS (version 9.4; SAS Institute, Cary, NC, USA) and R (version 4.2.2; The R Foundation for Statistical Computing, Vienna, Austria), with $p < 0.05$ considered statistically significant.

Table 2 VIBe grades assigned to each epidural bleeding site before and after hemostasis by observers

Observer	VIBe grade	Before hemostasis (sites)	After hemostasis (sites)	*p*-value
Operator				<0.0001*
	0	1 (0.36)	199 (70.82)	
	1	212 (75.44)	82 (29.18)	
	2	68 (24.20)	0 (0.00)	
Assistant				<0.0001*
	0	0 (0.00)	217 (77.22)	
	1	209 (74.38)	64 (22.78)	
	2	72 (25.62)	0 (0.00)	

Data presented as count (%)

*Indicates significance

VIBe, Validated Intraoperative Bleeding Severity Scale

Results

Patient baseline data

A total of 70 patients were enrolled, with a mean age of 69.24 ± 7.75 years. The majority of patients were ASA class II or III, and the mean CCI was 3.56 ± 1.43. The mean fusion level was 2.01 ± 1.07. The baseline demographics and operative characteristics are presented in Supplementary Tables 1 and 2.

Primary and secondary outcomes

A total of 281 epidural bleeding sites were assessed using VIBe. The highest observed grade was 2, with the majority initially graded as 1. Following hemostasis, all sites achieved successful bleeding control, with most reclassified as 0 ($p < 0.001$) (Table 2).

Thirty patients were randomized to the normotensive anesthesia group, and forty to the hypotensive group. Baseline demographic and clinical characteristics were comparable between the groups (Supplementary Table 1). Intraoperative SBP and MBP were significantly lower in the hypotensive group compared to the normotensive group (SBP: 104.55 ± 5.19 vs. 110.69 ± 8.97 mmHg, $p = 0.0017$; MBP: 74.55 ± 5.38 vs. 79.10 ± 7.34 mmHg, $p = 0.0038$). No significant differences were found between groups in EBL, transfusion volume, drain output, or other bleeding-related variables (Table 3).

Of the 281 bleeders, 122 were in the normotensive group and 159 in the hypotensive group. There were no significant between-group differences in VIBe assessments by either the operator or assistants, before or after hemostasis, or in the degree of score change. (Tables 4 and 5).

Among the 70 patients, 34 received combined active and passive hemostatic agents, while 36 received active agents alone. Baseline demographic and clinical characteristics were comparable (Supplementary Table 2). No significant differences were observed between groups in EBL, transfusion requirements, drain output, or other bleeding-related variables. The number of active hemostatic applications per bleeding site was comparable between groups (Table 6).

Of the 281 bleeders, 137 were managed with combined agents. Operator-assessed VIBe scores before and after hemostasis did not differ between groups. Assistant observers rated pre-hemostasis bleeding higher in the active-only group ($p = 0.0267$), but post-hemostasis grades and VIBe changes were comparable across groups and observers (Tables 7 and 8).

The operator's maximum VIBe score per patient was significantly correlated with EBL (Spearman $\rho = 0.305$, $p = 0.010$) and transfusion volume ($\rho = 0.264$, $p = 0.027$).

Table 3 Comparison of bleeding and hemostasis between normotensive and induced hypotensive anesthesia groups

Variable	Normotensive ($n=30$)	Hypotensive ($n=40$)	p-value
Intraoperative hemodynamics			
Pre-op SBP (mmHg)	123.633 ± 16.374	124.500 ± 17.087	0.8314
Intra-op SBP (mmHg)	110.693 ± 8.972	104.550 ± 5.188	0.0017*
Intra-op MBP (mmHg)	79.100 ± 7.336	74.550 ± 5.378	0.0038*
Bleeding-related outcomes			
Estimated blood loss (mL)	620.000 ± 455.162	767.250 ± 540.565	0.2323
Transfusion volume (mL)	110.667 ± 209.749	184.725 ± 318.297	0.2457
Pre-op Hemoglobin (g/dL)	12.863 ± 1.338	12.605 ± 1.696	0.4935
Post-op Hemoglobin (g/dL)	9.413 ± 1.233	9.055 ± 1.032	0.1905
Drain output (mL)	962.807 ± 415.164	968.250 ± 418.544	0.9571
Operative characteristics			
Operation duration (min)	199.867 ± 64.701	211.500 ± 66.944	0.4680
Fusion levels (n)	2.03 ± 0.999	2.00 ± 1.132	0.8970
Number of bleeders	4.067 ± 1.999	3.975 ± 2.247	0.8601
Hemostatic agent use			
Active hemostat/site	0.408 ± 0.217	0.450 ± 0.158	0.357
Passive hemostat/site	0.124 ± 0.190	0.131 ± 0.191	0.865
Intraoperative confounding factors			
Dural tear (%)	3 (10.00)	1 (2.50)	0.3067
Hemostasis outcome			
Hemostasis success (%)	30 (100.00)	40 (100.00)	> 0.9999

Data presented as Mean ± Standard deviations or Count (%)

*Indicates significance

SBP, Systolic blood pressure; MBP, Mean blood pressure

Table 4 VIBe grades of each epidural bleeding site before and after hemostasis by anesthesia type

Observer		VIBe grade	Normotensive ($n=122$)	Hypotensive ($n=159$)	p-value
Operator	Before hemostasis	0	1 (0.82)	0 (0.00)	0.6119
		1	91 (74.59)	121 (76.10)	
		2	30 (24.59)	38 (23.90)	
	After hemostasis	0	80 (65.57)	119 (74.84)	0.0903
		1	42 (34.43)	40 (25.16)	
Assistant	Before hemostasis	1	91 (74.59)	118 (74.21)	0.9429
		2	31 (25.41)	41 (25.79)	
	After hemostasis	0	91 (74.59)	126 (79.25)	0.3564
		1	31 (25.41)	33 (20.75)	

Data presented as count (%)

VIBe, Validated Intraoperative Bleeding Severity Scale

Table 5 VIBe grade change patterns of each epidural bleeding site before and after hemostasis by anesthesia type

Observer	VIBe grade change	Normotensive ($n=122$)	Hypotensive ($n=159$)	p-value
Operator	2 → 0	6 (4.92)	10 (6.29)	0.2100
	2 → 1	24 (19.67)	28 (17.61)	
	1 → 0	73 (59.84)	109 (68.55)	
	1 → 1	18 (14.75)	12 (7.55)	
	0 → 0	1 (0.82)	0 (0.00)	
Assistant	2 → 0	17 (13.93)	17 (10.69)	0.0707
	2 → 1	14 (11.48)	24 (15.09)	
	1 → 0	74 (60.66)	109 (68.55)	
	1 → 1	17 (13.93)	9 (5.66)	

Data presented as count (%)

VIBe, Validated Intraoperative Bleeding Severity Scale

Table 6 Comparison of bleeding and hemostasis by hemostatic agent use

Variable	Active + Passive ($n=34$)	Active Only ($n=36$)	p-value
Intraoperative hemodynamics			
Pre-op SBP (mmHg)	127.412 ± 17.773	121.028 ± 15.153	0.1098
Intra-op SBP (mmHg)	106.847 ± 6.365	107.500 ± 8.762	0.7237
Intra-op MBP (mmHg)	76.265 ± 6.131	76.722 ± 7.170	0.7756
Bleeding-related outcomes			
Estimated blood loss (mL)	711.765 ± 447.393	696.944 ± 564.845	0.9039
Transfusion volume (mL)	137.676 ± 259.067	167.444 ± 297.165	0.6573
Pre-op Hemoglobin (g/dL)	12.806 ± 1.577	12.631 ± 1.537	0.6391
Post-op Hemoglobin (g/dL)	9.332 ± 1.182	9.092 ± 1.079	0.3762
Drain output (mL)	929.353 ± 354.483	1000.450 ± 465.859	0.4768
Operative characteristics			
Operation duration (min)	211.853 ± 75.961	201.472 ± 55.086	0.5132
Fusion levels (n)	1.88 ± 0.977	2.14 ± 1.150	0.3170
Number of bleeders	4.029 ± 2.263	4.000 ± 2.028	0.9545
Hemostatic agent use			
Active hemostat/site	0.456 ± 0.164	0.410 ± 0.204	0.3020
Passive hemostat/site	0.264 ± 0.196	0	< 0.001*
Intraoperative confounding factors			
Dural tear (%)	2 (5.88)	2 (5.56)	> 0.9999
Hemostasis outcome			
Hemostasis success (%)	34 (100.00)	36 (100.00)	> 0.9999

Data presented as Mean ± Standard deviations or Count (%)

*Indicates significance

SBP, Systolic blood pressure; MBP, Mean blood pressure

Table 7 VIBe grades of each epidural bleeding site before and after hemostasis by hemostatic agent use

Observer		VIBe grade	Active + Passive ($n=137$)	Active Only ($n=144$)	p-value
Operator	Before hemostasis	0	0 (0.00)	1 (0.69)	0.0823
		1	110 (80.29)	102 (70.83)	
		2	27 (19.71)	41 (28.47)	
	After hemostasis	0	104 (75.91)	95 (65.97)	0.0669
		1	33 (24.09)	49 (34.03)	
Assistant	Before hemostasis	1	110 (80.29)	99 (68.75)	0.0267*
		2	27 (19.71)	45 (31.25)	
	After hemostasis	0	111 (81.02)	106 (73.61)	0.1387
		1	26 (18.98)	38 (26.39)	

Data presented as count (%)

*Indicates significance

VIBe, Validated Intraoperative Bleeding Severity Scale

Table 8 VIBe grade change patterns of each epidural bleeding site before and after hemostasis by hemostatic agent use

Observer	VIBe grade change	Active + Passive ($n=137$)	Active Only ($n=144$)	p-value
Operator	2 → 0	9 (6.57)	7 (4.86)	0.1742
	2 → 1	18 (13.14)	34 (23.61)	
	1 → 0	95 (69.34)	87 (60.42)	
	1 → 1	15 (10.95)	15 (10.42)	
	0 → 0	0 (0.00)	1 (0.69)	
Assistant	2 → 0	13 (9.49)	21 (14.58)	0.1435
	2 → 1	14 (10.22)	24 (16.67)	
	1 → 0	98 (71.53)	85 (59.03)	
	1 → 1	12 (8.76)	14 (9.72)	

Data presented as count (%)

*Indicates significance

VIBe, Validated Intraoperative Bleeding Severity Scale

Table 9 Inter-observer agreement of vibe (operator vs. assistant)

	Cohen's kappa (95% CI)	p-value
Before hemostasis	0.934 (0.887, 0.982)	<0.0001*
After hemostasis	0.834 (0.761, 0.907)	<0.0001*
VIBe change	0.856 (0.793, 0.920)	<0.0001*

*Indicates significance

VIBe, Validated Intraoperative Bleeding Severity Scale

The assistant observers' averaged VIBe scores also demonstrated a significant correlation with EBL ($\rho=0.284$, $p=0.017$).

Agreement of VIBe

Inter-rater reliability for VIBe grading was consistently high. Inter-rater agreement between the assistants was strong when assessed before hemostasis ($\kappa=0.962$; 95% CI: 0.925–0.999, $p<0.001$) and after hemostasis ($\kappa=0.926$; 95% CI: 0.873–0.980, $p<0.001$). Agreement between the operator and assistants before hemostasis yielded a Cohen's kappa of 0.934 (95% CI: 0.887–0.982), and after hemostasis 0.834 (95% CI: 0.761–0.907). Agreement on change in VIBe scores was also strong ($\kappa=0.856$; 95% CI: 0.793–0.920), with all p-values < 0.001 (Table 9).

Discussion

This study evaluated two established methods for reducing intraoperative bleeding during lumbar spinal fusion—induced hypotensive anesthesia and the use of local hemostatic agents—using the VIBe as a standardized intraoperative bleeding assessment tool. VIBe-based evaluations were consistent with conventional measures, including EBL, drain output, and transfusion volume.

Induced hypotension has been shown to reduce intraoperative bleeding and improve surgical field visualization [5, 11]. Standard targets include SBP of 80-90mmHg or MBP of 50-65mmHg in normotensive patients and a 30% MBP reduction in hypertensive patients [12]. In this study, intraoperative SBP and MBP were significantly reduced compared to baseline but remained above ideal targets. This may explain the lack of significant differences in intra- and postoperative bleeding between the hypotensive and normotensive groups.

Despite protocolized goals, achieving target hypotensive thresholds proved difficult due to real-world constraints. Spine surgery patients are often elderly and carry a high comorbidity burden, and the prone position further limits blood pressure modulation due to altered hemodynamics [13–17]. Although patients with overt contraindications were excluded, the enrolled cohort still had a relatively high mean age (69.24 ± 7.75 years), and nearly half were ASA class III—reflecting the typical case mix at tertiary centers. Ischemic complications associated with induced hypotension in such populations have been reported [5, 18–20], likely contributing to conservative intraoperative blood pressure management. These feasibility challenges may have attenuated the differences between groups but underscore the value of objective intraoperative tools like VIBe, which can assess bleeding severity independently of hemodynamic targets.

Neural decompression often exposes the epidural venous plexus, a frequent bleeding source where mechanical or thermal control may risk neural injury. Systemic agents such as tranexamic acid have shown inconsistent effectiveness in spine surgery [21], making local hemostatic agents the preferred strategy for epidural bleeding control [22].

In this study, two local approaches were compared: a combination of a flowable (active) hemostatic agent with a

microfibrillar collagen (MFC) based mechanical (passive) agent, and the use of a flowable agent alone. Both strategies effectively controlled epidural venous bleeding, as demonstrated by intraoperative and postoperative bleeding metrics—including VIBe assessments. Notably, the number of active agent applications was comparable between groups, and no additional hemostatic benefit was observed with the addition of passive agents.

There remains limited clinical guidance on the optimal use and sequencing of hemostatic agents in spinal surgery. A matched-pair analysis by Ramirez et al.. using a large U.S. database compared a flowable matrix to a combination approach involving flowable and passive agents (gelatin sponges and thrombin). Their results favored the active-only group across several outcomes, including transfusion rates, blood loss complications, length of stay, operative time, and total hemostat volume [23]. However, their retrospective design and lack of protocolized agent application limited the interpretability of their findings. In contrast, the present study employed a prospective, protocol-driven approach, applying the active agent first in both groups and standardizing surgical technique. While similar outcomes were observed between groups, the addition of passive agents—such as MFC—did not provide added hemostatic benefit. This may be due, in part, to the limited evidence supporting the hemostatic efficacy of MFC, particularly when it becomes moistened, which can impair adherence and function and even lead to operative challenges such as adhesion to gloves or instruments [7]. At the time and location of this study, the approximate cost per unit was $300 for Floseal (active) and $100 for Avitene (passive). Given the lack of added efficacy and the consistent use of active agents across groups, initiating bleeding control with a flowable hemostatic agent alone may reduce unnecessary expenditure without compromising clinical outcomes. Although this study does not demonstrate the superiority of an active-only approach, it suggests that exclusive use of an active hemostatic agent may be sufficient for most epidural bleeding scenarios in lumbar fusion procedures. These findings may contribute to the development of cost-conscious clinical guidelines for hemostatic agent use in spine surgery.

The inter-observer reliability of VIBe assessments for bleeding severity and hemostasis was found to be near-perfect in this study. To the authors' knowledge, this is the first investigation to evaluate VIBe reliability among different observers—within the same surgical procedure—under real-time clinical conditions. The observed agreement was consistent with prior validation studies in spinal surgery [9], and the distribution of VIBe grades encountered intraoperatively was also similar to previous findings [10].

Importantly, observers in this study achieved a high level of agreement despite receiving only standardized video- and simulation-based training, suggesting that VIBe is highly reproducible even with brief, structured instruction. This highlights its potential utility not only within surgical teams but also in interdisciplinary settings. VIBe provides a common, objective language for describing bleeding severity, which can support more efficient and standardized communication between surgeons and anesthesiologists—particularly when real-time surgical field visualization is limited.

In addition to reproducibility, our findings also support the clinical utility of VIBe in guiding intraoperative decision-making. As a real-time grading system, VIBe offers a standardized alternative to conventional bleeding metrics such as estimated blood loss or drain output, which are often imprecise or retrospective. In our study, VIBe scores showed statistically significant correlations with both estimated blood loss and transfusion volume, reinforcing its relevance to actual intraoperative bleeding. The scale's structured format may also assist anesthesiologists in titrating fluids, managing blood pressure, and anticipating transfusion needs based on bleeding severity rather than subjective interpretation. By enabling more timely and informed transfusion decisions, VIBe may help reduce treatment delays and improve coordination, both of which have been associated with better perioperative outcomes [24].

Beyond its immediate clinical use, VIBe may also serve as a valuable teaching tool in academic settings, helping trainees calibrate intraoperative bleeding assessments. In research, its standardized grading system provides an objective endpoint for bleeding severity, enhancing the reproducibility of outcomes across trials.

Limitations and strengths

This study has several limitations. First, it was conducted at a single academic tertiary center, and all procedures were performed by a single surgeon. While this may have reduced variability in surgical technique and hemostat usage, it also limits the generalizability of the findings. Larger, multicenter trials are needed to validate these results across broader clinical settings. Second, although both bleeding severity and volume were assessed, the time to hemostasis was not recorded. This is an important parameter in evaluating hemostatic efficacy, as timely bleeding control not only reduces blood loss but also improves visualization of the surgical field. Third, the highest VIBe grade observed in this study was 2. As a result, the findings—particularly those related to the sufficiency of active agents alone—may not be generalizable to procedures involving more severe bleeding scenarios.

Nonetheless, this is the first randomized controlled trial to evaluate the role of induced hypotensive anesthesia and hemostatic agent use in spinal surgery with real-time

bleeding assessment. It also includes the largest prospective cohort to date using VIBe in this context, whereas prior studies have largely relied on retrospective data [6, 7, 23, 25]. The use of VIBe adds objectivity and reproducibility to intraoperative bleeding assessment, addressing a critical gap in current surgical practice and research.

Conclusions

The VIBe provided a reliable and reproducible method for assessing intraoperative bleeding and hemostasis in lumbar spinal surgery. Comparable outcomes were observed with active-only versus combined hemostatic agent use, supporting a simplified and potentially more cost-effective strategy.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s00586-025-09328-4.

Author contributions B.H.L. and N.K. designed the study and performed the surgical procedures. N.K. collected the data and wrote the initial manuscript draft. S.R.P. and J.W.S. contributed to data collection and preliminary manuscript editing. J.W.K., S.Y.P., and J.O.P. contributed to data interpretation and critically revised the manuscript. K.S.S., S.H.M., and H.S.K. provided senior supervision and input on study design and manuscript refinement. All authors reviewed and approved the final manuscript.

Data availability The datasets generated and/or analyzed during the current study are not publicly available due to privacy and ethical restrictions but are available from the corresponding author upon reasonable request.

Declarations

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