Submitted: 08 August, 2024 Accepted: 18 October, 2024 Published: 08 April, 2025 DOI:10.22514/sv.2025.052

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ORIGINAL RESEARCH

Comparison of TIVA and sevoflurane: ensuring hemodynamic and respiratory stability in prone position spinal surgeries: a randomized controlled trial

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Abstract

Background: This study evaluates the impact of total intravenous anesthesia (TIVA) versus sevoflurane anesthesia on respiratory mechanics and hemodynamic parameters during spinal surgery in the prone position. **Methods**: A randomized controlled trial was conducted on 52 patients (26 in the TIVA group and 26 in the sevoflurane group). Respiratory mechanics, such as peak airway pressure (Ppeak), mean airway pressure (Pmean), positive end-expiratory pressure (PEEP), end-tidal carbon dioxide ($ETCO_2$), and dynamic compliance (Cdyn) were measured at various intervals. Hemodynamic parameters including systolic blood pressure, diastolic blood pressure, and heart rate were monitored. **Results**: There were no significant differences between the TIVA and sevoflurane groups in any of the measured respiratory and hemodynamic parameters. Ppeak at 30 minutes was 20 cmH_2O in the TIVA group and 19 cmH_2O in the sevoflurane group ($p = 0.550$). Mean Cdyn was 35.0 mL/cmH_2O for TIVA and 34.3 mL/cmH_2O for sevoflurane ($p = 0.796$). Both groups maintained stable hemodynamic parameters throughout surgery, with heart rate and mean arterial pressure within the normal range. **Conclusions**: TIVA and sevoflurane are equally effective in maintaining respiratory and hemodynamic stability during prone spinal surgeries. These findings provide flexibility for anesthesiologists in selecting the appropriate anesthesia technique based on patient and surgical factors. **Clinical Trial Registration**: ClinicalTrials.gov: NCT06558695. Date: 14 August 2024 Retrospectively registered.

Keywords

Total intravenous anesthesia; Sevoflurane; Respiratory mechanics; Hemodynamic parameters; Spinal surgery; Prone position

1. Introduction

Spinal surgeries are critical for addressing neurological disorders, repairing traumatic damage, and alleviating symptoms of degenerative diseases. These procedures are often performed in the prone position, which, while offering optimal surgical access and minimizing blood loss, presents significant challenges in anesthesia management due to unique physiological changes [1].

The prone position significantly impacts respiratory mechanics by potentially increasing functional residual capacity while restricting chest wall and lung compliance. Hemodynamically, it can reduce venous return and negatively affect cardiac output, requiring careful consideration in the selection and management of anesthesia [2, 3].

In spinal surgeries, the primary anesthesia techniques are total intravenous anesthesia (TIVA) and inhalation anesthesia. TIVA is often preferred in procedures requiring intensive neuromonitoring due to its minimal impact on neural transmission. This is particularly beneficial as neuromonitoring is crucial for detecting and mitigating potential neurological damage during surgery [4]. Conversely, inhalation anesthetics like sevoflurane offer advantages in controlling anesthesia depth, which is essential for maintaining stability in the respiratory and circulatory systems during prolonged surgeries [5].

This study aims to compare the effects of total intravenous anesthesia (TIVA) and sevoflurane anesthesia on respiratory mechanics and hemodynamic parameters in patients undergoing spinal surgery in the prone position. Understanding the advantages and limitations of each method is essential for developing safer and more effective anesthesia management strategies. Additionally, the study evaluates how these anesthesia choices impact neuromonitoring applications, which are crucial for optimizing neurological protection during spinal procedures [6, 7].

2. Materials and methods

2.1 Study design

This randomized controlled study was conducted between 01 May 2023 and 30 June 2023, following the guidelines of the Helsinki Declaration. Additionally, the study adheres to the CONSORT guidelines to ensure transparency and rigor in reporting clinical trials.

2.2 Participants

The study included male and female patients aged 18 to 65 years who were scheduled for lumbar spinal stabilization and fusion surgery under general anesthesia. Patients were categorized based on the American Society of Anesthesiologists (ASA) physical status classifications I, II and III. Exclusion criteria were:

- Diagnosis of asthma or chronic obstructive pulmonary disease (COPD).
- Major cardiac conditions, such as recent myocardial infarction or a left ventricular ejection fraction (EF) less than 55%.
- Second and third degrees atrioventricular blocks.
- Allergies to any drugs.
- Severe neurological disorders.
- History of sedative or opioid use.

2.3 Randomization and blinding

Participants were randomly assigned to one of two groups using a computer-generated list: the Sevoflurane group (Sevo group) and the Total Intravenous Anesthesia group (TIVA group), each comprising 26 patients. The assignment and subsequent anesthesia management were conducted in a double-blind manner, ensuring that neither the patients nor the clinicians administering the treatments or assessing the outcomes were aware of the group allocations (Fig. 1).

2.4 Anesthesia administration

Anesthesia was induced using 0.05 mg/kg midazolam, followed by 3 mg/kg propofol and 1 mg/kg lidocaine in both groups. Neuromuscular blockade was achieved with 0.6 mg/kg rocuronium, and analgesia was maintained with 1 mcg/kg fentanyl. Patients were intubated using a spiral endotracheal tube.

In the Sevoflurane group, anesthesia was maintained with sevoflurane at 0.8–1.0 minimum alveolar concentration (MAC). In the TIVA group, a combination of propofol (50–150 μg/kg/min) and remifentanil (0.02–0.2 μg/kg/min) was used instead of inhalational agents.

Constant-flow volume-controlled ventilation (VCV) was utilized for ventilation. The fraction of inspired oxygen was 0.5 in an air and oxygen mixture. The goal was to maintain constant end-tidal carbon dioxide tension ($ETCO_2$) levels within the range of 35–38 mmHg by adjusting the respiratory frequency accordingly. Tidal volume was calculated as 6–8 mL/kg. For antiemetic purposes, 10 mg of metoclopramide was administered 30 minutes before the end of surgery, and 100 mg of tramadol was selected for postoperative analgesia.

2.5 Monitoring and measurements

All patients were monitored using a standard protocol that included measurements of the bispectral index (BIS) to maintain anesthesia depth, end-tidal CO_2, oxygen saturation, heart rate, and arterial blood pressure using the Covidien BIS^{TM} complete monitoring system (Covidien, Boulder, CO, USA).

2.6 Neuromonitoring and stability

In our study, intraoperative neuromonitoring was performed using somatosensory evoked potentials (SSEPs) and electromyography (EMG), two widely recognized techniques for monitoring the integrity of neural pathways during spinal surgeries. SSEPs measure the electrical activity generated by the brain in response to peripheral nerve stimulation, providing real-time feedback on the functional status of the sensory pathways. EMG, on the other hand, monitors muscle activity to detect any nerve irritation or damage during the procedure.

For SSEP monitoring, bilateral posterior tibial nerves were stimulated, and the resulting cortical responses were recorded. Baseline SSEPs were obtained after patient positioning but prior to the start of surgical manipulation. Continuous SSEP monitoring was conducted throughout the procedure, with amplitudes and latencies of cortical responses tracked to detect any significant changes. Similarly, EMG activity was recorded from multiple lower extremity muscle groups to ensure no undue pressure or damage to the neural structures.

Both TIVA and sevoflurane anesthesia protocols were adjusted to maintain optimal neuromonitoring conditions. In the TIVA group, a combination of propofol and remifentanil was used, which is known for its minimal interference with SSEP and EMG signals. In the sevoflurane group, sevoflurane concentrations were kept within 0.8–1.0 MAC to prevent significant suppression of neuromonitoring signals.

Throughout the study, both groups maintained stable neuromonitoring signals. No significant changes in SSEP amplitudes or latencies, nor any abnormal EMG activity, were observed in either group, indicating that both anesthesia techniques provided sufficient neuroprotection and did not interfere with the neuromonitoring data. This stability is crucial, especially in spinal surgeries, where intraoperative neuromonitoring plays a vital role in preventing permanent neurological damage.

Continuous monitoring of systolic, diastolic and mean arterial pressure (MAP) was conducted via a radial artery catheter. The goal was to maintain MAP and heart rate (HR) within 80% and 120%, respectively, of the preoperative values. If MAP fell below 80% of the baseline level for more than 5 minutes, fluid resuscitation along with medications such as ephedrine and noradrenaline was administered. Patients with an HR lower than 40/min were treated with 0.5 mg of atropine.

Specific respiratory parameters, including positive end-expiratory pressure (PEEP), end-tidal carbon dioxide ($ETCO_2$) (mmHg), tidal volume (VT) (mL), peak airway pressure (Ppeak), mean airway pressure (Pmean), heart rate (HR), systolic and diastolic blood pressure, respiratory rate (RR), and minute volume (MV), were recorded at multiple time points: immediately after intubation, 5, 15 and 30 minutes

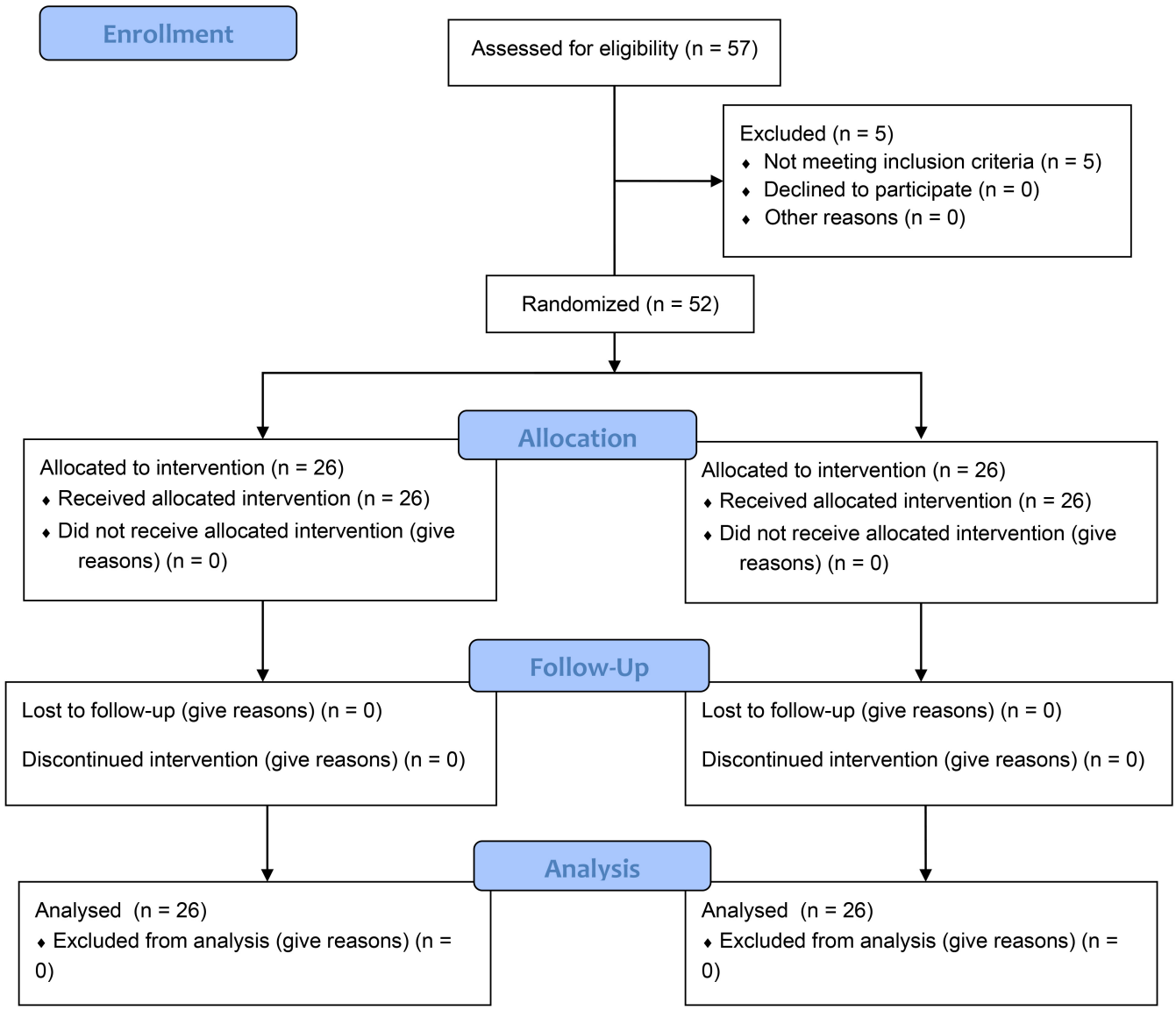

FIGURE 1. CONSORT flow diagram. Among 57 adults, 3 were excluded from the study because of morbid obesity (body mass index (BMI) $\geq$30 kg/m^2), and 2 were excluded because of a medical history of pulmonary disease. A total of 52 patients were randomly allocated into 2 groups.

after positioning in the prone position. Dynamic compliance (Cdyn) (mL/cm/H_2O), PaO_2/FiO_2 (PaO_2, Partial Pressure of Oxygen in Arterial Blood, FiO_2, Fraction of Inspired Oxygen) and the dead space/tidal volume ratio (VD/VT) (%) were noted in the supine position after intubation and in the prone position at the 30th minute. A Nicolet® Endeavor^{TM} CR IOM System (Natus medical Incorporated, Middleton, WI, USA) was used in the TIVA group. Respiratory mechanics were evaluated first, followed by hemodynamic changes.

2.7 Statistical analysis

Statistical analysis was performed using IBM SPSS Statistics for Windows, Version 23.0 (SPSS Inc., Chicago, IL, USA). The primary outcome of the study was to assess differences in respiratory mechanics and hemodynamic stability between the two anesthesia methods. Continuous variables were analyzed using Student's *t*-test or Mann-Whitney U test, depending on their distribution. Categorical data were compared using the Chi-square test or Fisher's exact test as appropriate. A *p*-value of less than 0.05 was considered statistically significant.

2.8 Power analysis

A power analysis was done before the study to assess sample size for detecting clinically relevant changes in both hemodynamic parameters and respiratory mechanics comparing TIVA *vs.* sevoflurane groups. A minimal clinically important difference was set at 0.5 times the SD (Standard Deviation) of a key respiratory or hemodynamic variable based on previously published data and expert opinion [7, 8]. The power analysis indicated that at least 26 patients per group would be required to have a power of 80% with $p < 0.05$ for the detection this effect-size (Fig. 1). The calculations were made with the G*Power (version 3.1.9.7, Heinrich-Heine-Universitat Düsseldorf, Düsseldorf, NRW, Germany), which is a recognized

software for statistical power estimation in clinical trials.

Power analysis ensured that the study was adequately powered to detect differences with appropriate clinical significance, minimizing Type II errors. Such an approach strengthens the reliability of this study findings.

3. Results

For this study, we investigated and compared the effects of total intravenous anesthesia (TIVA; propofol-remifentanil infusion) with sevoflurane inhalation anesthesia on respiratory mechanics and hemodynamic parameters in patients undergoing spinal surgery in a prone position. We concluded that there were no significant differences in process of respiratory and hemodynamic parameters between two anesthesia techniques.

Upon review of the patient demographics, we found age distribution as 53.1 ± 10.1 years. As a part of the study population, most patients were male (n = 38; 73.1%) and had ASA II physical grade status (n = 29; 55.8%). They had an average BMI of 28.2 kg/m^2. No differences were found between the two groups in age, sex, ASA score and BMI variables (Table 1).

Measured data with normal distribution are expressed as means ± standard deviations, Non-normally distributed data are expressed as medians (interquartile ranges). Qualitative data are expressed as n (%). Continuous variables were compared between groups using Student's *t*-test for normally distributed data and the Mann-Whitney U test for non-normally distributed data. A p-value < 0.05 was considered statistically significant.

3.1 Respiratory mechanics

The hemodynamic parameters including the HR and MAP, were recorded during patient positioning with TIVA or sevoflurane anesthesia immediately after intubation (T0) and at 5, 15 and 30 minutes as well as sharing at other time points. There were no significant differences between both groups regarding peak airway pressure (Ppeak), mean airway pressure (Pmean), positive end-expiratory pressure (PEEP), end-tidal carbon dioxide ($ETCO_2$), tidal volume (VT), respiratory rate (RR) and minute ventilation (MV). These findings suggest that both TIVA and sevoflurane had stable respiratory mechanics in the prone position during spinal surgery.

We measured dynamic compliance (Cdyn) (mL/cm/H_2O), the PaO_2/FiO_2 ratio, and the dead space/tidal volume ratio (VD/VT) (%) in the supine position after intubation and again in the prone position at 30 minutes. There was no significant difference in the (Cdyn) (mL/cm/H_2O), PaO_2/FiO_2, or dead space/tidal volume ratio (VD/VT) (%) between the two groups (Tables 2,3,4,5,6,7,8,9) (Fig. 2).

3.2 Hemodynamic parameters

Similarly, the comparison of systolic and diastolic blood pressures, and heart rate between both groups showed no statistically significant differences at the assessed time points. This indicates that both anesthetic methods provided comparable hemodynamic stability during spinal surgeries in the prone position.

3.3 Comparative analysis

The data derived from this study supports the conclusion that TIVA and sevoflurane are equally effective in maintaining respiratory and hemodynamic stability in patients undergoing spinal surgery in the prone position. This finding is crucial for anesthesiologists as it suggests flexibility in choosing the anesthesia technique based on patient-specific factors and surgical requirements, rather than differences in physiological outcomes.

3.4 Statistical significance

All statistical analyses were performed using a significance level set at $p < 0.05$. The lack of significant differences was consistent across all primary and secondary outcomes, reinforces the equivalence in performance between the two anesthesia modalities under the studied conditions.

4. Discussion

The comparative evaluation of total intravenous anesthesia (TIVA) and sevoflurane during prone spinal surgeries in our study has shown no significant differences in respiratory and

TABLE 1. Demographic data of patients and comparison between groups.

Variables	Total (n = 52)	TIVA group (n = 26)	Sevo group (n = 26)	*p*-value
Age, yr	53.1 ± 10.1	53.6 ± 10.4	53.0 ± 10.3	0.457
Gender				
Male	38 (73.1)	20 (76.9)	18 (69.2)	0.532
Female	14 (26.9)	6 (23.1)	8 (30.8)	
ASA, n (%)				
I	18 (34.6)	9 (34.6)	9 (34.6)	
II	29 (55.8)	15 (57.7)	14 (53.8)	0.889
III	5 (9.6)	2 (7.7)	3 (11.5)	
BMI, kg/m^2	28.2 ± 3.5	27.8 ± 3.4	28.5 ± 3.5	0.415

Sevo: Sevoflurane; TIVA: total intravenous anesthesia; ASA: American Society of Anesthesiologists; BMI: body mass index.

TABLE 2. Comparison of groups in terms of respiratory, and mechanical ventilation parameters after intubation.

Variables	TIVA group (n = 26)	Sevo group (n = 26)	*p*-value
Ppeak, cmH_2O, median/IQR	15.0 (13.0–16.0)	14.5 (12.0–17.0)	0.789
Pmean, cmH_2O, median/IQR	7.6 (7.0–8.0)	7.3 (6.0–8.8)	0.545
PEEP, cmH_2O, median/IQR	4 (4–4)	4 (4–4)	0.795
$ETCO_2$, mmHg, mean ± SD	32.8 ± 2.9	33.3 ± 3.0	0.813
VT, mL, mean ± SD	525.9 ± 57.6	510.3 ± 77.9	0.417
RR, breaths/min, median/IQR	10 (9–11)	10 (9–11)	0.829
MV, L/min, mean ± SD	5.6 ± 0.8	5.7 ± 1.3	0.660
Cdyn, mL/cmH_2O, mean ± SD	48.9 ± 14.0	44.7 ± 13.6	0.273
PaO_2/FiO_2 ratio, mean ± SD	275.3 ± 57.3	290.3 ± 66.8	0.388
VD/VT, %, mean ± SD	13.1 ± 7.9	12.1 ± 4.9	0.588

n: number; IQR: interquartile range; SD: standard deviation; Sevo: Sevoflurane; TIVA: total intravenous anesthesia; Ppeak: peak airway pressure; Pmean: mean airway pressure; PEEP: positive end-expiratory pressure; $ETCO_2$: end-tidal carbon dioxide; VT: Tidal volume; RR: respiratory rate; MV: minute volume; Cdyn: dynamic compliance; PaO_2/FiO_2: Partial Pressure of Oxygen in Arterial Blood/Fraction of Inspired Oxygen; VD/VT: dead space/tidal volume ratio. Continuous variables were compared between groups using Student's t-test for normally distributed data and the Mann-Whitney U test for non-normally distributed data. A p-value < 0.05 was considered statistically significant.

TABLE 3. Comparison of groups in terms of vital parameters after intubation.

Variables	TIVA group (n = 26)	Sevo group (n = 26)	*p*-value
Systolicblood pressure, mmHg, mean ± SD	127.9 ± 23.7	132.4 ± 26.0	0.514
Diastolicblood pressure, mmHg, mean ± SD	71.3 ± 13.1	75.3 ± 16.4	0.342
HR, beats/min, mean ± SD	74.8 ± 11.7	75.1 ± 12.1	0.654

n: number; SD: standard deviation; TIVA: total intravenous anesthesia; Sevo: Sevoflurane; HR: heart rate. Continuous variables were compared between groups using Student's t-test for normally distributed data and the Mann-Whitney U test for non-normally distributed data. A p-value < 0.05 was considered statistically significant.

TABLE 4. Comparison of groups in terms of respiratory, and mechanical ventilation parameters at the 5th minute after the prone position.

Variables	TIVA group (n = 26)	Sevo group (n = 26)	*p*-value
Ppeak, cmH_2O, median/IQR	18 (16.0–20.0)	18 (16.5–19.5)	0.394
Pmean, cmH_2O, median/IQR	8.6 (7.8–9.4)	8.3 (7.6–9.0)	0.267
PEEP, cmH_2O, median/IQR	4 (4–4)	4 (4–4)	0.970
$ETCO_2$, mmHg, mean ± SD	33.6 ± 3.1	33.9 ± 3.2	0.953
VT, mL, mean ± SD	527.1 ± 59.5	517.9 ± 79.0	0.636
RR, breaths/min, medyan/IQR	10.0 (9.0–11.0)	10 (9.5–10.5)	0.465
MV, L/min, mean ± SD	5.6 ± 0.5	5.4 ± 1.0	0.402

n: number; IQR: interquartile range; SD: standard deviation; TIVA: total intravenous anesthesia; Sevo: Sevoflurane; Ppeak: peak airway pressure; Pmean: mean airway pressure; PEEP: positive end-expiratory pressure; $ETCO_2$: end-tidal carbon dioxide; VT: Tidal volume; RR: respiratory rate; MV: minute volume. Continuous variables were compared between groups using Student's t-test for normally distributed data and the Mann-Whitney U test for non-normally distributed data. A p-value < 0.05 was considered statistically significant.

TABLE 5. Comparison of groups in terms of vital parameters at the 5th minute after the prone position.

Variables	TIVA group (n = 26)	Sevo group (n = 26)	*p*-value
Systolicblood pressure, mmHg, mean ± SD	123.3 ± 21.9	118.6 ± 16.0	0.391
Diastolicblood pressure, mmHg,mean ± SD	68.4 ± 14.5	69.1 ± 12.9	0.865
HR, beats/min, mean ± SD	71.8 ± 11.0	72.3 ± 11.9	0.753

n: number; SD: standard deviation; TIVA: total intravenous anesthesia; Sevo: Sevoflurane; HR: heart rate. Continuous variables were compared between groups using Student's t-test for normally distributed data and the Mann-Whitney U testfor non-normally distributed data. A p-value < 0.05 was considered statistically significant.

TABLE 6. Comparison of groups in terms of respiratory, and mechanical ventilation parameters at the 15th minute after the prone position.

Variables	TIVA group (n = 26)	Sevo group (n = 26)	*p*-value
Ppeak, cmH_2O, median/IQR	19 (17–21)	17.5 (15–20)	0.782
Pmean, cmH_2O, median/IQR	9.0 (8.5–9.0)	9.0 (8.2–9.9)	0.564
PEEP, cmH_2O, median/IQR	4 (4–4)	4 (4–4)	0.575
$ETCO_2$, mmHg, mean ± SD	33.6 ± 3.5	33.0 ± 2.9	0.499
VT, mL, mean ± SD	524.3 ± 50.2	518.3 ± 80.5	0.750
RR, breaths/min, median/IQR	10 (9–11)	10 (9.5–10.5)	0.187
MV, L/min,mean ± SD	5.5 ± 0.7	5.2 ± 0.6	0.171

n: number; IQR: interquartile range; SD: standard deviation; TIVA: total intravenous anesthesia; Sevo: Sevoflurane; Ppeak: peak airway pressure; Pmean: mean airway pressure; PEEP: positive end-expiratory pressure; $ETCO_2$: end-tidal carbon dioxide; VT: Tidal volume; RR: respiratory rate; MV: minute volume. Continuous variables were compared between groups using Student's t-test for normally distributed data and the Mann-Whitney U test for non-normally distributed data. A p-value < 0.05 was considered statistically significant.

TABLE 7. Comparison of groups in terms of vital parameters at the 15th minute after the prone position.

Variables	TIVA group (n = 26)	Sevo group (n = 26)	*p*-value
Systolicblood pressure, mmHg, mean ± SD	115.8 ± 19.4	111.3 ± 19.0	0.403
Diastolicblood pressure, mmHg, mean ± SD	65.0 ± 14.4	65.5 ± 13.1	0.896
HR, beats/min, mean ± SD	67.7 ± 10.8	75.1 ± 15.6	0.050

n: number; SD: standard deviation; TIVA: total intravenous anesthesia; Sevo: Sevoflurane; HR: heart rate. Continuous variables were compared between groups using Student's t-test for normally distributed data and the Mann-Whitney U test for non-normally distributed data. A p-value < 0.05 was considered statistically significant.

TABLE 8. Comparison of groups in terms of respiratory, and mechanical ventilation parameters at the 30th minute after the prone position.

Variables	TIVA group (n = 26)	Sevo group (n = 26)	*p*-value
Ppeak, cmH_2O, median/IQR	20 (18.5–21.5)	19 (16.0–22.0)	0.550
Pmean, cmH_2O, median/IQR	9.1 (8.4–9.8)	9.3 (8.3–10.3)	0.876
PEEP, cmH_2O, median/IQR	4.0 (4.0–4.0)	4.0 (3.5–4.5)	0.173
$ETCO_2$, mmHg,mean ± SD	31.5 ± 2.7	32.5 ± 3.2	0.173
VT mL, mean ± SD	533.1 ± 57.7	512.2 ± 69.1	0.242
RR, breaths/min, medyan/IQR	10.5 (9.5–11.5)	10.0 (9.5–10.5)	0.132
MV, L/min, mean ± SD	5.6 ± 0.7	5.5 ± 0.7	0.143
Cdyn, mL/cmH_2O, mean ± SD	35.0 ± 10.4	34.3 ± 10.2	0.796
PaO_2/FiO_2 ratio, mean ± SD	335.6 ± 81.7	320.9 ± 85.4	0.529
VD/VT, % mean ± SD	17.3 ± 7.6	16.0 ± 5.4	0.468

n: number; IQR: interquartile range; SD: standard deviation; TIVA: total intravenous anesthesia; Sevo: Sevoflurane; Ppeak: peak airway pressure; Pmean: mean airway pressure; PEEP: positive end-expiratory pressure; $ETCO_2$: end-tidal carbon dioxide; VT: Tidal volume; RR: respiratory rate; MV: minute volume; Cdyn: dynamic compliance; PaO_2/FiO_2: Partial Pressure of Oxygen in Arterial Blood/Fraction of Inspired Oxygen; VD/VT: dead space/tidal volume ratio. Continuous variables were compared between groups using Student's t-test for normally distributed data and the Mann-Whitney U test for non-normally distributed data. A p-value < 0.05 was considered statistically significant.

TABLE 9. Comparison of groups in terms of vital parameters at the 30th minute after the prone position.

Variables	TIVA group (n = 26)	Sevo group (n = 26)	*p*-value
Systolicblood pressure, mmHg, mean ± SD	110.8 ± 13.6	110.4 ± 14.9	0.916
Diastolicblood pressure, mmHg, mean ± SD	61.1 ± 10.9	65.3 ± 11.1	0.178
HR, beats/min, mean ± SD	64.7 ± 10.3	69.3 ± 12.9	0.162

n: number; SD: standard deviation; TIVA: total intravenous anesthesia; Sevo: Sevoflurane; HR: heart rate. Continuous variables were compared between groups using Student's t-test for normally distributed data and the Mann-Whitney U test for non-normally distributed data. A p-value < 0.05 was considered statistically significant.

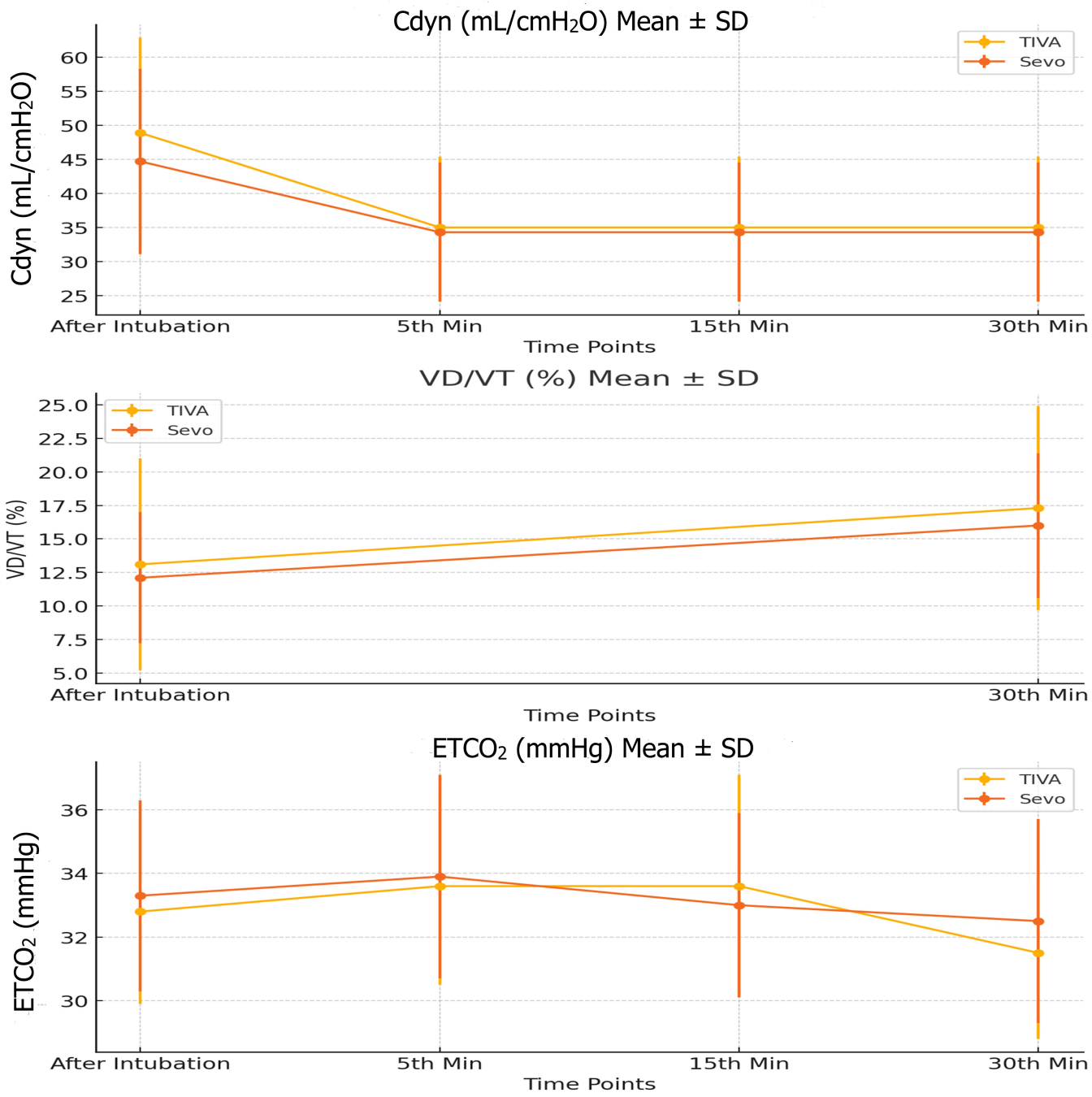

FIGURE 2. Cdyn (mean ± SD), VD/VT (mean ± SD) and $ETCO_2$ (mean ± SD). Cdyn: dynamic compliance; SD: standard deviation; TIVA: total intravenous anesthesia; Sevo: Sevoflurane; VD/VT: dead space/tidal volume ratio; $ETCO_2$: end-tidal carbon dioxide.

hemodynamic parameters, suggesting that both anesthetics are clinically viable. This outcome provides anesthesiologists with flexibility in choosing an anesthesia technique that can be tailored to individual patient needs, operative conditions, and resource availability.

The selection between TIVA and sevoflurane often extends beyond their immediate clinical effects. Pharmacokinetic properties such as the rapid onset and offset times of TIVA, make it particularly useful in settings requiring quick recovery from anesthesia. On the other hand, sevoflurane's low solubility in blood allows for precise control over anesthetic depth, making it ideal for maintaining stable intraoperative conditions during lengthy or complex surgeries. Additionally, the minimal metabolism of sevoflurane presents a lower risk of organ toxicity, which may be a critical consideration in patients with pre-existing organ dysfunction [8, 9].

Neuroprotection is a significant concern in spinal surgeries, particularly in procedures involving the proximity to the spinal cord or brain. TIVA is often associated with better preservation of cerebral autoregulation and reduced cerebral metabolic demand compared to inhalational agents. This can be particularly advantageous in surgeries where neurological risks are heightened. Furthermore, several studies have indicated that TIVA may be associated with a reduced incidence of postoperative cognitive dysfunction, which is crucial consideration for surgeries involving elderly or neurologically vulnerable patients [10, 11].

Anesthesia practice is not only influenced by clinical factors but also by socioeconomic considerations. The cost of sevoflurane per procedure can be higher than propofol-based TIVA, especially in settings where anesthetic gas recovery systems are unavailable. Moreover, the operational requirements for storing and delivering these anesthetics differ significantly, with sevoflurane requiring specialized vaporizers and scavenging systems. These factors can influence hospital policies and individual anesthesiologist's choice, particularly in resource-limited settings [12].

Recent discussions in the medical community have also highlighted the environmental impact of anesthetic agents. Volatile anesthetic agents like sevoflurane are potent greenhouse gases, whereas TIVA, typically consisting of propofol, has a significantly lower environmental footprint. This consideration is increasingly important in the selection of anesthetic agents, particularly in institutions committed to reducing their carbon emissions [13].

The findings of our study, which demonstrated equivalent respiratory and hemodynamic stability under both TIVA and sevoflurane during prone spinal surgeries, also invite a focused discussion on the implications of these anesthesia methods for intraoperative neuromonitoring—a critical component in neuro sensitive surgeries.

Intraoperative neuromonitoring (IONM) is essential for detecting potential neurological deficits during spine surgery, allowing for immediate interventions that can prevent permanent damage. The effectiveness of IONM can be influenced significantly by the choice of anesthesia, as some agents can alter the threshold and amplitude of neuromonitoring signals. It is imperative that the anesthesia regimen supports the clarity and reliability of these monitoring signals.

TIVA is generally favored in settings requiring extensive neuromonitoring because it typically exerts minimal interference with the electromyography (EMG) and somatosensory evoked potentials (SSEPs) used in these procedures. Studies have shown that propofol, a key component of TIVA, maintains more consistent baseline SSEP amplitudes compared to volatile agents, which can suppress these signals at deeper levels of anesthesia [14]. This characteristic makes TIVA particularly advantageous for complex spine or neurosurgical procedures where neuromonitoring is integral to patient safety.

While sevoflurane is a versatile anesthetic with favorable recovery profiles and organ protection properties, it can affect neuromonitoring fidelity by dampening SSEP and EMG signals at higher concentrations. However, when maintained at lower concentrations, sevoflurane can be used effectively without significantly compromising the quality of neuromonitoring data [15]. This flexibility allows for its application in a broader range of surgical procedures, provided careful management and monitoring of anesthetic depth are practiced.

Neuromonitoring is vital for detecting and mitigating potential neurological damage during spine surgeries, and the choice of anesthetic can significantly influence its efficacy. While TIVA is often preferred for its minimal interference with neuromonitoring signals, our study underscores the potential for using sevoflurane with careful management to achieve similar monitoring clarity. The implications extend beyond mere signal accuracy to encompass patient safety and surgical outcomes, emphasizing the need for anesthesiologists to consider not only the pharmacological profiles of anesthetics but also their operational impact on neuromonitoring technologies.

Although our study focused on immediate intraoperative parameters, the long-term neurological outcomes related to anesthetic choice during spine surgeries warrant further investigation. Anesthetics that better support neuromonitoring may contribute to reduced incidences of postoperative neurological deficits and enhance overall recovery trajectories. Future studies should aim to link intraoperative anesthetic choices with long-term neurological follow-ups to better understand these relationships [16].

Integrating a multidisciplinary approach that includes neurologists, anesthesiologists and surgical teams is essential for optimizing patient outcomes. This collaboration is crucial for tailoring anesthesia plans that accommodate both surgical demands and neuromonitoring requirements, potentially leading to innovations in anesthesia techniques that enhance both safety and efficacy during neuro sensitive surgeries.

Anesthesia practice is influenced by broader socioeconomic and environmental factors. The cost-effectiveness of TIVA versus sevoflurane, along with their environmental impacts, plays a crucial role in shaping hospital policies and practices. Anesthesia protocols need to balance clinical benefits with sustainable practices, particularly as healthcare systems globally move towards greener alternatives [7].

Given the differential impacts on neuromonitoring, the choice between TIVA and sevoflurane should be strategized based on the specific requirements of the surgery and the patient's condition. For surgeries with high risks of neurological complications, TIVA might be the preferred choice. In contrast, for procedures where rapid changes in

anesthetic depth are required, and neuromonitoring demands are less critical, sevoflurane could offer specific advantages.

Another aspect of our study is the prone position, which is frequently employed in operating rooms due to its advantageous effects on surgical exposure and outcomes. However, this positioning can result in physiological alterations not present in patients in the supine posture. In the prone position, there can be an increase in functional residual capacity and arterial partial pressure of oxygen, although chest wall and lung compliance may remain unchanged [17]. Venous return may decrease depending on the degree of constriction of the inferior vena cava, leading to a reduction in the preload of the left ventricle, cardiac index and stroke volume [18]. Additionally, increased abdominal pressure can compromise diaphragm movement, resulting in elevated peak airway pressure (Ppeak) and a reduction in dynamic compliance (Cdyn) [19].

Numerous studies have explored the impact of the prone positioning on respiratory parameters. For instance, one study compared the hemodynamic and respiratory effects of lumbar spine surgery using volume-controlled ventilation (VCV) and pressure-controlled ventilation (PCV) modes. It was found that the PCV group exhibited higher Ppeak values, along with lower mean blood pressure (MBP), cardiac output (CO), central venous pressure (CVP), and Cdyn values [20]. In contrast, our investigation included all patients in the VCV mode. No significant differences were detected in PEEP, $ETCO_2$, heart rate, Ppeak, Pmean, tidal volume (VT), respiratory rate (RR), minute ventilation (MV), Cdyn, PaO_2/FiO_2 or VD/VT between the Sevo and TIVA groups in the supine position post-intubation or at 5, 15 or 30 minutes after prone positioning. The inability to examine these parameters in PCV mode constitutes a limitation of our study.

Another study indicated that Ppeak values were lower in prone patients in the PCV group using the Wilson frame compared to those in the VCV group, although oxygenation parameters remained unchanged. Cdyn values decreased by 17% [21]. Similarly, Kandasamy P *et al.* [22] found that prone positioning with a spine frame led to a significantly greater increase in airway pressures and a decrease in dynamic compliance when compared to patients positioned prone without the spine frame. Our findings support these investigations, as we observed a decrease in Cdyn values when comparing the prone posture in VCV mode to the initial supine position in both groups.

Regarding the estimated physiological dead space ratio (VD/VT), several studies have reported no discernible difference between supine and prone postures in VCV mode [23]. However, similar to the patients in a study [24], we observed an increase in the VD/VT ratio in both groups when positioned prone position compared to the initial supine position. There was no statistically significant difference between the TIVA and Sevo groups concerning the VD/VT ratio. Notably researchers in that study [24] also reported an improvement in oxygenation in the VCV mode of ventilation despite this increase in the VD/VT ratio.

$ETCO_2$ values have also been studied in both supine and prone positions, with some studies indicating an increase in the $ETCO_2$ gradient when in the prone position [25]. In our investigation, we found that $ETCO_2$ values decreased in both groups (Fig. 2). Adjustments to the respiratory rate during surgery, based on $ETCO_2$ values, likely contributed to this decrease.

TIVA is a general anesthesia method frequently employed not only in neurosurgery but also in various other surgical procedures. Bang SR *et al.* [26] studied respiratory mechanics during laparoscopic cholecystectomies in the Trendelenburg position, comparing propofol-remifentanil and sevoflurane groups. Similar to our study, they found no significant differences in Ppeak and Cdyn values. Ozturk MC *et al.* [27] compared respiratory mechanics in patients undergoing laparoscopic sleeve gastrectomy with propofol, desflurane and sevoflurane, and found no significant differences in Ppeak, Cdyn, and plateau pressure (Pplato) values. Our findings corroborate these studies, demonstrating no significant changes in these parameters between the TIVA and sevoflurane groups.

A pertinent question arises regarding the potential extrapulmonary complications associated with TIVA compared to traditional inhalational agents. Several studies have investigated this issue. Li *et al.* [8] compared inhalational agents and TIVA for postoperative pulmonary complications in pulmonary resection operations and found no significant differences. Zhou D *et al.* [28] examined head and neck procedures and reported a reduced frequency of mild pulmonary complications with sevoflurane compared to TIVA. In our study, no such postoperative complications were observed in either group.

Sharma S *et al.* [29] investigated pulmonary functions in patients undergoing mastoid surgery with desflurane and TIVA, reporting a reduction in lung function during both anesthesia maintenance methods. Postoperative pulmonary function tests showed a slight decreased with TIVA in the early postoperative period; however, desflurane led to a more significant decrease after 24 hours [29]. In our study, we did not perform postoperative pulmonary function tests, which constitutes another limitation.

Given the complexity of factors influencing anesthesia outcomes, further research should integrate a multidisciplinary approach to assess not only the immediate clinical effects but also long-term outcomes and broader impacts. Future studies could explore the comparative effects of these anesthetics on patient recovery times, satisfaction, and long-term neurological outcomes. Additionally, evaluating the environmental impact of anesthesia practices could help in establishing guidelines that balance clinical efficacy with sustainability.

Moreover, future research should also focus on optimizing anesthesia protocols to enhance the compatibility of various anesthetic agents with neuromonitoring techniques. Prospective studies comparing the effects of modified anesthesia regimens on the quality of neuromonitoring signals could yield insights into tailoring anesthesia approaches to individual surgical scenarios, thereby enhancing both safety and efficacy.

Clinicians and researchers should consider developing guidelines that integrate findings from multiple disciplines to provide a holistic approach to anesthesia management in spine surgery. Furthermore, ongoing research should explore innovative anesthetic techniques and technologies that minimize environmental impact without compromising patient safety.

Both TIVA and sevoflurane present effective options for

anesthesia during prone spinal surgeries, with their respective advantages allowing for tailored application based on various factors ranging from clinical needs to environmental considerations. As the field of anesthesiology continues to evolve, ongoing research and practice refinement must take these broader aspects into account to optimize patient care and operational efficiency.

Understanding the nuances of how TIVA and sevoflurane interact with neuromonitoring technologies is crucial for maximizing patient safety during spine surgeries. Our study contributes valuable data to this field, supporting the safe use of both anesthetics under monitored conditions while highlighting the superior compatibility of TIVA with neuromonitoring requirements.

This discussion extends the implications of our findings to suggest that while both TIVA and sevoflurane are viable for maintaining intraoperative stability, their selection should be considered within a broader clinical, technological and environmental context. As the landscape of surgical anesthesia continues to change, our approaches to ensuring optimal patient outcomes and sustainable practices must also evolve.

While this study offers valuable insights into the comparative effects of TIVA and sevoflurane on respiratory mechanics and hemodynamic parameters, several limitations must be acknowledged:

(1) Sample Size: Although the sample size was sufficient to detect significant differences in the primary outcomes, it may not be adequate to identify less common complications or subtler effects. Additionally, the homogeneity of the sample limits the generalizability of the findings to broader populations.

(2) Single-Center Study: The study was conducted in a single hospital setting, which may limit the applicability of the findings to institutions with different protocols and practices.

(3) Monitoring Parameters: Our focus on respiratory and hemodynamic metrics excluded more extensive monitoring of other factors such as anesthesia depth. Additionally, the study did not use advanced neuromonitoring techniques that could provide further insights into neurological impacts.

(4) Short-Term Observation: The study focused on intraoperative stability but lacked postoperative follow-up, limiting our ability to assess longer-term effects, such as recovery quality or postoperative complications.

(5) External Factors: Variables such as operating room conditions and surgical team efficiency were not controlled, which may have influenced the outcomes.

(6) Univariate Analysis for Repeated Measurements: One limitation of the study is the use of univariate analysis to compare measurements taken at multiple time points. This approach does not account for the within-subject correlation over time, potentially oversimplifying the relationships between variables and overlooking dynamic trends in respiratory and hemodynamic parameters throughout the surgery. Multivariate techniques, such as repeated measures ANOVA (Analysis of Variance) or linear mixed models, would have offered a more robust analysis by considering both the time-dependent nature of the data and individual patient variability across time points. The use of univariate methods could increase the risk of Type I errors (false positives) or Type II errors (false negatives) when interpreting the data.

Future research should include multicenter trials, broader demographic samples, and long-term postoperative monitoring to further assess the effects of TIVA and sevoflurane.

5. Conclusions

The article compares the effects of Total Intravenous Anesthesia (TIVA) and sevoflurane anesthesia on respiratory mechanics, hemodynamic parameters, and neuromonitoring stability in patients undergoing spinal surgeries in the prone position. The study measured parameters such as dynamic compliance (Cdyn), dead space to tidal volume ratio (VD/VT), end-tidal CO_2 ($ETCO_2$), and respiratory and hemodynamic stability. Neuromonitoring methods, including Somatosensory Evoked Potentials (SSEPs) and Electromyography (EMG), were employed to ensure neurological integrity during surgery. Both anesthesia methods showed similar effects, with no significant differences in the primary parameters. This study provides valuable insights into the comparative effectiveness of TIVA and sevoflurane anesthesia in maintaining respiratory and hemodynamic stability during prone spinal surgeries. The findings support the continued use of both anesthesia methods, allowing for tailored anesthesia management that optimizes patient outcomes in spinal surgery.

6. Key points

(1) Objective:

○ To compare the effects of Total IntravenousAnesthesia (TIVA) and sevofluraneanesthesia on respiratorymechanics, hemodynamic parameters, and neuromonitoring during prone position spinal surgeries.

(2) Methodology:

○ A randomized controlled trial involving 52 patients scheduled for lumbar spine surgery, randomly assigned to either TIVA or sevoflurane groups.

○ Respiratory and hemodynamic parameters were measured at various time points.

(3) Results:

○ No significant differences were found between the TIVA and sevoflurane groups in terms of respiratory mechanics or hemodynamic stability.

○ Both anesthesia techniques maintained stable intraoperative conditions.

(4) Clinical Implications:

○ Anesthesiologists can flexibly choose between TIVA and sevoflurane based on patient-specific factors and surgical requirements.

○ TIVA may be preferred in surgeries with high neurological risk due to its compatibility with neuromonitoring.

(5) Future Research:

○ Studies with broader patient populations and long-term outcomes are needed to further refine anesthesia management strategies.

○ Research on the environmental impact and cost-effectiveness of anesthesia techniques is also important.

ABBREVIATIONS

TIVA, Total Intravenous Anesthesia; Cdyn, Dynamic Compliance; VD/VT, Dead Space to Tidal Volume Ratio; $ETCO_2$, End-Tidal Carbon Dioxide; SSEP, Somatosensory Evoked Potentials; EMG, Electromyography; MAP, Mean Arterial Pressure; HR, Heart Rate; MAC, Minimum Alveolar Concentration; PEEP, Positive End-Expiratory Pressure; RR, Respiratory Rate; VT, Tidal Volume; MV, Minute Ventilation; ASA, American Society of Anesthesiologists; BIS, Bispectral Index; FiO_2, Fraction of Inspired Oxygen; PaO_2, Partial Pressure of Oxygen in Arterial Blood; BMI, Body Mass Index; VCV, Volume-Controlled Ventilation; PCV, Pressure-Controlled Ventilation; Ppeak, peak airway pressure; Pmean, mean airway pressure; COPD, chronic obstructive pulmonary disease; EF, ejection fraction; Sevo group, Sevoflurane group; SD, Standard Deviation; IQR, interquartile range; IONM, Intraoperative neuromonitoring; MBP, mean blood pressure; CO, cardiac output; CVP, central venous pressure; Pplato, plateau pressure.

AVAILABILITY OF DATA AND MATERIALS

The corresponding author can provide the data sets used in the current work upon reasonable request.

AUTHOR CONTRIBUTIONS

YY—designed the research study. YY and CO—performed the research. YY, CO, OS and SAK—analyzed the data. YY—wrote the manuscript. YY, OS, SAK, BG, EA and BC—reviewed the manuscript extensively for significant intellectual content. To guarantee that any doubts regarding the precision or honesty of any portion of the work are duly examined and settled, all authors consented to take complete responsibility for the project. All of the authors authorized the final version of the manuscript for publication.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

University of Health Sciences Kartal Dr. Lutfi Kirdar City Hospital Research Ethics Committee approved our study on 27 April 2023 (2023/514/248/20). All patients signed a written informed consent. The study was retrospectively registered on ClinicalTrials.gov (Trial Registration number: NCT06558695, Date: 14 August 2024).

ACKNOWLEDGMENT

Not applicable.

FUNDING

No particular grant from a governmental, private, or nonprofit organization was given for this research.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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How to cite this article: Yucel Yuce, Ceren Onal, Secil Azime Karakus, Ozlem Sezen, Banu Cevik, Bulent Guclu, *et al*. Comparison of TIVA and sevoflurane: ensuring hemodynamic and respiratory stability in prone position spinal surgeries: a randomized controlled trial. Signa Vitae. 2025; 21(4): 50-61. doi: 10.22514/sv.2025.052.