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Original Research Article

Comparison of Pressure Controlled Versus Volume Controlled Ventilation Modes in Patients Undergoing Lumbar Spine Surgery in Prone Position

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Abstract

Background: Prone positioning during lumbar spine surgery under general anaesthesia significantly alters respiratory mechanics and hemodynamics due to changes in thoraco-abdominal compliance and intra-thoracic pressure. The choice of intraoperative ventilation mode may influence pulmonary mechanics, cardiovascular stability, intraoperative blood loss, and surgical stress response.

Evidence comparing pressure-controlled ventilation (PCV) and volume-controlled ventilation (VCV) in this setting remains inconsistent.

Objectives: To compare PCV and VCV with respect to pulmonary mechanics, hemodynamic parameters, intraoperative blood loss, and stress response in patients undergoing elective lumbar spine surgery in the prone position.

Material and Methods: This prospective, randomized comparative study included 60 adult patients (ASA I–II) scheduled for elective lumbar spine surgery. Patients were randomized to receive either PCV or VCV (n=30 each). Ventilation was standardized with tidal volume of 8 mL /kg and PEEP of 5 cm H_2O. Hemodynamic and respiratory parameters were recorded after intubation in supine position and 30 minutes after prone positioning. Dynamic compliance was calculated, surgical stress response assessed using random blood glucose levels, and intraoperative blood loss estimated at the end of surgery.

Results: Demographic characteristics were comparable between groups. Peak airway pressure was significantly lower and dynamic compliance significantly higher in the PCV group compared to the VCV group ($p<0.001$). Mean arterial pressure showed a lesser decline in the PCV group ($p=0.02$). Intraoperative blood loss was significantly lower with PCV ($p<0.001$). Heart rate, end-tidal carbon dioxide, and blood glucose levels showed no significant intergroup differences.

Conclusion: Pressure-controlled ventilation provides superior respiratory mechanics and reduced intraoperative blood loss with good hemodynamic stability and no significant stress response compared to volume-controlled ventilation during prone lumbar spine surgery.

Keywords: Anaesthesia; Artificial; Blood Loss; General; Pulmonary Compliance; Respiration; Prone Position; Spine Surgery; Surgical.

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Introduction

Spine surgeries have increased in the past decade owing to improvements in diagnostic modalities and surgical techniques. Prone position is most commonly used to provide surgical access for lumbar spine surgeries. Prone positioning in addition to general anaesthesia poses several mechanical and hemodynamic effects. The prone position alters thoraco- abdominal mechanics, reduces lung compliance, increases intra-abdominal and intra- thoracic pressures. This impairs venous return, reducing cardiac output. The increased intra- abdominal pressure can also lead to increased intra-operative blood loss. The overall hemodynamic instability is reflected in terms of intraoperative stress response. Given the above changes, the mode of ventilation used during general anaesthesia plays a significant role in either exacerbating or limiting the mechanical and hemodynamic changes caused by prone positioning. Volume controlled ventilation (VCV) is the most frequently used mode, in which a pre-set tidal volume is delivered regardless of airway pressures. This can potentially lead to high peak airway pressures. Conversely, pressure controlled ventilation (PCV) delivers a set inspiratory pressure, which may reduce risk of barotrauma. However, the delivered tidal volume varies with changes in lung compliance and airway resistance, which may affect carbon dioxide elimination.

Previous studies have demonstrated variable findings regarding the superiority of either ventilation mode. Several gaps remain in our understanding since most studies are heterogeneous in technique and measurement and yield inconsistent results. Therefore, this study aims to provide a comprehensive comparison of four parameters— pulmonary mechanics, hemodynamics, intraoperative blood loss, and stress response in patients undergoing lumbar spine surgery in prone position using pressure-controlled versus volume- controlled ventilation. The findings of this research may guide anesthesiologists in refining intraoperative ventilatory strategies, promoting better respiratory stability and patient safety.

Material and Methods

This prospective comparative study was conducted on 60 patients of either gender, aged above 18 years, belonging to ASA physical status I and II, scheduled for elective lumbar spine surgery requiring prone positioning, after obtaining approval from Institutional Ethics Committee (IEC approval number: SSMC/MED/IEC−149/ OCTOBER−2025) and registration in Clinical Trials Registry of India (CTRI /2025/12/099742). Informed written consent was obtained from all participants. Patients with significant cardio-pulmonary disease (e.g., COPD, asthma, restrictive lung disease, uncontrolled hypertension, heart failure NYHA III–IV, recent myocardial infarction (<6 months), severe valvular disease, unstable arrhythmias), severe hepatic or renal impairment, obesity (BMI > 35 kg/m²), or those posted for emergency surgery were excluded from the study.

Patients were randomly allocated into two equal groups (n = 30 each) using a computer- generated simple randomization sequence placed in sealed opaque envelopes opened immediately prior to induction of anaesthesia.

All patients underwent standard preoperative evaluation and fasting protocols. Upon arrival in the operation theatre, intravenous fluids were connected and standard ASA monitoring (ECG, SpO_2, $EtCO_2$, NIBP) initiated. Patients were pre-medicated with midazolam 0.05 mg/kg IV + glycopyrrolate 0.004 mg/kg IV + fentanyl 2 mcg/kg IV. General anaesthesia was induced with propofol 2 mg/kg and muscle relaxation achieved with vecuronium 0.1 mg/kg, followed by endotracheal intubation. Anaesthesia was maintained with isoflurane in oxygen–nitrous oxide mixture to achieve a MAC of 1.0 and intermittent muscle relaxant dosing. Ventilator settings were adjusted based on group allocation -

PCV Group: Inspiratory pressure adjusted to achieve a tidal volume of 8 mL/kg, maintaining ETCO2 between 35–40 mmHg.

VCV Group: Tidal volume of 8 mL/kg, respiratory rate adjusted to maintain ETCO2 between 35–40 mmHg, with an inspiratory: expiratory ratio of 1:2.

PEEP of 5 cmH_2O was applied in both groups. FiO_2 and fresh gas flow were kept constant throughout the study period. Patients were positioned prone on bolsters with appropriate padding, and ensuring the abdomen was free and eyes were protected in the head-ring. Hemodynamic parameters including heart rate, non-invasive systolic, diastolic and mean blood pressure (SBP, DBP, MAP) were continuously monitored, and recorded into case proforma after intubation in supine position (T0) and 30 minutes after prone positioning (T1).

Respiratory parameters including delivered tidal volume (TV), minute ventilation (MV), peak airway pressure (P peak), end tidal carbon dioxide (ETCO2) were recorded at T0 and T1.

Dynamic compliance (C dyn) was calculated from TV, P peak, PEEP using standard formula [C dyn = TV/(P peak – PEEP)]. Stress response was measured using glucose random blood sugar (GRBS) at T0 and T1.

Intraoperative blood loss was calculated at the end of surgery as the sum of blood collected in suction apparatus (suction volume minus irrigation) and blood absorbed on gauze and pads.

Standardized approximations were made based on size of gauze/pad and degree of soakage. Transfusion details (if any) were noted. Intraoperative events and complications (if any) were noted.

Post - operative outcomes in terms of recovery time, and incidence of respiratory or hemodynamic complications were noted.

Statistical Analysis: The collected data was entered in Microsoft Excel 2016 and analysed with IBM SPSS Statistics for Windows, Version 29.0.(Armonk, NY: IBM Corp). Descriptive statistics were described using mean & S.D for continuous variables. To find the significant difference between the bivariate samples in independent groups, independent sample t-test was used. Probability value <=0.05 is considered as statistically significant.

Results

Demographic parameters and ASA status distribution were comparable between both groups. The distribution of the type of lumbar spine surgery was also similar in both groups. [Table 1]

Table 1: Demographic parameters and surgical procedures

Parameter		**PCV Group**	**VCV Group**	**P value**
		N = 30	**N = 30**	
Age (years)		52.2 ± 12.75	52.4 ± 13.57	0.95
Gender	Male	17	14	0.44
	Female	13	16	
ASA	1	10	10	1.00
	2	20	20	
Type of surgery	IVDP – Decompression + Fixation	24	23	0.79
	IVDP - Microdiscectomy	1	2	
	Vertebral fracture - Fixation	0	2	
	Pott's Spine – Decompression + Fusion	1	1	
	Fenestration	3	2	
	Implant removal	1	0	

The trends in delivered tidal volume (TV), heart rate, ETCO2 and GRBS showed no statistically significant difference between the two groups.

Table 2: Comparison of study parameters (t-test)

Parameter		**N**	**Mean**	**SD**	**P value**
TV SUPINE (T0)	PCV	30	428.33	24.37	0.027
	VCV	30	418.00	26.28	
TV PRONE (T1)	PCV	30	416.33	24.37	0.719
	VCV	30	418.00	26.28	
P PEAK SUPINE (T0)	PCV	30	17.53	1.31	0.0005
	VCV	30	22.20	1.73	
P PEAK PRONE (T1)	PCV	30	17.53	1.31	0.0005
	VCV	30	25.08	1.67	
ETCO2 SUPINE (T0)	PCV	30	36.18	1.02	0.459
	VCV	30	36.05	0.95	
ETCO2 PRONE (T1)	PCV	30	35.35	0.55	0.327
	VCV	30	35.45	0.57	
C DYN SUPINE (T0)	PCV	30	34.17	3.96	0.0005
	VCV	30	24.07	2.65	
C DYN PRONE (T1)	PCV	30	32.95	4.16	0.0005
	VCV	30	20.73	2.13	
HR SUPINE (T0)	PCV	30	107.82	8.05	0.056
	VCV	30	110.75	8.56	
HR PRONE (T1)	PCV	30	97.82	8.05	0.0005
	VCV	30	124.75	8.56	
MAP SUPINE (T0)	PCV	30	105.03	6.36	0.045
	VCV	30	107.84	8.63	
MAP PRONE (T1)	PCV	30	97.85	5.60	0.002
	VCV	30	94.75	5.15	
GRBS SUPINE (T1)	PCV	30	118.87	21.27	0.764
	VCV	30	117.70	21.27	
GRBS PRONE (T2)	PCV	30	140.70	21.50	0.127
	VCV	30	134.70	21.27	
BLOOD LOSS	PCV	30	158.33	24.37	0.0005
	VCV	30	288.00	26.28	

The observed peak airway pressures were significantly lower (p 0.0005) in the PCV group (mean 17.53 +/- SD 1.31) compared to VCV group (mean 25.08 +/- SD 1.67). Dynamic compliance calculated was significantly higher (p .0005) in PCV group (mean 32.95 +/- SD 4.16) compared to

VCV group (mean 20.73 +/- SD 2.13). PCV group showed significantly lesser (p 0.02) fall in mean arterial blood pressure (mean 97.85 +/- SD 5.60) compared to VCV group (mean 94.75 +/- SD 5.15).

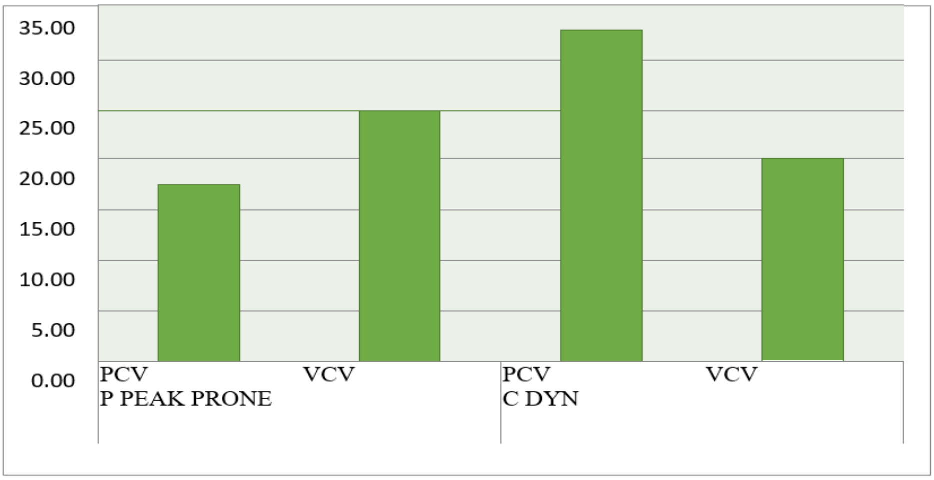

Figure 1: Comparison of respiratory parameters

Intraoperative blood loss was significantly lower (p 0.0005) in PCV group (mean 158.33 +/- SD 24.37) compared to VCV group (mean 288.00 +/- SD 26.28). (Figure 2)

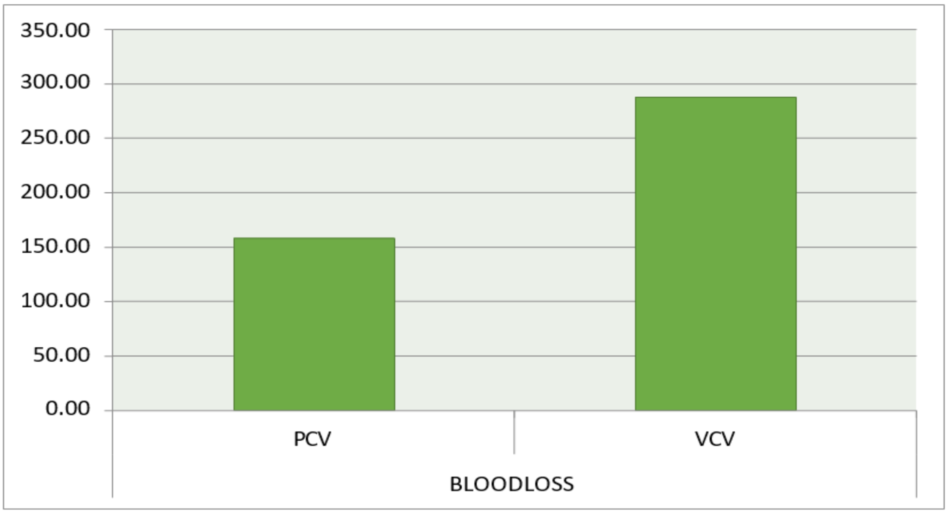

Figure 2: Comparison of intra-operative blood loss

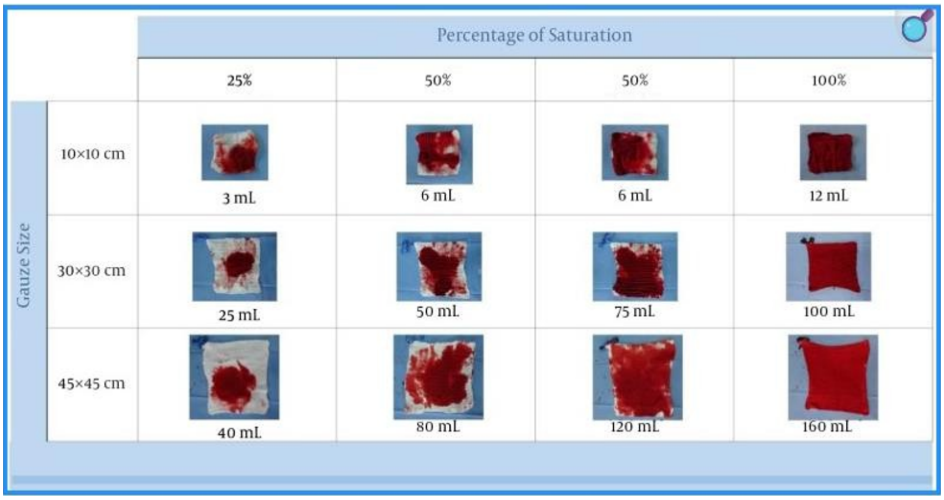

Figure 3: Visual analogue for estimation of surgical blood loss [11]

Adverse events were observed in two patients in the PCV group and seven patients in the VCV group; In the PCV group, two patients had hypotension. In VCV group, five patients had hypotension, one patient had rhochi post extubation, and one patient had delayed recovery. However, the difference between the two groups was not statistically significant (p = 0.14), and these adverse effects could be attributed to patient – related factors such as smoking and diabetic autonomic neuropathy.

Discussion:

Prone positioning by itself disrupts the cardio-respiratory mechanic in multiple ways. Compression of the abdomen against the rigid operation table displaces the abdominal organs towards the diaphragm, reducing lung compliance and increasing intra-abdominal and intra- thoracic pressures, unless this is prevented by ensuring that the abdomen is free using appropriate bolsters. The compression of inferior vena cava coupled with raised intra-thoracic pressure impedes venous return causing pooling of blood in extremities, leading to a fall in cardiac output.

The initiation of positive pressure ventilation additionally exacerbates the disrupted physiology by further increasing the intra-thoracic pressure and application of positive end expiratory pressure (PEEP), which further reduces cardiac output. The PEEP however, improves oxygenation by preventing atelectasis at end-expiration.[1]

Thus, the choice of ventilatory mode should be such that it maintains appropriate respiratory mechanics to allow adequate oxygenation, at the same time not lead to further hemodynamic instability.

The most frequently used mode is volume controlled ventilation (VCV) wherein a fixed tidal volume is delivered using constant inspiratory flow, and the airway pressure varies in order to achieve the set tidal volume. Thus, peak airway pressure (P peak) rises in response to increased resistance or decreased compliance, potentially leading to barotrauma.

In contrast, pressure controlled ventilation (PCV) targets preset inspiratory pressure, which cannot spike beyond the set limit. PCV also uses a decelerating inspiratory flow pattern with initial high flow which gradually decreases as alveoli fill, leading to lesser airway resistance. This reduces overall risk of barotrauma. However, PCV may not ensure a consistent tidal volume, leading to inadequate removal of carbon dioxide. Hence it requires close monitoring of delivered tidal volume (TV) and end tidal carbon dioxide (ETCO2).[1] In our study, PCV group showed lower p peak values with higher dynamic compliance, suggesting that it could be a more favorable, alternative ventilation mode to VCV. This is consistent with the findings of previous studies [2-8] which showed better respiratory mechanics in PCV group compared to VCV group.

The fall in cardiac output during prone ventilation could manifest as a fall in blood pressure with a compensatory increase in heart rate. However, it may be not be evident as it is counter- balanced by an increase in systemic vascular resistance. This was the case in our study population, where the heart rate trends showed no significant difference between the two groups, although the mean arterial pressure was found to be greater in the PCV group, owing to lower intra-thoracic pressure. Similarly, Lee et al. found no significant difference in the hemodynamics among PCV and VCV modes in prone lumbar spine surgery.[9] This was in contrast to the findings of Ragheb et al. where the heart rate and mean arterial blood pressure were significantly lower in PCV group.[10]

The tissue-injury due to surgery, coupled with deranged hemodynamics due to prone positioning, triggers a complex neuro-endocrine reaction, leading to systemic stress response. It causes release of counter-regulatory hormones such as catecholamines (adrenaline, noradrenaline), cortisol, glucagon and growth hormone, causing increased hepatic glucose production and insulin resistance, leading to peri-operative hyperglycemia. This could lead to surgical site infections, delayed wound healing, prolonged hospital/ICU stay, and increased overall morbidity and mortality.

Ragheb et al. observed that the heart rate, mean arterial blood pressure, serum glucose level, and serum cortisol were statistically significantly lower in patients ventilated with PCV than VCV group during lumbar spine surgery, reflecting a higher systemic stress response in the VCV group.10 However, in our study we found no significant difference in the surgical stress response, evidenced by comparable heart rate and GRBS trends in both groups. This could be due to efficient anaesthetic management such as pre-operative anxiolysis (pre-medication with midazolam), maintenance of adequate depth of anaesthesia, good peri-operative analgesia, short duration of surgery (leading to lesser cytokine release) and avoidance of additional stressors such hypoxia, hypotension, hypovolaemia, hypothermia and anaemia.

Increased intra- abdominal pressure in prone position raises the venous pressure in the compressed inferior vena cava, which is transmitted to the thin-walled, valve-less epidural venous plexus. This contributes to increased intra-operative blood loss, which is further exacerbated in hypertensive patients. This obscures surgical field, and mandates use of vasopressors, volume expansion using intravenous fluids, transfusion of blood and blood products, and can lead to poor post-operative outcomes owing to anemia, transfusion- related adverse effects and poor wound healing. Intra-operative blood loss is calculated as the sum of blood collected in suction apparatus (suction volume minus irrigation) and blood absorbed on gauze and pads. Standardised approximations have been made using size of gauze/pad and degree of soakage, based on previous studies by Algadiem et al.[11] and Stoker et al.[12]

Our results show that patients ventilated with PCV showed significantly lower intra-operative bleeding, likely due to the lower peak inspiratory pressures and gradual rise of peak airway pressure, compared to VCV group. Although the overall blood loss was less in both groups, with none of the patients requiring blood transfusion, the amount was significantly higher in the VCV group. This was consistent with the findings of Kundra et al [13] and Hajijafari et al.[14] where bleeding was significantly less in lumbar spine surgery patients ventilated with PCV than in the VCV group.

Our study had a few inevitable limitations. Firstly, the observer was not blinded to the group allocation as it would not be practically possible. However, the same standard anaesthesia protocol was used in both groups to prevent observer bias. The surgical team was also blinded to group allocation.

Secondly, we included only ASA 1 and 2 patients, and avoided those with significant cardio-pulmonary disease or obesity (ASA 3 and above) to minimize confounding factors, although such patients would benefit more with this mode of ventilation.

Thirdly, we used the visual analogue method for estimation of intra-operative blood loss as it is simple and the most commonly used method. However, it is a subjective method and gravimetric or calorimetric methods would have been more accurate, although no gold standard has been identified.

Conclusion:

Pressure controlled ventilation offers better respiratory mechanics and reduced intra-operative bleeding, with no significant change in hemodynamics or surgical stress response, without significant adverse effects compared to volume-controlled ventilation in patients undergoing elective prone lumbar spine surgery. This study can help anaesthesiologists adopt safer ventilator strategies, leading to better patient outcomes.

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