Effect of Mechanical Ventilation Mode Type on Intra- and Postoperative Blood Loss in Patients Undergoing Posterior Lumbar Interbody Fusion Surgery

A Randomized Controlled Trial

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ABSTRACT

Background: The aim of study was to evaluate the effect of mechanical ventilation mode type, pressure-controlled ventilation (PCV), or volume-controlled ventilation (VCV) on intra- and postoperative surgical bleeding in patients undergoing posterior lumbar interbody fusion (PLIF) surgery.

Methods: This was a prospective, randomized, single-blinded, and parallel study that included 56 patients undergoing PLIF and who were mechanically ventilated using PCV or VCV. A permuted block randomization was used with a computer-generated list. The hemodynamic and respiratory parameters were measured after anesthesia induction in supine position, 5 min after patients were changed from supine to prone position, at the time of skin closure, and 5 min after the patients were changed from prone to supine position. The amount of intraoperative surgical bleeding, fluid administration, urine output, and transfusion requirement were measured at the end of surgery. The amount of postoperative bleeding and transfusion requirement were recorded every 24 h for 72 h.

Results: The primary outcome was the amount of intraoperative surgical bleeding, and 56 patients were analyzed. The amount of intraoperative surgical bleeding was significantly less in the PCV group than that in the VCV group (median, 253.0 [interquartile range, 179.0 to 316.5] ml in PCV group vs. 382.5 [328.0 to 489.5] ml in VCV group; P < 0.001). Comparing other parameters between groups, only peak inspiratory pressure at each measurement point in PCV group was significantly lower than that in VCV group. No harmful events were recorded.

Conclusion: Intraoperative PCV decreased intraoperative surgical bleeding in patients undergoing PLIF, which may be related to lower intraoperative peak inspiratory pressure. (Anesthesiology 2016; 125:115-23)

Various approaches for posterior lumbar interbody fusion (PLIF) surgery can be used, but the posterior approach in the prone position is popular due to its effective access. Maintaining intraabdominal pressure is important when changing the patient from the supine to the prone position for PLIF, and various methods have been studied. Usually, the change from the supine to the prone position for PLIF after inducing anesthesia is subject to hemodynamic and respiratory changes. The prone position is associated with a decrease in cardiac output due to inferior vena cava (IVC) compression and a decrease in venous return resulting from the increase in abdominal pressure. Additionally, the prone position is known to decrease the compliance of the left ventricle. Concerning the respiratory function, the prone position is associated with increases in intrathoracic and abdominal pressure, airway resistance, and a decrease in dynamic compliance of lung compared with the supine position. These factors cause venous engorgement in the back, resulting in an increase in surgical bleeding and surgical field interruption.

Among various mechanical ventilation modes, the pressure-controlled ventilation (PCV) mode provides the same tidal volume with a lower peak inspiratory pressure (PIP) and a more even distribution of ventilated gas to the whole lung field than the volume-controlled ventilation (VCV)
mode.12–15 Therefore, PCV with a lower PIP would be expected to show less IVC compression, less venous engorge-
ment, and less surgical bleeding.

We hypothesized that PCV would be associated with less surgical bleeding than VCV in PLIF in the prone position. The aim of this study was to evaluate the effect of different mechanical ventilation modes on intra- and postoperative bleeding in patients undergoing PLIF in the prone position.

Materials and Methods

Study Population

After obtaining the approval (KUH 1160046; July 10, 2012) of the Institutional Review Board of Konkuk University Medical Center, Seoul, Korea, registration at http://cris.nih.go.kr (KCT0000486, principal investigator: S.-H.K., date of registration: July 19, 2012), and informed consent at an anesthesia previsit for patients undergoing PLIF (2 or 3 level), patients were evaluated prospectively at the univer-
sity teaching hospital from July 2012 to May 2013. Patient exclusion criteria were as follows: (1) an urgent or emergency case, (2) patient age less than 16 yr, (3) reduced left and right ventricular function (ejection fraction less than 40%), (4) previous respiratory disease, (5) arterial partial pressure of oxygen (Pao2)/fraction of inspired oxygen (FiO2) ratio less than 300 mmHg before inducing anesthesia, (6) preopera-
tive dysrhythmia, (7) severe hepatic disease, (8) severe renal disease, (9) reoperation, (10) concurrent other operation, and (11) patients with dermatological disease that interfered with the attachment of the noninvasive cardiac output mon-
toring (NICOM) strips. The study was prospective, random-
ized, single-blinded, and parallel (allocation ratio = 1:1). For participant allocation, permuted block randomization was used with a computer-generated list of random numbers, using sealed envelopes. Surgeons and nurses involved in patient care were aware that the study was being conducted, but were blind to the details of the study protocol. The surgical procedure was performed by one surgeon and a single surgical team using the same method.

Anesthetic Regimen

Anesthesia was induced and maintained by the attending anesthesiologist, who managed anesthesia using a standard regimen in the study protocol, but was blinded to the details of the study protocol. After establishing routine invasive sys-
temic arterial blood pressure and noninvasive patient mon-
toring (pulse oximetry, electrocardiography, and bispectral index [BIS] measurement), the NICOM electrode strips were placed on the patient’s chest and connected to the NICOM controller (NICOM; Cheetah Medical, USA). Each elect-
rode sensor strip consisted of two contact points. Upper thoracic electrode strips were placed at both mid-subclavian regions, and lower electrode strips were placed in both mid-
der regions of the lower costal margin. After initial calibra-
tion of the NICOM system, the cardiac index and stroke volume variation (SVV) were monitored continuously. The NICOM system signal processing unit determines the relative phase shift (Δ) between input and output signals. The phase shift between the input and output signals is caused by the change in blood volume in the aorta: \( SV = C \times VET \times \frac{dV}{dt_{max}} \) where \( SV \) is stroke volume, \( C \) is the propor-
tionality constant, \( VET \) is ventricular ejection time, and \( \frac{dV}{dt_{max}} \) is the peak rate of change of \( \Delta \).16,17 Anesthesia was induced after administration of lidocaine 0.5 mg/kg to reduce the pain induced by propofol. Propofol 1.5 mg/kg was intravenously administered to induce anesthesia, and remi-
fentanil 0.2 µg · kg\(^{-1}\) · min\(^{-1}\) was continuously administered and maintained until the end of the surgery. Rocuronium 0.6 mg/kg was administered for muscle relaxation after loss of consciousness under the guidance of peripheral neuro-
muscular transmission (NMT) monitoring. Tracheal intu-
bution was performed at a train-of-four count of 0. During anesthesia maintenance, remifentanil was fixed at 0.2 µg · kg\(^{-1}\) · min\(^{-1}\), and sevoflurane was adjusted to maintain BIS values between 40 and 60. In the PCV group, the follow-
ing ventilator (ADU; Datex-Ohmeda, Finland) settings were used: 4 l/min, consisting of air (3 l/min) and oxygen (1 l/
min); the PIP was adjusted to achieve a tidal volume cal-
culated as the ideal body weight (50 [female: 45.5] + 0.91 · [height – 152.4]) × 8 ml; the respiratory rate was controlled using the end-tidal carbon dioxide pressure (ETCO2) ranging from 35 to 40 mmHg through capnography (S/5 Compact Anesthesia Monitor; Datex-Ohmeda); and no positive end-
expiratory pressure and inspiratory/expiratory ratio = 1:2. In the VCV group, the same ventilator settings were applied, with the exception of using the prescribed tidal volume, which was calculated using the same method as in the PCV group, instead of adjusting PIP. A central venous catheter for drug or fluid administration with central venous pres-
sure (CVP) monitoring was inserted into the right internal jugular vein. Pressure transducers (PX600F; Edwards Life-
sciences, USA) for pressure monitoring were placed on the mid-axillary line with guidance from a laser leveler (Phys-
iotrac; Edwards Lifesciences) and were fixed to the opera-
tion table to keep the transducer at the atrial level during the entire protocol. Additional rocuronium was administered under the guidance of the peripheral monitoring of NMT. The patients’ position was changed from the supine to the prone position using the Wilson frame, and the surgical pro-
cedure was started. Phenytozpine 30 µg (if the mean arterial blood pressure [MAP] was less than 60 mmHg and the heart rate [HR] was more than 40 beats/min), ephedrine 4 mg (if MAP less than 60 mmHg and HR less than 40 beats/min), or atropine 0.5 to 1.0 mg (if HR less than 40 beats/min) was injected to prevent hypotension or bradycardia. Phenytozpine was continuously infused if MAP less than 60 mmHg was not treated with repetitive phenytozpine injections. Nicardipine 0.5 mg was injected at a systolic blood pressure greater than 180 mmHg or diastolic blood pressure greater than 110 mmHg, and esmolol 30 mg was injected at a MAP greater than 60 mmHg and HR greater than 110 beats/min
during anesthesia. Crystalloid solution (Plasma solution A Inj.; CJ HealthCare, Korea) was administered according to fluid maintenance requirements, redistribution, and evaporative surgical fluid losses based on body weight (4 ml · kg⁻¹ · h⁻¹). The attending anesthesiologist performed additional separate laboratory tests in cases of acute surgical bleeding. If hematocrit was greater than 30%, then colloid solution (Volulyte®; Fresenius Kabi, Germany) was administered to replace blood loss and maintain stable hemodynamic status until the laboratory values reached indications for transfusion. Erythrocytes were transfused when the hematocrit was less than 30%. After the end of the surgery, the patient was changed from the prone to the supine position, and all anesthetics were stopped. The lung recruitment maneuver (holding of one breath at 30 cm H₂O for 10 s, repeated three to four times) was applied before the patient emerged from anesthesia to improve oxygenation and prevent atelectasis. Residual neuromuscular paralysis was antagonized by neostigmine 0.05 mg/kg and glycopyrrolate 0.01 mg/kg under the guidance of peripheral NMT monitoring. Tracheal extubation was performed after confirming sufficient recovery (train-of-four ratio greater than 90%; BIS greater than 80, ability to open the eyes, ability to obey the anesthesiologist’s verbal commands, and ability to maintain a regular breathing pattern). The patient was then transferred to the postanesthesia care unit. After the confirmation of anesthesia recovery, the patient was transferred to the general ward. The postoperative care in general ward was managed by the orthopedic surgeon with institutional protocol.

**Measurements**

All data were measured and recorded by one trained observer who did not participate in patient care. The measured parameters were as follows: (1) MAP (mmHg), HR (beats/min), and CVP (mmHg) derived from an invasive systemic arterial pressure monitoring device and central venous catheter; (2) cardiac index (l · min⁻¹ · m⁻²) and SVV (%) derived from a NICOM device; and (3) PIP (cm H₂O) and mean inspiratory pressure (P mean' cm H₂O) derived from the monitoring system attached to a mechanical ventilator. The parameters were measured after anesthesia induction in the supine position (T₀), 5 min after the patient was changed from the supine to the prone position (T₁), at the time of skin closure after the end of the main surgical procedure (T₂), and 5 min after the patient was changed from the prone to the supine position (T₃). PaO₂ (mmHg) and arterial partial pressure of carbon dioxide (PaCO₂, mmHg), hemoglobin (g/dl), and hematocrit (%) were measured by arterial blood gas analysis, and the PaO₂/FIO₂ ratio was calculated and recorded at the same time points. The amount of intraoperative surgical bleeding was recorded at the end of the surgery by measuring the total amount of blood collected in the suction bottle, less the lavage fluid volume used for wound irrigation. In addition, the surgical gauze was weighed before and after use. Intraoperative fluid administration (ml), urine output (ml), and intraoperative transfusion requirement were checked at the end of the surgical procedure. Postoperative hemoglobin and hematocrit levels were checked after arrival at general ward. The amount of postoperative bleeding was recorded every 24 h until postoperative 72 h by checking the closed wound drainage system (EZ-VAC®; e-G Medisys, Korea). At the same time, postoperative transfusion requirement was assessed.

**Statistics**

The primary outcome variable was the amount of intraoperative surgical bleeding. The intraoperative surgical bleeding was 370 ± 206 ml from the pilot study, with 10 patients undergoing the VCV mode. A minimum detected difference of 50% (approximately 185 ml) between the groups was considered clinically significant. A sample size of 28 in each group was calculated to be appropriate to achieve a power of 0.9 and an α value of 0.05. The secondary outcome variable was the total amount of postoperative bleeding until 24 and 72 h postoperatively. By applying the same method of sample size determination for the amount of postoperative bleeding until 24 and 72 h postoperatively (the pilot study showed values of 660 ± 367 ml and 894 ± 486 ml, respectively), sample sizes of 28 and 26 in the respective groups were calculated. Statistical analyses were conducted using SigmaStat software (version 3.1; SYSTAT Software, USA). Continuous variables were analyzed using Student’s t test after the normality test (Kolmogorov–Smirnov method) or the Mann–Whitney rank sum test or two-way repeated-measures ANOVA with Bonferroni method as a post hoc test was used for intergroup comparisons. One-way repeated-measures ANOVA with the Bonferroni method or Friedman test was used for intragroup comparisons. Categorical variables were analyzed using a chi-square test. Data are expressed as the numbers of patients, and means ± SD or medians (25 to 75%, interquartile range). A P value less than 0.05 was considered to indicate statistical significance.

**Results**

During the study, 122 PLIFs were performed, and 56 patients were eligible for the study. Sixty-six of 122 were excluded: 23 for refusal to participate in the study; 18 for previous respiratory disease; 12 for preoperative dysrhythmia; 9 for re-operation; and 4 for instrumental error. Therefore, a total of 28 patients were included in each group (fig. 1). The study was terminated once the planned sample size was attained. No harmful results or unintended events due to the investigation occurred in the study group patients. The patients’ demographic and preoperative coagulation profiles were similar (table 1).

On comparing the hemodynamic and respiratory variables between the two groups, it was found that only the PIP values at every measuring point in the PCV group were significantly lower than those in the VCV group (P < 0.001 for all comparisons; table 2). MAP, HR, SVV, tidal volume,
respiratory rate, the PaO2/FIO2 ratio, and PaCO2 were not different within each group. CVP values in the prone position (T1 and T2) in both groups were significantly higher than those in the supine position (T0 and T3) (P < 0.05 for all comparisons). Cardiac index values in the prone position (T1 and T2) in both groups were significantly lower than those in the supine position (T0 and T3) (P < 0.05 for all comparisons). PIP values at T1, T2, and T3 in both groups were significantly higher than those at T0 (P < 0.05 for all comparisons), and PIP values at T2 in the VCV group were significantly higher than those at T1 (P < 0.05). Pmean values at T2 and T3 in the PCV group were significantly higher than those at T0 (P < 0.05 for all comparisons). Hemoglobin and hematocrit at T2 and T3 in both groups were significantly lower than those at T0 and T1 (P < 0.001 for all comparisons).

The amount of intraoperative surgical bleeding in the PCV group was significantly less than that in the VCV group (253.0 [179.0 to 316.5] ml in the PCV group vs. 382.5 [328.0 to 489.5] ml in the VCV group, difference: 168.7 [95% CI, 94.7 to 243.2], P < 0.001; fig. 2). The amount of postoperative bleeding for 24 and 72 h was not different between the groups (407.3 ± 187.4 ml in the PCV group vs. 508.7 ± 299.4 ml in the VCV group for 24 h postoperatively, difference: 101.4 [95% CI, −32.0 to 235.8], P = 0.14; fig. 3A, 585.0 [422.5 to 810.0] ml in the PCV group vs. 637.5 [425.0 to 1,027.5] ml in the VCV group for 72 h postoperatively, difference: 134.1 [95% CI, −56.5 to 324.7], P = 0.34; fig. 3B). The transfusion requirements for intraoperative and postoperative 72 h were not different between the groups. However, the postoperative transfusion requirement for 24 h in the PCV group was significantly less than that in the VCV group (0.0 [0.0 to 0.0] ml in the PCV group vs. 0.0 [0.0 to 500.0] ml in the VCV group, difference: 151.4

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**Table 1. Demographic and Preoperative Coagulation Profiles**

<table>
<thead>
<tr>
<th></th>
<th>PCV Group (n = 28)</th>
<th>VCV Group (n = 28)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yr)</td>
<td>64 ± 13</td>
<td>66 ± 9</td>
<td>0.49</td>
</tr>
<tr>
<td>Sex (male/female)</td>
<td>9/19</td>
<td>8/20</td>
<td>0.77</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>156.7 ± 7.7</td>
<td>156.6 ± 6.8</td>
<td>0.97</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>61.2 ± 12.5</td>
<td>63.7 ± 8.5</td>
<td>0.40</td>
</tr>
<tr>
<td>BMI</td>
<td>24.8 ± 3.3</td>
<td>26.0 ± 3.7</td>
<td>0.19</td>
</tr>
<tr>
<td>Surgical procedure</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 level/3 level</td>
<td>20/8</td>
<td>21/7</td>
<td>0.76</td>
</tr>
<tr>
<td>Coagulation profiles</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PT (s)</td>
<td>12.3 ± 0.7</td>
<td>12.3 ± 0.6</td>
<td>0.89</td>
</tr>
<tr>
<td>aPTT (s)</td>
<td>33.9 ± 3.3</td>
<td>33.3 ± 3.5</td>
<td>0.52</td>
</tr>
<tr>
<td>PLT (10^3/μl)</td>
<td>254 ± 65</td>
<td>243 ± 54</td>
<td>0.51</td>
</tr>
</tbody>
</table>

Data are expressed as mean ± SD.

aPTT = activated partial thromboplastin time; BMI = body mass index; PCV = pressure-controlled ventilation; PLT = platelet counts; PT = prothrombin time; VCV = volume-controlled ventilation.
### Table 2. Intraoperative Hemodynamic and Respiratory Variables

<table>
<thead>
<tr>
<th></th>
<th>PCV Group (n = 28)</th>
<th>VCV Group (n = 28)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>T0</td>
<td>T1</td>
</tr>
<tr>
<td>MAP (mmHg)</td>
<td>76.3±6.7</td>
<td>77.5±6.2</td>
</tr>
<tr>
<td>HR (beats/min)</td>
<td>67.3±11.3</td>
<td>63.3±9.4</td>
</tr>
<tr>
<td>CVP (mmHg)</td>
<td>3.7±2.4</td>
<td>8.9±3.1*</td>
</tr>
<tr>
<td>Cardiac index (l·min⁻¹·m⁻²)</td>
<td>2.5±0.5</td>
<td>2.0±0.5*</td>
</tr>
<tr>
<td>SVV (%)</td>
<td>12.8±4.0</td>
<td>13.6±3.3</td>
</tr>
<tr>
<td>Tidal volume (ml)</td>
<td>417±53</td>
<td>416±53</td>
</tr>
<tr>
<td>RR (times/min)</td>
<td>11±2</td>
<td>11±2</td>
</tr>
<tr>
<td>PIP (cm H₂O)</td>
<td>13.5 (13.0–16.0)§</td>
<td>15.5 (14.0–17.0)§</td>
</tr>
<tr>
<td>Pmean (cm H₂O)</td>
<td>7.0 (7.0–8.0)</td>
<td>7.5 (7.0–8.0)</td>
</tr>
<tr>
<td>PaCO₂/FIO₂ ratio (mmHg)§</td>
<td>465.2±109.4</td>
<td>496.8±75.3</td>
</tr>
<tr>
<td>PaCO₂ (mmHg)</td>
<td>35.3±3.0</td>
<td>352.2±2.2</td>
</tr>
<tr>
<td>Hemoglobin (g/dl)</td>
<td>11.9±1.3</td>
<td>11.6±1.3</td>
</tr>
<tr>
<td>Hematocrit (%)</td>
<td>35.6±3.9</td>
<td>34.7±3.9</td>
</tr>
</tbody>
</table>

Data are expressed as mean ± SD or median (25–75% interquartile range).

*P < 0.05 compared with after anaesthesia induction in the supine position (T0). †P < 0.05 compared with 5 min after the patient changed from the supine to the prone position (T1). ‡P < 0.05 compared with at the time of skin closure after the main surgical procedure (T2). §P < 0.05 compared with the volume-controlled ventilation (VCV) group at each measured point.¶ No positive end-expiratory pressure and FIO₂ 0.4.

CVP = central venous pressure; FIO₂ = fraction of inspired oxygen; HR = heart rate; MAP = mean arterial blood pressure; PaCO₂ = arterial partial pressures of carbon dioxide; PaO₂ = arterial partial pressures of oxygen; PIP = peak inspiratory pressure; PCV = pressure-controlled ventilation; Pmean = mean inspiratory pressure; RR = respiratory rate; SVV = stroke volume variation; T3 = 5 min after the patient changed from the prone to the supine position.
Ventilation Mode for Lumbar Interbody Fusion Surgery

During postoperative 24 h, the transfusion incidence was lower in the PCV group than that in the VCV group (6 of 28 in the PCV group vs. 13 of 28 in the VCV group, \( P = 0.048 \). Postoperative hemoglobin and hematocrit in the PCV group were significantly higher than those in the VCV group (11.1 ± 1.2 g/dl in the PCV group vs. 10.6 ± 0.7 g/dl in the VCV group for hemoglobin, difference: 0.5 [95% CI, 0.1 to 1.1], \( P = 0.04 \), 32.6 ± 3.3% in the PCV group vs. 31.0 ± 2.3% in the VCV group for hematocrit, difference: 1.6 [95% CI, 0.5 to 3.1], \( P = 0.04 \), respectively). Intraoperative fluid administration, urine output, use of vasopressor, and operation and anesthesia durations were similar in the two groups (table 4).

Discussion

Our results show that the amount of intraoperative surgical bleeding in the PCV group was less than that in the VCV group in patients undergoing PLIF in the prone position for approximately 3.5 h. Although the difference in intraoperative surgical bleeding between the two groups was less than 50% of our hypothesis, it was statistically significant. We expected that the 50% reduction in intraoperative surgical bleeding would be associated with a reduced transfusion requirement. Although there were no differences between the groups in the intraoperative transfusion requirement and transfusion incidence with intraoperative hemoglobin and hematocrit levels, the smaller postoperative transfusion requirement and transfusion incidence for the first 24 h, and higher levels of postoperative hemoglobin and hematocrit in the PCV group than those in the VCV group might have

Fig. 2. Comparison of intraoperative surgical bleeding. All data were included in the analysis. Box plot indicates median, 253.0 (interquartile range, 179.0 to 316.5) ml in the pressure-controlled ventilation (PCV) group versus 382.5 (328.0–489.5) ml in the volume-controlled ventilation (VCV) group. Error bar indicates maximum and minimum values excluding outlier (maximum 424 ml and minimum 212 ml in the PCV group, maximum 704 ml and minimum 168 ml in the VCV group). The amount of intraoperative surgical bleeding in the PCV group is less than that in the VCV group \( (P < 0.001) \). Empty dot is outlier.

[95% CI, 49.7 to 253.2], \( P = 0.04 \); table 3). The transfusion incidence for intraoperative period and postoperative 72 h was not different between the two groups (6 of 28 in the PCV group vs. 8 of 28 in the VCV group during intraoperative period, \( P = 0.54 \); 10 of 28 in the PCV group vs. 13 of 28 in the VCV group during postoperative 72 h, \( P = 0.42 \)).

Fig. 3. (A) Comparison of postoperative bleeding for 24 h. All data were included in the analysis. Box plot indicates mean ± SD, 407.3 ± 187.4 ml in the pressure-controlled ventilation (PCV) group versus 508.7 ± 299.4 ml in the volume-controlled ventilation (VCV) group. Error bar indicates maximum and minimum values excluding outlier (maximum 750 ml and minimum 110 ml in the PCV group, maximum 970 ml and minimum 110 ml in the VCV group). There is no difference between the groups. Empty dot is outlier. (B) Comparison of postoperative bleeding for 72 h. Box plot indicates median, 585.0 (interquartile range, 422.5–810.0) ml in the PCV group versus 637.5 (425.0–1,027.5) ml in the VCV group. Error bar indicates maximum and minimum values excluding outlier (maximum 1,071 ml and minimum 175 mL in the PCV group, maximum 1,890 ml and minimum 118 ml in the VCV group). There is no difference between the groups.
been affected by the smaller intraoperative surgical bleeding in the PCV group.

Despite that the amount of intraoperative surgical bleeding was different between the groups, no differences in hemoglobin or hematocrit levels were observed between the groups at any of the measuring points, suggesting that hemoglobin and hematocrit are not good indicators of acute intraoperative bleeding due to various factors, such as fluid shift.18

There were no differences in postoperative bleeding at 24 and 72 h between the two groups, but the measurement of postoperative bleeding until 24 h was performed to determine the effect of mechanical ventilation mode on postoperative bleeding. Because the equipment for postoperative drainage was usually removed 72 h after the surgical procedure, the amount of postoperative bleeding until 72 h was recorded.

The lower intraoperative surgical bleeding in the PCV group might be associated with the lower PIP compared with the VCV group because the other hemodynamic and respiratory variables were not different between the two groups. In this study, when the tidal volume is maintained at the same level, PIP in the PCV mode is lower than that in the VCV mode. This finding was due to the specific features of the PCV mode: a maximal pressure gradient between the driving pressure and alveolar pressure at the beginning of inspiration and the decelerating pattern of inspiratory flow.10,15,19,20 In the VCV mode, ventilation was continuously supplied regardless of PIP to maintain the preset tidal volume so that PIP would be higher than that in the PCV mode.21 A higher PIP could worsen IVC compression and spinal venous engorgement. In addition, when external pressure due to surgical manipulation is applied, PIP in the VCV mode would be higher; therefore, the effects on IVC compression and spinal venous engorgement might be greater. The amount of postoperative bleeding until 24 and 72 h did not differ between the two groups. These results also suggested that the difference in PIP values between the two groups affected the amount of intraoperative surgical bleeding. Koh et al.22 reported a correlation between increased airway pressure caused by patients’ change of position from supine to prone and intraoperative surgical blood loss. The VCV group, which had higher airway pressure in our study, also had more intraoperative surgical bleeding. In this study, the difference in intraoperative surgical bleeding was relatively small but significant, which may be associated with the small surgery (PLIF 2 or 3 level). The results are meaningful, despite the small sample size of 28 patients in each group. These results were achieved because the study was conducted by one surgeon who performed similar surgeries on patients with similar status. If our study was performed in a much larger surgery with more bleeding, the difference in intraoperative surgical bleeding would have been greater. In these cases, our study results would be useful with other modalities, such as deliberate hypotension or use of antifibrinolytics, to reduce surgical bleeding.

On comparing the hemodynamic parameters within each group, it was found that CVP was higher and cardiac index was lower in the prone position (T1, T2) than in the supine position (T0, T3) regardless of the group. These results indicated that the venous return to the heart would be decreased in the prone position despite use of various methods to prevent it, which is consistent with previous reports.23,24 The lower cardiac index during the prone position may be associated with the measuring device because NICOM calculates the cardiac index using the principle of bioreactance. However, the trends in both groups were similar, and the difference would be limited. During (T1 and T2) and after the surgical procedure (T3), PIP in both groups was higher than that after anesthesia induction and before the surgical procedure (T0). These higher PIP values might be associated with factors related to anesthesia, such as atelectasis, increased dead spaces, an intrapulmonary shunt, and a ventilation/pressure/flow mismatch.

### Table 3. Perioperative Transfusion Requirements

<table>
<thead>
<tr>
<th>Transfusion (ml)</th>
<th>PCV Group</th>
<th>VCV Group</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intraoperative</td>
<td>0.0 (0.0–0.0)</td>
<td>0.0 (0.0–300.0)</td>
<td>0.66</td>
</tr>
<tr>
<td>Postoperative 24 h</td>
<td>0.0 (0.0–250.0)</td>
<td>0.0 (0.0–500.0)</td>
<td>0.21</td>
</tr>
<tr>
<td>Postoperative 72 h</td>
<td>0.0 (0.0–250.0)</td>
<td>0.0 (0.0–500.0)</td>
<td>0.21</td>
</tr>
</tbody>
</table>

Data are expressed as median (25–75% interquartile range).

*Vasopressor is phenylephrine.

### Table 4. Intraoperative Parameters

<table>
<thead>
<tr>
<th>Fluid administration (ml)</th>
<th>PCV Group</th>
<th>VCV Group</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crystallloid</td>
<td>637.5 ± 216.3</td>
<td>582.1 ± 286.8</td>
<td>0.42</td>
</tr>
<tr>
<td>Colloid</td>
<td>500.0 (450.0–650.0)</td>
<td>500.0 (500.0–800.0)</td>
<td>0.68</td>
</tr>
<tr>
<td>Urine output (ml)</td>
<td>240.0 (225.0–550.0)</td>
<td>243.0 (200.0–425.0)</td>
<td>0.07</td>
</tr>
<tr>
<td>Use of vasopressor (n, %)*</td>
<td>5/28 (18%)</td>
<td>5/28 (18%)</td>
<td>1.00</td>
</tr>
<tr>
<td>Operation duration (min)</td>
<td>155.9 ± 35.7</td>
<td>156.8 ± 33.3</td>
<td>0.94</td>
</tr>
<tr>
<td>Anesthesia duration (min)</td>
<td>204.5 ± 37.9</td>
<td>205.2 ± 39.8</td>
<td>0.95</td>
</tr>
</tbody>
</table>

Data are expressed as mean ± SD or median (25–75% interquartile range).

*Vasopressor is phenylephrine.
perfusion mismatch, as well as the patient’s position and surgical manipulation.25,26

Some limitations of this study should be discussed. First, PIP does not reflect precise alveolar pressure.27,28 To determine the exact effects and degree of lung expansion during IVC compression and spinal venous engorgement, exact alveolar and pleural pressures should be obtained regardless of the patient’s position. Pleural pressure is reflected by esophageal pressure. We did not measure esophageal pressure because the correct balloon position could not be confirmed under anesthesia in the prone position on a Wilson frame. Mediastinal artifacts also have to be considered. However, esophageal pressure was influenced by abdominal contents in the prone position in both groups. Therefore, esophageal pressure may have been similar in the groups. Moreover, alveolar pressure is usually measured using plateau pressure. PCV mode with identical tidal volume results in lower PIP and lower plateau pressure compared with those of the VCV mode.15,19,29 Although plateau pressure was not measured in this study, PIP in the PCV group at all time points was lower than that in the VCV group. Therefore, plateau pressure in the PCV group may also have been lower at all time points than that in the VCV group. Finally, the difference in PIP between the two groups may have been associated with differences in intraoperative surgical bleeding. Second, the conditions of the patients’ respiratory system might have affected the results. Since the precise alveolar pressure was not measured, several factors—such as airway resistance, inspiratory flow, lung compliance, and external pressure due to surgical manipulation—could have affected the magnitude of PIP that is associated with IVC compression and spinal venous engorgement. However, the patients with previous respiratory disease or a PaO2/FIO2 ratio less than 300 mmHg by arterial blood gas analysis before anesthesia induction were excluded from the current study, and the surgical procedures were performed by a single surgical team. Therefore, the effects of several factors on PIP should have been similar. Third, the bias of single blinding may have affected the results. Actually, bias could only have occurred by the attending anesthesiologist. However, the anesthetic regimen was standardized to the study protocol. Moreover, anesthetic factors affecting surgical bleeding would be limited in patients with normal coagulation profiles. Additionally, the surgeon was blinded to the patients’ group allocation. Therefore, the effect of the single-blinded study on the results would be limited.

In conclusion, the intraoperative ventilation mode of PCV decreased intraoperative surgical bleeding in patients undergoing PLIF in the prone position, which might be related to the lower intraoperative PIP compared with the VCV mode.

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Competing Interests
The authors declare no competing interests.

Reproducible Science
Full protocol available from Dr. Seong-Hyop Kim: yshkim75@daum.net. Raw data available from Dr. Seong-Hyop Kim: yshkim75@daum.net.

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References