

Retrospective analysis of ventilation strategies for blunt pulmonary trauma patients: comparing the effectiveness of synchronized intermittent mandatory ventilation, continuous positive airway pressure, and pressure-controlled ventilation

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Abstract

Objective: To compare the efficacy of various ventilation approaches to the treatment of patient with patients with severe blunt chest trauma.

Method: The retrospective study was conducted at the Cardiorespiratory Syndrome Ward of the First People's Hospital of Linping District, Hangzhou, China, and comprised data of patients with blunt pulmonary trauma admitted from December 2019 to February 2023. The patients were divided into three groups based on the ventilation support mode. Group 1 received synchronised intermittent mandatory ventilation + positive end-expiratory pressure, Group 2 received continuous positive airway pressure + pressure support ventilation, and Group 3 recieved pressure-controlled ventilation. Clinical curative effect, respiratory mode parameters, and blood gas analysis indicators of the groups were compared before and after the treatment. Data was analysd using SPSS 20.

Results: Of the 227 patients, 71(31.3%) were in Group A; 62(87.3%) males and 9(12.7%) females with mean age 69.6±5.9 years. There were 74(32.6%) patients in Group 2; 59(79.7%) males and 15(20.3%) females with mean age 71.2±6.2 years. In Group 3, there were 82(36.1%) patients; 61(74.4%) males and 21(25.6%) females with mean age 69.0±6.0 years ($p>0.05$). Most patients 146(64.32%) recovered with no significant differences in treatment effect across the groups ($p>0.05$). Group 2 showed significant differences in respiratory parameters and blood gas indicators compared to the other groups ($p<0.001$).

Conclusion: While all the three ventilation strategies had comparable treatment effect, continuous positive airway pressure + pressure support ventilation was associated with the most favourable respiratory parameters and blood gas analysis indicators.

Key Words: Pulmonary injuries, Ventilation techniques, Comparative effectiveness, Blood gas analysis. (JPMA 75: 601; 2025) DOI: <https://doi.org/10.47391/JPMA.21036>

Introduction

Pulmonary injuries may result from various incidents, such as blunt force, penetrating wounds, or explosive trauma, and present a significant challenge in terms of patient care.¹ The complexity of treating these patients often necessitates the involvement of multiple medical specialties and a variety of interventions to ensure effective respiratory support and to mitigate potential complications.¹ A crucial aspect of managing patients with pulmonary injuries is the implementation of appropriate ventilation techniques that play a vital role in improving clinical outcomes, minimising complications and promoting patient recovery.²

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Synchronised intermittent mandatory ventilation (SIMV), continuous positive airway pressure (CPAP) and pressure-controlled ventilation (PCV) are the three most frequently used ventilation methods in the treatment of pulmonary injury patients.^{3,4} These approaches aim at ensuring sufficient gas exchange, maintain ideal lung volume, and prevent lung damage caused by the mechanical forces of ventilation.³⁻⁵

SIMV is a form of mechanical ventilation that combines patient-initiated breaths with mandatory breaths³, thus improving the level of patient's comfort, and decreasing the effort of breathing. Positive end-expiratory pressure (PEEP), as an addition to SIMV, adds positive pressure at the end of expiration to prevent alveolar collapse, thereby increasing oxygenation and decreasing the risk of ventilator-induced lung injury.⁴ The combination of SIMV and PEEP is frequently used in treating pulmonary injury patients due to its ability to facilitate weaning from mechanical ventilation (MV) and to improve patient outcomes.

CPAP is a type of non-invasive ventilation that provides continuous positive airway pressure, preserving airway openness and enhancing gas exchange.⁶ This ventilation mode is commonly used in patients with acute respiratory failure, obstructive sleep apnoea and cardiogenic pulmonary oedema. When combined with pressure support ventilation (PSV), a ventilation method that supplements spontaneous breaths of the patient with pressure support, CPAP can be an effective strategy for managing pulmonary injury in patients who need respiratory support, but are not yet suitable candidates for invasive MV.⁶

PCV is an invasive MV mode in which the pressure applied to the airway remains constant during inspiration, while the tidal volume varies depending on the patient's lung compliance and resistance. This approach can offer benefits to patients with pulmonary injuries, as it may decrease the risk of barotrauma, reduce the likelihood of volutrauma, and optimise patient-ventilator synchrony. PCV has been used in various clinical settings, including acute respiratory distress syndrome (ARDS) and patients with increased airway resistance.⁷

Despite the frequent use of these ventilation approaches in the treatment of pulmonary injury patients, there is a lack of data comparing their effectiveness in terms of clinical outcomes, respiratory mode parameters, and blood gas analysis indicators. The current study was planned to fill the gap in literature by comparing the efficacy of various ventilation approaches to the treatment of pulmonary injuries in patients with severe blunt chest trauma.

Materials and Methods

The retrospective study was conducted in March 2023 at the Cardiorespiratory Syndrome Ward of the First People's Hospital of Linping District, Hangzhou, China, and comprised data of patients with blunt pulmonary trauma admitted from December 2019 to February 2023. The sample was raised using consecutive sampling technique. The patients were divided into three groups based on the ventilation support mode. Group 1 received SIMV + PEEP, Group 2 received CPAP + PSV, and Group 3 received PCV.

Blunt pulmonary trauma in the study was defined as lung injury resulting from non-penetrating trauma to the chest. This typically includes injuries sustained from high-impact events, such as motor vehicle collisions, falls from significant heights, or direct blows to the thoracic cavity. Patients eligible for inclusion were those who had a clinical and radiological diagnosis of blunt pulmonary trauma, as evidenced by chest X-ray (CXR) or computed tomography (CT) scan findings consistent with such

injuries. These findings could include, but were not limited to, pulmonary contusions, haemothorax, pneumothorax, or rib fractures indicative of blunt force impact. The diagnosis was confirmed by a team of experienced thoracic surgeons and radiologists. The patients included were aged ≥ 18 years, and were haemodynamically stable. Those excluded were patients with contraindications to any of the ventilation modes, failure to complete or respond to the consent form, and inability to participate in the awareness sessions due to cognitive impairment or severe mental health issues. Data was collected only for patients who had furnished written informed consent.

Other than demographic details, the study data included the time from trauma occurrence to medical treatment (hours), cause of injury, fracture type, treatment interventions, and treatment outcome. With respect to outcomes, 'recovery' meant patients demonstrating a marked improvement in respiratory parameters, resolution of acute respiratory distress symptoms, and stabilisation of vital signs to within normal limits. Patients in this category were typically able to resume normal or near-normal activities without significant respiratory compromise. 'Average' effect referred to patients who experienced some improvement in their condition, but did not reach the level of 'recovery'. These patients showed moderate improvement in respiratory parameters and symptoms, but still required some form of ongoing medical support or intervention. 'Invalid response' referred to patients who showed no significant improvement or worsening of their condition post-treatment.

Baseline and post-treatment comparisons were noted for partial pressure of oxygen (PaO₂), partial pressure of carbon dioxide (PaCO₂), oxygen saturation (SaO₂), and ratio of PaO₂ to fraction of expired oxygen (FiO₂) (PaO₂/FiO₂). Baseline measurements were taken immediately upon the patient's admission to the ward, while post-treatment measurements were determined based on specific clinical criterion, rather than at a fixed time point. The criterion included the resolution of acute respiratory distress symptoms, stabilisation of vital signs, and the attending physician's assessment that the patient had responded to the ventilation strategy. Generally, these measurements were taken within 24-48 hours after the initiation of the treatment, although the exact timing varied according to the patient's individual response to therapy.

Each ventilation mode was used in line with the standard clinical protocols, and adjusted to meet individual respiratory needs of the patient. Ventilator settings,

including the respiratory rate, tidal volume, inspiratory time and pressure levels, were monitored and adjusted by the attending physicians and respiratory therapists throughout the treatment.

Intergroup comparisons were conducted at two distinct points. The first comparison was based on respiratory parameters and patient responses immediately following the initial stabilisation using the assigned ventilation mode. The primary aim was to assess how effectively each mode supported the patient's oxygenation and ventilation during the early stages of treatment. The second point of comparison involved evaluating the effectiveness of the ventilation modes during the weaning phase, which was defined as the period when clinical parameters indicated a readiness to begin reducing ventilatory support, and the patient demonstrated sustained respiratory stability.

To minimise variability in response to ventilation, all the patients received standardised sedation protocols that were tailored to their clinical condition and ventilation requirements. The patients were administered sedatives according to institutional protocols aimed at maintaining a Richmond Agitation-Sedation Scale (RASS)⁸ target ranging between -2 and -3, indicating light to moderate sedation. For patients managed with CPAP + PSV, lighter sedation levels were employed, sufficient to ensure patient-ventilator synchrony while maintaining spontaneous breathing capability. Besides, the use of neuromuscular blocking agents (paralytics) was primarily restricted to patients undergoing SIMV + PEEP or PCV modes during the initial stabilisation phase, particularly if patient-ventilator dyssynchrony posed a significant risk of barotrauma. Paralytic agents were typically avoided during the weaning phase to facilitate assessment of respiratory function and ensure spontaneous respiratory effort, especially with CPAP + PSV.

Blood gas analysis was performed using arterial blood samples drawn from the patients at baseline before the initiation of ventilation treatment, and post-treatment. The samples were immediately analysed using a blood gas analyzer following standard operating procedures.

PaO₂ represented the concentration of oxygen dissolved in arterial blood, providing an indication of how efficiently oxygen was being transferred from the lungs to the bloodstream.⁹ PaCO₂ measured the level of CO₂ dissolved in arterial blood, offering insight into the efficiency of the lungs' ability to expel CO₂.¹⁰ SaO₂ was the proportion of haemoglobin (Hb) in the arterial blood that was carrying oxygen, which reflected the blood's overall capacity to deliver oxygen to body tissues.¹¹ The

oxygenation index indicated the ratio of PaO₂ to FiO₂, helping assess the degree of lung injury and the effectiveness of the administered oxygen therapy.¹²

Respiratory parameters were continuously monitored and logged during treatment via the ventilator's internal monitoring systems. The parameters analysed included MV, which represented duration in minutes to help assess the total volume of air moved in and out of the lungs per minute, providing a measure of the overall effectiveness of ventilation.¹³ Peak inspiratory pressure (PIP) was the maximum pressure reached during inspiration, which reflected airway resistance and the compliance of the respiratory system.¹⁴

Data was stored in Excel and analysed using SPSS 20. Continuous variables were reported as mean +/- standard deviation, or as median with interquartile range (IQR), depending on the normality of distribution, which was assessed using the Shapiro-Wilk test. The statistical significance of differences in continuous variables among the groups was assessed using one-way analysis of variance (ANOVA) for normally distributed data. Bonferroni post-hoc test was used for pairwise comparisons. For continuous variables that were not normally distributed, Kruskal-Wallis test/Mann Whitney U/Wilcoxon rank sum test was used to compare median values. Categorical variables were reported as frequencies and percentages, and intergroup differences were assessed using chi-square or Fisher's exact test, as appropriate. Two-sided $p < 0.05$ was considered statistically significant.

Results

Of the 227 patients, 71(31.3%) were in Group A; 62(87.3%) males and 9(12.7%) females with mean age 69.6±5.9 years. There were 74(32.6%) patients in Group 2; 59(79.7%) males and 15(20.3%) females with mean age 71.2±6.2 years. In Group 3, there were 82(36.1%) patients; 61(74.4%) males and 21(25.6%) females with mean age 69.0±6.0 years ($p > 0.05$). Most patients 146(64.32%) recovered with no significant differences in treatment effect across the groups ($p > 0.05$) There were no significant differences among the groups related to median time from trauma occurrence to medical treatment initiation, cause of injury, fracture type, and treatment strategies (Table 1).

With regard to respiratory parameters, Group 1 had the lowest mean MV and highest PIP values, while Group 2 had the highest MV and lowest PIP values, with Group 3 showing the intermediate values (Table 2).

In terms of SaO₂, Group 2 presented the highest mean

Table-1: Characteristics of the patients (n=227).

Characteristics	Group 1 (SIMV+PEEP) (n=71)	Group 2 (CPAP+PSV) (n=74)	Group 3 (PCV) (n=82)	Total	P-value
Age (Mean ± SD)	69.6 ± 5.9	71.2 ± 6.2	69.0 ± 6.0	227	0.06
Gender (Male/Female)	62/9 (87.32%/12.68%)	59/15 (79.73%/20.27%)	61/21 (74.39%/25.61%)	182/45	0.99
Time to Treatment Initiation in hours (Median [interquartile range (IQR)])	7 [4, 9]	7 [5, 14]	7 [5, 15]	227	0.93
Causes of Injury					
Traffic accident	55 (29.41%)	62 (33.16%)	70 (37.43%)	187	0.93
Injured by smashing	8 (44.44%)	5 (27.78%)	5 (27.78%)	18	
Fall and hurt oneself	5 (41.67%)	4 (33.33%)	3 (25.00%)	12	
Squeezed injury	2 (33.33%)	2 (33.33%)	2 (33.33%)	6	
Other	1 (25.00%)	1 (25.00%)	2 (50.00%)	4	
Fracture Type					
Bilateral rib fractures	43 (33.33%)	43 (33.33%)	43 (33.33%)	129	0.78
Unilateral hemopneumothorax	12 (35.29%)	9 (26.47%)	13 (38.24%)	34	
Bilateral hemopneumothorax	6 (23.08%)	9 (34.62%)	11 (42.31%)	26	
Flail chest	4 (19.05%)	9 (42.86%)	8 (38.10%)	21	
Lung contusion and laceration	2 (28.57%)	3 (42.86%)	2 (28.57%)	7	
Compound injury	4 (40.00%)	1 (10.00%)	5 (50.00%)	10	
Thoracotomy Exploration					
Thoracotomy exploration	60 (31.25%)	64 (33.33%)	68 (35.42%)	192	0.91
Laparotomy exploration	9 (37.50%)	6 (25.00%)	9 (37.50%)	24	
Closed thoracic drainage	2 (22.22%)	3 (33.33%)	4 (44.44%)	9	
Removal of epidural hematoma	0 (0.00%)	1 (50.00%)	1 (50.00%)	2	
Treatment Effect					
Recovery	48 (67.61%)	47 (63.51%)	51 (62.20%)	146	0.58
The effect is average	22 (30.99%)	25 (33.78%)	31 (37.80%)	78	

SIMV: Synchronised intermittent mandatory ventilation, PEEP: Positive end-expiratory pressure, CPAP: Continuous positive airway pressure, PSV: Pressure support ventilation, PCV: Pressure-controlled ventilation.

Table-2: Comparison of the respiratory parameters among the groups after the initiation of treatment

Respiratory Parameter	Group 1 (SIMV+PEEP)	Group 2 (CPAP+PSV)	Group 3 (PCV)	p Value
MV (L/min)	15.46 ± 0.69	17.30 ± 0.77	16.66 ± 0.59	<0.001
PIP (kPa)	4.52 ± 0.31	3.33 ± 0.21	4.22 ± 0.31	<0.001
SaO ₂ (%)	94.86 ± 3.43	97.28 ± 2.65	93.32 ± 3.85	<0.001
PaO ₂ (kPa)	7.33 ± 0.74	8.59 ± 0.77	7.77 ± 0.85	<0.001
PaCO ₂ (kPa)	6.10 ± 0.35	5.05 ± 0.55	5.85 ± 0.50	<0.001

NPC: Nasopalatine Canal, SD: Standard deviation, Buccal Bone 1: Buccal bone width at level of nasal spine, Buccal Bone 2: Buccal bone width at mid-point of Buccal Bone 1 and Buccal Bone 3, Buccal Bone 3: Buccal bone width at the most oral end: from the most anteroinferior aspect of buccal cortical plate.

Table-3: Comparison of blood gas parameters among the groups.

Blood gas Parameter	Group 1 (SIMV+PEEP) (Before treatment)	Group 1 (SIMV+PEEP) (After treatment)	Group 2 (CPAP+PSV) (Before treatment)	Group 2 (CPAP+PSV) (After treatment)	Group 3 (PCV) (Before treatment)	Group 3 (PCV) (After treatment)	Before treatment difference (P-Value)	After treatment difference (P-Value)
PaO ₂ (kPa)	8.20 ± 0.52	9.52 ± 0.63	7.99 ± 0.62	9.80 ± 0.80	8.10 ± 0.68	9.63 ± 0.72	0.13	.06
PaO ₂ (kPa)	8.20 ± 0.52	9.52 ± 0.63	7.99 ± 0.62	9.80 ± 0.80	8.10 ± 0.68	9.63 ± 0.72	0.13	0.06
PaCO ₂ (kPa)	3.61 ± 0.52	3.94 ± 0.56	3.69 ± 0.54	4.07 ± 0.57	3.65 ± 0.58	3.98 ± 0.61	0.68	0.35
SaO ₂ (%)	88.45 ± 4.77	93.59 ± 3.28	89.30 ± 5.09	94.69 ± 3.51	90.23 ± 4.06	94.07 ± 3.75	0.06	0.17
PaO ₂ /FiO ₂ (kPa)	174.21 ± 7.06	201.70 ± 8.90	173.86 ± 6.95	214.74 ± 10.15	173.38 ± 7.23	208.41 ± 9.93	0.76	<0.001

SIMV: Synchronised intermittent mandatory ventilation, PEEP: Positive end-expiratory pressure, CPAP: Continuous positive airway pressure, PSV: Pressure support ventilation, PCV: Pressure-controlled ventilation, SaO₂: Oxygen saturation, PaO₂: Partial pressure of oxygen, PaCO₂: Partial pressure of carbon dioxide, FiO₂: Fraction of expired oxygen.

value, followed by Group 1 and Group 3, while PaO₂ was highest in Group 2, followed by Group 3 and Group 1 (Table 2). PaCO₂ was the lowest in Group 2 and the highest in Group 1, with Group 3 having the intermediate value (Table 2).

There were no significant differences in PaO₂, SaO₂ and PaCO₂ levels among the groups when baseline values were compared to post-treatment values (p>0.05). After the treatment, significant differences were observed in PaO₂/FiO₂ among the groups (p<0.001), with Group 2 having the highest values (Table 3).

Discussion

The main finding of the current study is the significant differences in respiratory parameters among the three groups. Specifically, Group 2 (CPAP+PSV) demonstrated the highest mean values for MV, SaO₂ and PaO₂, while exhibiting the lowest mean value for PIP and PaCO₂. These findings suggest that CPAP + PSV could offer superior respiratory support for patients with severe blunt chest trauma compared to the other two ventilation strategies.

The improved respiratory parameters observed in Group 2 could be attributed to the unique characteristics of the CPAP + PSV ventilation strategy. CPAP maintains a constant positive airway pressure throughout the respiratory cycle, which helps prevent alveolar collapse, improve lung compliance, and enhance oxygenation.¹⁵ PSV, on the other hand, regulates patients' respiratory rate and tidal volume while providing pressure support during inspiration, resulting in reduced breathing effort.¹⁶ The combination of these two modes appears to provide better respiratory support than SIMV + PEEP or PCV alone in patients with severe blunt chest trauma.

Despite the significant differences in respiratory parameters, the overall treatment effect was similar in all the groups. This finding may be due to several factors. First, it was possible that the differences in respiratory parameters, while statistically significant, were not clinically relevant, resulting in similar treatment outcomes. Second, factors other than respiratory parameters, such as the patients' overall medical condition, the severity of their injuries, and the effectiveness of other treatments, may have influenced the treatment effect.^{17,18} The lack of significant differences in blood gas parameters before and after the treatment among the groups, except for PaO₂/FiO₂, further confirmed that the three ventilation strategies provided comparable treatment outcomes. However, the significantly higher mean PaO₂/FiO₂ values in Group 2 after the treatment indicated that CPAP + PSV may be more effective in improving oxygenation in patients with severe blunt chest trauma.

Another important aspect to consider was the potential role of nursing care in the management of patients with severe blunt chest trauma. High-quality nursing care is crucial for improving patient outcomes, particularly in those receiving MV.^{19,20} In the current study, all patients received standardised nursing care, including monitoring of vital signs, pain management, and the provision of chest physiotherapy, which may have contributed to the similar treatment effects observed among the groups.

However, different ventilation strategies may have varying impacts on the nursing workload and patient comfort, which were not assessed in the current study, which was a limitation. Future research should also investigate the effect of these ventilation strategies on nursing workload, patient comfort, and patient-reported outcomes to provide a more comprehensive understanding of their impact on the overall management of patients with severe blunt chest trauma.

Furthermore, the study did not evaluate the long-term outcomes of patients receiving the different ventilation strategies. While the short-term respiratory parameters and treatment effects were assessed, it is crucial to examine the potential long-term benefits or complications associated with each ventilation strategy, such as the risk of ventilator-associated pneumonia (VAP), chronic respiratory failure, or post-traumatic stress disorder (PTSD).²¹ This would have provided valuable insights into the potential long-term consequences of these strategies, and helped guide clinical decision-making.

Among the other limitations, the relatively small sample size may have reduced the statistical power of the study to detect differences in the treatment across the groups. The retrospective design inherently limited the ability to control for selection bias and confounding factors. Additionally, due to the retrospective design, the study was unable to ensure that the diagnosis of pulmonary contusion in patients was confirmed by a thorough physical examination, CXR or CT scan. That may explain lower than estimated rates of lung contusions reported in the study. The choice of ventilation strategy was based on clinical judgment and patient-specific needs, introducing variability that was challenging to account for the retrospective nature of the study. Additionally, due to the constraints of retrospective data-collection, some relevant clinical details, such as the exact criterion used for selecting a particular ventilation strategy, MV duration, sedation protocols, the timing of the post-treatment blood gas analysis relative to extubation were not uniformly available for all patients. These limitations should be considered when interpreting the current findings.

Despite the limitations, however, the findings provided valuable preliminary insights into the differences in respiratory parameters among the three ventilation strategies in patients with severe blunt chest trauma.

Prospective studies with randomised controlled designs would significantly enhance the ability to infer causality, and to control biases and confounding factors. Future

studies, ideally with a prospective design, should focus on categorising patients based on the invasiveness of ventilation (endotracheal intubation, tracheostomy, or non-invasive methods) and the severity of lung injury. Such data would allow for a more nuanced understanding of the relationship involving the method of ventilation, the extent of lung injury, and patient outcomes. Additionally, detailed documentation of clinical decision-making criteria for the selection of ventilation strategies would enable a more nuanced understanding of their effectiveness in specific patient populations. Research focussing on a more standardised approach to categorise and assess the severity of pulmonary injuries could also contribute to a clearer understanding of the relationship between injury severity and the success of different ventilation modalities. Future prospective studies should use standardised protocols for timing blood gas measurements, such as taking post-treatment samples at fixed time points. This would allow for a more precise comparison of respiratory parameters across the different ventilation strategies.

Conclusion

While SIMV + PEEP, CPAP + PSV and PCV provided adequate respiratory support in patients with severe blunt chest trauma, CPAP + PSV was associated with superior respiratory parameters. However, the overall treatment effect was similar among the three treatment groups, suggesting that factors other than respiratory parameters may be influencing the treatment outcomes.

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AUTHORS' CONTRIBUTIONS:

LW: Design, drafting and final approval.

YH & YL: Data acquisition, analysis, interpretation and final approval.