DOI: https://doi.org/10.70749/ijbr.v3i4.1078

INDUS JOURNAL OF BIOSCIENCE RESEARCH
https://induspublishers.com/IJBR
ISSN: 2960-2793/ 2960-2807

Comparing the Effect of Volume-controlled Ventilation and Synchronized Intermittent Mandatory Ventilation on Respiratory Parameters of Traumatic Brain Injury Patients

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ARTICLE INFO

Keywords

Volume-Controlled Ventilation, Synchronized Intermittent Mandatory Ventilation, Traumatic Brain Injury, Respiratory Parameters.

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Declaration

Authors' Contribution: All authors equally contributed to the study and approved the final manuscript.
Conflict of Interest: No conflict of interest.
Funding: No funding received by the authors.

Article History

Received: 14-01-2025 Revised: 20-03-2025
Accepted: 07-04-2025 Published: 21-04-2025

ABSTRACT

Introduction: Traumatic brain injury (TBI) often necessitates mechanical ventilation to support respiratory function. This study compares the outcomes of volume-controlled ventilation (VCV) and synchronized intermittent mandatory ventilation (SIMV) in TBI patients, focusing on respiratory and neurological outcomes. **Materials and Methods:** This study was conducted at Lady Reading Hospital in Peshawar, Pakistan from March 2024 to September 2024. A total of 100 TBI patients (50 VCV, 50 SIMV) were enrolled. Demographic data, including age, gender, BMI, smoking status, and comorbidities, were collected. Respiratory parameters (respiratory rate, tidal volume, PaO_2, $PaCO_2$, pH, SpO_2) were recorded at baseline and after 48 hours. Neurological outcomes were assessed using the Glasgow Coma Scale (GCS) at day 7. Statistical comparisons were made using t-tests and chi-square tests. **Results:** Demographic and clinical characteristics were similar between the VCV and SIMV groups. Baseline respiratory parameters showed no significant differences. After 48 hours, the VCV group had a lower respiratory rate (18.3 vs. 19.5 breaths/min, p = 0.03), higher PaO_2 (90.2 vs. 85.6 mmHg, p = 0.02), and more effective carbon dioxide elimination ($PaCO_2$ 37.0 vs. 39.1 mmHg, p = 0.01). Complications, such as ventilator-associated pneumonia, barotrauma, and oxygen toxicity, were comparable between groups. Neurological outcomes showed a trend toward improvement in the VCV group (48% vs. 34%, p = 0.14). **Conclusion:** VCV provided better respiratory outcomes than SIMV, with improved oxygenation and more efficient carbon dioxide elimination. Though both ventilation strategies had similar complication rates, VCV may offer a slight advantage in neurological recovery. Further research is needed to confirm these findings.

INTRODUCTION

About 10% of patients in Intensive Care Units (ICUs) require prolonged mechanical ventilation, and this group of patients allocates the most human and financial resources of the hospital. Mechanical ventilation is a complex process including interactions between pressure, flow, volume, and time. In a simple classification, ventilation modes are classified into pressure control ventilation, volume control ventilation, or both(1). In volume mode, regardless of the pressure and airway resistance, a certain amount of volume is delivered to the lungs which may cause damages due to pressure or pneumothorax. In contrast, pressure mode continues ventilation support to reach the predetermined pressure and prevents injuries caused by pressure; however, in the case of inappropriate volume, lungs may reach to the predetermined pressure too quickly, and the patient suffers from hypoventilation and respiratory acidosis(2–4). Each of pressure or volume modes has its own advantages. Accordingly, to take advantage of the benefits of both modes, manufacturing companies have decided to design modes which have two pressure and volume control components in combination(5).

In pressure regulated volume control (PRVC) mode which was introduced by Siemens Company, a certain volume is given to the patient. Thus, the device guarantees this volume by regulating pressure, i.e., the device may increase the pressure to achieve the desired volume(6,7). Advantages of this mode compared to the ventilation pattern with volume control are lower maximum inspiratory pressure, flow coordination of ventilation pattern, less manipulation of the device by operator, and automatic decease of ventilator support.

The clinical outcome of patients who have been treated by this mode has not been well examined(8–11). Therefore, this study was designed to compare two VC and synchronized intermittent mechanical ventilation (SIMV) modes in terms of sedation, ventilation weaning, and hemodynamic stability in patients with traumatic brain injury (TBI) admitted to ICU.

MATERIALS AND METHODS

A prospective, randomized controlled trial (RCT) was designed to evaluate and compare the outcomes of two different mechanical ventilation strategies, volume-controlled ventilation (VCV) and synchronized intermittent mandatory ventilation (SIMV), in patients with traumatic brain injury (TBI). This study aimed to assess the effectiveness of these two ventilation modes in terms of respiratory function and neurological recovery in TBI patients. The trial was conducted in the Intensive Care Units (ICUs) of Lady Reading Hospital in Peshawar, Pakistan from March 2024 to September 2024. The setting focused on patients diagnosed with severe TBI, all of whom required mechanical ventilation within 24 hours of hospital admission.

To determine the appropriate sample size for the study, Slovin's formula was used, which accounts for the margin of error in the sample size calculation. With a margin of error of 0.5 and a total population of 137, the calculated sample size was 100 patients. This sample size was sufficient to ensure robust statistical analysis and reliable results. A simple random sampling technique was employed to assign the patients to either the SIMV or VCV group, ensuring that each patient had an equal chance of being allocated to either group, minimizing selection bias.

The study was conducted over a period of four months. Inclusion criteria for the study were patients aged between 18 and 65 years, diagnosed with severe TBI, defined by a Glasgow Coma Scale (GCS) score of 8 or less, and those requiring mechanical ventilation within the first 24 hours of admission. Informed consent was obtained from the next of kin of the patients. Exclusion criteria were applied to patients who had preexisting neurological disorders, multi-organ failure, or those who were pregnant, as these factors could confound the results and interfere with the study's objectives.

Ethical considerations were a priority throughout the study. Informed consent was provided to the patients' families, ensuring that they understood the study's purpose, potential benefits, and their right to withdraw at any time without affecting the patient's treatment. Additionally, the study was approved by the Institutional Review Board (IRB) of Superior University to ensure that it adhered to ethical standards and protected the rights of all participants. Confidentiality was maintained by anonymizing the patient data and securely storing it in compliance with privacy laws.

Data was collected using a pre-structured questionnaire, which was adapted from previous studies to gather relevant demographic information and pulmonary function test results. The questionnaire included essential details such as age, gender, BMI, smoking status, and the patients' vital signs, as well as measures of pulmonary function like tidal volume, respiratory rate, and arterial blood gas parameters. The collected data were then analyzed using SPSS software. Continuous variables such as age and pulmonary function parameters were compared using t-tests or Mann-Whitney U tests, depending on the distribution of the data, while categorical variables like gender and smoking status were analyzed using chi-square tests. A p-value of less than 0.05 was considered statistically significant, meaning that any p-value below this threshold would indicate a meaningful difference between the two ventilation groups. This approach ensured that the results of the trial were valid and reliable, contributing to a better understanding of the optimal ventilation strategy for TBI patients.

RESULT

The demographic and clinical characteristics of patients in both the VCV and SIMV groups were generally comparable, with no statistically significant differences observed across variables. The mean age was similar between groups (VCV: 36.4 ± 12.5 years; SIMV: 37.2 ± 13.1 years, $p = 0.74$), and the gender distribution showed a predominance of males in both groups (VCV: 70%; SIMV: 66%, $p = 0.67$). The mean Glasgow Coma Scale (GCS) score on admission did not differ significantly (VCV: 7.8 ± 1.4; SIMV: 8.0 ± 1.6, $p = 0.45$), indicating a similar level of injury severity. Road traffic accidents were the most common cause of traumatic brain injury in both groups, followed by falls and assaults, with no significant differences in distribution ($p = 0.83$). Mean BMI values were nearly identical (VCV: 24.1 ± 3.2; SIMV: 24.5 ± 3.5, $p = 0.58$), and smoking status was balanced (VCV: 40% smokers; SIMV: 36% smokers, $p = 0.68$). Comorbidity profiles were also similar, with hypertension and diabetes present in both groups at comparable rates and over half of the patients in each group reporting no comorbid conditions ($p = 1$). These findings support the validity of comparisons between groups in subsequent outcome analyses.

Table 1

Demographic and Baseline Characteristics of TBI Patients by Ventilation Mode

Variable	VCV Group (n=50)	SIMV Group (n=50)	p-value
Age (years), Mean ± SD	36.4 ± 12.5	37.2 ± 13.1	0.74
Gender, n (%)			
- Male	35 (70%)	33 (66%)	0.67
- Female	15 (30%)	17 (34%)	
GCS on admission, Mean ± SD	7.8 ± 1.4	8.0 ± 1.6	0.45

Cause of Injury, n (%)			
- Road Traffic Accident	28 (56%)	30 (60%)	0.83
- Fall	14 (28%)	12 (24%)	
- Assault	8 (16%)	8 (16%)	
BMI (kg/m²), Mean ± SD	24.1 ± 3.2	24.5 ± 3.5	0.58
Smoking Status, n (%)			
- Current Smoker	20 (40%)	18 (36%)	0.68
- Non-Smoker	30 (60%)	32 (64%)	
Comorbidities, n (%)			
- Hypertension	12 (24%)	10 (20%)	0.63
- Diabetes Mellitus	9 (18%)	11 (22%)	0.61
- None	29 (58%)	29 (58%)	1

The analysis of respiratory parameters between the VCV and SIMV groups revealed no statistically significant differences, indicating that both ventilation modes maintained comparable respiratory function among traumatic brain injury patients. The mean respiratory rate was similar (VCV: 20.5 ± 3.1 breaths/min; SIMV: 20.1 ± 3.3 breaths/min, $p = 0.52$), as was tidal volume (VCV: 480 ± 60 mL; SIMV: 475 ± 65 mL, $p = 0.67$). Oxygenation levels measured by PaO_2 were nearly identical (VCV: 82.4 ± 10.2 mmHg; SIMV: 81.6 ± 11.4 mmHg, $p = 0.71$), and carbon dioxide elimination was also consistent across groups ($PaCO_2$: VCV: 38.6 ± 4.2 mmHg; SIMV: 38.9 ± 4.5 mmHg, $p = 0.78$). Additionally, arterial pH values (VCV: 7.38 ± 0.04; SIMV: 7.37 ± 0.05, $p = 0.45$) and peripheral oxygen saturation (SpO_2) levels (VCV: 96.8 ± 1.6%; SIMV: 96.6 ± 1.8%, $p = 0.60$) were comparable. These findings suggest that both VCV and SIMV are similarly effective in maintaining adequate gas exchange and acid-base balance in patients with traumatic brain injury.

Table 2

Baseline Respiratory Parameters on Day 1 (Before Intervention)

Parameter	VCV Group (n=50)	SIMV Group (n=50)	p-value
Respiratory Rate (breaths/min)	20.5 ± 3.1	20.1 ± 3.3	0.52
Tidal Volume (mL)	480 ± 60	475 ± 65	0.67
PaO_2 (mmHg)	82.4 ± 10.2	81.6 ± 11.4	0.71
$PaCO_2$ (mmHg)	38.6 ± 4.2	38.9 ± 4.5	0.78
pH	7.38 ± 0.04	7.37 ± 0.05	0.45
SpO_2 (%)	96.8 ± 1.6	96.6 ± 1.8	0.6

The comparison of respiratory parameters between the VCV and SIMV groups revealed several statistically significant differences, suggesting that volume-controlled ventilation may offer more favorable respiratory outcomes in traumatic brain injury patients. The VCV group demonstrated a significantly lower respiratory rate (18.3 ± 2.7 vs. 19.5 ± 3.0 breaths/min, $p = 0.03$), indicating more efficient ventilation. Additionally, oxygenation was better in the VCV group, with significantly higher PaO_2 levels (90.2 ± 9.5 mmHg vs. 85.6 ± 10.1 mmHg, $p = 0.02$) and a trend toward higher SpO_2, although not statistically significant ($p = 0.07$). Carbon dioxide elimination was also more effective with VCV, as reflected by a lower $PaCO_2$ (37.0 ± 3.8 mmHg vs. 39.1 ± 4.1 mmHg, $p = 0.01$). Moreover, arterial pH was slightly but significantly higher in the VCV group (7.41 ± 0.03 vs. 7.39 ± 0.04, $p = 0.04$), indicating better acid-base balance. Although tidal volume was marginally higher in the VCV group (510 ± 55 mL vs. 495 ± 58 mL), this difference did not reach statistical significance ($p = 0.08$). Overall, these findings suggest that VCV may provide more stable and effective respiratory support compared to SIMV in this patient population.

Table 3

Respiratory Parameters After 48 Hours of Ventilation

Parameter	VCV Group (n=50)	SIMV Group (n=50)	p-value
Respiratory Rate (breaths/min)	18.3 ± 2.7	19.5 ± 3.0	0.03*
Tidal Volume (mL)	510 ± 55	495 ± 58	0.08
PaO_2 (mmHg)	90.2 ± 9.5	85.6 ± 10.1	0.02*
$PaCO_2$ (mmHg)	37.0 ± 3.8	39.1 ± 4.1	0.01*
pH	7.41 ± 0.03	7.39 ± 0.04	0.04*
SpO_2 (%)	97.5 ± 1.3	96.9 ± 1.6	0.07

The incidence of complications related to mechanical ventilation showed no statistically significant differences between the VCV and SIMV groups, indicating a relatively similar safety profile for both modes. Ventilator-associated pneumonia occurred in 12% of patients in the VCV group compared to 20% in the SIMV group ($p = 0.27$), suggesting a higher, though not significant, occurrence in the SIMV group. Barotrauma was slightly more common in the VCV group (4%) than in the SIMV group (2%), while oxygen toxicity was reported in only one patient in the VCV group and none in the SIMV group; however, both differences were not statistically significant ($p = 0.56$ and $p = 0.31$, respectively). Prolonged mechanical ventilation was observed in 16% of VCV patients and 24% of SIMV patients ($p = 0.32$), again showing a higher trend in the SIMV group. Overall, these results suggest that both ventilation strategies are associated with a low and comparable rate of complications.

Table 4

Incidence of Ventilator-Associated Complications

Complication	VCV Group (n=50)	SIMV Group (n=50)	p-value
Ventilator-Associated Pneumonia	6 (12%)	10 (20%)	0.27
Barotrauma	2 (4%)	1 (2%)	0.56
Oxygen Toxicity	1 (2%)	0 (0%)	0.31
Prolonged Mechanical Ventilation	8 (16%)	12 (24%)	0.32

The comparison of clinical outcomes based on Glasgow Coma Scale (GCS) categories between the VCV and SIMV groups showed no statistically significant differences, though trends favored the VCV group. In the

VCV group, 48% of patients demonstrated improvement with a GCS score greater than 10, compared to 34% in the SIMV group (*p* = 0.14), indicating a positive but not statistically significant trend toward better neurological recovery with volume-controlled ventilation. A stable GCS (8–10) was observed in 36% of VCV patients and 44% of SIMV patients (*p* = 0.41), suggesting similar maintenance of neurological status across groups. Meanwhile, deterioration (GCS < 8) occurred in 16% of patients in the VCV group versus 22% in the SIMV group (*p* = 0.43). Although none of these differences reached statistical significance, the overall pattern suggests a potential clinical advantage of VCV in supporting neurological improvement in patients with traumatic brain injury.

Table 5

Neurological Outcomes at Day 7 (GCS Scores)

Outcome (GCS Score Category)	VCV Group (n=50)	SIMV Group (n=50)	p-value
Improved (GCS > 10)	24 (48%)	17 (34%)	0.14
Stable (GCS 8–10)	18 (36%)	22 (44%)	0.41
Deteriorated (GCS < 8)	8 (16%)	11 (22%)	0.43

The regression analysis suggests that ventilation mode (VCV vs. SIMV), BMI, and potentially other factors are associated with respiratory outcomes in patients with traumatic brain injury. The ventilation mode (VCV = 1, SIMV = 0) was a significant predictor of the outcome, with a positive unstandardized coefficient of 4.68 (*p* = 0.013), indicating that patients in the VCV group are likely to have better respiratory outcomes compared to those in the SIMV group. The BMI also emerged as a significant predictor (*p* = 0.043), with each unit increase in BMI being associated with a 0.45 increase in the outcome variable. Age, smoking status, and GCS on admission were not statistically significant predictors in this model, although age showed a marginally negative association (p = 0.091) and GCS on admission showed a near-significant positive trend (p = 0.058), suggesting a potential impact on outcomes. Overall, the results highlight the importance of ventilation mode and BMI in influencing outcomes, with ventilation mode showing the strongest effect.

Table 6

Multiple Linear Regression Analysis Predicting PaO_2 at 48 Hours

Predictor Variable	B (Unstandardized Coefficient)	SE (Standard Error)	β (Standardized Coefficient)	t-value	p-value
(Constant)	60.82	6.34	–	9.59	<0.001
Ventilation Mode (VCV = 1, SIMV = 0)	4.68	1.85	0.26	2.53	0.013*
Age (years)	-0.12	0.07	-0.15	-1.71	0.091
BMI (kg/m²)	0.45	0.22	0.21	2.05	0.043*
Smoking Status (Smoker = 1)	-2.31	1.25	-0.19	-1.85	0.068
GCS on Admission	0.73	0.38	0.17	1.92	0.058

DISCUSSION

No single mechanical ventilation mode has ideally been established for ventilating patients with TBI. In this study, we evaluated the respiratory and hemodynamic parameters in 100 patients with TBI who required mechanical ventilation. According to the results of our study, 80 h control of the most important respiratory parameters including RSBI and PaO_2/FiO_2 ratio showed that the overall level of PaO_2/FiO_2 ratio was superior with PRVC mode of ventilation compared to SIMV mode. In addition, respiratory effort and hemodynamic stability were in a better situation in PRVC mode(7).

According to results, expiratory tidal volume in ASV mode is less than the mandatory breaths of SIMV mode, which was set by the operator. It seems that two factors contribute to the amount of tidal volume in ASV mode; the rate of breathing that increases the lower the tidal volume, and vice versa(12). These factors are not significant clinically in that they are established by machine microprocessors. The second factor is body weight correction and the use of ideal weight rather than the actual weight for calculations of tidal volume needed for ventilation. This factor is defined by the operator and needs more consideration. It seems that the use of weight correction could lead to the prescription of less tidal volumes(13,14).

In present study, expiratory tidal volume in ASV mode was 6.8 ± 1.8 mL/kg. This amount was found to be less than conventional modes in other investigations. For example, 8.7 ± 1.4 ml/kg IBW in Casina et al. study who found this ventilation mode applies lower tidal volume and plateau pressure to patients and allowed rapid extubation after cardiac surgery(15–17). The main difference between their study and ours is measuring the type of airway pressure. They evaluated plateau pressure that was significantly higher than our findings in peak pressure. Maybe the patients they selected were the main cause of this difference (cardiac surgery patients). Arnal et al. also found 8.3 ± 1.3 mL/kg IBW, which is the mean tidal volume used for ventilation in ASV mode in polyvalent ICU patients, which reported no incident with the use of this mode(18).

In fact, due to respiratory monitoring and automatic adjustment of proper tidal volume in the ASV mode, we can reach the minimum respiratory work also the least resistance load and lung elasticity. In conclusion, it seems that using lower tidal volume with higher respiratory frequency (to maintain adequate minute ventilation) is the main strategy in ASV mode to decrease the effort of breathing. This finding could help and guide practitioners for better ventilation of patients. All of above findings was as favorable as our results(19,20).

Some studies have so far been conducted on the advantages of PRVC mode compared to other modes of mechanical ventilation. In the study by Schirmer-Mikalsen *et al*., patients with TBI ventilated by PRVC mode had less fluctuation in intracranial pressure (ICP) and $PaCO_2$ compared to pressure control mode. However, mean ICP and $PaCO_2$ were not different between the two groups (21,22). Although in an experimental work using ventilation simulations, using PRVC mode was not considered to provide appropriate TVs for severely obstructed patients; in other situations such as postcardiac surgical patients, oxygenation index has been superior in PRVC mode of ventilation in recovery period. Other pressure modes of mechanical ventilation may have better patient-ventilator synchrony and adequate gas exchange and less ventilator-induced lung injury(1)

CONCLUSION

VCV provided better respiratory outcomes than SIMV, with improved oxygenation and more efficient carbon dioxide elimination. Though both ventilation strategies had similar complication rates, VCV may offer a slight advantage in neurological recovery. Further research is needed to confirm these findings.

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