Asia Pacific Science Press

Asia Pacific Journal of Clinical Medical Research
ISSN(O):3079-8345
ISSN(P):3079-8337
Vol. 1 No.4 (2025)

Comparison of the Effect of Different Tidal Volume Combined with Breath-Holding Function in Clearing Airway Retention

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Abstract: This study aimed to compare the effectiveness and safety of different tidal volumes combined with breath-holding during inhalation for clearing airway retention, and to explore optimized strategies for preventing ventilator-associated pneumonia (VAP). The study enrolled 105 adult patients receiving mechanical ventilation at the Emergency ICU of Dalian University of Technology Affiliated Central Hospital from April 2023 to June 2024. Using a randomized digital table method, patients were divided into three groups (A, B, C) with tidal volumes of 8ml/kg, 10ml/kg, and 12ml/kg respectively. Standardized VAP prevention measures were implemented alongside daily four-time-point airway clearance through ventilator-assisted breath-holding. Results showed that Group C demonstrated significantly higher post-operation airway clearance ($p<0.001$) and more frequent coughing (median 3 vs. 2 times) compared to Groups A and B, indicating that higher tidal volumes enhance secretions expulsion. No significant differences were observed in airway retention characteristics (color, viscosity) among groups ($p>0.05$). Regarding safety, all groups maintained normal heart rate and blood pressure fluctuations before and after procedures, with oxygenation index briefly declining but rapidly recovering without severe hypoxemia. However, Group C exhibited a higher proportion of peak airway pressure>35 cmH_2O (8.6%) compared to Groups A and B (2.9%). Clinically, Group C had a lower VAP incidence (14.2%) than Group A (22.9%) but higher than Group B (11.4%), though statistically insignificant ($p=0.32$). ICU length of stay was shorter in Group C, but this difference was not statistically significant ($p=0.15$). No aspiration or suffocation occurred across all groups. This study demonstrates that the combination of 12ml/kg tidal volume and breath-holding during inhalation can more effectively clear airway retention without significantly increasing safety risks. We recommend prioritizing this approach for mechanically ventilated patients with adequate lung function, while adjusting tidal volume through individualized assessment. Future research should further validate long-term outcomes and evaluate its efficacy across multiple centers.

Keywords: Tidal Volume; Ventilator; Ventilator-associated Pneumonia; Critical Care

Published: Sept 24, 2025

DOI: https://doi.org/10.62177/apjcmr.v1i4.603

1.Background

Tracheal cuff secretions typically refer to bacterial deposits accumulated above the endotracheal tube cuff, which may increase the risk of ventilator-associated pneumonia (VAP). As the most common preventable iatrogenic condition in intensive care units, VAP has been shown to carry mortality rates ranging from 24% to 54% [1]. Contaminated secretions entering the lower respiratory tract through cuff-tracheal airway gaps constitute a major contributing factor to VAP development [2]. Effective clearance of these secretions is crucial for preventing VAP.

Clinically, the primary methods for clearing airway debris from endotracheal tubes are subglottic suction and tidal flow technique [3]. The tidal flow technique is further divided into two subtypes: simple balloon tidal flow and ventilator-assisted tidal flow with breath-holding. Research indicates that the ventilator-assisted tidal flow technique offers distinct advantages over manual resuscitation with simple resuscitators, including visual guidance, precise control of cuff removal timing, accurate gas volume adjustment, and enhanced nurse coordination [4].

Existing guidelines recommend that the range of tidal volume setting for adults is 8-10ml/kg, and the tidal volume can be set to 12ml/kg when the platform pressure is less than 30cmH2O [5]. However, there are no reports on how the retention effect of the cyst is cleared under different tidal volume airflow impact.

2.Methodology

1.1 Subjects

This study was conducted after obtaining informed consent from patients and their families, with approval from the Ethics Committee of Dalian University of Technology Affiliated Central Hospital (Dalian Central Hospital) (Approval No.: YN2022-096-16). The study enrolled 105 adult patients who received artificial airway establishment and mechanical ventilation treatment in the Emergency ICU of the hospital from April 2023 to June 2024. Inclusion criteria included: patients aged over 18 years; those receiving artificial airway establishment and mechanical ventilation; and those expected to require ventilation for over 48 hours. Exclusion criteria included: patients under 18 years old; those with artificial airway establishment less than 48 hours; patients with acute respiratory distress syndrome (ARDS); those with peak expiratory pressure (PEEP) greater than 10cmH2O and/or oxygen inhalation concentration (FiO2) exceeding 0.8; patients with contraindications to supine positioning (intracranial pressure over 20 mmHg); hemodynamically unstable patients; and those with pre-existing pulmonary infections upon admission. Withdrawal criteria were death within 4 days of hospitalization or discharge. Patients were randomly assigned into three groups (A, B, C) using a random number table based on admission time sequence, with 35 patients in each group. Group A received a tidal volume of 8 ml/kg; Group B received 10 ml/kg; and Group C received 12 ml/kg. Daily suctioning of airway secretions was performed at four time points: 0:00,6:00,12:00, and 18:00.

1.2 VAP prevention measures

All groups used the ventilator suction breath-hold method to clear retained air from the endotracheal tube cuff. Group A used a tidal volume of 8ml/kg for clearance; Group B used 10ml/kg; Group C used 12ml/kg. Meanwhile, nurses from the VAP prevention team implemented a series of nursing measures to prevent VAP. ① VAP Prevention Team: Composed of six ICU nurses with over five years of experience. Before the study began, team members received theoretical training and assessment on VAP prevention and control. After passing the assessment, they practiced clinical scenario simulations using endotracheal tube simulation props. Two-person teams cooperated in practicing the ventilator breath-hold method to clear airway secretions, requiring five consecutive successful assessments before clinical operation. ② Preventive measures for VAP determined according to the "China Guidelines for Diagnosis and Treatment of Hospital-Acquired Pneumonia and Ventilator-Related Pneumonia (2018 Edition)" included strict hand hygiene, elevating the head of bed by 30°-45°, chlorhexidine oral care (every 8 hours), regular monitoring (every 4 hours) to maintain cuff pressure at 25-30 cmH2O, turning and back percussion (every 4-6 hours), mechanical vibration sputum clearance (every 6 hours), morning extubation assessment, and weekly/or contaminated replacement of disposable ventilator tubing. ③ Within 30 minutes before each procedure, all groups stopped oral feeding or enteral nutrition pump input, cleared subglottic secretions, and recorded secretion volume. Procedures were scheduled at 0:00,06:00,12:00, and 18:00 daily. ④ All groups used the ventilator inhalation breath-hold method to remove the retention on the airbag.

1.3 operatonal process

Two nurses work together:

① First, nurse 1 adjusted the inhaled oxygen concentration of the ventilator to 100% for 2 minutes to fully aspirate and remove the secretions in the patient's trachea and oropharynx, and adjusted the patient to supine position.

② Before operation, nurse 2 measured the vital signs of the patient and adjusted the capacity control ventilation. According to the group of the patient, the inhalation tidal volume was set as 8ml/kg, 10ml/kg and 12ml/kg respectively, and the PEEP was

set as 5cmH2O.

③ Nurse No.1 performed hand hygiene and put on sterile gloves, prepared sterile sputum collector, pressed the inhalation breath-hold button after the suction phase of the ventilator, and kept the pressure waveform below the level of 30cmH2O to avoid ventilator-related lung injury caused by high pressure.

④ Nurse No.2 connected the artificial airway cuff to a 10ml syringe and quickly evacuated the air. Using the breath-holding airflow from the lungs, she rapidly blew any retained material from the cuff into the oropharynx through the gap between the airway and the tracheal tube cuff. Simultaneously, Nurse No.1 used a sterile sputum collector to suction any remaining material into the oropharynx. ⑤ When the breath-holding airflow ended, Nurse No.2 immediately inflated the cuff and adjusted its pressure to 25-30cmH2O using a cuff pressure gauge. This step was repeated ③④ 2 or 3 times until all retained material from the cuff was aspirated.

⑥ After the operation, nurse No.1 measured the patient's vital signs again, restored the patient to the position before the operation, and recorded the research data.

3.Results

Regarding the clearance efficiency of retained material in the cyst, Group C (12 ml/kg) demonstrated significantly higher clearance volume after a single procedure compared to Groups A (8 ml/kg) and B (10 ml/kg), with statistically significant differences ($p<0.001$). Additionally, Group C showed a significantly higher number of coughs within one minute post-procedure (median 3 vs. 2 in Groups A and B), suggesting that higher tidal volume may enhance airway secretion expulsion capacity. Regarding retained material characteristics, most specimens (78%) were yellowish-white in color, with medium viscosity (65% of cases). No statistically significant differences were observed between groups in these two aspects ($P>0.05$).

Table 1 Comparison of three groups for removal of retention on the cyst (p value)

divide into groups	A	B	C
A	1	0.944	<0.001
B	0.944	1	<0.001
C	<0.001	<0.001	1

Regarding vital signs and safety, hemodynamic analysis showed that heart rate and blood pressure fluctuations remained within normal ranges before and after the procedures across all three groups, with no statistically significant differences observed between or within groups ($P>0.05$). In oxygenation metrics, although the oxygenation index (PaO_2/FiO_2) briefly decreased post-procedure, it returned to baseline levels within 10 minutes without severe hypoxemia ($SpO_2<90\%$). However, regarding barotrauma risk, Group C exhibited an 8.6% incidence of peak airway pressure exceeding 35 cmH_2O (3/35), significantly higher than Groups A (2.9%) and B (2.9%). Fortunately, no barotrauma-related complications such as pneumothorax occurred.

Regarding clinical outcomes, the incidence of VAP was 14.2% in Group C, lower than Group A's 22.9% but higher than Group B's 11.4%. However, the differences among the groups were not statistically significant ($P=0.32$). Additionally, there were no statistically significant differences in mechanical ventilation duration or VAP incidence across the groups. For ICU length of stay, Group C had a median hospitalization of 8 days (IQR: 6-10), shorter than Group A's 10 days (IQR: 8-12) and Group B's 9 days (IQR: 7-11), though the differences remained statistically insignificant ($P=0.15$). In terms of adverse events, none of the groups experienced aspiration, asphyxia, or balloon pressure loss of control.

Table 2 Comparison of three groups of outcome indicators

project	A group	B group	C group	P price
Mechanical ventilation time (h)	170.36±57.49	167.54±59.34	184.21±110.50	0.646
VAP incidence (%)	22.9	11.4	14.2	0.32
28-day mortality rate(%)	31.4	28.6	40	0.573

4.DISCUSSION

This study investigated the effectiveness of different tidal volumes combined with breath-holding during single maneuver for clearing airway retention. The results demonstrated that the 12ml/kg tidal volume group (Group C) achieved higher clearance efficiency after a single procedure compared to the 8ml/kg (Group A) and 10ml/kg (Group B) groups. This advantage likely stems from the stronger expiratory flow generated by elevated tidal volume, which more effectively propels retained material into the oropharynx for easier aspiration. However, Group C showed a greater increase in peak airway pressure than Groups A and B, suggesting clinicians should carefully adjust tidal volume parameters based on factors like lung compliance to balance clearance efficacy with potential pulmonary injury risks. Future research could explore precise tidal volume calibration tailored to individual patient characteristics, aiming to maximize clearance benefits while minimizing lung injury risks.

From a safety perspective, although Group C exhibited higher tidal volume, all three groups maintained hemodynamic parameters (heart rate, blood pressure) within normal ranges with no statistically significant differences before and after the procedure. Although oxygenation index briefly decreased post-procedure, it recovered rapidly without severe hypoxemia or other adverse events. This fully demonstrates that the ventilator's breath-holding technique effectively clears airway obstructions while causing minimal hemodynamic disturbance, aligning with the guideline-recommended "precise gas volume control" principle. The method proves clinically viable and well-tolerated. Notably, none of the groups experienced aspiration, asphyxia, or airway pressure instability, with no significant differences in procedural complication rates, further validating its safety. Future clinical practice should enhance safety through standardized protocols and enhanced staff training to ensure safe implementation of this technique.

From the perspective of VAP prevention, although the incidence of VAP shows a decreasing trend with increased tidal volume [6], the differences among the three groups were not statistically significant. This may be related to the relatively small sample size included in this study, which limited the statistical validity of inter-group differences. Additionally, various confounding factors such as the use of antibiotics in clinical practice may interfere with the results regarding VAP incidence, potentially obscuring the true correlation between tidal volume and VAP occurrence. However, Group C's VAP incidence (14.2%) was lower than Group A's (22.9%), which to some extent reflects the potential advantage of higher tidal volume combined with breath-holding maneuver in preventing VAP. This may be attributed to the method's effectiveness in clearing airway retention, thereby reducing bacterial proliferation and lower respiratory tract infection risks. Future studies requiring larger sample sizes and stricter control of confounding factors are urgently needed to further validate this finding, providing more definitive evidence for clinical VAP prevention strategies. Simultaneously, integrating other preventive measures like optimized nursing protocols and enhanced oral care may further improve prevention efficacy.

Research limitations

This study has several limitations. First, the relatively small sample size (35 cases per group) may have reduced statistical power for assessing inter-group differences in secondary endpoints such as VAP incidence, potentially obscuring subtle variations. Future studies should expand the sample size to improve statistical efficacy. Second, the absence of dynamic cuff pressure monitoring makes it challenging to precisely quantify real-time interactions between tidal volume, cuff seal integrity, and peak airway pressure. This limitation may overlook potential impacts of minor air leaks or over-inflation on mucus clearance efficiency, preventing comprehensive evaluation of their dynamic effects throughout the procedure. Introducing advanced monitoring technologies like real-time pressure monitoring systems could address this shortcoming. Third, the inclusion criteria exclude critically ill patients with ARDS, high PEEP dependency, or severe hypoxia, restricting the study's generalizability to these pathophysiologically heterogeneous patient groups. Future research should explore these populations to validate the method's applicability and effectiveness.

5.CONCLUSIONS

The results of this study demonstrate that the combined 12 ml/kg tidal volume with breath-holding during inhalation can more effectively clear airway retention without significantly increasing safety risks, achieving a good balance between efficacy and safety. This approach should be prioritized as the preferred clinical intervention. It is recommended to implement this

strategy first for patients receiving mechanical ventilation with adequate lung function, while making precise tidal volume adjustments based on individual ventilatory conditions, airway pressure, and respiratory compliance. Future research should focus on evaluating long-term impacts of this strategy on clinical endpoints including ventilator-associated pneumonia (VAP) incidence, mechanical ventilation duration, and ICU length of stay. Multicenter randomized controlled trials should further validate its universality and reliability to promote broader application of this optimized approach in diverse patient populations.

Funding

No

Conflict of Interests

The authors declare that there is no conflict of interest regarding the publication of this paper.

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