ORIGINAL

Effect of positive-pressure ventilation before extubation on respiratory function : physiological evaluation under simulated extubation

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Abstract : Background : Positive-pressure ventilation (PPV) before extubation may improve oxygenation and reduce complications after extubation. However, no study has quantitatively evaluated the effects of extubation on breathing and lung volume. Methods : A crossover randomized study was performed on 16 patients who received mechanical ventilation and planned to undergo extubation in the intensive-care unit. We used the automatic tube compensation (ATC) mode to simulate extubation. We used electrical impedance tomography and an esophageal balloon catheter to evaluate the work of breathing and lung volume after simulated extubation. We compared the work of breathing and lung volume with and without PPV before simulated extubation. Result : There were no differences in the changes in end-expiratory lung impedance (-7.4 [-18.2–2.3] vs. -11.2 [-16.6–1.1] arbitrary units, *p*=0.53), anterior-to-posterior ventilation ratio (0.60 [0.49–0.74] vs. 0.60 [0.52–0.79], *p*=0.75), esophageal pressure swing (4.9 [2.1–8.7] vs. 5.4 [1.9–6.6] cmH_2O, *p*=0.61), dynamic transpulmonary pressure (7.2 [6.7–9.9] vs. 7.6 [6.6–9.7] cmH_2O, *p*=0.93), and pressure time product (2.4 [1.4–4.2] vs. 3.1 [1.0–4.3] cmH_2O*s, *p*=0.84) with and without PPV before simulated extubation. Conclusion : PPV before extubation did not affect breathing work or lung volume after extubation. Therefore, it may delay extubation and increase patient stress. J. Med. Invest. 72 : 361-366, August, 2025

Keywords : *spontaneous breathing test, electrical impedance tomography, Intensive Care Unit, extubation, transpulmonary pressure*

BACKGROUND

In mechanically ventilated patients, safe extubation reduces mortality rate and healthcare costs. Due to respiratory failure after extubation, 5%-30% of patients require reintubation and have a high mortality rate (1-4). Therefore, an appropriate evaluation before extubation is important. Before liberation from mechanical ventilation (MV), a spontaneous breathing trial (SBT) is recommended to evaluate whether or not a patient can be extubated. An appropriate SBT can predict respiratory failure after extubation and prevent unsafe extubation. However, inappropriate SBT can induce respiratory muscle fatigue and hypoxemia due to lung collapse (5).

Recent guidelines for extubation recommend SBT with low-pressure support ventilation (PSV) and positive end-expiratory pressure (PEEP) rather than the T-piece technique (5). It has also been reported that high PEEP + PSV before extubation prevents pulmonary collapse and respiratory muscle fatigue and decreases the frequency of reintubation (6, 7).

The UK Difficult Airway Society guidelines and the latest edition of Miller's Anesthesia recommend pressurized extubation rather than suction extubation, which causes lung collapse, as the method of extubation upon awakening from anesthesia (8). However, there are also reports that the effect of pressurized extubation on lung volume and oxygenation is temporary (9).

All previous studies have been comparative studies with SBT, including the T-piece method. This does not fit the current SBT that uses PSV + PEEP. In addition, as mentioned above, no study has quantitatively evaluated the effect of positive-pressure ventilation (PPV) before extubation on the work of breathing and lung volume after extubation. In this study, we evaluated the effect of PPV before extubation on respiratory physiology after extubation using transpulmonary pressure and electrical impedance tomography (EIT) with simulated extubation.

METHOD

This physiological crossover randomized controlled study included all consecutive adult patients admitted to the intensive-care unit (ICU) of Tokushima University Hospital between February 2023 and June 2024. This study was approved by the Clinical Research Ethics Committee of Tokushima University Hospital (approval number 4352) and registered in a clinical

Abbreviations :
ICU : intensive-care unit ; IQR : interquartile range ; VS : versus

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trial (UMIN-Clinical Trials Registry : 000055489). Written informed consent was obtained from the patients or their authorized surrogate decision makers.

Study population

Adult patients ≥18 years old who were under MV in the ICU for more than 24 h and were considered for weaning from mechanical ventilation were included in this study.

Exclusion criteria were an inability to maintain airway patency (impaired consciousness, weak cough reflex, high airway secretions, or positive cuff leak test), severe obesity (body mass index ≥35 kg/m^2), chest trauma, or other reasons for unclear EIT monitoring.

Study design and procedures

The study protocol was designed to compare respiratory workload and lung volume after extubation between PPV and non-PPV patients before extubation (Fig. 1). Patients were monitored using an esophageal balloon catheter (NutriVent™ ; Hamilton Medical AG, Bonaduz, Switzerland) and EIT (Enlight 2100™ ; Medtronic, Dublin, Ireland). Data were collected in automatic tube compensation (ATC) mode as simulated extubation. ATC mode is a ventilatory mode designed to compensate for the additional work of breathing caused by the resistance of endotracheal or tracheostomy tubes in intubated patients. This is also known as "electrical extubation" (10).

The experimental protocol for this timeline is summarized in Figure 1. To avoid the time effect of the intervention on the respiratory workload and lung volume after extubation, the sequence of experimental intervention (PPV vs. non-PPV) was randomly assigned in each patient using the closed-envelope method. Therefore, patients received either the first PPV or ATC mode (n=8) or vice versa (n=8). In detail, when the patient was ready to consider extubation, SBT (CPAP + PSV mode, PSV 5 cmH_2O, PEEP 5 cmH_2O) was performed for 30 min, and the timing of SBT was decided by the attending physician. Next, 8 patients were managed in CPAP + PS mode (PS 10 cmH_2O, PEEP 15 cmH_2O) for 10 min as a PPV, and then, the ventilator mode was switched to ATC mode (%support 100%, E_{SENS} 25%, V_{SENS} 3.0 L/min) for 10 min to simulate extubation. After the washout period (CPAP + PS mode, PS 5 cmH_2O, PEEP 5 cmH_2O) for 10 min, patients were kept in ATC mode for 10 minutes. Conversely, the other eight patients first received ATC mode for 10 minutes and then PPV for 10 minutes. Data were recorded for each ATC mode. The F_IO_2 was set the same as before the trial.

Measurements

In the present study, EIT and balloon esophageal catheters were used to monitor each parameter continuously. The body position during the measurement was kept constant because the parameters varied depending on the body position. The data obtained were analyzed offline, and the EIT data evaluated by EIT were end-expiratory lung impedance (ΔEELZ) and anterior-to-posterior ventilation ratio (A/P ratio), each of which was calculated using the analysis software program developed by Timpel. Data obtained from esophageal pressure were calculated using the Labchart 8 analysis software program (AD Instruments, Dunedin, New Zealand). We measured esophageal pressure swing (ΔPes), dynamic transpulmonary pressure (PL_{dyn}), end-inspiratory transpulmonary pressure (PL), and pressure time product (PTP) as indicators of work required to breathe after extubation, the A/P ratio as an indicator of ventilation distribution, and ΔEELZ as an indicator of functional residual capacity. The details of each indicator are presented below.

- ΔPes : Variation in esophageal pressure during inspiration. It is calculated as the difference between the end-expiratory and end-inspiratory esophageal pressures. It is an index that indirectly reflects the activities of the diaphragm and other respiratory muscles (11).
- PL_{dyn} : The difference between the peak inspiratory and end-expiratory transpulmonary pressures during tidal breathing, important indicators of breathing (12, 13).
- PL : The difference between airway pressure and pleural pressure at the end of inspiration. It is an index of lung stress and dynamic strain (14).
- PTP : Calculated by integrating the pressure developed by the respiratory muscles over the duration of inspiration (11). It provides a quantitative measure of the work performed by respiratory muscles during breathing (11).
- ΔEELZ : An indicator of changes in the functional residual capacity (15).
- A/P ratio : Distribution of ventilation between the anterior and posterior regions of the lungs (16). Differences in the A/P ratio indicate lung recruitment or collapse in different lung areas (16).

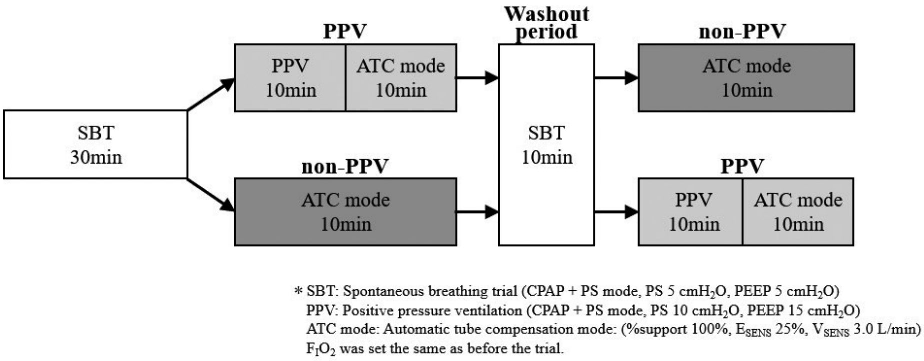

Figure 1. Ventilator settings after the patients were enrolled in each group : no PPV and PPV. When the patient was ready to undergo extubation, SBT (CPAP + PS mode, PS 5 cmH_2O, PEEP 5 cmH_2O) was performed for 30 min. Next, the patients in the PPV group were managed in CPAP + PS mode (PS 10 cmH_2O, PEEP 15 cmH_2O) for 10 min. Subsequently, extubation was simulated in ATC mode (%support 100%, E_{SENS} 25%, V_{SENS} 3.0 L/min). Conversely, patients in the no PPV group were managed in ATC mode after SBT. The washout period (CPAP + PS mode, PS 5 cmH_2O, PEEP 5 cmH_2O) was 10 min. After the washout period, the patients in each group were crossed over to the opposite group. PPV, positive-pressure ventilation ; SBT, spontaneous breathing trial ; ATC, automatic tube compensation.

Outcomes

The primary outcome of this study was the change in the ΔEELZ, A/P ratio, ΔPes, PL_{dyn}, PL, and PTP between ATC modes with and without PPV.

Statistical analyses

Based on an alpha value of 0.05, power set at 80%, and assuming an effect size similar to that of a previous study on the effect of breathing on SBT (17), we calculated that the feasible sample size was 16 patients. Continuous data were presented as the mean ± standard deviation or median (interquartile range [IQR]), whereas categorical data were expressed as numbers. Variables obtained from the control and rest groups were compared using Wilcoxon's signed-rank test. Data analyses were performed using the SPSS software program, version 26 (IBM Corp., Armonk, NY, USA). All statistical tests were 2-tailed, and a p value <0.05 was regarded as statistically significant.

RESULTS

Patient characteristics

Patient characteristics are shown in Table 1. Sixteen patients (9 males and 7 females ; age, 66 ± 18 years old) were enrolled in the study. The acute Physiology and Chronic Health Evaluation II score was 23 (IQR, 18–26). The duration from intubation to SBT was 44.8 (IQR, 31.4–87.5) h. The BMI was 22.7 (IQR, 20.1–25.0) kg/m^2. There were no significant differences in the vital signs between PPV and non-PPV (Table 2).

Table 1. Patient Characteristics

	n=16
Age, years, mean (SD)	66 (±18)
Gender (M/F)	9/7
Body mass index, kg/m^2	22.7 (20.1-25.0)
APACHE Ⅱ	23 (18-26)
Non-surgical/Surgical	10/6
Duration of MV, hr	44.8 (31.4-87.5)

Data are expressed as median (Interquartile Range).

SD = standard deviation, APACHE II = Acute Physiology and Chronic Health Evaluation II, MV = Mechanical ventiration

EIT as an indicator of functional residual capacity

The ΔEELZ results are shown in Figure 2. There was no marked difference in the ΔEELZ (no PPV vs. PPV : -7.4 [IQR, -18.2–2.3] vs. -11.2 [IQR, -16.6–1.1] arbitrary units, p=0.53).

EIT as an indicator of ventilation distribution

The A/P ratios are shown in Figure 2. There were no marked differences in the A/P ratio (no PPV vs. PPV : 0.60 [IQR, 0.49–0.74] vs. 0.60 [IQR, 0.52–0.79], p=0.75).

Transpulmonary pressure as a measure of inspiratory effort

The results for ΔPes, PL_{dyn}, PL, and PTP are shown in Figure 3. There were no marked differences between no PPV and PPV in the ΔPes (4.9 [IQR, 2.1–8.7] vs. 5.4 [IQR, 1.9–6.6] cmH_2O, p=0.61), PL_{dyn} (11.2 [IQR, 7.4–15.0] vs. 10.7 [IQR, 7.3–13.3] cmH_2O, p=0.41), PL (7.2 [IQR, 6.7–9.9] vs. 7.6 [IQR, 6.6–9.7] cmH_2O, p=0.93), and PTP (2.4 [IQR, 1.4–4.2] vs. 3.1 [IQR, 1.0–4.3] cmH_2O*s, p=0.84).

DISCUSSION

Although we hypothesized that PPV before extubation decreased respiratory muscle fatigue and atelectasis induced by SBT, PPV before extubation did not reduce the work of breathing or lung volume after extubation. There were also no marked differences in oxygenation or ventilation between the two groups.

Respiratory workload and lung volume did not change with the PPV. There are two reasons for this finding. First, the benefit to lung volume from PPV before extubation was lost immediately after extubation. Therefore, there may have been no significant differences in oxygenation or respiratory workloads. In a previous study, there was no significant difference in postoperative oxygenation between obese patients managed with high PEEP and those managed with low PEEP during major surgery (18). In another previous study, there was a possibility that the effect of PPV before extubation on respiratory workload and lung volume was temporary (9), and positive pressure before extubation reduced desaturation just after extubation (19). In the present study, because the evaluation was performed only 10 minutes after PPV, the effect of positive pressure may not have been sufficient to maintain the lung volume.

Second, there were no signs of respiratory muscle fatigue in patients at the end of SBT ; therefore, the benefit of PPV before extubation in reducing respiratory fatigue was lost. In fact, PTP during ATC mode was within the normal range, even with non-PPV. Because SBT was performed for a short period (30 min)

Table 2. Vital signs between control group and rest group

	Non-PPV (n=16)	PPV (n=16)	p value
Respiratory rate, breaths/min	18 (16-20)	17 (16-19)	0.57
SpO_2, %	97 (95-98)	97 (96-98)	1.00
Systric blood pressure, mmHg	119 (106-131)	126 (108-135)	0.53
Diastric blood pressure, mmHg	74 (64-81)	71 (65-82)	0.98
Mean blood pressure, mmHg	92 (74-97)	88 (78-98)	0.97
Heart rate, bpm	77 (71-95)	79 (67-92)	0.83
$EtCO_2$, mmHg	39 (36-41)	39 (36-42)	0.77

Data are expressed as median (Interquartile Range).

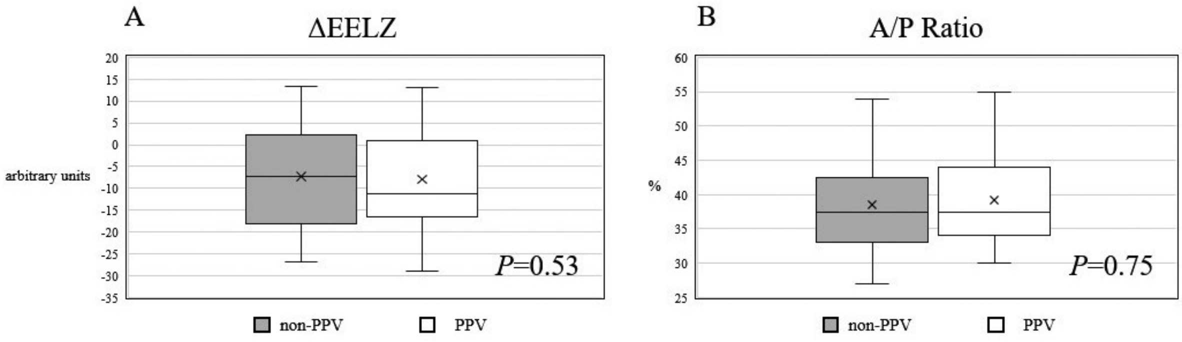

Figure 2. The ΔEELZ and A/P ratio. There was no significant difference in the ΔEELZ between the no PPV and PPV groups (-7.4 [IQR, -18.2–2.3] vs. -11.2 [IQR, -16.6–1.1] arbitrary units, p=0.53 in) (A). Furthermore, there was no significant difference in the A/P ratio between the no PPV and PPV groups (0.60 [IQR, 0.49–0.74] vs. 0.60 [IQR, 0.52–0.79], p=0.75) (B). ΔEELZ, change in end-expiratory lung impedance ; A/P ratio, anterior-posterior ventilation ratio ; PPV, positive-pressure ventilation.

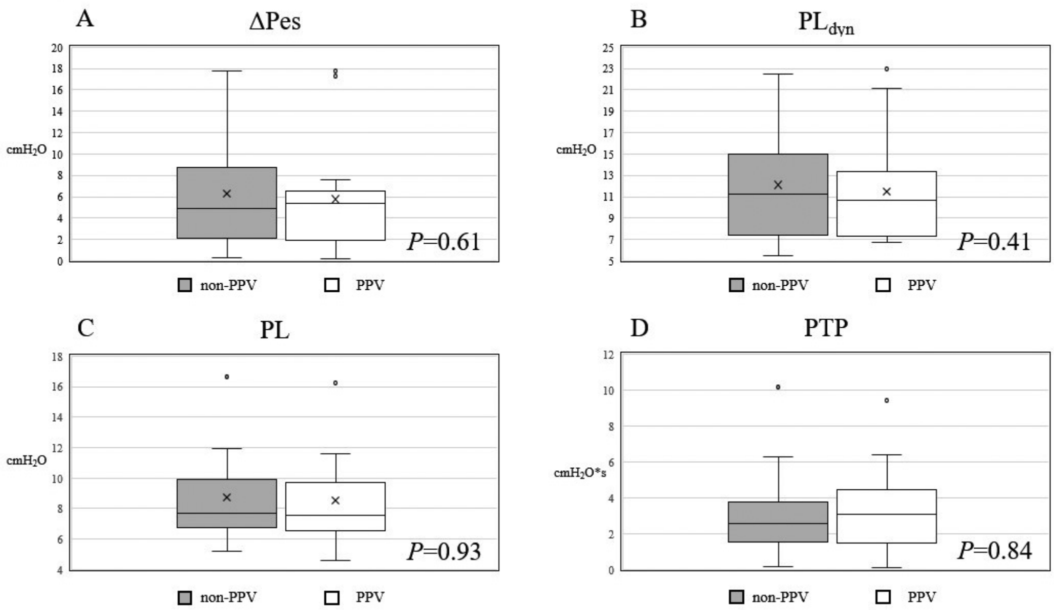

Figure 3. The ΔPes, PL_{dyn}, PL, and PTP. There were no significant differences between the no PPV and PPV groups in the ΔPes (4.9 [IQR, 2.1–8.7] vs. 5.4 [IQR, 1.9–6.6] cmH_2O, p=0.61) (A), PL_{dyn} (11.2 [IQR, 7.4–15.0] vs. 10.7 [IQR, 7.3–13.3] cmH_2O, p=0.41) (B), PL (7.2 [IQR, 6.7–9.9] vs. 7.6 [IQR, 6.6–9.7] cmH_2O, p=0.93) (C), or PTP (2.4 [IQR, 1.4–4.2] vs. 3.1 [IQR, 1.0–4.3] cmH_2O*s, p=0.84) (D). ΔPes, esophageal pressure swing ; PPV, positive-pressure ventilation ; PL_{dyn}, dynamic transpulmonary pressure ; PL, end-inspiratory transpulmonary pressure ; PTP, pressure time product.

before simulated extubation and PSV was used, patients may not have experienced respiratory muscle fatigue. Conversely, SBT was performed with the T-peace method, and the SBT period before extubation was a long time (≥2 h) in a previous study (7).

SBT is important for predicting post-extubation respiratory failure and preventing potentially avoidable reintubation. However, during SBT, the patient is awake and under an additional respiratory load (20). The criteria for stopping SBT include worsening agitation, anxiety, and discomfort (21). Therefore, SBT not only induces respiratory muscle fatigue in the patient but may also stress the patient mentally (20, 21) Originally, SBT was recommended to be performed for 2 h. (22) However, since reducing the duration to 30-minute SBT does not significantly change the outcome (23), 30-minute SBT is now recommended to avoid psychological stress and delayed weaning from MV (21). Therefore, the results of this study suggest that PPV to prevent respiratory failure after extubation may lead to unnecessary stress and prolong the ventilatory period. The effects of PPV are considered temporary, and careful judgment may be required.

Several limitations associated with the present study warrant mention. First, the patients were not actually extubated ; extubation was only simulated using the ATC mode. Because the ATC mode does not perfectly reproduce the extubation condition, collecting data in this mode may have influenced the work of breathing and lung volume after extubation. Second, the previous study managed in PPV for 60 minutes (6, 7), but this study we managed for 10 minutes. So, it may have led to different results. However, it has been reported that changes in FRC and compliance become plateau in a few minutes after changing settings (24, 25). In addition, about respiratory muscle fatigue, there are two pattern fatigues : high- and low-frequency fatigue. It has been reported that low-frequency fatigue does not cause weaning failure (26), and high-frequency fatigue can be improved in 10-15 minutes (27), so we thought this difference about duration of PPV is not a major issue. And finally, this was a single-center open-label study. Therefore, a multicenter study with a large sample size is needed to evaluate the effect of pre-extubation PPV on post-extubation breathing and lung volume.

CONCLUSION

Administering PPV before extubation did not affect breathing or oxygenation after extubation. Therefore, the results of this study suggest that PPV to prevent respiratory failure after extubation may lead to unnecessary stress and prolongation of the ventilatory period.

COMPETING INTERESTS

The authors declare that they have no competing interests

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AVAILABILITY OF DATA AND MATERIAL

The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

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