Differences in Respiratory Parameters during Continuous Positive Airway Pressure and Pressure Support Ventilation in Infants and Children

KUNIHICO HOSHI, YUTAKA EJIMA, RYUICHI HASEGAWA, KOHI SATOH, SHUN SATOH and SHUH MATSUWA

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HOSHI, K., EJIMA, Y., HASEGAWA, R., SATOH, K., SATOH, S. and MATSUWA, S. Differences in Respiratory Parameters during Continuous Positive Airway Pressure and Pressure Support Ventilation in Infants and Children. Tohoku J. Exp. Med., 2001, 194 (1), 45-54 — The extubation criteria of pressure support ventilation (PSV) in infants and children were not yet established. We studied the differences in respiratory parameters during continuous positive airway pressure (CPAP) using a constant flow type ventilator and PSV using a demand valve type ventilator. Nineteen children (1.9 ± 2.9 years old) who were ready to extubate were studied. All patients had recovered from their respiratory failure and had finished the weaning process of the ventilatory support. They were scheduled for extubation on the next day when their ventilatory mode had attained to a PSV of 3 cmH2O with a positive end-expiratory pressure (PEEP) of 3 cmH2O. On the extubation day, tidal volume (TV) and respiratory frequency (RR) were measured with a respiratory monitor at two modes (CPAP of 3 cmH2O and PSV), and the duty ratio (DR) and mean inspiratory flow (MF) were calculated. The sequence of the ventilatory mode was random. No case required reintubation. TV was 61.6 ± 54.9 during CPAP and 67.7 ± 61.4 ml during PSV, and RR was 38.5 ± 10.6 and 37.1 ± 8.8 beats/min., respectively. DR was 0.382 ± 0.067 and 0.359 ± 0.085, and MF was 96.6 ± 78.3 and 101.0 ± 69.0 ml/sec., respectively. The measured parameters and calculated values showed no significant difference between CPAP and PSV. It was found that the respiratory parameters were almost the same with CPAP and PSV immediately before the extubation, and the previous extubation criteria of CPAP can be used. ——— respiratory parameters; spontaneous breathing; CPAP; PSV; infant and children
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Previously, the respiratory care of infants and children in our intensive care unit (ICU) was performed using a constant flow, time-cycled, and pressure-limited type ventilator. Our procedure of weaning from that ventilator was as follows: 1) We started the mechanical ventilation with continuous positive pressure ventilation (CPPV), then changed the ventilatory mode to intermittent mandatory ventilation (IMV). 2) We observed the patients under a continuous positive airway pressure (CPAP) of 3 cmH₂O with a reservoir bag for 12–24 hours. 3) After that, we extubated the tracheal tube of the patients while referring to the tidal volume (TV), respiratory frequency (RR), and other respiratory parameters which were classical extubation criteria.

Recently, pressure support ventilation (PSV) using a demand valve type ventilator came to be widely used in the respiratory care of adults. PSV, which can preserve the patient's inspiratory effort, practices inspiratory assistance during the patient's spontaneous inspiration. PSV reduces the work of breathing and decreases the oxygen consumption of the respiratory muscles because it has excellent synchrony (Brochard et al. 1991). However, if PSV were used in the respiratory care of infants and children, a high sensitivity and rapid response for their small and quick spontaneous breathing would be required. Because of recent advances in ventilator technology, PSV has now become possible in infants and children (Tokioka et al. 1997). In our ICU, respiratory care using the SV300 (Simens-Elema, Salna Sweden) in infants and children is now being performed. SV300 is a new demand valve type ventilator. The procedure of weaning using the SV300 is as follows: 1) We start the mechanical ventilation with pressure regulated volume control (PRVC), and change it to IMV plus PSV. 2) Then we shift it to PSV alone and keep the patients under PSV of 3 cmH₂O with 3 cmH₂O of positive end-expiratory pressure (PEEP) for 12–24 hours. 3) After that, we extubate the tracheal tube referring to TV and RR which are the conventional extubation criteria.

TV and RR are the most widely used parameters as the weaning criteria. Those values had been measured during the T-piece trial or CPAP. CPAP and PSV are fundamentally different ventilatory modes and the extubation criteria of PSV in infants and children is not yet established. Regardless of the values of TV and RR during CPAP and PSV were the same or not, we extubated the tracheal tube using the conventional extubation criteria. Therefore, we examined the respiratory parameters during the CPAP and PSV mode in infants and children who were ready to be extubated.

**SUBJECTS**

Nineteen children (14 male and 5 female, 0 ~10 years old; mean age 1.9 ± 2.9 years old) who had been admitted to our ICU for respiratory care, were studied just before extubation (Table 1). All patients had been ventilated using the SV300. They had been intubated using a naso-tracheal tube (NTI) with a leak-free seal at an airway pressure of less than 20 cmH₂O. They had recovered from their respiratory failure and their weaning had been completed up to a PSV of 3 cmH₂O and PEEP of 3 cmH₂O. We included the infants and children whose weaning had been finished uneventfully without severe pulmonary and circulatory complications during their clinical courses. The infants and children who had developed phrenic nerve palsy and/or had had neuromuscular disease were excluded from this study. Fentanyl and midazolam were continuously administered till 6:00 am on the extubation day, and all the patients were almost awake at the time of the study in the morning.

All subjects could be extubated immediately after the study. No patient required reintubation.
Table 1. Characteristics of the patients

<table>
<thead>
<tr>
<th>Patient</th>
<th>Age (months)</th>
<th>Weight (kg)</th>
<th>Height (cm)</th>
<th>Diagnosis</th>
<th>NTT (mm)</th>
<th>Duration of ventilator (days)</th>
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<tr>
<td>1</td>
<td>12</td>
<td>7.50</td>
<td>69.5</td>
<td>Bidirectional Glenn operation</td>
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<td>2</td>
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<td>3</td>
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<td>6</td>
<td>36</td>
<td>10.50</td>
<td>88.6</td>
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<tr>
<td>9</td>
<td>1</td>
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<td>5</td>
</tr>
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<td>0</td>
<td>3.51</td>
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<td>3.80</td>
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<tr>
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<td>13</td>
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<td>14</td>
<td>6</td>
<td>6.42</td>
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<td>100.0</td>
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<td>16</td>
<td>8</td>
<td>7.74</td>
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<td>Liver transplantation</td>
<td>4.0</td>
<td>4</td>
</tr>
<tr>
<td>17</td>
<td>108</td>
<td>19.30</td>
<td>117.0</td>
<td>Tricuspid valve replacement</td>
<td>5.5</td>
<td>3</td>
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<tr>
<td>18</td>
<td>24</td>
<td>10.20</td>
<td>81.5</td>
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<td>50.0</td>
<td>ECD radical operation</td>
<td>4.0</td>
<td>11</td>
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</table>

NTT, internal diameter of tracheal tube; TAPVR, Total Anomalous Pulmonary Venous Return; VSD, Ventricular Septal Defect; B-T shunt, modified Blalock-Taussing shunt; PA banding, Pulmonary Artery banding; ECD, Endocardial cushion defect; TCPC, Total Cavo–Pulmonary Connection.

METHODS

On the extubation day, patients were randomly assigned to the CPAP or PSV mode for 30 minutes, then the following measurements were recorded and arterial blood samples were obtained. CPAP was performed by a Sechrist IV-100B (Sechrist Clinical Services, Inc.; Anaheim CA, USA) or a Newport E100 (Newport Medical Ins., Inc.; Newport Beach, CA, USA) which was a time-cycled, pressure limited and constant flow type ventilator. The constant flow rate of the ventilator was set so that negative pressure did not appear on the airway pressure manometer of the ventilator in the inspiration phase. After the measurement, each of the two ventilatory modes was switched to the other.

Arterial blood gas analyses were performed with an ABL640 (Radiometer A/S; Copenhagen, Denmark). TV, RR, and other respiratory parameters were measured with a Ventrac Model 1550 monitoring system (Novametrix Medical Systems Inc., Wallingford, CT, USA) during CPAP and PSV. The Ventrac 1550 is a new respiratory monitoring system that can be used to measure respiratory parameters easily in the clinical situation. It can measure flow and airway pressure from the neonate to the adult by attaching the appropriate flow sensor between the tracheal tube and the ventilatory circuit, and automatically calculate the ventilatory parameters (such as TV, RR, and inspiration/expiration ratio). It also can measure the carbon dioxide concentration of the expired gas and calculate the carbon dioxide elimination (Wenzel et al. 1999). Minute ventilation (MV) is automatically given by adding the volume in every breath for 1 minute and TV is automatically given by MV/RR. Maximum
expiratory flow (MEF) is measured at each breath. The duty ratio (DR), mean inspiratory flow (MF), and rapid shallow breathing index (RSI) were calculated. DR is represented by inspiratory time/breathing time (TI/TTOT) and expresses the timing of respiration. MF is represented by TV/inspiration time (TV/ TI) and reflects the neuro-mechanical drive of respiratory center. RSI is represented by RR/TV and has been recently included among extubation criteria (Yang 1992).

In this study, we used the neonatal-type flow sensor (dead space: less than 1 ml) in the patients with an NTT the inner diameter of which was less than 4.0 mm, and used the adult/children-type flow sensor (dead space: 8 ml) in the patients with an NTT the inner diameter of which was more than 4.5 mm.

The values of MV, TV, RSI, MF, and MEF were normalized as indexed by body weight (BW), respectively. All the data were expressed as mean ± s.d.. Statistical analyses, such as regression line and paired-t test, were performed with StatView5.0 software (SAS Institute Inc.; Cary, NC, USA). Significance was accepted at a level of p < 0.05.

**RESULTS**

The mean BW of the patients was 9.5±8.0 kg (2.9~37.1 kg), the mean height was 73.1±25.6 cm (48.0~143.6 cm), and the duration of the ventilatory support of the patients was 8.8±7.4 days (3~28 days).

Table 2 shows the respiratory parameters at each mode. There was no significant difference between CPAP and PSV in all respiratory parameters measured and calculated in this study.

Fig. 1 shows the relationships between MV, TV, RR, and BW. There were positive correlations between MV and BW at CPAP and PSV. There were positive correlations between TV and body weight at CPAP and at PSV. There was no correlation between RR and BW at CPAP, but there was a negative correlation at PSV. At CPAP and PSV, there was no significant difference in the regression line between MV, TV, RR, and BW.

<table>
<thead>
<tr>
<th></th>
<th>CPAP</th>
<th>PSV</th>
</tr>
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<tbody>
<tr>
<td>PaO2 (mmHg)</td>
<td>106.8±44.3</td>
<td>109.1±46.5</td>
</tr>
<tr>
<td>PaCO2 (mmHg)</td>
<td>40.3±6.1</td>
<td>39.0±5.7</td>
</tr>
<tr>
<td>MV (L/min.)</td>
<td>2.2±1.9</td>
<td>2.0±1.4</td>
</tr>
<tr>
<td>TV (ml)</td>
<td>61.6±54.9</td>
<td>67.7±61.4</td>
</tr>
<tr>
<td>Respiratory Rate (beats/min.)</td>
<td>38.5±10.6</td>
<td>37.1±8.8</td>
</tr>
<tr>
<td>Inspiratory Time (sec.)</td>
<td>0.621±0.137</td>
<td>0.618±0.171</td>
</tr>
<tr>
<td>Duty ratio</td>
<td>0.359±0.085</td>
<td>0.382±0.067</td>
</tr>
<tr>
<td>MIF (ml/sec.)</td>
<td>96.6±78.3</td>
<td>101.0±69.0</td>
</tr>
<tr>
<td>MEF (L/min.)</td>
<td>6.62±3.28</td>
<td>6.54±3.04</td>
</tr>
<tr>
<td>RSI (beats/min./ml)</td>
<td>1.12±0.83</td>
<td>1.09±0.90</td>
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<tr>
<td>CO2 elimination (ml/min.)</td>
<td>68.2±70.4</td>
<td>56.4±47.1</td>
</tr>
<tr>
<td>MV/BW (L/min./kg)</td>
<td>0.239±0.074</td>
<td>0.223±0.068</td>
</tr>
<tr>
<td>TV/BW (ml/kg)</td>
<td>6.27±1.65</td>
<td>6.93±2.28</td>
</tr>
<tr>
<td>RSI/BW (beats/min./ml/kg)</td>
<td>6.75±3.29</td>
<td>6.68±5.73</td>
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<td>MF/BW (ml/sec./kg)</td>
<td>10.52±3.95</td>
<td>11.26±2.80</td>
</tr>
<tr>
<td>MEF/BW (L/min./kg)</td>
<td>0.872±0.236</td>
<td>0.895±0.379</td>
</tr>
</tbody>
</table>

Mean±s.d.

MV, minute ventilation; TV, tidal volume; RSI, rapid shallow index; MIF, mean inspiratory flow; MEF, maximum expiratory flow; BW, body weight.
Fig. 1. The relationships between the respiratory parameters (minute ventilation [MV], tidal volume [TV], respiratory rate [RR]) and body weight (W). Closed circle (●) represents CPAP and open circle (○) PSV.

Top: The relationships between MV and body weight.

CPAP: MV = 0.054 + 0.227 × W \( R^2 = 0.87 \) \( p < 0.001 \)
PSV: MV = 0.405 + 0.164 × W \( R^2 = 0.86 \) \( p < 0.001 \)

Middle: The relationships between TV and body weight.

CPAP: TV = −2.540 + 6.703 × W \( R^2 = 0.95 \) \( p < 0.001 \)
PSV: TV = −1.700 + 7.257 × W \( R^2 = 0.89 \) \( p < 0.001 \)

Bottom: The relationships between RR and body weight.

CPAP: RR = 41.51 − 0.31 × W \( R^2 = 0.055 \)
PSV: RR = 43.65 − 0.69 × W \( R^2 = 0.39 \) \( p < 0.01 \)

Fig. 2 shows the relationships between RSI, MF, DR, and body weight. There were negative correlations between RSI and body weight at CPAP and PSV. There were positive correlations between MF and body weight at CPAP and PSV. There were no correlations between DR and body weight at CPAP and PSV. At CPAP and PSV, there was no significant difference in the regression line between RSI, MF and body weight.

There were positive correlations between MEF and body weight at CPAP and PSV.
Fig. 2. The relationships between the calculated parameters (rapid shallow index [RSI], mean inspiratory flow [MF], duty ratio [DR]) and body weight (W). Closed circle (●) represents CPAP and open circle (○) PSV.

Top: The relationships between RSI and body weight.
CPAP: RSI = 1.742 - 0.065 × W, R² = 0.39, p < 0.001
PSV: RSI = 1.684 - 0.062 × W, R² = 0.31, p < 0.05

Middle: The relationships between MF and body weight.
CPAP: MF = 6.848 + 9.379 × W, R² = 0.91, p < 0.001
PSV: MF = 24.737 + 7.972 × W, R² = 0.85, p < 0.001

Bottom: The relationships between DR and body weight.
CPAP: DR = 0.376 - 0.002 × W, R² = 0.028
PSV: DR = 0.385 - 0.0003 × W, R² = 0.001

1.786 + 0.601 × BW, R² = 0.68, p < 0.0001) and PSV (MEF = 2.656 + 0.483 × BW, R² = 0.52, p < 0.01). There were positive correlations between CO₂ elimination and body weight at CPAP (CO₂ elimination = -11.578 + 7.888 × BW, R² = 0.86, p < 0.001) and PSV (CO₂ elimination = 1.368 + 5.448 × BW, R² = 0.92, p < 0.001).

There was no correlation between TI and body weight at CPAP, but there was a weak positive correlation at PSV (TI = 0.516 + 0.011 × BW, R² = 0.25, p < 0.05). There was no
Fig. 3. The relationships between the respiratory parameters divided by BW (MV/BW, TV/BW, RSI/BW) and body weight (W). Closed circle (●) represents CPAP and open circle (○) PSV.

Top: The relationships between MV/BW and body weight.

CPAP: \( \text{MV/BW} = 0.252 - 0.003 \times W \) \( R^2 = 0.116 \)
PSV: \( \text{MV/BW} = 0.249 - 0.001 \times W \) \( R^2 = 0.014 \)

Middle: The relationships between TV/BW and body weight.

CPAP: \( \text{TV/BW} = 6.057 + 0.024 \times W \) \( R^2 = 0.013 \)
PSV: \( \text{TV/BW} = 6.698 + 0.024 \times W \) \( R^2 = 0.007 \)

Bottom: The relationships between RSI/BW and body weight.

CPAP: \( \text{RSI/BW} = 7.663 + 0.095 \times W \) \( R^2 = 0.054 \)
PSV: \( \text{RSI/BW} = 8.014 + 0.14 \times W \) \( R^2 = 0.038 \)

There was no correlation between the respiratory parameters divided by BW and body weight.

correlation between expiratory time (TE) and BW at CPAP, but there was a weak positive correlation at PSV (TE = 0.861 + 0.029 × BW, \( R^2 = 0.32 \), \( p < 0.05 \)).

Fig. 3 shows the relationships between MV/BW, TV/BW, RSI/BW, and body weight. There were no correlations between these three parameters and the body weight. There were
no correlations between MF/BW, MEF/BW and BW at CPAP and PSV.

**DISCUSSION**

Until recently, the respiratory care of infants and children had been performed with a time-cycled, pressure-limited, and constant flow type ventilation. As for the ventilatory mode of weaning from such ventilators, there were T-piece, IMV, and CPAP. Especially, CPAP had been popular as a weaning mode.

PSV is a recently developed mode of ventilatory assistance designed to maintain a constant preset positive airway pressure during spontaneous inspiration. PSV diminishes the work of breathing and decreases the oxygen consumption of respiratory muscles in patients under weaning from mechanical ventilation (Brimacombe et al. 2000). PSV came to be widely used for respiratory management of an adult. But, the time lag between the inspiratory effort and the demand flow delivery also impairs the effectiveness of PSV. The infants and children have to produce enough negative pressure to trigger the ventilator through a narrow tracheal tube that requires more work for triggering. PSV for infants and children required a high sensitivity and a rapid response. Because of recent developments in ventilators, the PSV of a new ventilator can now be used for respiratory management of infants and children (Matsukawa et al. 1994). The procedure of weaning using PSV is that the pressure of PSV is gradually decreased depending on the patient’s condition (Stroetz and Hubmayr 1995) and the extubation is performed at PSV of 3 to 5 cmH\(_2\)O. But, in PSV of infants and children, there is not a clear extubation criteria including the respiratory parameters and the pressure level of PSV.

The rates of weaning failure differed among the weaning methods and the rates of weaning failure in the three weaning methods were 43% in T-pieces, 42% in SIMV, and 23% in PSV (Brochard et al. 1994). In adult acute respira-

tory insufficiency patients after early extubation, TV during PSV was found to be significantly larger than that during CPAP, and RR during PSV significantly lower than that during CPAP (Kilger et al. 1999). There were also possible differences in TV and RR during CPAP and PSV in infants and children prior to extubation. Therefore, we prospectively evaluated the respiratory parameters of CPAP and PSV in infants and children just before extubation.

As extubation criteria for children, MV, TV, RR, blood gas analyses, maximum inspiration negative pressure (P\(_{\text{Imax}}\)), and vital capacity (VC) have conventionally been used (Yang and Tobin 1991). RSI, which is useful to predict pediatric extubation success, has been used recently as an extubation criteria (Thiagarajan et al. 1999). Although measurement of the work of breathing with an esophageal balloon may be useful for weaning (Gluck et al. 1995), its use is clinically restricted because of the difficulty in determining the appropriate placement of the balloon in the esophagus and the necessity of using a special monitor. In our ICU, we have recently begun using RSI based on MV, TV, RR, and blood gas analyses.

In the present study, there was no significant difference between CPAP and PSV in all measured respiratory parameters and calculated values. PSV of 3 cmH\(_2\)O did not have large influence on the timing of respiration and the neuro-mechanical drive of respiratory center. There were positive correlations between TI, TE and body weight at PSV, but there were not correlations between TI, TE and body weight at CPAP. Further validation studies of effect on the respiratory center are needed in the future. The relationships between TV and BW were TV (ml) = −2.54 ± 6.70\times BW (kg) during CPAP and TV (ml) = −1.70 ± 7.26\times BW (kg) during PSV. These relationships were almost the same during CPAP as in our previous study (TV [ml] = −0.88 ± 7.97\times BW [kg]) (Hoshi et al. 1998),
but these were a little higher than those of another report (VT [ml] = 5.4 ± 4.6 × BW [kg]) (Lindahl et al. 1984). MV, TV, MF, MEF and CO₂ elimination during CPAP and PSV increased with the BW as in another report (Haddad et al. 1979). RR during CPAP and PSV were the downward tendency with the increase in the BW. TV/BW was 6.286 ± 1.653 at CPAP and 6.928 ± 2.278 (ml/kg) at PSV, MF/BW was 10.52 ± 3.95 and 11.26 ± 2.80 (ml·sec⁻¹·kg⁻¹), respectively. The values of TV/BW and MF/BW were almost the same as in previous reports and not correlated with body weight. After birth in normal infants, MV and TV increase with body weight while RR steadily declines through infancy. But, the increase and decrease of MV were dependent on RR instead of a body weight.

It has been reported that extubation was possible when RSI/BW was less than 8 beat·ml⁻¹·kg⁻¹. In the present study, the values were 6.75 ± 3.29 at CPAP and 6.68 ± 5.73 at PSV, which had been found to be satisfactory values.

In the present study, the measured parameters and calculated values had no significant differences between CPAP using the constant flow type ventilator and PSV using the demand valve type ventilator. However, because the appropriate pressure level of PSV at extubation is still unknown, further validation is needed.

**CONCLUSIONS**

It was found that the respiratory parameters were almost the same with CPAP and PSV in infants and children immediately before the extubation and the previous extubation criteria can be used. However, further validation is needed to determine the appropriate pressure level of PSV.

**References**


