Assessment of respiratory drive and muscle function in the pediatric intensive care unit and prediction of extubation failure

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**Background:** Extubation failure can result from poor respiratory drive, impaired respiratory muscle function, or excessive inspiratory load. Measurement of airway pressure changes either during tidal breathing or after end-expiratory occlusion allows assessment of respiratory drive and muscle function.

**Objective:** To determine whether the results of airway pressure measurements characterized children who subsequently failed extubation and identify which test’s results had the highest predictive performance.

**Design:** A prospective study.

**Setting:** Pediatric intensive care unit.

**Patients:** A sample of 42 stable intubated pediatric patients who were judged clinically ready for extubation.

**Methods:** A pneumotachograph was placed between the endotracheal tube and ventilator circuit. Airway pressure was measured from the pneumotachograph. The flow and pressure signals were amplified and displayed in real time on a laptop computer. During a temporary disconnection from the ventilator, the airway was occluded at end-expiration and the occlusion maintained for at least five breaths. From the first inspiratory effort during the occlusion, the pressure generated after 0.1 sec of occlusion (P0.1) and the largest negative pressure (P1) were calculated. From the series of breaths during the occlusion, the maximum P0.1 (P0.1 max) and maximum P1 (P1 max) were determined and P0.1/P0.1 max, P1/P1 max, and P0.1/P1 max calculated. From spontaneous, tidal breaths during ventilatory support the pressure time product was calculated.

**Results:** Thirty-six (84%) of the children were successfully extubated. The children who failed extubation were characterized by a lower median P0.1 (< .06), P0.1/P0.1 max, P1/P1 max (< .05 and P0.1/P1 max (< .02). P0.1 and P0.1/P1 max and performed best in predicting extubation failure (areas under the receiver operator characteristic curves, 0.76 and 0.77 respectively).

**Conclusion:** Assessment of P0.1 was the most useful airway pressure measurement in predicting extubation failure. Assessment of P0.1 may help to characterize children likely to fail extubation. (Pediatr Crit Care Med 2000; 1:124–126)

**Key Words:** pediatric intensive care; weaning; extubation failure; respiratory drive; respiratory muscle; mechanical ventilation

**M**echanical ventilation can be lifesaving, but prolonged use is associated with side effects. It is therefore desirable to extubate patients as soon as safely possible. Unfortunately, between 15% and 20% of children fail extubation (1, 2); that is, they require reintubation within 24 hrs. As a consequence, it is important to identify an accurate and easily assessed predictor of extubation success. Extubation failure may result from poor respiratory drive, impaired respiratory muscle function, and/or excessive inspiratory load (1). Measurement of airway pressure either during tidal breathing or after end-expiratory occlusion allows noninvasive assessment of respiratory drive and muscle function. The aim of this study was therefore to determine whether the results of such assessments characterized children who subsequently failed extubation and which test performed best with regard to prediction of extubation failure.

**PATIENTS AND METHODS**

Children were eligible for this study if they had been ventilated for ≥72 hrs and were considered by the clinician in charge ready to be extubated. Intravenous morphine infusions were stopped ~6–8 hrs before extubation and midazolam infusions were stopped 1–2 hrs before extubation. The exact timing of extubation was decided by the clinician in charge, and the decision was based on the child’s clinical condition, blood gases, and ventilatory variables. During ventilation, children were supported such that their pH was between 7.25 and 7.45 and their oxygen saturation was ≥92%. During an acute neurosurgical episode, the Paco2 was kept between 3.5 kPa and 4 kPa. Children were extubated if their inspired oxygen concentration was <35% and their pressure support <10 cm H2O. The decision to reintubate was also made by the clinician in charge, again based on clinical examination and/or the results of blood gas analysis. Children were reintubated if their supplementary oxygen requirements had increased to ≥60%, they were dyspneic, and/or they developed a respiratory acidosis (pH < 7.25).

The study was approved by the Research Ethics Committee of King’s Healthcare Trust and children were entered into the study once their parents had given informed written consent. The respiratory measurements were made when the child was in a stable condition; suction, physiotherapy, and posture changes having been performed ≥2 hrs previously. A pneumotachograph (series 4500, Hans Rudolph, Kansas City, MO) attached to a differential pressure transducer (VDP45 ± 2.5 cm H2O, Validyne, Northridge, CA) was placed between the ventilator circuit and endotracheal tube. Airway pressure was measured from a side arm on the pneumotachograph with a differential pressure transducer (Validyne MP45). The signals from the pressure transducers were amplified (Validyne CD 280 car-
effort during the occlusion (P0.1 max). The 0.1 sec from the beginning of any inspiratory the maximum inspiratory pressure generated produced by any inspiration attempt during the occlusion; the negative pressure measured 0.1 sec from the beginning of any inspiratory effort during the occlusion (P0.1 max). The mean for each pressure measurement was calculated from the results from the series of occlusions. P0.1/P1 max, maximum P I;P 0.1, pressure generated after 0.1 sec of occlusion; P 0.1 max, maximum P 0.1.

RESULTS

Six children failed extubation; two had undergone liver transplantation and two neurosurgical procedures, one had had a road traffic accident, and the sixth a paracetamol overdose. The six children differed with respect to their lower median P0.1 (p < .06), P0.1/P1 max (p < .05), and P0.1/P1 max (p < .02) (Table 1). Comparison of the areas under the receiver operating characteristic curves (Table 2) demonstrated that P0.1 and P0.1/P1 max were most predictive of extubation failure.

DISCUSSION

We have demonstrated only P0.1/P1 max and P0.1/P1 max differed significantly between children in whom extubation succeeded or failed, although there was an almost significant trend for a lower median P0.1 in the group who failed extubation. In adults, P0.1 results characterized patients with chronic obstructive pulmonary disease (4), neurologic abnormalities (5), and postoperative patients (6) who failed extubation and had equivalent sensitivity to f/VT and P0.1× f/VT in predicting weaning success (7). The trend to a lower P0.1 in the children who failed extubation was, however, unexpected, as in adults a higher P0.1 was found in those with adverse outcome (4–7). In adults, a high P0.1 value indicated a high respiratory drive needed to maintain adequate alveolar ventilation when faced with an increased mechanical load (5). The difference in the previous results in adults (4–7) and the present results in children may be explained by the nature of our population; a minority suffered from a primary respiratory diagnosis. The lower P0.1 in the children who failed extubation could be explained by poorer respiratory drive (8), decreased inspiratory muscle strength (9, 10), or hyperinflation (11). All the children followed the pediatric intensive care unit’s standard policies regarding stopping sedation as soon as weaning was commenced, but it is possible that because of different rates of metabolism of the agents, respiratory drive in certain children could have been partially suppressed by the previous sedation. If that is the explanation for the low P0.1, it is, however, surprising that, within a few breaths, the children who failed extubation were able to generate larger P0.1 values, as indicated by their low

Table 1. Comparison of children in whom extubation failed or succeeded

<table>
<thead>
<tr>
<th>Failure</th>
<th>Success</th>
</tr>
</thead>
<tbody>
<tr>
<td>No.</td>
<td>6</td>
</tr>
<tr>
<td>Age (mo.)</td>
<td>23</td>
</tr>
<tr>
<td>P0.1 max</td>
<td>32.0 (0.1–116.7)</td>
</tr>
<tr>
<td>P1 (cm H2O)</td>
<td>8.00 (6.87–29.00)</td>
</tr>
<tr>
<td>P1 max (cm H2O)</td>
<td>43 (11.4–60.7)</td>
</tr>
<tr>
<td>P0.1 (cm H2O)</td>
<td>2.95 (0.83–6.24)</td>
</tr>
<tr>
<td>P0.1 max (cm H2O)</td>
<td>17.00 (6.24–24.30)</td>
</tr>
<tr>
<td>P0.1 max</td>
<td>0.480 (0.150–0.700)</td>
</tr>
<tr>
<td>P0.1/P0.1 max</td>
<td>0.170 (0.097–1.000)</td>
</tr>
<tr>
<td>P0.1/P1 max</td>
<td>0.0567 (0.0478–0.5618)</td>
</tr>
</tbody>
</table>

P0.1, pressure-time product; P1, largest negative pressure generated after 0.1 sec of occlusion; P0.1 max, maximum P0.1; P1 max, maximum P1.

Table 2. Comparison of the areas under the receiver operator characteristic (ROC) curves

<table>
<thead>
<tr>
<th>Extubation Index</th>
<th>Area Under the ROC Curve</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>0.62</td>
</tr>
<tr>
<td>P0.1</td>
<td>0.53</td>
</tr>
<tr>
<td>P1 max</td>
<td>0.53</td>
</tr>
<tr>
<td>P0.1 max</td>
<td>0.57</td>
</tr>
<tr>
<td>P0.1</td>
<td>0.69</td>
</tr>
<tr>
<td>P0.1/P0.1 max</td>
<td>0.77</td>
</tr>
<tr>
<td>P0.1/P1 max</td>
<td>0.67</td>
</tr>
</tbody>
</table>

P0.1, pressure-time product; P1, largest negative pressure generated after 0.1 sec of occlusion; P0.1 max, maximum P0.1; P1 max, maximum P1.
and those who did not fail extubation, as these would not change so rapidly. Changes in blood gases, however, are likely as the occlusion was maintained and would act as a stimulus to respiratory drive (8). We, therefore, feel our results demonstrate that the children who failed extubation had reduced respiratory drive.

Falsely low P0.1 values can result from hyperinflation (11) or muscle exhaustion (12). Relating P0.1/P1 max avoids this problem as, for example, if the lungs are hyperinflated, the diaphragm is mechanically compromised and both inspiratory pressure values are proportionately underestimated, but the value of the ratio remains constant while the two factors taken separately diminish (13). In unsedated adult patients undergoing prolonged mechanical ventilation P0.1/P1 max had 98% accuracy in predicting extubation success (13). The efficiency of this index is suggested to be attributable to the fact that it reveals the balance between respiratory demand and respiratory muscle reserve. In adults, the performance of P0.1/P1 max appears to vary according to the underlying diagnosis (5). In the present population of children suffering from a variety of diagnoses, we found significantly different values of P0.1/P1 max between those who did and those who did not fail extubation.

P0.1/P1 max (the fraction of inspiratory effort reserve) in adult patients is significantly lower in those in whom extubation succeeded compared with those who failed extubation (14), with a threshold value of 0.3. P1 max was determined during a 20-sec period of airway occlusion (14, 15). Such a protracted period of occlusion may be detrimental and unnecessary in infants and children (16). In one study (16), the maximum negative pressure was reached in all patients within 12 secs (and in many within 6 secs) with no more than a transient drop in oxygen saturation. We, therefore, occluded the airway for only five breaths as we felt a test must be minimally disruptive to be clinically useful. As previously noted in children (16), we found no significant difference in P1, P1 max or P0.1/P1 max between those who did and those who did not fail extubation, and only a minor proportion of our study population were below the adult cutoff value of 0.3 for P0.1/P1 max (14).

The PTP correlates closely with the metabolic work or oxygen consumption of the respiratory muscles (17). Respiratory muscle endurance, however, depends on both the pressure generated and the duration of the contraction in relation to the cycle duration (18) and thus PTP may not adequately assess respiratory muscle endurance under certain circumstances (19–21). During inspiratory resistive breathing against fatiguing loads, work rate determines endurance independently of the PTP (19). Thus, perhaps it is unsurprising that no statistically significant differences between the median PTP of children in whom extubation failed or succeeded were demonstrated.

We conclude that results of assessment of P0.1 and P0.1/P1 max performed better than other airway pressure measurements with regard to predicting extubation failure. Assessment of P0.1 may be useful in characterizing children likely to fail extubation.

REFERENCES