Effect of endotracheal suction on lung dynamics in mechanically-ventilated paediatric patients

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Introduction

Endotracheal suctioning is performed regularly in ventilated infants and children to remove obstructive secretions. The effect of suctioning on respiratory mechanics is not known. This study aimed to determine the immediate effect of endotracheal suctioning on dynamic lung compliance, tidal volume, and airway resistance in mechanically-ventilated paediatric patients by means of a prospective observational clinical study. Lung mechanics were recorded for five minutes before and five minutes after a standardised suctioning procedure in 78 patients intubated with endotracheal tubes ≤ 4.0 mm internal diameter. Twenty-four patients with endotracheal tube leaks ≥ 20% were excluded from analysis. There was a significant overall decrease in dynamic compliance (p < 0.001) and mechanical expired tidal volume (p = 0.03) following suctioning with no change in the percentage endotracheal tube leak (p = 0.41). The change in dynamic compliance was directly related to both endotracheal tube and catheter sizes. There was no significant change in inspiratory or expiratory airway resistance following suctioning (p > 0.05). Although the majority of patients (68.5%) experienced a drop in dynamic compliance following suctioning, dynamic compliance increased in 31.5% of patients after the procedure. This study demonstrates that endotracheal suctioning frequently causes an immediate drop in dynamic compliance and expired tidal volume in ventilated children with variable lung pathology, intubated with small endotracheal tubes, probably indicating loss of lung volume caused by the suctioning procedure. There is no evidence that suctioning reduces airway resistance. [Morrow B, Futter M and Argent A (2006): Effect of endotracheal suction on lung dynamics in mechanically-ventilated paediatric patients. Australian Journal of Physiotherapy 52: 121–126]

Key words: Endotracheal Suctioning, Respiratory Mechanics, Mechanical Ventilation, Paediatrics, Lung Compliance, Complications
Demographic data were recorded for each patient, including: age, gender, weight and medical condition, as well as oxygenation and ventilatory requirements. Endotracheal tube size and the catheter size used for suctioning were recorded. Oxygenation index (OI) and ventilation index (VI) were calculated for each patient (Peters et al 1998) as well as PaO₂/FiO₂.

Suction for study purposes coincided with the nursing staff’s planned time of suction so that no additional patient discomfort was experienced. All patients received sedation and analgesia with intravenous morphine. Additional agents were not administered prior to the study intervention.

Patients were connected to a CO₂SMO Plus! monitor by means of a neonatal CO₂/flow sensor (< 1 ml deadspace) as recommended in the manufacturer’s User Manual for five minutes before and five minutes after a single pass suctioning procedure (see below). The CO₂SMO Plus! was chosen for this study as it has been validated as a sensitive tool capable of measuring applied volume changes within 0.9% (2.3% SD) accuracy (Main et al 2001). Similarly, pressure recordings were within 2% of those displayed by an electric manometer. The least squares algorithm used by the CO₂SMO Plus! to calculate compliance and resistance has previously been found to be accurate to within 5% (Main et al 2001).

Data were downloaded from the CO₂SMO Plus! using Analysis Plus for Windows. Dynamic compliance, dynamic expiratory (Rₑ) and inspiratory (Rᵢ) airway resistance; expiratory spontaneous and expiratory mechanical tidal volume (Vtₑ and Vtᵦₑ), total minute volume (MV) and total respiratory rate (RR) were automatically computed by the CO₂SMO Plus!. Breath-by-breath values were averaged over each minute of recording and used for analysis. Parameters were corrected for patient body weight, using the documented paediatric intensive care unit admission weight. Expired tidal volume was used rather than inspired tidal volume to minimise errors due to endotracheal tube leak in children with uncuffed endotracheal tubes (Kuo et al 1996, Main et al 2001).

The percentage leak around the endotracheal tube was calculated for each patient using each minute’s averaged values of mechanical inspired tidal volume (Vtᵦₑ) and Vtₑ according to the equation derived by Main and colleagues (Main et al 2001):

\[
\text{Leak} (%) = \left[ \frac{\text{Vtᵦₑ} - \text{Vtₑ}}{\text{Vtᵦₑ}} \right] \times 100.
\]

The suctioning procedure was performed as follows. The patient was pre-oxygenated with 100% inspired oxygen for ≤30 seconds prior to suctioning. He or she was disconnected from the ventilator, a suction catheter was passed down the endotracheal tube to just beyond the endotracheal tube tip, continuous suction was applied and the catheter withdrawn whilst rotating slightly. The patient was then immediately reconnected to the ventilator circuit. Any adverse events were documented. We used a range of catheter sizes, according to availability and endotracheal tube size. The suction apparatus was set on ‘medium’, corresponding to a vacuum pressure, measured at the source with tubing clamped, of approximately –360 mmHg. The suction catheter was in the endotracheal tube for ≤10 seconds. After suctioning was completed, the FiO₂ was immediately changed to presuction settings unless desaturation occurred, in which case FiO₂ was gradually turned down as SaO₂ improved. All the suctioning procedures were performed by the same physiotherapist.

Throughout the observation and suction period, there was continuous electrocardiological and pulse oximetry monitoring.

**Statistical analysis** Data were tested for normality using the Kolmogorov-Smirnov and Lilliefors tests. Normally
The patients were not paralysed and were therefore able to breathe spontaneously between mechanically delivered breaths. Twenty-four patients had endotracheal tube leaks ≥ 20% and these patients were excluded from subsequent analyses, with a resulting median leak of 2.5%.

Primary medical conditions for which the remaining 54 patients were admitted to the paediatric intensive care unit are listed in Table 2. Some patients had more than one diagnosis. Forty-six patients (85%) had primary lung pathology. Thirty-two patients (59%) conformed to the definition of acute respiratory distress syndrome (ARDS) with acute onset of respiratory disease, bilateral infiltrates on chest X-ray and $\mathrm{PaO_2}/\mathrm{FiO}_2 \leq 200 \text{ mmHg}$ (Bernard et al 1994). Thirty of these patients had primary pulmonary disease with two having secondary or nonpulmonary ARDS as a result of sepsis. Eight patients (15%) fulfilled the criteria for acute lung injury (ALI) with bilateral infiltrates on chest X-ray and $\mathrm{PaO_2}/\mathrm{FiO}_2 \leq 300 \text{ mmHg}$ (Bernard et al 1994). Eight patients (15%) were ventilated for non-pulmonary indications.

Table 3 presents pulmonary function parameters before and after suctioning. There was a significant overall decrease in dynamic compliance ($p < 0.001$) and $V_{te,mec}$ ($p = 0.03$) following suctioning. There was no statistical difference between pre- and post-suction $R_2$ ($p = 0.1$) or $R_2$ ($p = 0.09$). There was also no change in the percentage leak after suction ($p = 0.41$).

There was a variable response to suctioning, with the majority of patients (37, 68.5%) experiencing a drop in dynamic compliance following suctioning. Of these patients, dynamic compliance dropped by > 15% in 11 patients (20.4%) and by > 20% in 10 patients (18.5%). Seventeen of the 54 (31.5%) patients had an increase in dynamic compliance following suctioning, two (11.8%) of whom had a change of > 20%. The coefficient of variation of dynamic compliance readings before suctioning was 2.8% (SE 2.4%) and after suctioning it was 0.95% (SE 0.44%) ($p = 0.44$). There was also no change in dynamic compliance change between patients with ARDS ($\mathrm{PaO_2}/\mathrm{FiO}_2 < 200 \text{ mmHg}$) and without ARDS ($\mathrm{PaO_2}/\mathrm{FiO}_2 > 200 \text{ mmHg}$) ($p = 0.24$).

There was no correlation between the decrease in dynamic compliance following suctioning and the change in % leak ($p > 0.5$). There was a significant correlation between baseline dynamic compliance and the subsequent change in dynamic compliance following suctioning (Spearman’s $R = -0.43; p < 0.001$) (Figure 1). There was no correlation between the decrease in dynamic compliance and the change in % leak after suctioning ($p = 0.24$). The mean (SD; range) of the ratio of suction catheter external to area difference (internal area endotracheal tube–external area catheter) was 0.75 (0.25; 0.29 to 1.78). There was a significant correlation between the drop in dynamic compliance following suctioning and the change in % leak ($p = 0.1$).

Figure 1. The correlation between baseline dynamic compliance and the subsequent change in compliance following endotracheal suctioning (Spearman’s $R = -0.43; p < 0.001$).

Table 3. The median (IQR) pre- and post-suction lung function parameters ($n = 54$).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Before suction</th>
<th>After suction</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dynamic compliance (ml/cmH$_2$O/kg)</td>
<td>0.60 (0.45–0.82)</td>
<td>0.56 (0.41–0.75)</td>
<td>&lt; 0.001*</td>
</tr>
<tr>
<td>Inspiratory dynamic airway resistance (cmH$_2$O/l/s)</td>
<td>50.0 (32.3–84.3)</td>
<td>51.2 (29.0–76.7)</td>
<td>0.09</td>
</tr>
<tr>
<td>Expiratory dynamic airway resistance (cmH$_2$O/l/s)</td>
<td>72.4 (49–111)</td>
<td>73.8 (42.9–111.4)</td>
<td>0.12</td>
</tr>
<tr>
<td>ETT leak (%)</td>
<td>2.47 (~2.9–9.5)</td>
<td>3.45 (~2.6–10.2)</td>
<td>0.41</td>
</tr>
<tr>
<td>Mechanical expired tidal volume (ml/kg)</td>
<td>7.00 (5.45–8.24)</td>
<td>6.70 (5.38–8.18)</td>
<td>0.03*</td>
</tr>
<tr>
<td>Spontaneous expired tidal volume (ml/kg)</td>
<td>2.27 (0.2–3.9)</td>
<td>2.38 (0.76–3.75)</td>
<td>0.10</td>
</tr>
<tr>
<td>Total respiratory rate (breaths per minute)</td>
<td>49.5 (34–68)</td>
<td>52.5 (36–72)</td>
<td>0.006*</td>
</tr>
<tr>
<td>Total minute volume (l/kg)</td>
<td>0.25 (0.21–0.31)</td>
<td>0.28 (0.22–0.40)</td>
<td>&lt; 0.001*</td>
</tr>
</tbody>
</table>

* $p < 0.05$
Table 4. The median (IQR) before and after suction lung function parameters for patients who experienced an increase in dynamic compliance following suction (n = 17).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Before suction</th>
<th>After suction</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dynamic compliance (ml/cmH(_2)O/kg)</td>
<td>0.54 (0.44–0.75)</td>
<td>0.55 (0.47–0.84)</td>
<td>&lt; 0.001*</td>
</tr>
<tr>
<td>Inspiratory dynamic resistance (cmH(_2)O/l/s)</td>
<td>40.4 (27.2–69.3)</td>
<td>39.0 (24.6–69.0)</td>
<td>0.03*</td>
</tr>
<tr>
<td>Expiratory dynamic resistance (cmH(_2)O/l/s)</td>
<td>65.6 (33.1–98.8)</td>
<td>66.1 (35.4–103.0)</td>
<td>0.42</td>
</tr>
<tr>
<td>% Tracheal tube leak</td>
<td>2.3 (–3.1–10.34)</td>
<td>3.5 (0–10.5)</td>
<td>0.41</td>
</tr>
<tr>
<td>Total respiratory rate (breaths per minute)</td>
<td>59.5 (43–71)</td>
<td>62 (40.5–74.5)</td>
<td>0.23</td>
</tr>
<tr>
<td>Spontaneous expired tidal volume (ml/kg)</td>
<td>2.1 (0.8–3.7)</td>
<td>2.6 (0.8–3.5)</td>
<td>0.93</td>
</tr>
<tr>
<td>Mechanical expired tidal volume (ml/kg)</td>
<td>6.19 (4.78–7.80)</td>
<td>6.22 (4.79–8.31)</td>
<td>0.03*</td>
</tr>
<tr>
<td>Total minute volume (l/kg)</td>
<td>0.24 (0.21–0.3)</td>
<td>0.28 (0.23–0.35)</td>
<td>&lt; 0.001*</td>
</tr>
</tbody>
</table>

*p < 0.05

compliance and the ratio of suction catheter external area to area difference (Spearman’s R = 1.17; p = 0.004).

The 17 patients whose dynamic compliance increased following suctioning had a median age of 3.5 months (range 0.25 to 17), a baseline OI of 6.45 (1.35 to 15.20), VI of 19.9 (4.6 to 63.2) and PaO\(_2\)/FiO\(_2\) of 210.1 (80.25 to 747.90). There was no difference in age, VI, or PaO\(_2\)/FiO\(_2\) between patients who increased or decreased dynamic compliance after suctioning (p > 0.1). However, patients whose dynamic compliance increased had a higher OI (p = 0.03) and a lower baseline dynamic compliance (p < 0.001) than that of patients who experienced a drop in dynamic compliance following suctioning.

Table 4 presents selected parameters before and after suctioning in those patients whose dynamic compliance increased after suctioning. There was a significant decrease in R\(_i\) in these patients after suctioning (p = 0.03) and an increase in both Vte\(_\text{mech}\) (p = 0.03) and total MV (p < 0.001). One outlier, likely due to a measurement error, was removed prior to analysis. The removal of this patient’s values did not significantly alter the results.

Three patients desaturated transiently to < 85% as a result of the suctioning procedure. These episodes were all self-limiting. All other patients maintained SaO\(_2\) > 85% throughout the suctioning procedure, except for one patient with a cyanotic heart lesion who had baseline SaO\(_2\) of 83% before suctioning. One patient experienced a transient relative bradycardia during suctioning; this was self-limiting and no added intervention was needed. In all cases FiO\(_2\) was turned back to pre-suction settings within a minute after suction, with no further desaturation events occurring.

**Discussion**

In this study we recorded an overall decrease in dynamic compliance and Vte\(_\text{mech}\) following a standardised, single episode of endotracheal suctioning, in a heterogeneous patient group. The two children with inhalational burns were included in the analysis as their chests were not burnt and constrictive dressings were therefore not applied.

Dynamic compliance readings were highly repeatable with a small coefficient of variation (< 5%) which did not change from before to after suctioning. It is notable that the majority (69%) of patients experienced a drop in dynamic compliance following suctioning, and 39% of those dropped dynamic compliance by more than 15%, which is likely to be clinically significant. These results support the findings of Brandstater et al (1969) who documented a consistent fall in pulmonary compliance, interpreted as atelectasis, produced by endotracheal suctioning in a small group of paralysed neonates.

An artefactual change in compliance may be caused by a change in the leak around the endotracheal tube (Main et al 2001), while real changes in compliance may be caused by changes in the characteristics of the chest wall, by lung collapse (Davis et al 1996, Ingimarsson et al 2000) or by overdistention of the lung.

When a large leak is present, values of compliance and resistance are overestimated (Bernard et al 1994, Kondo et al 1997, Main et al 2001). Main et al (2001) emphasise that in the presence of a leak, apparent changes in compliance or resistance may not in fact reflect real clinical changes, but simply a change in the magnitude of the leak. As a result of this concern, all patients with endotracheal tube leaks ≥ 20% were excluded from this analysis with the resulting median leak being small at 2.5%. There was no change in leak following suctioning (p = 0.4), confirming that the decrease in dynamic compliance was not artefactual due to a change in the percentage leak around the endotracheal tube (Main et al 2001), and is more likely to reflect real changes.

Although there was a range of respiratory pathology represented in this sample, the majority of patients had low to normal compliance, and no patients with severe air-trapping were included in the sample. Ventilatory pressures were low, and no hyper- or re-inflation manoeuvres were performed. Thus overinflation is unlikely to explain the drop in compliance. Applied airway pressure was constant, there was no change in patient position, and no reason to consider that there were any changes in chest wall compliance (Davis et al 1996, Ingimarsson et al 2000, Nunn 1993). The decrease in dynamic compliance and mechanical tidal volume is, therefore, most likely to reflect a loss of lung volume.

In contrast to the findings of Fox et al (1978), who demonstrated a significant drop in R\(_i\) and a trend towards a drop in R\(_e\), we did not record an overall change in R\(_i\) or R\(_e\) as a result of suctioning. This may be partly explained by the fact that resistance is only likely to drop substantially if significant amounts of mucus were being removed during...
suctioning. Suctioning for this study was performed on patients who were undergoing regular, routine airway clearance, and who therefore did not necessarily have secretions in the airways.

We have shown previously (Morrow et al 2004) that the change in pressure recorded in a lung model was linearly related to the catheter area/area difference (difference between internal endotracheal tube area and external catheter area) ratio. We have now shown that a significant correlation also exists between the drop in compliance following suctioning and the ratio of suction catheter area to area difference. As the catheter increased in size relative to the internal endotracheal tube size, a larger drop in compliance occurred. This relationship suggests that the compliance changes recorded were, at least partly, due to the actual suctioning procedure as opposed to just being caused by the loss of airway pressure on disconnecting from the ventilator.

Patients with more compliant lungs experienced a greater drop in dynamic compliance following suctioning than those with poor baseline compliance, or “stiff” lungs. This is difficult to explain and awaits confirmation in further studies. The extent of compliance change could not be predicted using respiratory severity indicators or age.

There was a significant increase in total minute volume following suctioning. This may be explained by the increase in spontaneous respiratory rate (seen as a significant increase in total respiratory rate) following suctioning, possibly due to the distress or discomfort caused by the suctioning procedure.

An increase in dynamic compliance following suction was experienced by 32% of patients. We were unable to identify predictive factors (including diagnosis, age, weight, gender and ventilatory parameters) for the increase in dynamic compliance, but these patients did have higher OI and a lower baseline compliance than patients whose dynamic compliance dropped with suctioning. It seems likely that in these patients, secretions were present at the time of suctioning. Secretion volume was not measured but this hypothesis is supported by the significant drop in dynamic inspiratory airway resistance in this group of patients following suctioning. If secretions were drawn into the catheter during suctioning, suction flow would be blocked and the lung would not be exposed to negative pressure. As a result of this, lung volume loss is unlikely to occur, and a drop in dynamic compliance would not be recorded. In addition, removal of these obstructive secretions from the airways may have opened up a significant area of lung to gas exchange thus increasing lung volume and improving compliance. This is supported by the increase in $V_{te,mc}$ and minute volume in these patients ($p = 0.03$). Further investigation is required in order to identify groups of patients who are likely to benefit from suctioning.

There were few other complications of endotracheal suctioning in this study. The only side-effects were three episodes of transient desaturation and a single episode of relative bradycardia. These complications have been reported previously (Fox et al 1978, Graff et al 1987, Kohlhauser et al 2000, Skov et al 1992, Simbruner et al 1981, Rosen and Hillard 1962). The drop in dynamic compliance and tidal volume after a single-pass suction event therefore seemed to have little immediate clinical effect. However, repeated suction passes (as often occurs in the clinical situation) are likely to result in more complications and greater lung volume loss. Hypoxia may have been limited by hyperoxigenating the patients before and immediately after suctioning.

Despite the apparently minor clinical effects of suctioning reported here, the periodic derecruitment which appears to be induced by endotracheal suctioning could be harmful in patients with ALI or ARDS (Taskar et al 1997), where prevention of alveolar overdistension and derecruitment are the goals of lung protective ventilatory strategies (Maggiore et al 2003, Taskar et al 1997).

This study demonstrates that endotracheal suctioning frequently causes a drop in dynamic compliance and tidal volume in ventilated children with variable lung pathology, intubated with small endotracheal tubes. The change in compliance is related to both endotracheal tube and catheter sizes, and is likely to indicate loss of lung volume caused by the suctioning procedure. Further studies will be required to establish the clinical significance of these changes. The increase in dynamic compliance observed in a third of patients suggests that suctioning may have beneficial effects on lung mechanics when performed in the presence of obstructive secretions, but this requires further investigation. These results do, however, support the suggestion that suctioning should be performed only when indicated by the presence of secretions, and not on a routine basis.

We did not record lung mechanics beyond five minutes after suctioning and it is therefore a matter of conjecture as to what would happen in the hours following suctioning. Further investigation is therefore necessary to determine the mid- and long-term effects of endotracheal suctioning on lung mechanics, and whether recruitment manoeuvres are effective in reversing these effects.

Footnotes
(a)CO$_2$SMO Plus! Model 8000 Respiratory Profile Monitor (Novametrix Medical Systems Inc. USA)  
(b)Analysis Plus for Windows Version 5.0 (Novametrix Medical Systems Inc, USA)  
(c)Marquettehellige Eagle 3000 patient monitor, MILW, WL, USA; Ohmeda Biox Pulse Oximeter, Crest Healthcare, RSA  
(d)Models E100l and E100m, Newport Medical Instruments, Inc., USA.

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