Effects of a closed system suction connector on airway resistance in ventilated neonates

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Background/aim: Increased airway resistance reduces the effectiveness of ventilation treatment. Endotracheal tubes (ETTs) and connectors contribute to resistance. However, the effect of a closed system suction (CSS) connector is not well known. We compared the in vivo resistance occurring with a CSS connector with that of the standard connector.

Materials and methods: This prospective study was conducted at Gazi University Hospital’s neonatal intensive care unit. Intubated neonates were studied for two cycles; each cycle contained two periods of ETT + connector pairs (15 min/period) as follows: cycle 1 [A: long ETT + standard connector; B: long ETT + CSS connector] and cycle 2 [C: shortened ETT + standard connector; D: shortened ETT + CSS connector]. Resistance of 40 breaths/period was averaged for each case, and the means were analyzed by Wilcoxon test for pairwise comparisons between standard and CSS connectors. As each case provided two cycle data, 16 cycle data were compared.

Results: The CSS connector increased resistance by 13.8% (range: 3.0%–22.1%) compared to the standard connector; P < 0.001. The resistance increase was similar between long [17.3% (range: 3.0%–17.7%)] and shortened ETTs [15.3% (range: 5.0%–29.6%)]; P = 0.834.

Conclusion: CSS connectors were found to increase airway resistance in ventilated neonates. The contribution of CSS should be considered during ventilation, particularly in the presence of difficulty in providing sufficient tidal volume.

Key words: Mechanical ventilation, airway resistance, closed system suction, neonate

1. Introduction
Airway resistance is defined as the ratio of driving pressure to the rate of air flow and it is a result of the force of friction. Anatomical structures (trachea, bronchi, and bronchioles), ventilatory circuit, and endotracheal tube (ETT) are the components of the airway. Airway resistance increases as the gas flow rate, the length of airway, and gas density increases and decreases as diameter of airway or ETT increases. Neonates are intubated using narrow ETTs. Therefore, avoiding increases in airway resistance during mechanical ventilation is crucial. Increasing airway resistance hinders the attainment to the tidal volume level aimed during ventilation, and thus the effectiveness of ventilation treatment is reduced (1).

In in vitro studies, ETTs of different brands have been reported to have caused different airway resistance levels, and extending ETTs with connectors have also been reported to have increased tube resistance (2,3). ETT closed system suctions (CSS) have their own connectors. The CSS connector is 13 mm longer than the standard connector. Therefore, it may be assumed that a longer length of CSS connector would increase airway resistance. Kazancı et al. reported in their in vitro study that CSS connector increased airway resistance by 4%–16% (4). However, in vivo measurements of resistance could be higher than those of the in vitro results (5). The aim of the present study was to compare the effect of the CSS connector with the standard ETT connector as well as the length of the ETT on airway resistance in ventilated neonates.

2. Patients and methods
The study was conducted prospectively at the neonatal intensive care unit at Gazi University Hospital. Gazi University Medical Faculty Ethics Committee approved the study.

2.1. Study design
Neonates who were intubated for mechanical ventilation due to respiratory distress were included in the study. Those who received pre-intubation surfactant treatment...
within 2 h and neonates with pneumothorax, pulmonary hemorrhage, or pulmonary interstitial emphysema were excluded. We used 2.5 and 3.0 ETTs (Bıçakcılar, İstanbul, Turkey) and connectors belonging to either ETTs or the CSS (Covidien, Hampshire, UK).

2.2. Mechanical ventilation and ETT-connector pairs

Mechanical ventilation was performed by Draeger Babylog 8000 Plus ventilator (Draeger, Lubeck, Germany). The neonates were ventilated by pressure support ventilation with volume guarantee. Mechanical ventilation was maintained as four periods (A, B, C, D) of ETT + connector pairs as follows: cycle 1 [A: long ETT + standard connector; B: long ETT + CSS connector] and cycle 2 [C: shortened ETT + standard connector; D: shortened ETT + CSS connector]. The ETTs were shortened to 12 cm in length. Each period lasted 15 min. Ventilatory settings were as follows: inspiration time 0.3 s, trigger sensitivity 1, and flow rate 7 L/min. Sedative or analgesic treatments were not used. The patients were not aspirated before or during the study.

2.3. Data acquisition

The tidal volume (mL/kg) and fraction of inspired oxygen (FiO₂; %) were recorded manually. Resistance (cmH₂O/L/s), peak inspiratory pressure (cmH₂O), positive end-expiratory pressure (cmH₂O), and leak (%) were recorded in real time every 10 s using the software Babyview. The data were transferred onto a computer via the RS232 port of the mechanical ventilator. Before recording was initiated, it was checked that the leak level was below 40%. The recording time lasted 15 min for each period. The data were first transferred into a comma separated values file (Microsoft Corp., Redmond, WA, USA) and then this file was converted to a Microsoft Excel file (Microsoft Excel, Microsoft Corp.). At this stage, the data of each infant were transferred into SPSS V15.0 (SPSS, Inc., Chicago, IL, USA). Recorded breaths with any leak or peak inspiratory pressure equal to positive end-expiratory pressure were deleted during data cleaning as they did not reflect actual respiratory pressures. The first five breaths at the beginning of each period were not included in the study. Following the data cleaning, the first 40 breaths of each period were included in the data analysis.

2.4. Evaluation of airway resistance

Resistances of included breaths were averaged over each period for each case and the means were analyzed for the effect of CSS connector and tube shortening. The effect of the CSS connector was evaluated in both long and shortened ETTs. As each case provided two cycle data regarding 2 connector types, comparisons were performed in 16 cycle data. Pairwise comparisons of periods were performed for standard vs. CSS connector both for cycle 1 (period A vs. period B) and cycle 2 (period C vs. period D). The effect of tube length was also assessed similarly as period A vs. period C and period B vs. period D. The change in resistance was calculated in percentages.

2.5. Statistical analyses

Statistical analyses were performed using SPSS V15.0. Distribution of the measurements of resistance was evaluated by visual and analytical methods. Resistance data were not compatible with normal distribution and thus nonparametric tests were performed. The Mann–Whitney U test was used to analyze the difference in resistance values of the breaths within each patient. Wilcoxon’s test was used to examine the effects of CSS connectors and the reduction in ETT length on resistance. Any P value less than 0.05 was considered statistically significant. Values are defined as median (interquartile range).

We found no statistical data regarding standard deviations of measurements of resistances in in vivo studies and therefore we used the data from the in vitro study by Ivanov et al. as a reference to calculate the necessary number of breaths/period for each case (6). We assume that the standard deviation will be larger as this is an in vivo study; therefore we used twice the reference’s standard deviation value for power analyses. It revealed that 40 breaths per period achieved 80% power with 0.05 type 1 error when a 20% change in resistance values was considered significant. To determine the number of cases to be involved we run a power analysis for Wilcoxon’s test. It showed that 16 cycle data will give 80% power with 0.05 type 1 error (two-tailed) when a change of one standard deviation (effect size; 1.0) was considered significant. As each case provided two cycle data we included eight cases.

3. Results

The study included eight neonates (Table 1). A total of 160 breaths of each patient (40 breaths for each period) were evaluated. Actual values of resistance in each period for each patient are presented in the Figure.

The effects of CSS connector and tube shortening on resistance are shown in Table 2 as change in percentages. Switching from the standard connector to the CSS connector resulted in a 13.8% (3.0%–22.1%) increase in resistance, which was a statistically significant effect (P = 0.003). The CSS connectors increased resistance similarly when the long and shortened ETTs were compared (increase in resistance (%): long ETT 17.3% (3.0%–17.7%) and shortened ETT 15.3% (5.0%–29.6%), P = 0.834).

The reduction in ETT length caused a 17.3% (7.4%–36.8%) decrease in resistance, which was statistically significant (P < 0.001). Tube shortening decreased resistance similarly when either the standard or CSS connector was used (decrease in resistance (%): standard connector 19.9% (5.5%–31.1%) and CSS connector 14.9% (8.7%–37.6%), P = 0.645).
Table 1. Characteristics of patients included.

<table>
<thead>
<tr>
<th>Patient</th>
<th>Birth weight (g)</th>
<th>Gestational age (weeks)</th>
<th>Diagnosis</th>
<th>ETT number</th>
<th>FiO₂ (%)</th>
<th>Tidal volume (mL/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient 1</td>
<td>980</td>
<td>27</td>
<td>RDS</td>
<td>2.5</td>
<td>28</td>
<td>4.5</td>
</tr>
<tr>
<td>Patient 2</td>
<td>1000</td>
<td>29</td>
<td>RDS</td>
<td>2.5</td>
<td>46</td>
<td>4.2</td>
</tr>
<tr>
<td>Patient 3</td>
<td>1020</td>
<td>29</td>
<td>RDS</td>
<td>2.5</td>
<td>28</td>
<td>4.0</td>
</tr>
<tr>
<td>Patient 4</td>
<td>1200</td>
<td>30</td>
<td>RDS</td>
<td>3.0</td>
<td>30</td>
<td>4.0</td>
</tr>
<tr>
<td>Patient 5</td>
<td>1780</td>
<td>31</td>
<td>RDS</td>
<td>3.0</td>
<td>41</td>
<td>4.2</td>
</tr>
<tr>
<td>Patient 6</td>
<td>2125</td>
<td>34</td>
<td>RDS</td>
<td>3.0</td>
<td>37</td>
<td>4.0</td>
</tr>
<tr>
<td>Patient 7</td>
<td>2300</td>
<td>35</td>
<td>Pneumonia</td>
<td>3.0</td>
<td>38</td>
<td>4.1</td>
</tr>
<tr>
<td>Patient 8</td>
<td>2750</td>
<td>35</td>
<td>Pneumonia</td>
<td>3.0</td>
<td>26</td>
<td>4.0</td>
</tr>
</tbody>
</table>

RDS: Respiratory distress syndrome; ETT: endotracheal tube; FiO₂: fraction of inspired oxygen

Figure. Resistance values of different combinations of tube and connector. ETT: endotracheal tube, CSS: closed system suction.
4. Discussion
Resistance is an important issue in neonatal mechanical ventilation, during which the aim is to deliver targeted tidal volume. Neonates are usually intubated with narrow ETTs and have secretions, both of which are well known factors increasing resistance. Moreover, device (e.g., connector, flow sensor) induced dead space has an additional effect on resistance (3,6). In the present study, we found that CSS connectors increased airway resistance in mechanically ventilated neonates when compared to standard connectors.

In 1978, Hatch reported a study investigating the effects of five different shaped connectors on airway resistance. He showed that connector resistance is an important contributor to airway resistance. Of the different connectors that were investigated, the curved connector was found to alter resistance (3). Another type of connector is the one that belongs to CSS devices, with sizes suitable for different sized ETTs. This system is advantageous in terms of maintaining tidal volume during aspiration and thus they are widely used in NICUs (7,8). Previously, Kazancı et al. reported a 4%–16% increase in resistance with the use of CSS connectors when compared to standard connectors in their in vitro study (4). However, in both English and Turkish literature, there is no report examining the in vivo effects of CSS connectors on airway resistance. In the present study, the use of CSS connectors was shown to increase airway resistance by 13.8% (3.0%–22.1%) compared to the standard connectors, with either long or shortened ETTs. Wright et al. demonstrated that airway resistance in in vivo models was higher than that in in vitro models. In addition, the authors especially noted distinct individual differences (5). Similarly, in the present study, resistance increase was highly variable, being between 0% and 73%, which indicated distinct individual differences. In line with Wright et al.’s study, resistance changes in our study were slightly more than the difference stated in the in vitro study by Kazancı et al. This
can be attributed to individual differences in pulmonary mechanics in infants.

Based on the well-known Poiseuille's law, ETT resistance is directly proportional to the length of the ETT (L) and inversely proportional to the fourth power of the airway diameter (r) \( (L \times n/r^4; n: \text{viscosity of the gas}) \) (1). In the present study, this classical outcome was supported by the finding that airway resistance was significantly decreased by 2.2%–50.4% after shortening of ETTs even though great individual variability was also noted.

Recently, Ivanov reported the importance of reduction in the instrumental dead space for improvement of ventilation in their bench study. The authors demonstrated when the dead space in ETT connectors was decreased artificial lung ventilation improved, even though a slight increase in airway resistance and work of breathing occurred (6). Authors commented on this conflicting finding as the increase in resistance and work of breathing may affect patients especially during weaning as the importance of reduction in the instrumental dead space during weaning was previously emphasized (9).

The most important feature of the present study is that the effect of the CSS connector on airway resistance was compared with the standard connector for the first time via an in vivo design. The small number of patients involved in the present study is an important limitation. Both the wide distribution of patients in terms of gestational age (27–35 weeks) and birth weight (980–2750 g) and variable degrees of parenchymal problems may explain the remarkable individual differences, which were higher than expected. This observation may demonstrate that mechanical ventilation treatment requires optimization of multiple mechanics within each patient.

In conclusion, CSS connectors may alter ventilation treatment by increasing airway resistance and thus work of breathing. During volume-guarantee ventilation, in the case of difficulty in providing sufficient tidal volume, the effect of CSS connector should be taken into consideration. Monitoring resistance may be helpful when CSS connectors are used and set tidal volumes cannot be achieved.

References