Head Position and Oral vs Nasal Route as Factors Determining Endotracheal Tube Resistance*

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Study objective: We performed this in vitro study to determine the following: (1) if there is any significant difference in resistance between comparably sized endotracheal tubes (ETTs) in simulated anatomic oral and nasal conformations; (2) if neck flexion would increase the resistance of the ETT; and (3) if a wire-reinforced tube in simulated oral conformation would minimize the resistance increase at bends in the tube.

Design: The pressure drops (the change in pressure the flow through the ETT) at the proximal end of three sizes of tubes (6-, 7-, and 8-mm inner diameter) were measured in anatomic conformations at flows ranging from 20 to 100 L/min with the tubes warmed to 37°C.

Results: There were no significant differences in pressure drops between comparably sized ETTs in the nasal vs oral conformation at any flow tested. Maximal head flexion produced a small increase in pressure drop for the standard 6-mm ETT but not for the larger tubes. The wire-reinforced tubes, when compared with the standard 7- and 8-mm ETTs, actually had greater pressure drops across the tubes at high flows.

Conclusions: (1) Pressure differences between ETTs in nasal and oral conformations with comparable size and length are insignificant, even at high flow rates. (2) Maximal neck flexion does not deform the tube enough to make a clinically significant difference in resistance in vitro, although the 6-mm ETT had a slightly higher resistance in flexion. (3) A size 7- or 8-mm reinforced ETT has a higher resistance compared with a standard ETT.

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ETT=Endotracheal tube

The resistive work of moving air across the normal adult upper airway constitutes a relatively small fraction—about 10 percent—of the work of breathing. When an endotracheal tube (ETT) is present, it adds to the upper airway resistance, and this component of total work may double or even triple, but this represents an increase in work that can be handled easily by most patients under general anesthesia.

In critically ill patients with respiratory failure or in patients with air trapping requiring high inspiratory flows, the work of moving gas across an ETT becomes substantial and the resistance of the ETT must be considered whether the work is done by the patient or by a mechanical ventilator.

Prior measurements of the pressure drop across ETTs have generally been made under conditions that do not reflect the actual conformations of the ETT in the body. We studied the pressure drop across three sizes of ETTs at 37°C in anatomic positions to test the following hypotheses: (1) the conformational differences between comparably sized oral and nasal ETTs of the same length would not result in a significant difference in resistance; (2) neck flexion would increase the resistance of ETT; and (3) a wire-reinforced tube would minimize the deformation from a circular cross-sectional profile and thus minimize any resistance increase at bends in the tube.

Materials and Methods

We studied standard and reinforced ETTs (Hi-Lo Tracheal Tube and Reinforced Tracheal Tube, Mallinckrodt Critical Care, Glens Falls, NY) in 6-, 7-, and 8-mm inner diameter sizes and of identical length (26.5 cm). Lateral radiographic views of the neck were used to trace the conformation of the ETT. The tracings were made from radiographs taken for clinical reasons of anesthetized, tracheally intubated adult patients in a neutral supine position and from patients whose necks were flexed. The flexed views were from patients in marked flexion to represent the extreme that might be seen clinically. The conformations of the tube were then reproduced on a pegboard. Figure 1 shows one set

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analysis

Oxygen (Validyne, the kinetic nasal rate with measurements were made for each size and conformation of ETT. For each size, the identical ETT was tested in the oral and nasal conformation.

The measurements were made as depicted in Figure 2. A 15-cm-long entry flow tube was inserted between the pneumotachograph and the elbow connector to minimize entry flow effects and kinetic energy variation effect. Pressure at the proximal end of the ETT was measured with a differential pressure transducer (Validyne MP 45-30-871; Validyne, Northridge, Calif) and wall oxygen was used to deliver a predetermined steady gas flow, measured by a pneumotachograph (Hans Rudolph, Inc; Kansas City, Mo) coupled with a second differential pressure transducer (Validyne DP 45-14; Validyne). The flow values tested ranged from 20 to 100 L/min, representing extremes of flow generally seen in patients in the intensive care unit.

Data are presented as mean ± SD. Data were analyzed by analysis of variance and differences between specific conditions were identified using Duncan’s multiple-range test.

RESULTS

Data are presented in Tables 1 through 3. All data are presented as pressure drops since for any given flow, the resistance is directly proportional to the drop in pressure. The pressure drops in the nasal conformation did not differ from the pressure drop in comparable oral conformation at all flows. Flexion produced a small increase in pressure drop for the standard 6-mm ETT but not for the larger tubes. The wire-reinforced tubes, when compared with the standard 7- and 8-mm ETTS, actually had greater pressure drops across the tubes at high flows. The largest difference noted between two tubes of comparable size was the 7-mm ETT at 100 L/min flow. The reinforced tube showed a pressure drop of 36.27 ± 0.17 cm H2O vs 32.93 ± 0.55 cm H2O (p < 0.05) for the Hi-Lo tube in the neutral configuration.

DISCUSSION

The important findings of this in vitro study are as follows: (1) for comparable size and length of tube, an oral tube does not offer less resistance than a nasal tube; (2) contrary to our hypothesis, neck flexion is not a significant factor in increasing flow resistance under tube and flow conditions seen in vitro; and (3) contrary to our hypothesis, wire reinforcement does
not reduce the pressure drop across the tube and may actually increase it under some circumstances.

Endotracheal tube resistance is often evaluated at room temperature with the tube in the conformation determined by the curvature as manufactured. We performed our studies at 37°C because polyvinyl chloride becomes markedly softer with warming and conforms to the curves of the airway. As the tube is bent, the cross-sectional profile will deform from a circle to a smaller cross-sectional area and should theoretically increase resistance. Other factors that may differ between in vitro measurements include accumulated secretions and the effect of the gas exiting into the trachea rather than ambient pressure. We presumed these latter effects should not differ among the tubes and conformations we tested. Our study design included an entry tube between the pneumotachograph and proximal end of the ETT as the pneumotachograph will flatten the velocity profile of the gas.9

We determined pressure drops at a variety of flow rates rather than determining a single resistance value since with turbulent flow, resistance depends on flow rate. For flow rates above 15 L/min, the airflow through any tube with an internal diameter less than 10 mm becomes turbulent10 and high flow rates through irregular or bent tubing increase turbulence.11-14

A section of a 1988 Consensus Conference on Artificial Ventilation noted that the radius of curvature of a nasotracheal tube was less than that of an orotracheal tube11 and would thus produce a sharper bend and a higher resistance. However, we found no previously reported test of this hypothesis. In our study, the pressure drop for the standard 7- and 8-mm ETT in the nasal conformation or with flexion never differed by more than 1 cm H2O from the neutral value. These differences are unlikely to be of

### Table 1—Pressure Drops (cm H2O) for 6-mm ETT

<table>
<thead>
<tr>
<th>Flow, L/min</th>
<th>Neutral Oral</th>
<th>Flexion Oral</th>
<th>Hi-Lo ETT Nasal</th>
<th>Reinforced ETT</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>3.14±0.16</td>
<td>3.53±0.06†</td>
<td>3.11±0.85</td>
<td>3.18±0.18</td>
</tr>
<tr>
<td>40</td>
<td>10.81±0.11</td>
<td>11.72±0.06†</td>
<td>10.14±0.10</td>
<td>11.11±0.17</td>
</tr>
<tr>
<td>60</td>
<td>24.78±0.44</td>
<td>25.93±0.49</td>
<td>24.43±0.04</td>
<td>24.33±0.38</td>
</tr>
<tr>
<td>80</td>
<td>42.75±0.44</td>
<td>44.75±0.89†</td>
<td>41.25±1.32</td>
<td>45.22±0.55</td>
</tr>
<tr>
<td>100</td>
<td>66.43±0.24</td>
<td>69.48±2.00†</td>
<td>64.64±1.70</td>
<td>65.00±1.94</td>
</tr>
</tbody>
</table>

*Data are mean±SD.†p<0.05 vs oral Hi-Lo ETT in neutral position.

### Table 2—Pressure Drops (cm H2O) for 7-mm ETT

<table>
<thead>
<tr>
<th>Flow, L/min</th>
<th>Neutral Oral</th>
<th>Flexion Oral</th>
<th>Hi-Lo ETT Nasal</th>
<th>Reinforced ETT</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>1.70±0.14</td>
<td>1.73±0.12</td>
<td>1.63±0.18</td>
<td>1.70±0.05</td>
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<tr>
<td>40</td>
<td>5.54±0.06</td>
<td>5.90±0.08†</td>
<td>5.52±0.04</td>
<td>6.14±0.11†</td>
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<tr>
<td>60</td>
<td>12.41±0.08</td>
<td>12.64±0.16</td>
<td>12.20±0.31</td>
<td>13.50±0.27†</td>
</tr>
<tr>
<td>80</td>
<td>21.82±0.56</td>
<td>21.95±0.06</td>
<td>20.62±0.21</td>
<td>23.31±0.24†</td>
</tr>
<tr>
<td>100</td>
<td>32.93±0.55</td>
<td>33.46±0.64</td>
<td>31.81±0.75</td>
<td>36.27±0.17†</td>
</tr>
</tbody>
</table>

*Data are mean±SD.†p<0.05 vs oral Hi-Lo ETT in neutral position.

### Table 3—Pressure Drops (cm H2O) for 8-mm ETT

<table>
<thead>
<tr>
<th>Flow, L/min</th>
<th>Neutral Oral</th>
<th>Flexion Oral</th>
<th>Hi-Lo ETT Nasal</th>
<th>Reinforced ETT</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>0.99±0.13</td>
<td>1.12±0.04</td>
<td>0.99±0.11</td>
<td>0.92±0.04</td>
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<tr>
<td>40</td>
<td>3.20±0.12</td>
<td>3.33±0.11</td>
<td>3.21±0.18</td>
<td>3.46±0.04†</td>
</tr>
<tr>
<td>60</td>
<td>6.86±0.13</td>
<td>7.09±0.04</td>
<td>6.83±0.22</td>
<td>7.42±0.12†</td>
</tr>
<tr>
<td>80</td>
<td>11.85±0.21</td>
<td>11.09±0.12</td>
<td>11.39±0.33</td>
<td>12.42±0.22†</td>
</tr>
<tr>
<td>100</td>
<td>17.88±0.05</td>
<td>17.66±0.26</td>
<td>17.60±0.32</td>
<td>18.87±0.46†</td>
</tr>
</tbody>
</table>

*Data are mean±SD.†p<0.05 vs oral Hi-Lo ETT in neutral position.
any clinical significance in relation to the total work of breathing. Flexion increased the pressure drop for the 6-mm ETT by 2 cm H2O at high flows but this is also of little clinical significance since a 6-mm ETT required prohibitive inspiratory pressures at these flows. Thus, the hypothesis that flexion would increase the resistance was correct but only under conditions of little clinical consequence.

Our hypothesis that the reinforced tube would have a lower resistance because of resistance to cross-sectional deformation was proved incorrect. We were surprised to note that at flows exceeding 40 L/min, the reinforced tubes produced higher pressures. The flow of gas in a tube is influenced by two types of friction: the friction among the gas molecules themselves and the friction between the tube wall and the gas molecules.\textsuperscript{11,15} The irregular surface created by the wire reinforcement may have created greater friction. Any beneficial effects of resistance to deformation were thus more than offset by a presumed increase in turbulence or friction.

Our report casts doubt on the speculation that the conformation of a nasal ETT will produce resistance greater than that of a comparably sized oral ETT.\textsuperscript{11} However, the nose will often not accommodate as large an ETT as the mouth, and a nasal tube may need to be longer. These factors may favor the choice of an oral tube if resistance is an important consideration. Additionally, an oral tube can be cut to a shorter length than a nasal tube, which might reduce the resistance of the oral tube to less than that of a nasal tube. The actual differences can be determined only by testing, given the multiple factors involved.

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