Small tidal volume ventilation using a zero deadspace tracheal tube

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The zero deadspace tracheal tube (ZEDS-TT) is a double-lumen endobronchial tube with a truncated bronchial limb. Functionally it is unrelated to the familiar endobronchial tube used in lung isolation surgery. It is placed in the same position as a regular tracheal tube and, by means of special connectors, one limb is used for inspiration and the other for expiration, thereby greatly reducing anatomical and apparatus deadspace. In this study, we have compared respiratory and ventilatory effects of reduction of tidal volume (VT) via a single-lumen tracheal tube and the ZEDS-TT during controlled ventilation with a Siemens Elema 900C Servo ventilator. Eleven consenting adult patients (ASA I and II) undergoing elective peripheral surgery were studied. Starting at a VT value of 10 ml kg\(^{-1}\), data were recorded for each tube type. VT was reduced by 2.5 ml kg\(^{-1}\) every 10 min and stabilized data recorded. Minute volume was kept constant by increasing ventilatory frequency at each reduction in VT. We found that the ZEDS-TT produced a significant reduction in \(P_{aCO_2}\) and airway pressure for any VT used, while maintaining oxygenation.

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Deadspace is that fraction of tidal volume (VT) that does not take part in gas exchange.\(^{1,2}\) In ASA I and II subjects, deadspace ventilation is of little consequence but in critically ill patients it may be an important factor. The zero deadspace tracheal tube (ZEDS-TT) is designed to reduce deadspace, and a similar apparatus was used by Larsson in Sweden\(^{3}\) on pigs. Their lungs were ventilated with inspiration through one lumen of a truncated double-lumen tube and expiration through the other. \(P_{aCO_2}\) was reduced in these circumstances compared with using both lumens for both inspiration and expiration. Our study was designed to test the respiratory and ventilatory effects of reduction in tidal volume, comparing a simulated single-lumen tracheal tube and the ZEDS-TT during controlled ventilation in patients during anaesthesia.

Patients and methods

The ZEDS-TT is a double-lumen tracheal tube consisting of two identical lumens that lie in the trachea. One lumen acts as an inspiratory limb and the other as an expiratory limb (Fig. 1). The combined tube has a tracheal cuff.

The dimensions were checked by measuring a section of the No. 37 double-lumen tube in a Videoplan image analysing system (Kontron, Germany). The double-lumen tube comprised two back-to-back ‘D’ shaped lumens of 8 mm by 4 mm and a cross-sectional area of 35 mm\(^2\) (calculated by counting the squares on 1 mm\(^2\) graph paper). For reference, this was compared with the dimensions of a regular 7.5 mm tracheal tube which had a diameter of 7.5 mm and a cross-sectional area of 44 mm\(^2\). The volume of each of the lumens was 15 ml as was the volume of an uncut 7.5 mm tracheal tube. The Y-connector used in the single-lumen configuration comprised another 30 ml.

After obtaining approval from the Medical Committee for Research on Human Subjects at the University of the Witwatersrand, we studied 12 consenting adult ASA I and II patients undergoing peripheral surgery (Table 1). Cases were selected to exceed the 2.5 h required for the study. One case was abandoned because of early completion of surgery. Patients were anaesthetized in a standard manner which included an \(FIO_2\) of 50% and, after administration of vecuronium as the non-depolarizing neuromuscular blocking agent, volume-controlled ventilation.

Oxygen saturation (\(SaO_2\)) (Ohmeda, Biox 3740 pulse oximeter, BOC Healthcare, UK) and end-tidal carbon
Table 1 Patient characteristics

<table>
<thead>
<tr>
<th>Patient No.</th>
<th>Age (yr)</th>
<th>Sex</th>
<th>ASA</th>
<th>Surgery</th>
<th>Weight (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>33</td>
<td>M</td>
<td>I</td>
<td>Gross-Kempf nail right femur</td>
<td>72</td>
</tr>
<tr>
<td>2</td>
<td>53</td>
<td>F</td>
<td>II</td>
<td>Right hip replacement</td>
<td>62</td>
</tr>
<tr>
<td>3</td>
<td>38</td>
<td>M</td>
<td>I</td>
<td>Left nail femur</td>
<td>85</td>
</tr>
<tr>
<td>4</td>
<td>36</td>
<td>M</td>
<td>I</td>
<td>Left ear reconstruction</td>
<td>69</td>
</tr>
<tr>
<td>5</td>
<td>60</td>
<td>M</td>
<td>II</td>
<td>Right wrist arthrodesis</td>
<td>60</td>
</tr>
<tr>
<td>6</td>
<td>32</td>
<td>F</td>
<td>I</td>
<td>Left forearm plating</td>
<td>57</td>
</tr>
<tr>
<td>7</td>
<td>33</td>
<td>M</td>
<td>I</td>
<td>Left brachial artery repair and orthofix humerus</td>
<td>75</td>
</tr>
<tr>
<td>8</td>
<td>44</td>
<td>F</td>
<td>II</td>
<td>Left mastectomy and axillary clearance</td>
<td>68</td>
</tr>
<tr>
<td>9</td>
<td>26</td>
<td>M</td>
<td>I</td>
<td>Left brachial plexus exploration</td>
<td>65</td>
</tr>
<tr>
<td>10</td>
<td>38</td>
<td>M</td>
<td>I</td>
<td>Left arm tendon transplant and nerve graft</td>
<td>66</td>
</tr>
<tr>
<td>11</td>
<td>24</td>
<td>M</td>
<td>I</td>
<td>Right brachial plexus exploration and nerve graft</td>
<td>74</td>
</tr>
</tbody>
</table>

dioxide partial pressure ($P_{E \text{CO}_2}$) (Nihon-Koden, Japan) were measured and non-invasive pressure and ECG monitored. An arterial cannula was inserted to allow measurement of $P_{a \text{O}_2}$ and $P_{a \text{CO}_2}$. This was required by the Ethics Committee for patient safety, as this mode of ventilation has not been used previously in human subjects. Allen’s test for the patency of arteries was performed on all patients and no morbidity was reported on follow-up.

Ventilation was achieved using a Siemens Elema 900C Servo ventilator (Siemens-Elema Ventilator Division, Solna, Sweden) with an $I:E$ ratio of 1:2 (inspiratory time 25%; pause time 10%). Ventilation using one lumen of the ZEDS-TT only (single-lumen mode) was compared with ventilation with the ZEDS-TT (double-lumen mode) (Figs 2, 3). This was done to avoid multiple intubations which was deemed undesirable by the Ethics Committee. Changing from one mode to another was achieved rapidly by changing the ventilator connections. Patients’ lungs were ventilated using the single-lumen mode at a $V_t$ of 10 ml kg$^{-1}$. Ventilatory frequency was adjusted to achieve a $P_{E \text{CO}_2}$ of 4.66 ($\pm$ 0.67) kPa and allowed to stabilize for 10 min. Values for $S_{a \text{O}_2}$, $P_{E \text{CO}_2}$, mean airway pressure (MAP), peak airway pressure (PAP), pause airway pressure, tidal volume ($V_t$), ventilatory frequency ($f$), $P_{a \text{O}_2}$, and $P_{a \text{CO}_2}$ were noted.

The lungs were then ventilated for 10 min using the double-lumen mode with no change in ventilator settings and the readings repeated. $V_t$ was reduced serially to 7.5, 5 and 2.5 ml kg$^{-1}$, keeping minute volume constant by increasing $f$ to 10, 13, 21 and 40 bpm, respectively. Measurements were repeated after stabilization at each new setting.

The reduction in ventilation would have been reversed...
if end-tidal carbon dioxide partial pressure increased to more than 8.6 kPa for 1 min, to more than 7.3 kPa for 10 min, $P_{a CO_2}$ to more than 8.6 kPa or in the event of a decrease in $S_{a O_2}$ to less than 11.9 kPa or a decrease in $P_{a O_2}$ to less than 13.3 kPa.

**Statistical analysis**

Data were paired as each patient functioned as his or her own control. The outcome variables measured were not normally distributed when tested using the Shapiro–Wilk test. A log transformation of each of the variables was therefore performed. A three-way general linear model analysis (SAS 1989) was carried out with the log transformations as dependent variables while the lumen (single or double), tidal volume groups (10, 7.5, 5, 2.5) and individual patients were the independent variables. Each individual patient was included as a variable because multiple measures were performed on the same patient and the influence of each patient had to be examined. The three-way general linear model analysis was followed by the Tukey multiple comparison test to isolate which groups differed. Statistical significance was set at $P<0.05$ and power at 80%.

**Results**

We demonstrated that adequate oxygenation and carbon dioxide removal were possible at low tidal volumes with the ZEDS-TT. $S_{a O_2}$ and $P_{a O_2}$ remained normal. There were no significant differences in $S_{a O_2}$ or $P_{a O_2}$ between tidal volume groups or between tube types.

With the three-way general linear model analysis, there were highly significant reductions in $P_{E CO_2}$ and $P_{a CO_2}$ from the single-lumen group to the ZEDS tube group ($P=0.0001$). Mean changes in carbon dioxide partial pressure were 0.3–0.5 kPa, without any change in ventilator settings. Similarly, reductions in $P_{E CO_2}$ and $P_{a CO_2}$ at each tidal volume step from the single-lumen tube to the ZEDS tube were statistically significant ($P=0.0001$). Tukey’s test showed significant reductions in $P_{E CO_2}$ and $P_{a CO_2}$ from the single-lumen tube group to the ZEDS tube group. However, there were significant increases in $P_{a CO_2}$ and $P_{E CO_2}$ only in the $V_T$ 2.5 group (2.5 ml kg$^{-1}$). There were no significant differences between $V_T$ groups 10, 7.5 and 5 (Figs 4, 5).

Mean airway pressure was significantly lower in the ZEDS tube group compared with the single-lumen tube group ($P=0.0001$) and also within the tidal volume groups ($P=0.0009$) (Table 2).

Peak airway pressure decreased significantly between tube groups and also between $V_T$ reduction ($P=0.0001$) (Table 3). The pressure differences were expected, because of a reduction in flow through the tube as a result of the lower $V_T$ used in each step. There was no significant difference between tube groups in pause pressure ($P=0.6$), but as $V_T$ was reduced, pause pressure was reduced.

**Discussion**

Our study in 11 ASA I and II patients showed that with the ZEDS-TT, tidal volume was reduced significantly, with no increase in $P_{a CO_2}$ or reduction in $P_{a O_2}$, together with a decrease in airway pressure. With the ZEDS-TT, the Y-point,
usually outside the patient between the ventilator tubing and the tracheal tube, is moved into the trachea to just above the carina (Fig. 6). Therefore, much of the anatomical deadspace and all of the apparatus deadspace is eliminated. Various methods of ventilation have been devised to reduce tidal volume and thereby barotrauma in stiff lungs, for example, but still provide adequate oxygenation and carbon dioxide removal. These include pressure-controlled ventilation,\textsuperscript{6} expiratory tracheal gas insufflation,\textsuperscript{7,8} high-frequency jet ventilation\textsuperscript{9,10,11} and permissive hypercapnia.\textsuperscript{12,13}

The most frequently used is permissive hypercapnia. With the ZEDS-TT, this is obviated as carbon dioxide elimination is maintained, with clinically normal levels of $P_a\text{CO}_2$ at 2.5 ml kg$^{-1}$ ventilation. Therefore, barotrauma is limited by decreasing tidal volume with a consequent decrease in airway pressure, regardless of the size or resistance of the tube. Pause pressure was unaltered, which implies that lung compliance was essentially the same with both modes of ventilation.

The ZEDS-TT was tested in ASA I and II patients to confirm predicted function. Two minor problems were encountered. Insertion of the ZEDS-TT requires care as the double-lumen is not round but oval and with a larger external diameter than a standard tracheal tube. Individual lumens are smaller than those of a standard tube, indicating that suctioning might be more difficult.

One of the potential uses of the ZEDS-TT could be for long-term ventilation of ARDS patients. We postulate that with the ZEDS-TT, tidal volume can be reduced significantly and thus a proportional decrease in pressure with a reduction in barotrauma would be expected without having to resort to permissive hypercapnia.

In summary, the ZEDS-TT and its mechanics had no adverse effects in ASA I and II patients, and all indications are that it may facilitate ventilation of ARDS patients. Further studies are necessary.

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**References**