Increasing the length of the expiratory limb of the Ayre's T-piece: implications for remote mechanical ventilation in infants and young children

E. JACKSON, S. TAN, G. YARWOOD AND M. R. J. SURY

SUMMARY
We have assessed the effect of lengthening the expiratory limb of an Ayre's T-piece from 0.5 to 10 m for ventilation with a Nuffield series 200 ventilator and Newton valve, as this equipment is potentially suitable for infants and young children during anaesthesia for magnetic resonance imaging (MRI). We used lung models with compliances and resistances representative of the respiratory system with intubated trachea of a neonate, infant and child weighing 15-20 kg. The effects on ventilation were small, being greatest with the largest lung model where the longer T-piece resulted in a reduction in tidal volume from 261 to 236 ml and an increase in intrinsic and extrinsic positive end-expiratory pressure from 0.20 to 0.32 kPa and from 0.14 to 0.25 kPa, respectively. Such changes are unlikely to be clinically important and can be obviated by using the ventilator with the standard valve in children weighing 15-20 kg. (Br. J. Anaesth. 1994; 73: 154-156)

KEY WORDS
Anaesthesia: paediatric. Equipment breathing systems. Model lung

Infants and young children who need magnetic resonance imaging (MRI) often require general anaesthesia. An anaesthetic technique with intermittent positive pressure ventilation (IPPV) is desirable for some patients but all anaesthetic equipment with ferromagnetic components must be remote from the powerful magnetic field. A T-piece with extended expiratory limb connected to the Nuffield series 200 ventilator with a Newton valve has been used for the provision of IPPV during MRI in children weighing less than 25 kg [1]. However, the long extension of the expiratory limb may cause resistance to gas flow during expiration resulting in positive end-expiratory pressure (PEEP).

We have examined the effects of lengthening the expiratory limb of a T-piece from 0.5 to 10 m both at steady gas flow rates and during ventilation of paediatric lung models with the Nuffield ventilator and a Newton valve. The effects were also examined using the Nuffield ventilator and standard valve with the largest lung model.

METHODS
Portex 15-mm T-pieces were used with the expiratory limbs constructed of 10 mm internal diameter, neoprene-dipped, smooth walled rubber tubing (Southern Syringe Services). This tubing had a low compliance; the 0.5-m and 10-m length expiratory T-pieces can be pressurized to 2 kPa with 3 and 27 ml of air, respectively. The effect of lengthening the expiratory limb from 0.5 to 10 m for use with the Nuffield series 200 ventilator and Newton valve was assessed in two ways: first, with the lung model disconnected, the steady state decrease in pressure was measured across the T-piece with a constant fresh gas flow of 4 litre min⁻¹ and varying expiratory gas flow of 0-20 litre min⁻¹ introduced at the patient end. Pressure changes were measured both for the T-piece alone and when it was attached to the Newton valve of the ventilator (fig. 1). Second, the effect of lengthening the expiratory limb was assessed by ventilating a series of lung models with compliances and resistances representative of an intubated neonate, infant and child weighing 15-20 kg. Pressure, flow and volume changes within the system were measured.

An SLE neonatal lung simulator was used (compliance 30 ml kPa⁻¹, resistance 10 kPa litre⁻¹ s at 100 ml s⁻¹) and the infant and child models were constructed from glass aspirator bottles filled with copper wool and in series, with a linear resistance as described by Newton, Hillman and Varley [2] (static compliance 90 and 200 ml kPa⁻¹, respectively, resistance 2 kPa litre⁻¹ s at 200 ml s⁻¹).

Flow, tidal volume, airway pressure and lung pressure were measured using a pneumotachograph and pressure transducers, placed as shown in figure 1; airway pressure is measured at the connection of the T-piece to the pneumotachograph and lung pressure is the pressure within the lung model. The ventilator settings and fresh gas flows were chosen as representative of those commonly used in clinical practice.


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FIG. 1. Schematic diagram of the apparatus. Where the lung model was disconnected and the expiratory gas flow introduced for measurement of the steady state decrease in pressure across the T-piece.

practice. Fresh gas flows were 3, 4 and 4 and 6 litre min⁻¹ for the neonate, infant and child models, respectively. Inspiratory time was 1 s for all models and expiratory time 1 s for the neonate model and 2 s for the other models. The inspired flow on the ventilator was adjusted to give a measured peak airway pressure of 2 kPa. The child model was also ventilated using the Nuffield ventilator with a standard valve, set at its lowest flow setting, with a fresh gas flow of 4 litre min⁻¹, inspiratory time of 1 s and expiratory time of 2 s. Air was used for all studies and was supplied via calibrated flowmeters (Series 1100, Fisher Controls Ltd).

Flow was measured using Fleisch pneumotachographs sizes 0 (neonate model) and 1 (infant and child models) attached to a Validyne MP45±0.2 kPa differential pressure transducer. The pneumotachographs were linear to flows of 250 ml s⁻¹ and 500 ml s⁻¹ for sizes 0 and 1, respectively, with resistances of 0.4 and 0.1 kPa litre⁻¹ s at 100 ml s⁻¹, respectively. Calibration was with known flows (Series 1100 Flowmeters, Fisher Controls Ltd).

Flow was digitally integrated to volume. Pressures were measured using Validyne MP45±5 kPa pressure transducers calibrated using a water manometer. The output of all transducers was sampled at 200 Hz, digitized and recorded using a computer and RASP software (Physio Logic, Newbury, Berks, UK).

FIG. 2. Steady-state decrease in pressure across the T-piece with a fresh gas flow of 4 litre min⁻¹ and expiratory gas flows of 0–20 litre min⁻¹ for T-pieces with 0.5-m and 10-m expiratory limbs, alone and attached to the Newton valve (NV) of the Nuffield series 200 ventilator.

TABLE I. Tidal volume, peak expiratory flow (PEF) and peak-end-expiratory airway pressure and lung pressure during IPPV with 0.5-m and 10-m length expiratory limb T-pieces

<table>
<thead>
<tr>
<th>Lung model</th>
<th>Ventilator valve</th>
<th>Fresh gas flow (litre min⁻¹)</th>
<th>Length of expiratory limb (m)</th>
<th>Tidal volume (ml)</th>
<th>PEF (ml s⁻¹)</th>
<th>Airway pressure (kPa)</th>
<th>Lung pressure (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neonate</td>
<td>Newton</td>
<td>3</td>
<td>0.5</td>
<td>46</td>
<td>92</td>
<td>2.00/0.05</td>
<td>1.90/0.06</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10.0</td>
<td>45</td>
<td>85</td>
<td>2.00/0.09</td>
<td>1.91/0.13</td>
<td></td>
</tr>
<tr>
<td>Infant</td>
<td>Newton</td>
<td>4</td>
<td>0.5</td>
<td>144</td>
<td>253</td>
<td>2.00/0.05</td>
<td>1.88/0.06</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10.0</td>
<td>135</td>
<td>211</td>
<td>2.00/0.10</td>
<td>1.89/0.11</td>
<td></td>
</tr>
<tr>
<td>Child</td>
<td>Newton</td>
<td>4</td>
<td>0.5</td>
<td>261</td>
<td>247</td>
<td>2.00/0.14</td>
<td>1.58/0.20</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10.0</td>
<td>236</td>
<td>206</td>
<td>2.00/0.25</td>
<td>1.63/0.32</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>6</td>
<td>247</td>
<td>227</td>
<td>2.00/0.23</td>
<td>1.61/0.30</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>10.0</td>
<td>221</td>
<td>187</td>
<td>2.00/0.38</td>
<td>1.67/0.45</td>
<td></td>
</tr>
<tr>
<td>Standard</td>
<td>Newton</td>
<td>4</td>
<td>0.5</td>
<td>288</td>
<td>464</td>
<td>2.17/0.02</td>
<td>1.56/0.01</td>
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<tr>
<td></td>
<td></td>
<td>10.0</td>
<td>263</td>
<td>326</td>
<td>2.20/0.07</td>
<td>1.57/0.11</td>
<td></td>
</tr>
</tbody>
</table>

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makes a larger contribution to airway pressure than inspiratory flow reduced throughout expiration when 1 and a fresh gas flow of 6 litre min\(^{-1}\) are shown in figure 3. Airway pressure was increased and expiration when the T-piece was lengthened. The steady-state decrease in pressure across the T-piece with a fresh gas flow of 4 litre min\(^{-1}\) during introduction of "expiratory" gas flows of 0-20 litre min\(^{-1}\) through the 0.5-m and 10-m T-pieces alone and in series with the ventilator and Newton valve are shown in figure 2. The higher the expiratory gas flow, the greater the decrease in pressure caused by lengthening the expiratory limb of the T-piece. The Newton valve caused a greater decrease in pressure than extending the expiratory limb of the T-piece. Tidal volume, peak expiratory flow (PEF), airway pressures and lung pressures for each lung model using the Nuffield ventilator and a Newton valve. The changes were greatest for the largest lung model where fresh gas flow and expiratory flow were highest. The reduction in tidal volume with the longer T-piece, when used with the Newton valve, may be explained by the increase in PEEP, as the Nuffield ventilator with a Newton valve functions as a pressure generator. The reduction in tidal volume when the ventilator was used as a flow generator (with the standard valve) can be explained by loss of inspired volume because of the reduced compliance and greater gas compression that would be expected with the longer T-piece. The values obtained are likely to have been influenced by our choice of T-piece, particularly the nature of the tubing used for the expiratory limb. The 10 mm internal diameter, neoprene-dipped, smooth walled rubber tubing was chosen as it is in current use in our department. It is robust, reasonably compact and easy to connect using standard non-metallic connectors. Commercially available T-piece circuits do not incorporate extended expiratory limbs and would require modification and possible additional connections. Larger gauge tubing would be expected to have less resistance effects but may be more compliant and have greater effects on tidal volume when used with the Nuffield ventilator and standard valve in larger children.

We conclude that increasing the length of the expiratory limb of the T-piece from 0.5 to 10 m had only a small effect on ventilation of paediatric lung models using the Nuffield ventilator and a Newton valve. The changes are unlikely to be clinically significant provided excessive fresh gas flows are avoided. The Nuffield ventilator with standard valve also provided suitable ventilation with less expiratory obstruction when used with the extended T-piece and could be considered for children weighing 15-20 kg and more.

REFERENCES