The Papworth BiVent tube: a feasibility study of a novel double-lumen endotracheal tube and bronchial blocker in human cadavers

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Background. A novel double-lumen endotracheal tube, the Papworth BiVent tube, has been designed to allow the rapid passage of a blocker into either main bronchus, without fibreoptic endoscopic guidance.

Methods. The feasibility of lung isolation and one-lung ventilation (OLV) in human cadavers is examined, along with displacement of the bronchus blocker during head and neck movement.

Results. Cadaveric endotracheal intubation with the Papworth BiVent tube was straightforward and comparable with intubation with a conventional single-lumen tube (SLT). Reliable lung isolation was achieved considerably faster using the Papworth BiVent tube than with a bronchoscopically guided bronchial blocker through an SLT (mean 7.75 s BiVent tube vs 128.2 s SLT). The Papworth BiVent tube also prevented displacement of the blocker from its position in the bronchus on head movement.

Conclusions. This study in human cadavers has shown that it is feasible to use the Papworth BiVent tube to attain rapid and secure lung isolation for OLV. Further work is required in clinical settings.

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One-lung ventilation (OLV) and lung isolation are frequently required in thoracic surgery and occasionally necessary in other situations, for example, after chest trauma. OLV facilitates access to the collapsed lung and other structures within the chest cavity and provides a means of preventing soiling of the ventilated lung by blood or infected material. In clinical practice, lung isolation is most commonly achieved by the use of a double-lumen endotracheal tube (DLT) with the endobronchial limb in either the right main bronchus (RMB) or the left main bronchus (LMB). Alternatively, a bronchus blocker may be used; this is passed through the lumen of a standard single-lumen endotracheal tube (SLT) and guided into the main bronchus of the lung to be isolated from ventilation.

Each of these methods has disadvantages or technical limitations that can reduce the effectiveness of lung isolation, thus impeding surgical intervention and potentially compromising patient safety. DLTs can be difficult to pass through the larynx into the trachea because of their shape and size and may be more likely to cause oropharyngeal or dental damage than an SLT. DLTs can also be difficult to position correctly, particularly in the RMB without obstructing the orifice of the right upper lobe bronchus. Bronchial blockers on the other hand can be time-consuming and challenging to guide into the requisite position and, once positioned, the inflated blocker cuff is prone to dislodgement, occasionally herniating across the carina and occluding ventilation completely. Fibreoptic bronchoscopy is required to site the blocker correctly and may be repeatedly required intraoperatively to reposition the blocker. Currently available bronchial blockers, such as the blocker used in this study, may not achieve complete and secure lung isolation in all cases, even with assistance from fibreoptic guidance.

Declaration of interest. Dr S.G. is the inventor of the Papworth BiVent tube. Papworth Hospital Foundation Trust holds the patent for the Papworth BiVent tube. Dr S.G. and Papworth Hospital Foundation Trust have a financial interest in the commercial development of the Papworth BiVent tube.
as the Cohen Flexitip (Cook Critical Care, Bloomington, IN, USA) or the Phycon blocker (Fuji Systems, Tokyo, Japan), rely on the transmission of torque applied to the proximal end of the blocker to be transmitted to the distal tip to provide directional control. Similarly, the Arndt Blocker (Cook Critical Care), the most widely used bronchial blocker at present, can either be manipulated into the appropriate bronchus by the application of torque or positioned by railroading the nylon loop at its distal tip over a flexible bronchoscope. The only currently available endotracheal tube specifically designed for use with a bronchial blocker is the Torque Control Blocker Univent (TCBU, Vitalaid, Lewiston, NY, USA). This device is essentially a variant of the Univent tube and is an SLT with a narrow channel in its wall encasing the stalk of a bronchial blocker; however, flexible bronchoscopy is still required to aid correct positioning of the blocker.

A novel design of DLT, the Papworth BiVent tube, has been developed for use in conjunction with a bronchial blocker to rapidly and reliably secure OLV and lung isolation. The Papworth BiVent tube facilitates the correct positioning of the bronchial blocker and stabilizes it in position.

The Papworth BiVent tube (Figs 1 and 2) is constructed of moulded dry natural rubber and has two D-shaped lumens, separated by a central partition and configured in a ‘side by side’ arrangement. It has a single posterior concavity and a single cuff with a channel in the wall of the tube leading to a valved pilot balloon and inflation mechanism. The proximal end of the tube has separate openings for each lumen. The distal tip of the tube is forked, the arms of the fork being formed by two pliable, crescenteric flanges that arise from the termination of the central partition. The distal end of each lumen opens above these flanges. It is anticipated that commercial versions of the device will be latex-free and produced in sizes comparable with currently available Robertshaw tubes.

The tube is designed to be placed in the trachea with the forked tip seated on the carina; it has no endobronchial limb, thereby facilitating passage through the larynx in contrast to conventional designs of DLTs. The pliable flanges forming the tip of the tube splay out on either side of the carina, allowing the tube to be seated correctly on the carina. In this position, the openings of each lumen lie adjacent to orifices of the main bronchi. A bronchial blocker passed through either lumen to a depth greater than the length of the tube will emerge in the bronchus which lies adjacent to that lumen. Inflation of the cuff of the blocker will seal the bronchus and isolate that lung. This allows more rapid deployment of a bronchial blocker without the use of flexible bronchoscopy and should ensure that the required bronchus is isolated on every occasion. In addition, the blocker will be maintained in a stable position once inserted into the bronchus by the forked tip of the tube in position on the carina, and should not move despite changes in patient positioning.

Although other bronchial blockers can be used, a novel bronchial blocker made of dry natural rubber has been specifically designed for use with the Papworth BiVent tube. It has a spherical cuff inflated via a valved pilot balloon and a central lumen opening at the distal tip for suction. The blocker is provided with an aluminium stylet passed through the central lumen to increase the rigidity of the blocker; this is removed after deployment.

This study was performed to establish the feasibility of using the Papworth BiVent tube and bronchial blocker to secure lung isolation and OLV in human cadavers.

**Methods**

Cadavers of two adults who had donated their bodies for the advancement of medical science and education, to the Surgical Skills Cadaver Laboratory at the Freeman Hospital, Newcastle upon Tyne (UK), were used in this study. The regulatory provisions of the United Kingdom Human Tissue Act were adhered to.
The cadavers were frozen immediately after death and slowly thawed before being studied. Cadaver 1 (male) was 176 cm tall and 72 kg in weight; Cadaver 2 (female) was 158 cm tall and 49 kg in weight.

Three consultant anaesthetists, all with >5 yr experience in thoracic anaesthesia, undertook orotracheal intubation and lung isolation using the following protocol.

(i) An objective assessment of the laryngoscopic view with a Mackintosh laryngoscope and large (size 4) blade.
(ii) The trachea was intubated using the Papworth BiVent tube. Correct tube placement was confirmed by fiberoptic endoscopy (Olympus LF DP, Keymed Ltd, Southend-on-Sea, UK) and by stethoscope auscultation to confirm bilateral air entry on lung inflation by the anaesthetist performing the procedure with a self-inflating resuscitation device (Adult Silicone Resuscitator, Laerdal Medical Ltd, Orpington, UK).
(iii) The novel bronchial blocker was passed into a designated bronchus.
(iv) Correct placement of the blocker was checked in terms of adequacy of lung isolation: after inflation of the blocker cuff, the lungs were inflated and the efficacy of the gas tight seal in isolating one lung from the other was recorded by auscultation of both lungs and observation of chest wall movement (this was performed by the two anaesthetists not performing the procedure, and all results were agreed by both).
(v) The head of the cadaver was rotated from side to side and flexed until the chin touched the chest, then returned to the neutral position; auscultation was again performed by the same observers to determine if lung isolation was still successful.

This sequence was repeated using an SLT (Mallinckrodt, Hazelwood, MO, USA, size 8) and Arndt bronchial blocker (Cook Medical, Limerick, Ireland), positioned as per standard practice, with the aid of a fiberoptic endoscope.

The following variables were measured/observed:

(i) frequency of successful intubation;
(ii) time taken from visualization of larynx to declaration by anaesthetist of completed intubation;
(iii) time taken from placing the bronchial blocker at the proximal end of the tube to declaration by anaesthetist of blocker placement;
(iv) frequency of successful blocker placement on checking by fiberoptic endoscopy/lung isolation on application of positive pressure ventilation;
(v) incidence of displacement of the blocker on head turning and neck flexion.

Results

The laryngoscopic views obtained in both cadavers were classed as Grade 1 by all three anaesthetists; the trachea was successfully intubated with either the Papworth BiVent or conventional SLT at every attempt.

The mean time taken for tracheal intubation with the Papworth BiVent tube was 5.5 s compared with 3.2 s with an SLT (Table 1).

In Cadaver 1, the BiVent tube and bronchial blocker provided lung isolation considerably faster than the SLT and Arndt blocker (mean 7.75 vs 128.2 s), and was successful in every instance (Table 2).

In Cadaver 2, an anatomical abnormality of the trachea noted on bronchoscopy prevented satisfactory right single-lung ventilation and the study protocol was not completed in this case.

Turning the head or flexing the neck did not lead to displacement of the blocker with subsequent failure of lung isolation when using the BiVent tube; in contrast, this

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<th>Table 1</th>
<th>Time (s) taken from laryngoscopy to endotracheal intubation</th>
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<td>Cadaver 1</td>
<td>Anaesthetist 1</td>
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<td>Anaesthetist 3</td>
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<td>Cadaver 2</td>
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<th>Time (s) taken to bronchus blocker placement and lung isolation in Cadaver 1</th>
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<td>Anaesthetist 1</td>
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<th>Table 3</th>
<th>Displacement of blocker on head turn/neck flexion in Cadaver 1</th>
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occurred twice during the use of the conventional SLT and Arndt blocker (Table 3).

Discussion
This study demonstrates that the Papworth BiVent tube can be readily used to intubate the airway and rapidly isolate either lung in a human cadaver.

The forked tip of the Papworth BiVent tube was correctly positioned on the carina, determined by bronchoscopy, on first passage in each attempt in either cadaver. The mean time to intubation was slightly faster with an SLT compared with the Papworth BiVent tube; however, the time taken to correctly position a bronchial blocker into a designated bronchus was considerably faster when using the Papworth BiVent tube. The large difference in the time to correct blocker positioning is an indicator of the ease with which bronchial blockers can be positioned with the aid of the Papworth BiVent tube. Furthermore, correct positioning of the blocker could be achieved in all attempts without the need for fiberoptic bronchoscopy.

In Cadaver 1, an average-sized male, the Papworth BiVent was successful in all attempts at isolating either lung and providing satisfactory ventilation of the contralateral lung. In this cadaver, one anaesthetist failed when using an SLT to position an Arndt blocker in the LMB.

The blocker could not be dislodged after positioning in either bronchus by rotation of the head and flexion of the neck when using the Papworth BiVent tube, but was dislodged in two out of five occasions when using an SLT and Arndt blocker. The Papworth BiVent tube does appear to stabilize the inflated blocker cuff in position.

In Cadaver 2, a small female, a blocker could be deployed into either main bronchus via the Papworth BiVent tube. However, when the blocker was passed into the LMB and the blocker cuff inflated, ventilation of the right lung was found to be difficult. High pressure manual inflation was required to achieve air entry into the right lung. Bronchoscopic examination revealed that the lower third of the trachea was narrow and deviated to the left with partial occlusion of the RMB. Bronchoscopy via the right-sided lumen of the Papworth BiVent tube with the tip of the tube in position on the carina and a bronchial blocker inflated in the LMB demonstrated that the orifice of the right lumen of the tube was pressed against the tracheal wall. This accounted for the failure of adequate right lung ventilation in this cadaver when isolating the left lung. Owing to the abnormal tracheal anatomy, the study protocol was abandoned in this cadaver.

Previous studies have shown that bronchial blocker placement via an SLT is comparatively difficult and time-consuming, particularly when undertaken by anaesthetists with limited experience of anaesthesia for thoracic surgical procedures, thus conferring little benefit over the use of conventional DLTs. In certain circumstances, for example, in patients whose tracheas are difficult to intubate or have airway abnormalities, the Univent tube or use of an Arndt blocker with an SLT has proved beneficial. The use of bronchial blockers may also prove to be of value after thoracic trauma.

Magill originally described bronchial blockers for placement with the aid of a rigid bronchoscope either through or alongside an endotracheal tube in the 1930s. The advent of the Carlen and Robertshaw DLTs, however, resulted in the use of bronchial blockers falling out of favour. The subsequent lack of commercially available bronchial blockers led to the use of Fogarty embolectomy catheters to occlude a bronchus, with particular success in paediatric thoracic cases. Advances in fiberoptic bronchoscopic technology and the description of the Univent tube in the 1980s, and more latterly the Arndt blocker, have led to a resurgence of interest in using bronchial blockers and resumption of commercial production.

The Papworth BiVent tube was designed to make it easier and faster to attain lung isolation than with the current techniques of bronchial blocker placement. The design was also intended to prevent the tendency of bronchial blockers from moving out of position from within a main bronchus.

This study demonstrates the feasibility of using this new device to secure rapid and reliable lung isolation and OLV in human cadavers; whether this technique of bronchial blocker placement carries advantages over the use of conventional DLTs has yet to be established. A clinical trial to define the utility of the device in thoracic anaesthetic practice is planned to commence in the near future.

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