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Original Article

Cricothyroidotomy catheters: an investigation of mechanisms of failure and the effect of a novel intracatheter stylet*

P. D. Hebbard,[1,2] I. Ul Hassan[3] and E. K. Bourke[4]

1 Clinical Associate Professor, University of Melbourne, Melbourne, Victoria, Australia
2 Anaesthetist, Northeast Health Wangaratta, Wangaratta, Victoria, Australia
3 Emergency Registrar, 4 Anaesthetic Registrar, Monash Health, Melbourne, Victoria, Australia

Summary

Emergency catheter cricothyroidotomy often fails. Case reports have concentrated on kinking and displacement of the catheter as the major causes. We investigated catheter tip penetration of the trachea. Using insertion angles of 90°, 75°, 60°, 45° and 30° we advanced 14 G intravenous catheters into fresh isolated sheep tracheas during high pressure oxygen insufflation. At all angles, the catheter tip became blocked by pushing into the mucosa with submucosal gas injection on one or more attempts. Full thickness rupture with extratracheal gas also occurred on insertions at 90° and 60°. We then tested a Luer-mounted prototype wire stylet which remains in situ during insufflation. Using the same methodology, the stylet was able to be placed and prevented blockage at all angles of insertion. Mucosal trauma and submucosal gas injection occurred on insertions at 90° and 75°. Our results should guide further stylet design.

Correspondence to: P. D. Hebbard
Email: p.hebbard@bigpond.com
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Introduction

Inability to ventilate a patient remains one of the most common causes of mortality and morbidity in anaesthetics. Needle cricothyroidotomy can be successfully employed in managing ventilation failure, however, the NAP 4 study [1] showed a failure rate of 63%. In addition, a well-publicised patient death in the UK [2] emphasised the danger of high flow, high pressure oxygen insufflation after the passage of an airway exchange catheter from the trachea into the chest wall was facilitated by insufflation of high-pressure, high-flow oxygen.

Although rupture of the tracheal mucosa with cricothyroidotomy has been described, it was attributed by O'Sullivan and Healy to penetration by the transtracheal needle tip [3] or by Borgain et al. to an excessively stiff catheter hitting the posterior tracheal wall at the end of each insufflation [4]. Ravussin and Freeman [5] described a transtracheal catheter with two side holes to reduce distal pressure and a curve to hold the tip off the mucosa. In contrast, Klain and Smith [6] reported no mucosal damage in dogs using high pressure jet ventilation for 50 h via a 16 G angiocath. More recent reviews and editorials have not considered mucosal penetration by the catheter itself significant [1, 7].

A pilot investigation on sheep tracheas using oxygen insufflation via standard intravenous catheters showed us it was possible to inject oxygen both submucosally and through the wall of the trachea. We are not aware of any reports of cricothyroid catheters that have specifically described blockage of the catheter by pushing into the tracheal mucosa with subsequent rupture. We therefore decided to investigate gas insufflation during movement as a potential cause of failure of cricothyroid or transtracheal catheters.

One of the authors (PH) is developing a stylet to use inside intravascular catheters to prevent kinking and blockage. We speculated that a fine stiff wire stylet, that could be left in situ, may help to guide and maintain the catheter in a safe position within the lumen of the trachea. For this study, we investigated the effect of advancing transtracheal catheters during oxygen insufflation in fresh sheep tracheas, using different insertion angles. The method was then repeated using a prototype stylet.

Methods

Tracheas of 11 freshly killed sheep (<6 h) were obtained from our local abattoir. The dimensions and structure of the sheep trachea are similar to humans, being ~20 cm long and 18 mm internal diameter with C-shaped incomplete cartilage rings and a soft fascia posteriorly. The trachea was held in place by hand on a bed of 10% gelatine to simulate soft tissue. This supported the posterior trachea without providing a hard backstop, which could increase perforation.

Stylets were constructed using a 0.25 mm diameter plastic coated wire, which stiffens the inside of a 20 G catheter from a Plexolong/Meier nerve block catheter set (Pajunk GmbH, Geisingen Germany) and two Combi-Stoppers (B Braun, Melsungen Germany). A 3 mm hole was drilled through each of the Combi-Stoppers to convert them to male/female Luer connectors with a 3 mm lumen. The wire was cut to 12.5 cm lengths and the tip shaped by double folding over the distal 2–3 mm to create a smooth end to prevent the stylet breaking the mucosa. The tip was further shaped, so it did not catch in the catheter on removal. Finally, the distal 20 mm was curved to make it point towards the lumen of the trachea, rather than the wall, when used. The two modified Combi-Stoppers were screwed together via their luer fittings to hold the stylet tightly in place in the join, so that it could remain securely inside the lumen of the connector and the catheter during advancement and insufflation (Fig. 1).

A 14 G 50 mm length Optiva IV catheter (Smiths Medical International Ltd, Lancashire, UK) was inserted through the anterior wall of the sheep trachea by hand at pre-determined angles of 90°, 75°, 60°, 45° or 30° to the long axis using a protractor to determine the angle. As soon as the catheter had entered the lumen, the needle was removed and a "Leroy" Rapid-O_2 Cricothyroidotomy insufflation device (Meditech Systems Ltd, Shaftesbury, UK) was connected with the oxygen flow set on 15 $l.min^{-1}$ (250 $ml.s^{-1}$) at the high pressure wall oxygen outlet, in line with current recommendations in the literature and our department [8]. The catheters were then advanced, maintaining the original insertion angle, during oxygen insufflation to simulate the movement of the catheter that could occur during cardiopulmonary resuscitation, or by patient movement. The catheter was inserted as firmly as possible without kinking until it was stopped, either by catching on the posterior mucosa or reaching full insertion.

Five catheter insertions were performed at each angle using a fresh undamaged part of the trachea. For each insertion, the catheter was advanced five times unless gas injected into the posterior wall. After each advancement, the catheter had either been fully inserted or it had been stopped by pushing into and catching on the posterior mucosa which invariably blocked the lumen. If the catheter could not be fully inserted, or if the posterior wall had not ruptured after the five attempts, it was advanced up to another five

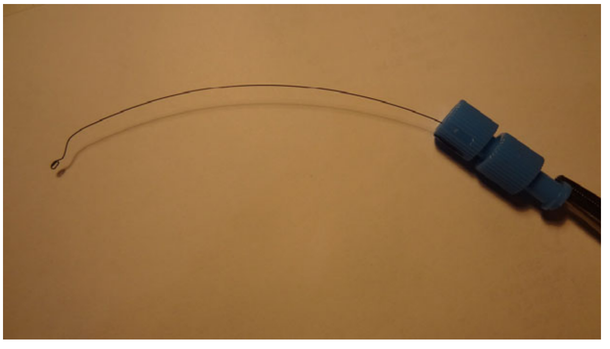

Figure 1 Shaped wire stylet mounted in a luer connector.

times. The final position of the catheter after each advancement was checked visually in the lumen.

The insertions were then repeated using the same method, with the stylet inserted into the 14 G catheter after the needle was removed. The curve of the stylet was positioned, so that it was directed towards the tracheal lumen. The stylet was advanced into the catheter until the luer lock fitting could be engaged and then the catheter and stylet were advanced together into the trachea.

Results

Table 1 shows the results of inserting the catheter alone. At all angles of insertion, the catheter without the stylet blocked and ruptured the tracheal mucosa on at least one of the five insertions (Figs 2 and 3). The catheter could not be inserted to lie free in the lumen at 90° or 75°.

Table 1 also shows the results with the addition of the stylet. Submucosal rupture occurred without blockage of the catheter during one insertion each at 90° and 75°. All the catheters were able to be passed into a position that allowed gas insufflation. The stylet could be passed down the catheter at all angles, although it sometimes caught, requiring partial retraction and re-insertion, with rotation, until it passed without resistance. Kinking occurred on two advancements at 90°, once when the catheter became jammed in the tracheal wall leading to kinking outside the trachea and once on the posterior wall with the kink inside the trachea. In both cases, oxygen was still able to be insufflated via the catheter, as it was not occluded.

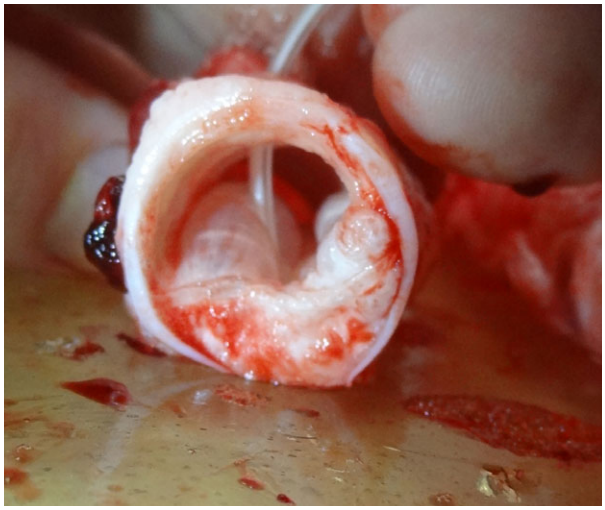

Figure 2 Submucosal oxygen within the sheep trachea.

Figure 3 Gas creating bubbles in the tissue around the trachea after injection through the wall of the trachea.

Discussion

The key finding of this study is that it demonstrates that mucosal penetration by a catheter with subsequent oxygen injection is all too easy to achieve and probably an important cause of failure of transcricothyroid oxygenation. In addition, we have also demonstrated

Table 1 Result of catheter insertion compared with catheter insertion with stylet.

	Blockage of catheter on insertion (n = 5)		Inserted to lie in lumen (n = 5)		Submucosal rupture (n = 5)		Extratracheal rupture (n = 5)		Kinking (n = 5)	
Angle (°)	Catheter	Stylet	Catheter	Stylet	Catheter	Stylet	Catheter	Stylet	Catheter	Stylet
90	5	0	0	5	3	1	2	0	2	1
75	5	0	0	5	3	1	0	0	1	1
60	5	0	3	5	2	0	2	0	0	0
45	2	0	4	5	1	0	0	0	0	0
30	1	0	5	5	1	0	0	0	0	0

Catheter, catheter only; Stylet, catheter insertion with stylet.

the feasibility of a stylet which may be a potential solution to this problem. The oxygen flow against the tracheal mucosa perhaps acts like a hydraulic drill. Once inserted through the wall into the trachea, a straight catheter at rest is always pointing towards and usually touching the opposite wall (Fig. 4). A stylet, by protruding from the catheter will always tend to keep the tip from the wall (Fig. 5).

We used the Optiva IV, because it is more readily available in operating suites than a purpose-built catheter. The catheter needs to be stiff to be passed effectively into the trachea, which also brings it into firm contact with the posterior wall. It was often hard to advance our catheter into the trachea as it jammed between the cartilaginous rings, suggesting that a significantly softer catheter would be difficult to insert. This effect has been noted in humans and is minimised by inserting through the cricothyroid membrane where possible [9].

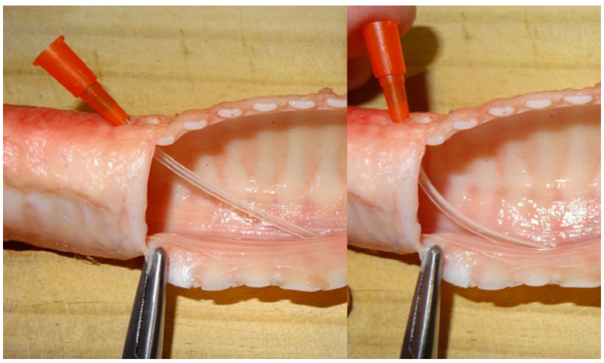

Figure 4 On the left a 50 mm 14 G Optiva catheter showing the resting position after insertion into an opened trachea with contact between the tip and the mucosa. On the right, when the same catheter is held in a more perpendicular position, the tip is more parallel with the tracheal wall.

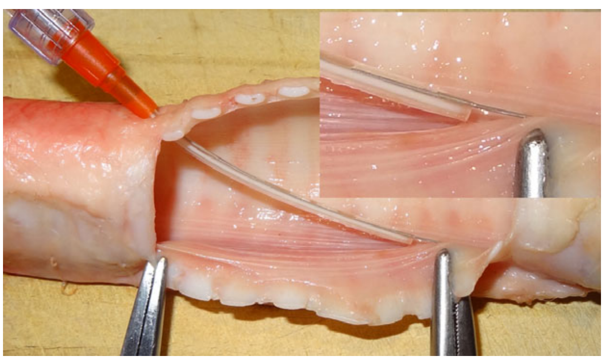

Figure 5 A stylet holding the catheter tip away from the mucosa by creating a more distal contact point.

Although we tried to insert the styleted catheters in the same way as the non-styleted, we do not suggest that this investigation of the stylet is more than an interesting feasibility study. The 0.25 mm stylet only takes up 2.3% of the lumen of the 14 G catheter and would only use 3.9% of a 16 G catheter. The ideal stylet design would be of small diameter, support the catheter from impacting the posterior trachea and be atraumatic in insertion. Full investigation of the stylet needs a more sophisticated stylet design suitable for clinical use and a properly blinded study protocol. Nevertheless, we feel our results with the catheters and the concept of the stylets will be of general interest to clinicians.

We used fresh sheep tracheas because, during our pilot investigations, the trachea became much stiffer and the mucosa less pliable after overnight refrigeration. Context and ethical considerations limit the possibility of conducting a similar study on human models. We feel the sheep trachea model is, however, a useful and realistic simulation of the clinical situation. The sheep were healthy animals; their tracheas therefore probably present a best-case scenario. Direct examination of the trachea provides a distinct advantage over live animal models due to the ability to inspect the trachea from both proximal and distal ends.

We believe our experimental scenario is realistic as in an emergency situation the patient is unlikely to be still, with ongoing upper airway manipulations, chest compressions and gasping. As the patient moves the pressure of the tip on the posterior wall is repeated. Although we used a variety of insertion angles down to 30°, the practicality of shallow angles in clinical situations is doubtful, particularly with a syringe attached. Many cases of failed oxygenation have limited head and neck movement and restricted access to the trachea. In many cases, an angle of 45–60° may be the best achievable.

Cricothyroidotomy catheter complications described in case reports include subcutaneous emphysema from the catheter pulling out of the trachea, barotrauma with pneumothorax from a blocked upper airway and blockage from kinking [7, 10–13]. We believe that the role of catheter tip blockage and subsequent perforation has not been adequately recognised as a cause of cricothyroidotomy catheter failure. The gas in our sheep trachea model often filled the paratracheal tissue like a balloon before escaping. In clinical situations, where there is no external space for the gas to escape, it would be in the mediastinum and may subsequently rupture into the pleural cavity. It could also pass anteriorly around the trachea and alongside the catheter into the subcutaneous tissue.

The area of the Leroy device that is occluded by the thumb to provide the oxygen jet is approximately 0.2 square inch. A thumb pressure of only 5 kg (11 lbs) will generate pressure in the device at the maximum wall pressure of around 400 kPa (58 psi). Although previous investigations have found that delivery of oxygen via a cricothyroidotomy catheter is inadequate for full ventilation from an anaesthetic machine pressure-limited circuit [14], lower pressures may be safer in view of the ability we have demonstrated of oxygen to rupture the tracheal mucosa.

We intend to conduct further testing of different catheters using the sheep trachea model and to optimise and test the stylet design. Although the stylet is covered by a patent application by one of the authors, we would be interested in making it readily and cheaply available if we can refine and improve the design, in order to reduce the risks of emergency needle cricothyroidotomy.

Acknowledgements

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Competing interests

PDH has a patent application for the catheter stylet used in this study. No external funding or other competing interests declared.

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