Ventilation via the 2.4 mm internal diameter Tritube® with cuff – new possibilities in airway management

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Background: A small tube may facilitate tracheal intubation and improve surgical access. We describe our initial experience with the Tritube® that is a novel cuffed endotracheal tube with a 2.4 mm internal diameter.

Methods: The Tritube® was used in seven adult Ear-Nose-and Throat surgical patients with airway narrowing or whose surgical access was facilitated by this small-bore endotracheal tube. Ventilation through Tritube® is performed with the manually operated Ventrain®-ventilator that allows active suctioning during expiration, therefore facilitating normoventilation through small diameter airways.

Results: The small diameter of Tritube® seemed to improve glottis visualisation during intubations and gave excellent working conditions for surgery. Two patients were intubated awake with a flexible scope and a guide wire or with an angulated video laryngoscope. One patient had almost complete glottic occlusion that just allowed for passage of the Tritube®. Adequate ventilation was achieved in all patients and intratracheal pressure was kept between 5 and 20 cm H_2O. The tube was well tolerated after emergence from anaesthesia and kept intratracheally in five awake patients in the post-operative recovery unit, in one case for more than 1 h. Ventilating with Ventrain® through Tritube® demands meticulous breath by breath measurement and adjustment of the intratracheal pressure.

Conclusion: The 2.4 mm internal diameter Tritube® seems to facilitate tracheal intubation and to provide unprecedented view of the intubated airway during oral, pharyngeal, laryngeal or tracheal procedures in adults. This technique has the potential to replace temporary tracheostomy, jet-ventilation or extra-corporal membrane oxygenation in selected patients.

Editorial Comment
It is well recognised that small bore endotracheal tubes can be required for airway control when there are airway stenoses, or to facilitate airway surgical visualisation and work, though they may have disadvantages concerning ventilation and endotracheal suctioning. In this report, clinical experience with a new, small, cuffed endotracheal tube along with a manually operated ventilation system is presented.

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Despite numerous advances in airway management several challenges persist, and failure to secure the airway is still a very important cause of mortality related to general anaesthesia,[1] treatment in the intensive care unit,[2] and in emergency situations.[2] Introduction of a standard tracheal tube may not be possible in patients with airway narrowing due to cancer, infection, allergic reactions, etc. In these situations, special techniques may be used, such as jet ventilation, tracheostomy or even extra-corporeal-membrane oxygenation but they have their challenges and side effects. A smaller-diameter tube may facilitate tracheal intubation in patients in general and particularly in patients with severe narrowing of the airways, and it may also improve surgical access during oral, pharyngeal, laryngeal and tracheal procedures.

The new Tritube®[3] is an endotracheal tube with a 2.4 mm internal diameter and a 4.4 mm outer diameter and has a cuff for sealing the trachea.

The large resistance to flow inherent to very small diameter airways necessitates use of high pressure oxygen/air sources for insufflation, and passive exhalation might be impaired or impossible. Therefore, ventilation through Tritube® is performed with the manually operated Ventrain®.[4] The Ventrain® allows ventilation via a small lumen by using expiration by suction, termed expiratory ventilation assistance (EVA).[5]

In this paper, we describe this novel tube and the initial experience with it in patients who underwent Ear-Nose-and Throat (ENT) surgery and in whom a small-diameter tube allowed intubation despite severe narrowing of the airway and in whom surgical access was facilitated during surgery in the airway or its vicinity.

Furthermore, we discuss the possible advantages and disadvantages as well as future perspectives of the technique for securing the airway and for adequate ventilation of patients.

Methods

The 2.4 mm internal diameter endotracheal tube (Tritube®)

The Tritube® (Ventinova Medical B.V., Eindhoven, the Netherlands), is a 40 cm long endotracheal tube with three different channels: one for ventilation, one for intratracheal pressure measurement and one for inflation of the cylindrical, high volume, low pressure cuff (Fig. 1). The ventilation lumen has a cross-sectional area corresponding to that of a 2.4 mm internal diameter tube and it is intended to be connected to devices with EVA technology (like Ventrain®) via a Luer connector. The ventilation lumen has a Murphy's eye. The intratracheal pressure measurement lumen can be connected to a manometer in order to continuously monitor intratracheal pressure. Inflation of the cuff will both provide airway protection and optimise ventilation[6] with Ventrain®. The tube has centimetre markings and a malleable stylet loaded in the ventilation lumen.

Due to its high resistance to flow, spontaneous ventilation through the Tritube is not possible and even assisting spontaneous ventilation through Tritube® is hardly possible. Thus, when the patient is emerging from anaesthesia, the cuff

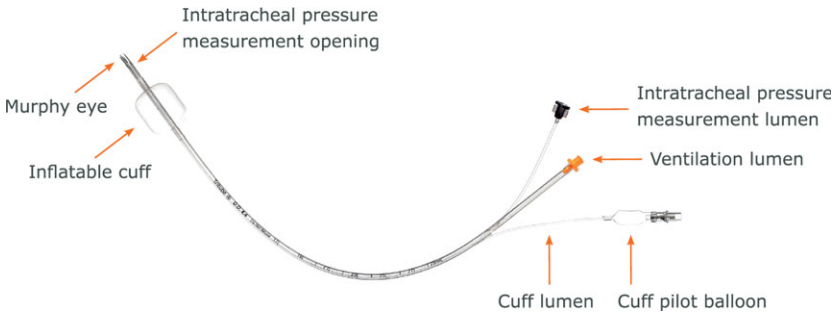

Fig. 1. The Tritube®, external view. Tritube® is a 40 cm long, small lumen endotracheal tube with three separate channels for ventilation, continuous intratracheal pressure measurement and for inflation or deflation of the thin-walled, cylindrical, high volume, low pressure cuff.

should be deflated to allow for spontaneous ventilation alongside the tube. Ventilation can then be continued while continuously monitoring intratracheal pressure and listening for leakage. In case of leakage one should consider to only insufflate air followed by passive expiration until spontaneous ventilation has fully recovered.

Expiratory ventilation assistance with Ventrain®

Ventrain® (Ventinova Medical B.V., Eindhoven, the Netherlands[4,7] is a manually operated ejector ventilator (Figs. 2 and 3) that was initially developed to ventilate patients with a highly or even completely obstructed upper airway via a needle cricothyrotomy.[7]

In addition to air/oxygen supply during inspiration, Ventrain® assists expiration by actively removing gas through small-bore cannulas and catheters by jet-flow generated suction (based on Bernoulli's principle). This technology has been introduced as EVA.[5] Animal studies have shown that compared to traditional high pressure source jet ventilation, active removal of gas from the lungs considerably reduces the risk of hyperinflation and subsequent barotrauma and/or haemodynamic deterioration, especially in case of a completely obstructed airway.[6,8]

In contrast to traditional jet ventilation, Ventrain® is a flow-controlled device, which means that by setting an appropriate flow at the high-pressure air/oxygen source one can adapt to the situational requirements or the patient's demands. In a bench study, a feeding-flow of 12 l/min resulted in a minute volume of 5.8 l/min whereas a feeding-flow of 15 l/min resulted in a minute volume of 6.9 l/min when

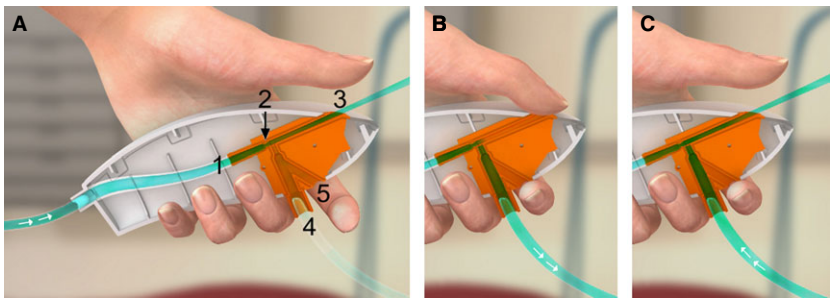

Fig. 2. Working principle of Ventrain®. (A) The Ventrain® is depicted in a longitudinal section. Tubing coming from the air/oxygen source (pressure compensated flowmeter(s) or flowregulator(s) attached to a wall outlet or an air/oxygen tank) is connected to the inlet (1). The air/oxygen flow is accelerated by a jet nozzle (2) and enters the exhaust pipe (3) at high speed, thereby creating sub-atmospheric pressure at the side-port (4) by Bernoulli's principle. A bypass (5) allows air to enter the ejector. Short tubing at the side-port connects the ejector by Luer lock to a small-bore tube in the patient's airway (not shown). As long as the bypass, functioning as the on/off switch, is open, there are no clinically relevant flows via the side-port to and from the catheter (= equilibration with the atmosphere). (B) To activate Ventrain® the bypass needs to be completely closed. Air/oxygen is insufflated (= inspiration) by simultaneously closing the outlet of the exhaust pipe that functions as the inspiration/expiration switch. (C) The flow through the small-bore catheter can be reversed by releasing the inspiration/expiration switch. Entrainment of gas by the high-speed flow of oxygen facilitates expiration and thus shortens expiration time (= active expiration). The figure is used with permission of Ventinova Medical, Eindhoven, the Netherlands.

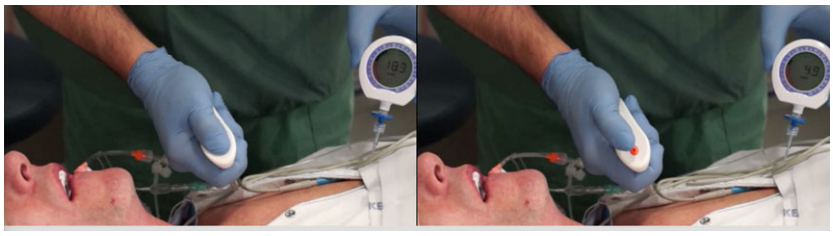

Fig. 3. Ventilation with Ventrain® via Tritube®. Left: The aperture of the exhaust pipe of the Ventrain® is occluded by the thumb and the intratracheal pressure is 18.3 cmH_20 (at the end of the inspiration). Right: The thumb is lifted so that active expiration is performed via the Tritube® and the intratracheal pressure is 4.9 cmH_2O (at the end of the expiration).

ventilation was performed via a transtracheal catheter with 2 mm internal diameter at a lung compliance of 50 ml/mbar.[7]

For transtracheal ventilation and oxygenation Ventrain is much more effective in the presence of airway obstruction than if the glottis is open.[6]

The side-port at the distal connection T-piece enables side-stream capnography. To measure end-tidal CO_2 one has to allow for slow passive expiration, because the sub-atmospheric pressure created by Ventrain® during active expiration interferes with the action of the side-stream capnometry pump that samples the gas.

By now use of Ventrain® has proved successful in animal studies for transtracheal ventilation[6] and for ventilation via a 100 cm long airway exchange catheter[9], in humans for emergency ventilation of small children in emergency via airway exchange catheters[10] and for elective ventilation via the cricothyroid membrane.[11,12]

In the present series, the gas supply consisted of a standard wall-outlet of air and oxygen connected to a standard, non-pressure compensated, double flowmeter with the range from 0 to 15 l/min for both air and oxygen. This allowed for choosing an air/oxygen mixture with a FiO_2 between 21% and 100% and a constant flow set to a total of 15 l/min.

Ventrain® should ideally be used in combination with a flow regulator or a pressure compensated flowmeter, which both are designed to regulate the gas at wall or tank outlet pressure. Consequently, a flow regulator as well as a pressure compensated flowmeter can handle the backpressure caused by the jet nozzle inside the Ventrain® and will thus correctly indicate the actual delivered flow without or with the Ventrain® attached. When using the Ventrain® in combination with a non-pressure compensated flowmeter, which is calibrated for a flow at atmospheric pressure, the desired flow has to be set before attaching the Ventrain®. On attachment the backpressure caused by the nozzle inside the Ventrain® will lead to an immediate change in flow reading, which is lower than the actual flow delivered, because the gas flowing through the flowmeter column is now compressed up to the driving pressure of the Ventrain®. This should not prompt the physician to increase the flow again as this will lead to an erroneously high flow setting. If a change of flow is desired during the procedure, the Ventrain® must be uncoupled from the non-pressure compensated flowmeter before adjusting the flow.

Ethical considerations

The Ventrain® and the Tritube® are CE-marked for clinical use. All patients gave oral and written consent to have their data and photos used for publication.

Results

Seven patients presenting for ENT surgery are described (Table 1). In all patients, the surgical field was in the pathway of the endotracheal tube necessitating an endotracheal tube with as small a cross-sectional area as possible to optimise surgical access. Additionally, in three patients there was severe narrowing of the airway necessitating the use of a small tube. Malignancy was suspected or had been diagnosed previously in all subjects.

Tracheal intubation with the Tritube®

Two patients underwent an awake intubation. In the other five patients, we used general anaesthesia combined with neuromuscular block with rocuronium, ensuring no response to train-of-four-stimulation. Anaesthesia was maintained with infusion of propofol and remifentanil.

During intubation with both direct laryngoscopy (patients #1 and #5) and with video laryngoscopy (patients #2, #4, #6 and #7) it was perceived as a considerable advantage that the tube took up so little of the visual field, allowing for a better view of the laryngeal inlet (Fig. 4 and video at: www.airwaymanagement.dk).

The stylet that comes with the Tritube® ends two centimetres proximally to the distal end of the tube. This stylet-tube combination facilitated oral intubation in five patients after induction of anaesthesia (patients #1, #2, #4, #5 and #6) whereas in one patient who underwent an awake intubation using a video laryngoscope (patient #7) the anaesthetist requested a more distal bend of the distal tip of the tube than what was possible with the stylet in its original position. This was achieved by 'unwinding' the loop at the proximal end of the malleable stylet,

Table 1 Patients having endotracheal intubation with the Tritube® and being ventilated with the Ventrain®.

Patient	1	2	3	4	5	6	7
Age (years)/gender	59/male	49/male	66/male	57/male	67/male	70/male	60/female
Weight (kg)/Height (cm)	70/173	65/179	90/179	65/173	72/175	83/174	78/173
ASA score	II	II	III	II	II	II	III
Airway evaluation							
MP	1	2	4	4	2	2	3
Mouth opening, cm	> 4	4	1.5	1.5	> 4	> 4	> 4
Ability to prognate	Yes	Yes	No	No	Yes		Yes
Mobility of neck	Full	Full	Restricted	Full	Restricted	Full	Limited
Surgeons pre-anaesthetic airway evaluation	Bulging of tissue from right tonsil to epiglottis, preventing view of vallecula	Left nas-endoscopy: Sequelae after radiation therapy. Oedema in the arytenoid region and possible fistula-opening.		Increased resistance when palpating left tonsil region. Trismus.	Tumour of right vocal fold.	Nas-endoscopy: Suspicious area on the laryngeal surface of epiglottis.	Huge Reincke-oedema in larynx, ballooning up and down.
Intubation with Tritube®							
Awake/Anaesthetised	Anaesthetised	Anaesthetised	Awake	Anaesthetised	Anaesthetised	Anaesthetised	Awake
Intubation (oral/nasal)	Oral	Oral	Nasal	Oral	Oral	Oral	Oral
Intubation technique	Direct laryngoscopy with Macintosh #3 blade	Initially McGrath Mac-video laryngoscope with Mac-blade #3 that did not allow view of vocal cords. Secondly McGrath Mac-video laryngoscope with the angulated X-blade.	A flexible scope introduced via the nose to mid-trachea and a 150 cm guidewire was placed in trachea via working channel and the Tritube® advanced over the guidewire (see details in the text)	McGrath Mac video laryngoscope with the angulated X-blade	Direct laryngoscopy with Macintosh #3 blade	Storz CMac video laryngoscope with Mac#3-blade.	Awake laryngoscopy with the Storz CMac video laryngoscope with the D-blade mounted. Only 4 mm of glottic opening visible due to the oedema. Stylet was manipulated (ring of stylet was unfolded) to make stylet longer
Cuff pressure (mbar)	25	25	30	25	30	30	30
Ventrain® ventilation							
Applied I:E ratio, seconds	nd	4 : 4	2 : 2	4 : 4 to 6 : 6	4 : 6	5–6:5–6	6 : 8
Oxygen feeding flow (L/min)	12	12	7.5	7.5	7.5	6	7
Air feeding flow (L/min)	3	3	7.5	7.5	7.5	9	8

Table 1 (Continued)

Patient	1	2	3	4	5	6	7
Total duration of Ventrain® ventilation (min)	90	95	34	130	67	65	124
Minimum arterial oxygen saturation during ventilation via Tritube®, %	100	100	100	100	100	100	100
Minimum pressure in trachea during Ventrain® ventilation cmH_2O	5	5	5	5	5	5	5
Maximum pressure in trachea during Ventrain® ventilation), cmH_2O	20	20	20	18	18	18	20
Tritube® use							
Timing of extubation (clinical signs)	When patient was awake	Awake and talking	After being fully awake for 65 min in the recovery room	When awake and talking in the recovery room	When awake and talking in the recovery room	When awake and talking in the recovery room	When awake and talking in the recovery room
Was secretion present in mouth/pharynx	Yes, suction was done during procedure	Yes	No	No	No	Yes, suction needed	No
Complications related to Tritube®/Ventrain®	No	No	No	No	No	No	No
Additional observations by the surgeon of use of Ventrain® + Tritube® during procedure.	Perfect view, very nice, lots of space	Perfect subglottic view, which would not have been possible with the standard 6.0 mm tube. Even possible to place an extra optical device.		Good view, no problems for tonsillectomy	Surgeon: very good view. Tritube® is easy to manipulate to access tumour.	Perfect view	Tube allows excellent surgical conditions in larynx

MP, Modified Mallampati score I-IV; nd, not documented; nd, not documented; ASA score, American Society of Anaesthesiologists physical status.

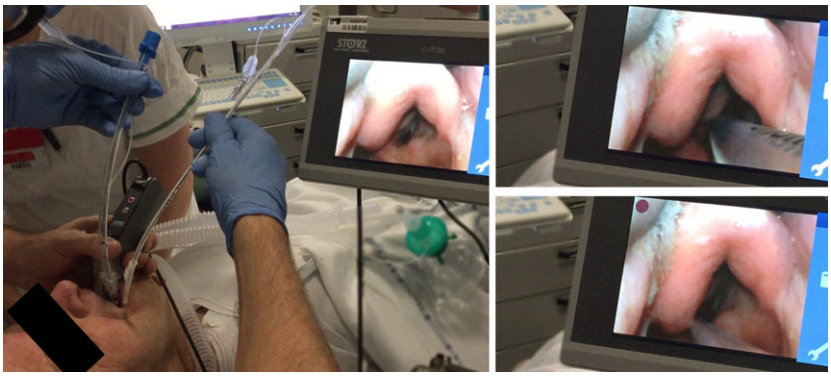

Fig. 4. A standard tube and the Tritube® in the same view. Left: A standard 6.0 mm internal diameter tube (left) and the Tritube® (right). Right upper: The video laryngoscopic view and the area occupied by the conventional 6.0 mm internal diameter tube. Right lower: The video laryngoscopic view and the area occupied by the 2.4 mm internal diameter Tritube®. See video at www.airwaymanagement.dk.

thus allowing further insertion of the stylet into the tube and for distal bending of the Tritube®. One patient underwent awake nasal flexible optical intubation after local anaesthesia of the nose with 4% cocaine and local anaesthesia of the larynx and trachea with lidocaine 4% via the flexible scope. A Pentax FI-13BS flexible fiberoptic scope (Pentax Medical, Tokyo, Japan) was inserted via the left nostril into the mid-trachea and subsequently a 150 cm long and 0.89 mm diameter guide wire, (EmeraldTM guide wire, Cordis Corporation, Miami Lakes, Florida) was introduced via the working channel of the fiberscope into a main stem bronchus. The fiberscope was withdrawn and reintroduced into the trachea alongside the guide wire. The Tritube® was threaded onto the guide wire and was railroaded into the trachea. The tip of the Tritube® was placed 5 cm proximally from the carina by observation via the fiberscope.

All intubations were successful and no adverse events were encountered.

Ventilation with the Ventrain® via the Tritube®

Depending on intratracheal pressure readings, inspiration lasted between 2 and 6 s and expiration between 2 and 8 s. In all patients, the intratracheal pressure was continuously measured with a GiO-3 pressure monitor (McArthur Medical, Ontario, Canada) and in six patients the pressure was simultaneously measured with a standard cuff pressure monitor (VBM Medizintechnik GmbH, Sulz a. N., Germany; Fig. 5). Similar pressures were recorded with these two devices. Intratracheal pressure was maintained between 18 and 20 cmH_2O at end-inspiration and 5 cm H_2O at end-expiration. Duration of ventilation (see the Table 1) through the Tritube varied from 34 to 130 min.

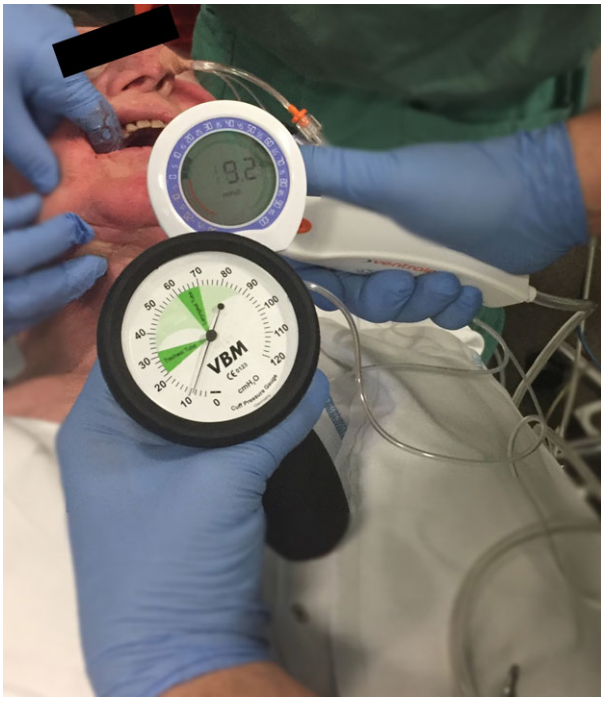

Fig. 5. Simultaneous real-time measurement of intratracheal pressure. Pressure measured with the dedicated airway manometer (upper) and with a standard manometer usually applied for measuring cuff pressure (lower).

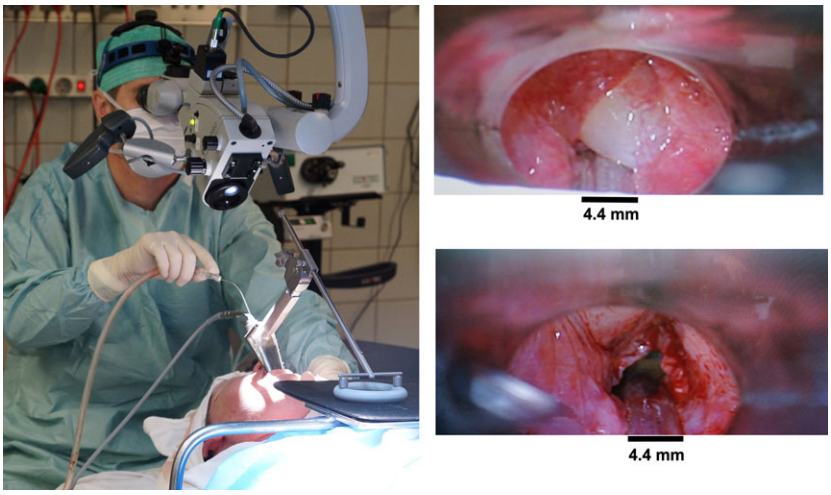

Fig. 6. Patient #7 with laryngeal obstruction and with the Tritube® in place before and after surgery. Left: Airway surgery via a suspension laryngoscope. Right, upper: The view via the laryngoscope shows that the laryngeal entrance is almost completely occupied by cystic tissue. The black bar shows the 4.4 mm diameter external diameter of the Tritube®. Right, lower: Same view as above after the cystic tissue has been removed.

End tidal CO_2 was measured at regular intervals via the capnography tubing of the anaesthesia machine attached to the side port of the Ventrain®. End-tidal CO_2 was measured after a passive expiration or equilibration manoeuvre (Fig. 2A) instead of active expiration.

The minimum and maximum end tidal CO_2 readings of each patient were recorded and all values were between 3.6 and 5.4 kPa. In one patient, we measured the arterial CO_2 after 101 min of ventilation via the Tritube®, it was 4.18 kPa, and the simultaneous reading of end-tidal CO_2 was 4.0 kPa.

Surgical access and surgical field

In all diagnostic laryngoscopy procedures, the field of vision, surgical access and the ability to move the Tritube® if desired were judged as excellent by the surgeon. In patient #2 the use of the Tritube® allowed exploration of the subglottic space due to the small cross-sectional area of the tube. This allowed diagnosis and treatment of a tracheal fistula.

In patient #7 the endolarynx was filled with excessive oedematous exophytic tissue that interfered with visualisation of the vocal cords during the surgeon's pre-operative endoscopy. The use of the Tritube®, inserted during awake video laryngoscopy by the anaesthetist, allowed intubation despite the very narrow glottic opening and also simultaneous ventilation and surgical removal of the pathological tissue. Figure 6 shows the endolarynx with the Tritube® in place before and after surgery.

Recovery

It was possible to ventilate all patients by facemask when the Tritube® was still in place with a deflated cuff (Fig. 7). This was possible because the outer diameter of the Tritube® was small enough not to interfere with the seal between the facemask and the skin.

After surgery and recovery of anaesthesia we left the Tritube® in place after deflation of the cuff in all but one patient and they all tolerated the Tritube® in their trachea well, and were able to talk with the tube still in place. In five patients, the Tritube® was left in tracheal position until they were in the recovery ward. In one patient, the Tritube® stayed intratracheally for more than 1 h in the recovery ward until it was obvious that he had fully recovered and that airway compromise would be very unlikely.

Discussion

We found that the Tritube® was easy to place in the trachea due to its small diameter and its

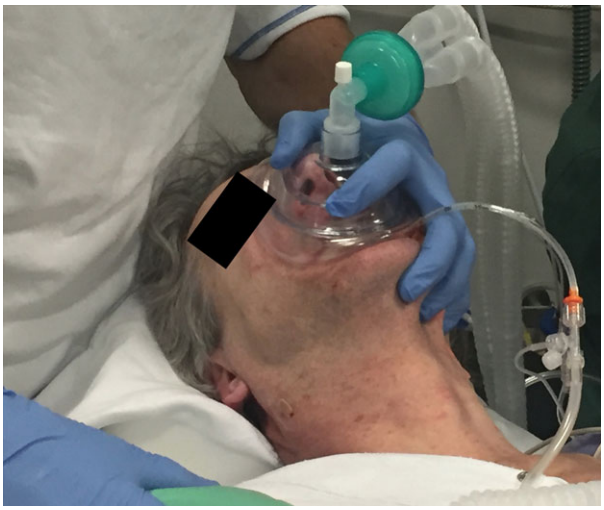

Fig. 7. Facemask ventilation with the Tritube® still in the trachea (cuff deflated). During emergence of anaesthesia facemask ventilation can be performed after deflating the cuff with the Tritube® still in the trachea.

malleability in combination with its stylet. Furthermore, the surgical access and field for ENT-interventions were superior to what we have previously obtained with an endotracheal tube in place. The small cross-sectional area of the tube also allows inspection and surgery of the subglottic space and if desired the cuff can be deflated to allow the surgeon to inspect the airway below the tip of the Tritube®. The laryngeal view during intubation seems to be less obstructed than with a conventionally sized endotracheal tube. Till now, if a surgical procedure precluded placement of an endotracheal tube, ventilation would typically be achieved with high-pressure source jet ventilation or the surgery would be done during apnoea. During jet ventilation, the airway needs to be patent to allow for passive expiration and hyperinflation is a well-known risk of this ventilation method. Also, there is no cuff to protect against aspiration. Ventilation with Ventrain® allows an unprecedented breath-by-breath control through the Tritube® allowing for ventilation through a small-bore catheter with an elective seal of the airway by cuff inflation. Intratracheal pressures can continuously be measured which we expect would increase safety of this ventilation method.

Postoperatively the tube can be left in the patient after deflation of the cuff – also in the post-operative recovery unit. This can be done if it is uncertain if the patient's airway will stay sufficiently patent post-operatively and if the patient can manage to breathe spontaneously. In this way, the use of a tube-exchange catheter becomes unnecessary. Small doses of topical lidocaine on the cuff were used in six patients. Combined with the small outer diameter of the Tritube® this led to patient comfort, despite having an artificial airway present while being awake.

Smaller diameter endotracheal tubes cause less throat pain, so it is possible that the Tritube® will decrease discomfort caused by a sore throat. Also, during awake nasal intubation the small cross-sectional diameter of the Tritube® is likely to cause less pain and discomfort than a conventional tube.

It is known that in order to intubate over a guide it is an advantage that the outer diameter of the tube is small and that the gap between the inner wall of the tube and the guide wire or flexible scope is as small as possible.[13] This means there is only a small risk of 'hanging up' on the laryngeal structures when intubating with the Tritube® over a guide wire, as was done in patient #3.

The possibility to ventilate by facemask when the Tritube® is still in place and the cuff is deflated, can be useful during emergence from anaesthesia when the patient may still need supplementary facemask ventilation or continuous positive airway pressure (Fig. 7).

With the cuffed Tritube®, Ventrain® ventilation can be performed in an elective setting in a safe environment for the patient, the instructor and the trainee. In this way clinicians may become experienced with this technique in case that they should be faced with the need for it (e.g. for transtracheal small-bore ventilation in an emergency setting).

However, it needs to be emphasised, that whenever ventilating with Ventrain® through Tritube® one should meticulously focus on the intratracheal pressure readings on the manometer. Any distraction while ventilating may lead to undesirably high or low intratracheal pressures. Switching to safe equilibration mode (deactivation and functional disconnection) (Fig. 2A) of Ventrain® will allow for proper end-tidal side-stream capnometry and is also a welcome short break for the person actively ventilating with Ventrain®.

Other *drawbacks* to the method include the inability to use a volatile anaesthetic and that insufflated air is not humidified. Secretions could possibly obstruct the small lumen, but the high flow during insufflation may help to constantly clear the lumen of the Tritube®. Secretions could also obstruct the small lumen for pressure monitoring and for the capnography tubing. Prompt flushing of these lumens with air or normal saline can be applied should this occur. When a flexible scope is used for intubation, it is necessary to place a guide wire first via the scope and subsequently thread the Tritube® over the guidewire and into trachea (under visual control).

In the future, a ventilator with EVA technology that could operate automatically within pre-set limits would be attractive to use during longer lasting operations where a Tritube® is used.

More systematic data on safe use of the Tritube® are needed and further experience combined with animal data would contribute substantially to the knowledge that we need for widespread use.

In conclusion, the cuffed Tritube® seems to facilitate both tracheal intubation and to provide unprecedented view of the intubated airway during oral, pharyngeal, laryngeal or tracheal procedures in adults. With Ventrain® expiratory ventilation assistance adults can be ventilated safely through this small-bore tube. Our early clinical experience suggests many promising future perspectives in airway management and the technique has the potential to replace current practices like temporary tracheostomy or jet ventilation in selected patients.

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