

ORIGINAL ARTICLE

Glottic visibility for laryngeal surgery: Tritube vs. microlaryngeal tube

A randomised controlled trial

Johannes Schmidt, Franziska Günther, Jonas Weber, Vadim Kehm, Jens Pfeiffer, Christoph Becker, Christin Wenzel, Silke Borgmann, Steffen Wirth and Stefan Schumann

BACKGROUND Good visibility is essential for successful laryngeal surgery. A Tritube with outer diameter 4.4 mm, combined with flow-controlled ventilation (FCV), enables ventilation by active expiration with a sealed trachea and may improve laryngeal visibility.

OBJECTIVES We hypothesised that a Tritube with FCV would provide better laryngeal visibility and surgical conditions for laryngeal surgery than a conventional microlaryngeal tube (MLT) with volume-controlled ventilation (VCV).

DESIGN Randomised, controlled trial.

SETTING University Medical Centre.

PATIENTS A total of 55 consecutive patients (>18 years) undergoing elective laryngeal surgery were assessed for participation, providing 40 evaluable data sets with 20 per group.

INTERVENTIONS Random allocation to intubation with Tritube and ventilation with FCV (Tritube–FCV group) or intubation with MLT 6.0 and ventilation with VCV (MLT–VCV) as control. Tidal volumes of 7 ml kg^{-1} predicted body weight, and positive end-expiratory pressure of $7 \text{ cmH}_2\text{O}$ were standardised between groups.

MAIN OUTCOME MEASURES Primary endpoint was the tube-related concealment of laryngeal structures, measured

on videolaryngoscopic photographs by appropriate software. Secondary endpoints were surgical conditions (categorical four-point rating scale), respiratory variables and change of end-expiratory lung volume from atmospheric airway pressure to ventilation with positive end-expiratory pressure. Data are presented as median [IQR].

RESULTS There was less concealment of laryngeal structures with the Tritube than with the MLT; 7 [6 to 9] vs. 22 [18 to 27] %, ($P < 0.001$). Surgical conditions were rated comparably ($P = 0.06$). A subgroup of residents in training perceived surgical conditions to be better with the Tritube compared with the MLT ($P = 0.006$). Respiratory system compliance with the Tritube was higher at $61 [52 \text{ to } 71]$ vs. $46 [41 \text{ to } 51] \text{ ml cmH}_2\text{O}^{-1}$ ($P < 0.001$), plateau pressure was lower at $14 [13 \text{ to } 15]$ vs. $17 [16 \text{ to } 18] \text{ cmH}_2\text{O}$ ($P < 0.001$), and change of end-expiratory lung volume was higher at $681 [463 \text{ to } 849]$ vs. $414 [194 \text{ to } 604] \text{ ml}$, ($P = 0.023$) for Tritube–FCV compared with MLT–VCV.

CONCLUSION During laryngeal surgery a Tritube improves visibility of the surgical site but not surgical conditions when compared with a MLT 6.0. FCV improves lung aeration and respiratory system compliance compared with VCV.

TRIAL REGISTRY NUMBER DRKS00013097.

Published online 18 October 2019

Introduction

Laryngeal procedures pose a particular challenge both for the anaesthetist and the surgeon. General anaesthesia is usually employed with a secured airway for ventilation and subsequent oxygenation, but the endotracheal tube

(ETT) can impair visualisation of the surgical field and hinder the operation.^{1–4} Strategies to overcome these competing interests include ventilation via microlaryngeal tubes (MLTs), jet ventilation and intermittent

From the Department of Anaesthesiology and Critical Care (JS, FG, JW, VK, CW, SB, SW, SS) and Department of Otorhinolaryngology (JP, CB), Medical Centre – University of Freiburg, Faculty of Medicine, University of Freiburg, Freiburg, Germany

Correspondence to Dr Johannes Schmidt, Department of Anaesthesiology and Critical Care, Medical Centre – University of Freiburg, Hugstetter Str. 55, 79106 Freiburg, Germany

Tel: +49 761 270 26390; e-mail: johannes.schmidt@uniklinik-freiburg.de

0265-0215 Copyright © 2019 The Author(s). Published by Wolters Kluwer Health, Inc. on behalf of the European Society of Anaesthesiology.

DOI:10.1097/EJA.0000000000001110

This is an open access article distributed under the terms of the Creative Commons Attribution-Non Commercial-No Derivatives License 4.0 (CCBY-NC-ND), where it is permissible to download and share the work provided it is properly cited. The work cannot be changed in any way or used commercially without permission from the journal.

apnoea after removal of the ETT,⁵ but all of these strategies share major limitations for patient safety. The outer diameter of MLTs can still block vision and their high artificial flow resistance may promote intrinsic positive end-expiratory pressure (PEEP) with the risk of dynamic hyperinflation. During jet ventilation and intermittent apnoea, the trachea is open and at risk of aspiration. In addition, since ventilation is poorly controlled, there is risk of hypoventilation, desaturation and formation of atelectasis.^{6,7}

Recently a new airway device, the Tritube (Ventinova Medical B.V., Eindhoven, The Netherlands) with an outer diameter of only 4.4 mm has been introduced and promises better conditions for ear, nose and throat (ENT) surgery.⁸ The Tritube offers a sealed trachea and fully controlled ventilation with a ventilator with 'Expiratory Ventilation Assistance' (EVA) technology first described by the group of Enk. Until recently only the manually operated Ventrain ventilation device (Ventinova Medical B.V.) was available to exploit this technology,⁹ but since 2017, an automated ventilator with EVA technology has become commercially available (Evone; Ventinova Medical B.V.). The new automated ventilation mode was termed 'Flow-Controlled Ventilation' (FCV) and its first use in clinical practice has been recently reported.¹⁰ The Tritube and Evone form a new ventilation system that might be beneficial for laryngeal surgery and we hypothesised that visualisation of the larynx would be better with a Tritube. In this randomised controlled trial, we assessed the degree of concealment of laryngeal structures (primary endpoint) when using a Tritube and compared this with a conventional MLT during elective laryngeal surgery. In addition, we evaluated the subjective surgical conditions and the duration of surgery.

FCV is necessary for the use of the Tritube and comes with some features that differ from conventional ventilation, the most prominent being the constant expiratory flow that was associated with lung recruitment in healthy pigs.¹¹ Accordingly, we also compared FCV with conventional volume-controlled ventilation (VCV) with respect to inspiratory plateau pressure (P_{plat}), PEEP, the P_{plat} and PEEP (ΔP) difference, tidal volume (V_T), respiratory rate, minute volume, end-tidal CO₂ partial pressure (PetCO₂), semi-static respiratory system compliance (C_{RS}) and change of end-expiratory lung volume ($\Delta EELV$).

Methods

The study was approved by our local ethics committee (Ref: 392/17), date of approval: 18.09.2017; Ethics committee of the University of Freiburg, Engelberger Strasse 21, 79106 Freiburg, and was registered in the German register for clinical studies (Ref: DRKS00013097) prior to inclusion of the first patient. Written informed consent was obtained before participation. Patients were enrolled at the Medical Centre of the University of Freiburg,

Germany. It was designed as a parallel arm, randomised, controlled trial with an allocation ratio of 1:1. Randomisation was carried out in blocks of 10 by a computer-generated allocation sequence and was kept in closed envelopes until disclosure.

Inclusion and exclusion criteria

Patients more than 18 years of age scheduled for an elective laryngeal procedure were eligible. Exclusion criteria were American Society of Anesthesiologists physical status more than III, planned laser surgery, suspected difficult airway, active implants (pacemaker, cardioverter-defibrillator – due to interference with the measurement of thoracic electrical impedance), chronic obstructive airway disease (COPD) more than GOLD II and elevated risk of aspiration.

Induction and maintenance of general anaesthesia

According to local protocols, total intravenous anaesthesia was induced and maintained with propofol (Propofol 1%, Fresenius Kabi, Bad Homburg, Germany; target controlled infusion, effect site target concentration for induction: 6 to 8 $\mu\text{g ml}^{-1}$, for maintenance: 3 to 5 $\mu\text{g ml}^{-1}$) and remifentanyl (Remifentanyl, TEVA GmbH, Ulm, Germany; induction: 1 to 2 $\mu\text{g kg}^{-1}$, maintenance: 0.15 to 0.3 $\mu\text{g kg}^{-1} \text{ min}^{-1}$). To standardise intubation conditions, cis-atracurium (0.05 mg kg^{-1}) was given. Norepinephrine was continuously infused to maintain a mean arterial pressure more than 65 mmHg, if necessary.

Experimental protocol

After induction of anaesthesia, the randomised allocation to one of the two study groups (intervention or control) was disclosed. For all patients, a videolaryngoscope (C-MAC, KARL STORZ, Tuttlingen, Germany, Macintosh blade #4) was used for the intubation procedure. The patients of the intervention group (Tritube-FCV) were intubated with a Tritube and subsequently ventilated with FCV (Evone; Ventinova Medical B.V.). Those of the control group (MLT-VCV) were intubated with a MLT with an inner diameter of 6.0 mm and an outer diameter of 8.2 mm (MLT 6.0; Shiley, Medtronic, Meerbusch, Germany) and ventilated with VCV (Primus IE; Dräger Medical, Lübeck, Germany). The cuff pressure was adjusted to 25 to 30 cmH_2O . Tidal volume (7 ml kg^{-1} predicted body weight) and PEEP (7 cmH_2O) were fixed for both groups. Respiratory rate was set to achieve a PetCO₂ of 4.5 to 6 kPa. Respiratory data were recorded continuously via the built-in serial interface of the respective ventilators and analysed offline.

Endpoints of the study

The primary endpoint of the study was the area of the larynx that was concealed by the ETT, measured on photographs taken directly after successful intubation with the videolaryngoscope. Dedicated software (ImageJ2; National Institutes of Health, Bethesda, Maryland,

USA) was used for the visual determination of the region of interest, which was bordered by the epiglottis, the aryepiglottic fold, and the interarytenoid area. Relative concealment was defined as the percentage of the region of interest that was concealed by the respective tube.

Secondary endpoints included an evaluation of the surgical conditions rated by the ENT surgeon on a categorical four-point rating scale (poor, acceptable, good and optimal) according to a recently suggested approach.¹² In addition, the duration of the surgical procedure was recorded. The respiratory data were recorded continuously during the procedure and were analysed with dedicated software (MATLAB R2017b; MathWorks Inc., Natick, Massachusetts, USA) to determine Pplat, PEEP, ΔP , V_T , respiratory rate, minute volume, PetCO₂ and C_{RS} calculated as $V_T \Delta P^{-1}$. For each patient, a mean of each variable was calculated and used to represent the intra-operative value, neglecting the induction phase and emergence from anaesthesia. Thoracic electrical impedance tomography (PulmoVista 500; Dräger Medical) was used to determine the end-expiratory lung volume during apnoea with static atmospheric airway pressure and during the respective ventilation mode. The difference of both values was calculated to represent the $\Delta EELV$ as described previously.¹³ In brief, the intratidal change of thoracic electrical impedance was adjusted to the known V_T to calculate the respective volume change. Haemodynamic variables, noninvasive measured blood pressure,

heart rate and pulse oximetric oxygen saturation were recorded every 5 min and conjoined to a mean value.

Retrospectively, an exploratory subgroup analysis of the evaluation of the surgical conditions was performed, dividing those patients treated by residents in training and those treated by consultants.

Statistical analysis

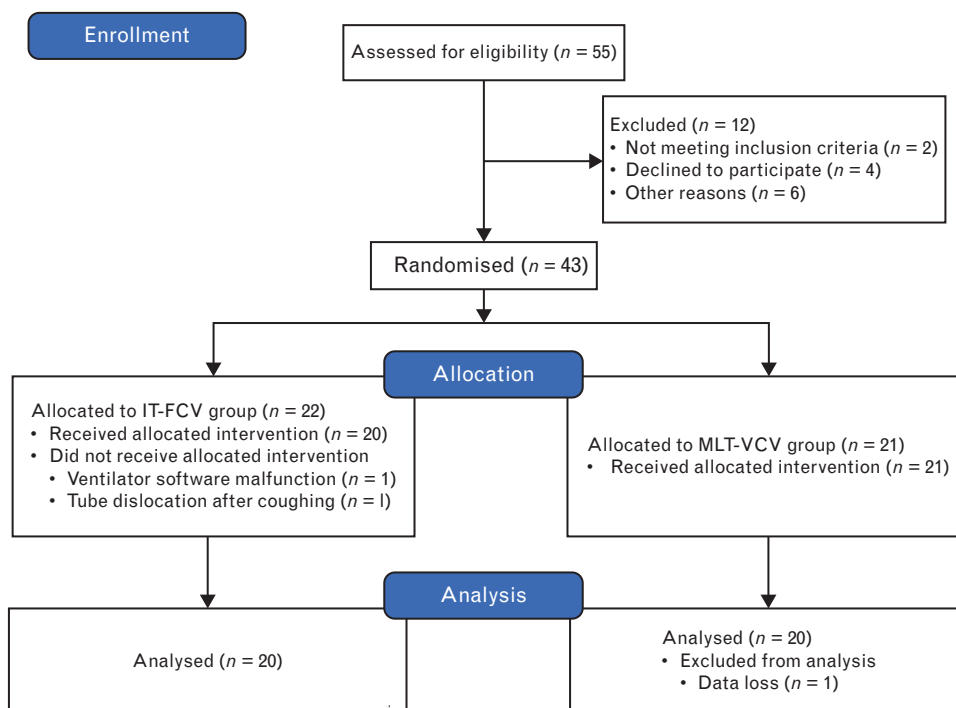
An a priori sample size calculation was based on previously taken videolaryngoscopic photographs that showed a conventional MLT in place. For an estimated mean reduction of concealment from 0.30 to 0.15 with an estimated SD of 0.15, 17 patients per group would be required to find a statistically significant difference with an alpha error of 0.05 with a power of 0.8. To adjust for an underlying non-Gaussian distribution, 15% of the total were added, resulting in an estimated sample size of 20 patients per group.¹⁴

Data are presented as median [IQR]. Differences between the two groups were assessed with a Mann–Whitney test and a χ^2 test, respectively. Statistical significance was defined as *P* less than 0.05.

Results

From 19 October 2017 to 7 May 2018, 55 patients were assessed for enrolment, and 40 were included in the data analysis, 20 for each group. Figure 1 shows the

Fig. 1



CONSORT flow diagram. FCV, flow-controlled ventilation; MLT, microlaryngeal tube; VCV, volume-controlled ventilation.

Table 1 General and clinical characteristics and procedures for both groups

Variable	TT-FCV, <i>n</i> = 20	MLT-VCV, <i>n</i> = 20
Female, <i>n</i>	13	9
Age (years)	54 [45 to 62]	57 [49 to 68]
Body weight (kg)	66 [61 to 73]	81 [62 to 93]
Predicted body weight (kg)	62 [56 to 66]	67 [57 to 72]
Smoker, <i>n</i>	9	12
Comorbidity		
Cardiovascular, <i>n</i>	5	5
Pulmonary, <i>n</i>	2	3
Neoplastic, <i>n</i>	3	4
Alcohol abuse, <i>n</i>	2	3
Metabolic, <i>n</i>	5	3
Other, <i>n</i>	2	6
ASA physical status classification		
I, <i>n</i>	5	3
II, <i>n</i>	10	13
III, <i>n</i>	5	4
Mallampati classification		
I, <i>n</i>	4	4
II, <i>n</i>	13	14
III, <i>n, n</i>	3	2
Cormack/Lehane classification (conventional)		
I, <i>n</i>	10	12
II, <i>n</i>	10	7
III, <i>n</i>	0	1
Cormack/Lehane classification (video-laryngoscopic)		
I, <i>n</i>	13	12
II, <i>n</i>	7	8
III, <i>n</i>	0	0
Surgical procedure		
Endoscopic diagnostic biopsy, <i>n</i>	9	6
Excision of laryngeal lesion, <i>n</i>	7	7
Microlaryngeal intervention, <i>n</i>	4	7
Predetermined respiratory variables		
V_T [ml]	447 [418 to 480]	476 [440 to 510]
V_T per [ml kg ⁻¹ PBW]	7.1 [6.8 to 7.9]	7.2 [6.7 to 7.4]
PEEP (cmH ₂ O)	7 [7 to 7]	7 [7 to 7]
Anaesthetics, analgesics and NMBA		
Propofol induction C_{et} (µg ml ⁻¹)	7 [6 to 8]	6 [6 to 7]
Propofol maintenance C_{et} (µg ml ⁻¹)	4 [3 to 4]	4 [3 to 4]
Remifent. induction (µg kg ⁻¹)	1.7 [1.5 to 1.9]	1.7 [1.3 to 2.0]
Remifent. maintenance (µg kg ⁻¹ min ⁻¹)	0.29 [0.22 to 0.32]	0.25 [0.20 to 0.32]
Cis-atracurium (mg kg ⁻¹)	0.06 [0.05 to 0.06]	0.06 [0.05 to 0.06]

Data presented as *n* or median [IQR]. C_{et} , target effect site concentration; FCV, flow-controlled ventilation; MLT, microlaryngeal tube; NMBA, neuromuscular blocking agent; PBW, predicted body weight; PEEP, positive end-expiratory pressure; TT, Tritube; VCV, volume-controlled ventilation; V_T , tidal volume.

CONSORT flow chart with the excluded patients. No significant differences were noted between groups concerning general and clinical characteristics (Table 1).

Concealment of laryngeal structures and assessment of surgical conditions

Concealment of laryngeal structures by the ETT was lower in the Tritube-FCV group compared with the MLT-VCV group, 7 [6 to 9] vs. 22 [18 to 27]%; P less than 0.001; Fig. 2.

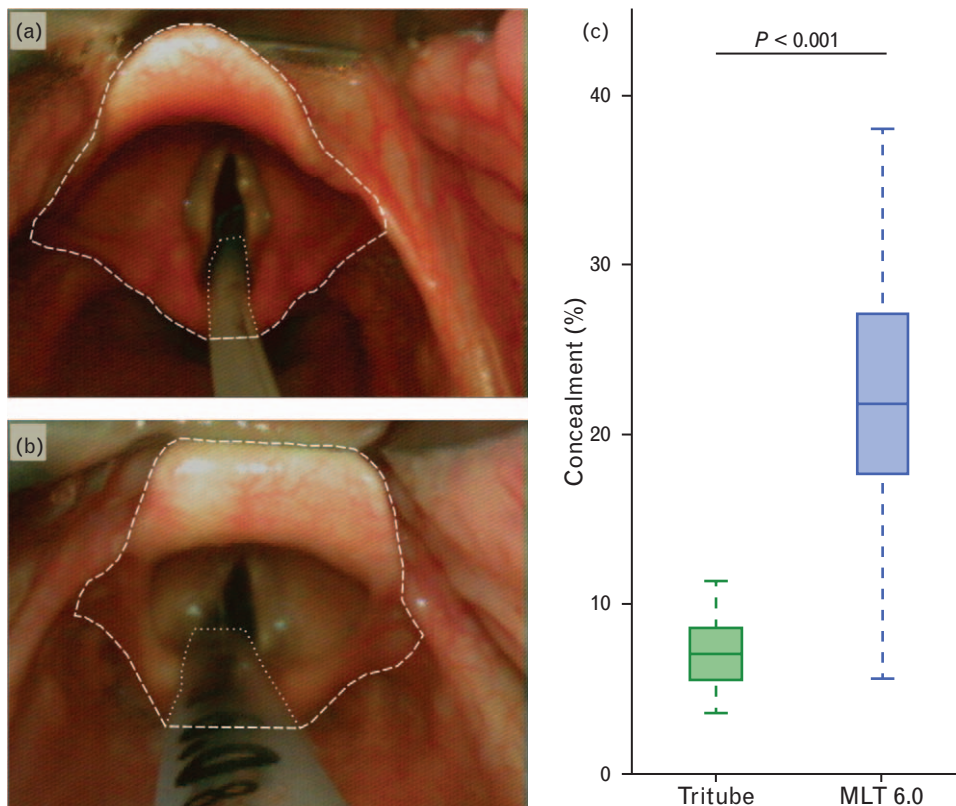
Surgical conditions of the two groups were not significantly different, Tritube: 1/1/5/13 vs. MLT: 2/5/8/5, (poor/acceptable/good/optimal); $P = 0.064$. An exploratory subgroup analysis of ear, nose and throat consultants' assessments showed comparably perceived surgical conditions for both groups, Tritube-FCV: 1/1/5/4 vs. MLT-VCV: 2/2/1/3; $P = 0.62$. The exploratory subgroup

analysis showed that residents in-training assessed surgical conditions better for the Tritube-FCV group, compared with the VCV-MLT group, Tritube-FCV: 0/0/2/9 vs. MLT-VCV: 0/3/7/2; $P = 0.0061$; Fig. 3. The durations of the procedures were comparable for both groups, Tritube-FCV: 33 [28 to 35] vs. MLT-VCV: 38 [28 to 45] min; $P = 0.31$.

Respiratory variables

Compared with MLT-VCV, P_{plat} was lower in the Tritube-FCV group, [13 to 15] vs. 17 [16 to 18] cmH₂O; P less than 0.001 (Table 2) with comparable V_T and PEEP (Table 1). ΔP was lower, 7 [7 to 8] vs. 10 [9 to 11] cmH₂O; P less than 0.001, C_{RS} was higher, 61 [52 to 71] vs. 46 [41 to 51] ml cmH₂O⁻¹; P less than 0.001, and $\Delta EELV$ was higher, 681 [463 to 849] vs. 414 [194 to 604] ml; $P = 0.0228$ in the Tritube-FCV group (Fig. 4). Respiratory rate, 10 [8 to 11] vs. 12 [11 to 12] min⁻¹, P less than 0.001, and

Fig. 2



Representative videolaryngoscopic photographs of a Tritube with an outer diameter of 4.4 mm (a) and a microlaryngeal tube with an outer diameter 8.2 mm (b) after endotracheal placement. Dashed lines indicate defined total laryngeal areas, dotted lines indicate concealed areas; (c) concealment of laryngeal structures for the study groups as boxplot, indicating median, interquartile range and full range.

minute volume, 4.7 [4.2 to 5.2] vs. 5.3 [4.7 to 5.6] l min⁻¹; $P=0.029$ were lower in the Tritube-FCV group, while PetCO₂, 4.9 [4.6 to 5.2] vs. 4.9 [4.7 to 5.2] kPa; $P=0.76$, was comparable for both groups. A summary of the collected respiratory and haemodynamic data can be found in Table 2.

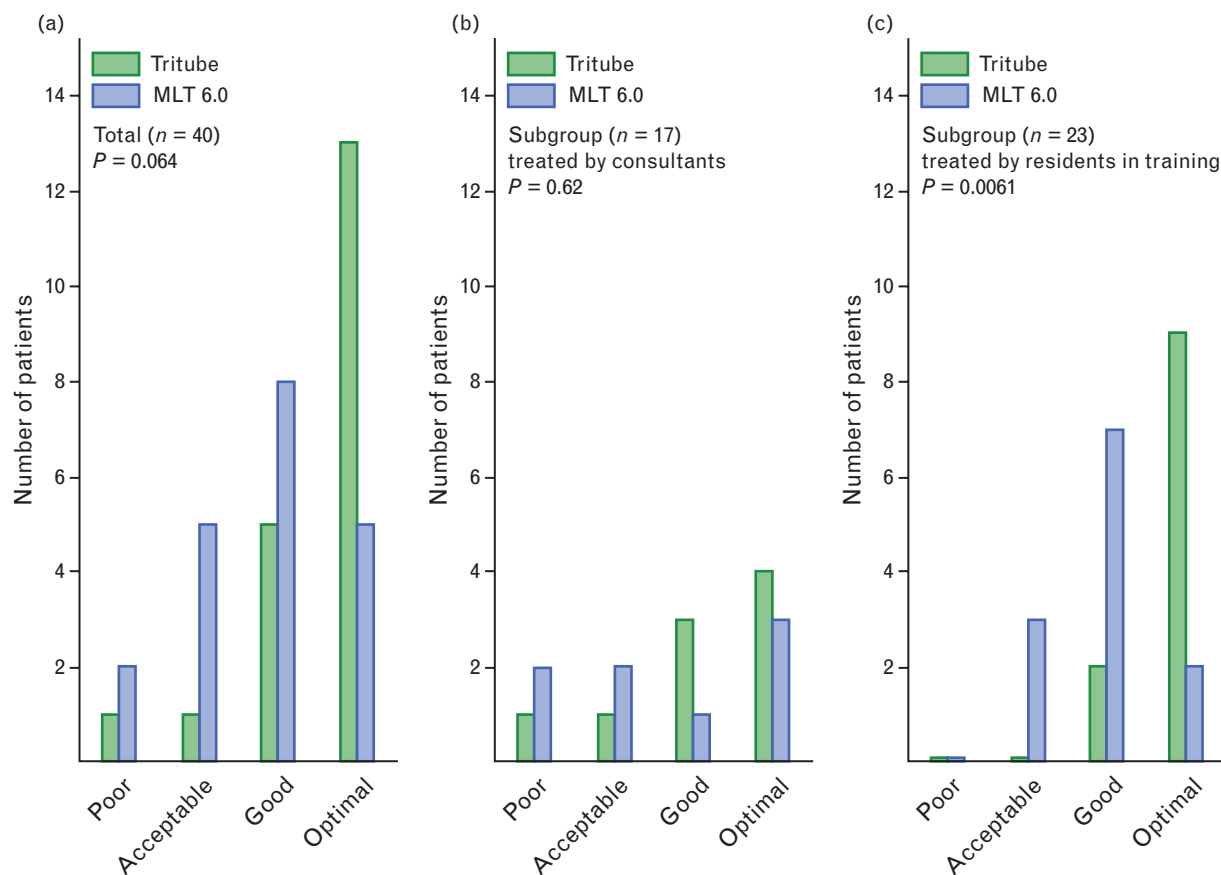
Discussion

This randomised controlled trial was intended to compare two major aspects of two different ventilation systems. These were the differences in laryngeal concealment of the two airway devices and the surgical conditions for laryngeal surgery, and the comparison of two ventilation modes during mandatory intra-operative ventilation. The Tritube concealed fewer laryngeal structures than the MLT 6.0 but did not improve the surgical conditions and the duration of surgery. Concerning ventilation, electrical impedance tomography measurements revealed enhanced lung aeration during FCV, as indicated by an elevated Δ EELV with comparable PEEP. Consequently, C_{RS} was higher during FCV resulting in a lower Pplat and a lower driving pressure in the FCV group, compared with VCV.

Comparison of airway devices

To overcome the challenge of the shared airway the preference of the anaesthetist would be a sealed trachea during upper airway surgery, but the surgeon would opt for the least interfering airway device. A Tritube in combination with FCV might unite the competing interests of both parties. The cuff of the Tritube can be inflated during the entire surgical procedure to prevent aspiration of blood and secretions while the tube's outer diameter of 4.4 mm conceals fewer laryngeal structures than a conventional MLT, as demonstrated by our objective measurements. However, enhanced visibility did not necessarily lead to improved surgical conditions in this study, as the subjective assessment of the surgical conditions demonstrated. Although there were more surgical interventions in the Tritube-FCV group rated with optimal surgical conditions, this effect was mainly caused by the perception of a subgroup of surgeons with a lower level of expertise. Apparently, residents in training evaluate the smaller outer diameter of the Tritube as better for surgical conditions while experienced surgeons do not feel limited by a conventional MLT. An MLT with an ID of 6 mm is our standard airway device for laryngeal surgery as recommended recently,⁵ and our local ENT

Fig. 3



Subjective evaluation of surgical conditions on a four point rating scale for total study cohort (a), for patients treated by ear, nose and throat consultants (b), and for patients treated by ear, nose and throat residents in training (c). A χ^2 test was used to determine a *P* value. MLT, microlaryngeal tube, inner diameter 6.0 mm.

consultants are accustomed to it; this fact might have contributed to our results. Since the sample size calculation was based on the primary endpoint, a larger study might reveal a significant improvement in surgical conditions or the duration of the procedure, both found to be comparable in our study.

However, visibility of laryngeal structures is not only determined by the tube used. Laryngeal exposure is influenced by a multitude of factors, including limited neck extension, the neck circumference and mouth opening. In addition, there are individual differences in the performance of laryngoscopy. For this study, two anaesthetists performed laryngoscopy for each patient trying to achieve best visualisation after the intubation procedure. The distribution of the Cormack/Lehane grades was comparable for both study groups, indicating that laryngeal exposure did not influence the study results. In addition, the distance and the angle of the ETT to the camera lens will have a major influence on visibility, even with a Cormack/Lehane grade I view on the vocal cords. As described in a previous

study,¹⁰ a Tritube is extremely flexible, hence optimal bending and positioning of the tube in relation to the camera lens might have been easier to achieve. This supposed simple positioning for optimal exposure also might explain why residents in training perceive a Tritube as beneficial.

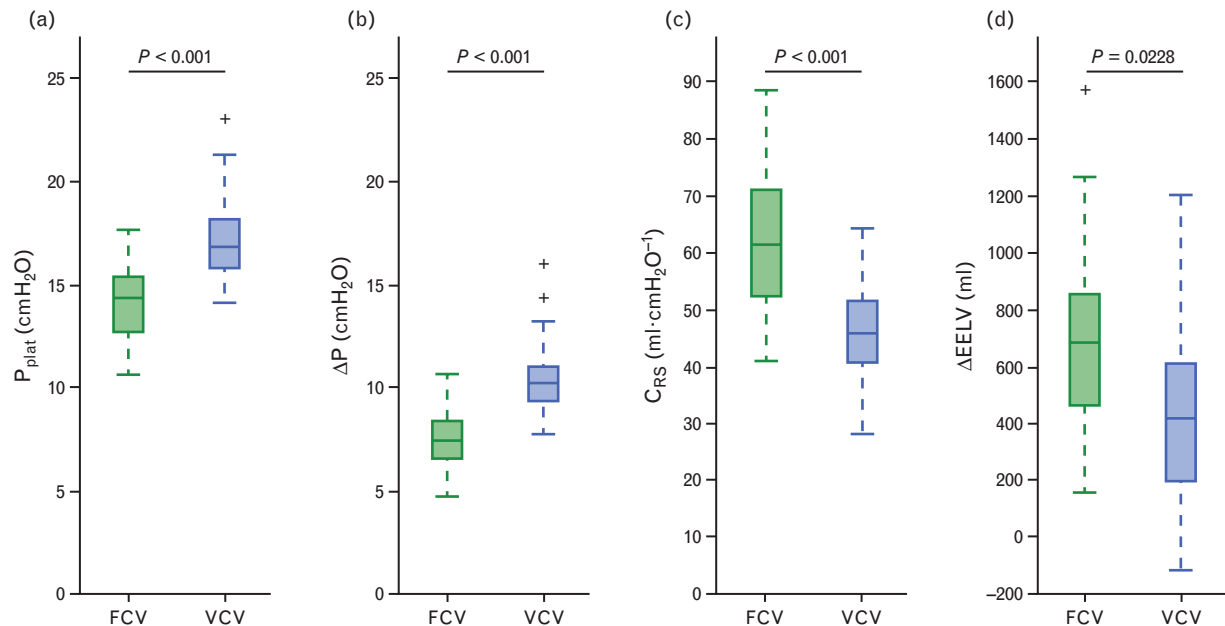
In summary, our results reflect the multidimensional influences on laryngeal visibility and demonstrate that enhanced visibility does not necessarily lead to improved surgical conditions, at least in a cohort without anticipated difficult airway.

However, one might speculate that in patients with a difficult airway, surgical conditions might be substantially improved by a thinner tube. Therefore, specific clinical trials are needed to examine the possible benefits of a Tritube as an airway device in particular clinical situations such as difficult airway.

Comparison of ventilation modes

Controlled ventilation with the Tritube necessarily required a new ventilation mode, FCV. To test for any

Fig. 4



Inspiratory plateau pressure, difference of plateau pressure and positive end-expiratory pressure (ΔP), respiratory system compliance and change in end-expiratory lung volume for volume-controlled ventilation and flow-controlled ventilation. Boxplots indicate median, interquartile range and full range. Outliers indicated by black crosses and defined as data points outside median ± 1.5 interquartile range.

potential shortcomings of FCV, this study was designed not only to compare two airway devices but also to compare two ventilation modes. The Tritube/FCV ventilation system is close to conventional ventilation regarding a sealed upper airway and alternate inspiration and expiration. In addition, FCV is closer to VCV since both modes use a constant inspiratory flow, in contrast to pressure-controlled ventilation. Hence, the comparison of Tritube/FCV with MLT/VCV seemed to be an appropriate approach.

C_{RS} was better during FCV compared with VCV, in agreement with several studies that demonstrated the

beneficial effects on respiratory system variables^{15,16} and gas exchange^{11,17} of a ventilation mode with a linear decline in airway pressure during expiration compared with passive expiration. The constant deflation of the lung tissue seems to attenuate intratidal derecruitment as indicated by the elevated $\Delta EELV$. Consequently, C_{RS} is improved which in turn leads to a decrease of P_{plat} and ΔP . This is the first study to describe this effect of a constant expiratory flow on $EELV$ and C_{RS} .

The ventilation settings of this study reflect our current ventilation standard and it was chosen according to recently published clinical reviews on intra-operative lung protective ventilation with low tidal volume and moderate PEEP.^{18,19} These ventilation settings influence the respiratory system and different settings may produce different results. However, we feel confident that the chosen settings represent common clinical practice. In addition, there were no relevant differences concerning the ventilation settings between the study groups, hence we can attribute the observed results to the ventilation mode in use.

Table 2 Intra-operative respiratory and haemodynamic variables for both groups

Variable	TT-FCV	MLT-VCV	P value
ΔP (cmH ₂ O)	7 [7 to 8]	10 [9 to 11]	<0.001
P_{plat} (cmH ₂ O)	14 [13 to 15]	17 [16 to 18]	<0.001
C_{RS} (ml·cmH ₂ O ⁻¹)	61 [52 to 71]	46 [41 to 51]	<0.001
MV (l·min ⁻¹)	4.7 [4.2 to 5.2]	5.3 [4.7 to 5.6]	0.029
RR (min ⁻¹)	10 [8 to 11]	12 [11 to 12]	<0.001
PetCO ₂ (kPa)	4.9 [4.6 to 5.2]	4.9 [4.7 to 5.2]	0.76
Mean NiBP (mmHg)	76 [69 to 86]	82 [76 to 87]	0.11
HR (min ⁻¹)	55 [50 to 63]	62 [54 to 67]	0.10
SpO ₂ (%)	99 [99 to 100]	99 [99 to 100]	0.57

Data presented as median [IQR]. ΔP , difference of plateau pressure and positive end-expiratory pressure; C_{RS} , respiratory system compliance; FCV, flow-controlled ventilation; HR, heart rate; MLT, microlaryngeal tube; MV, minute volume; NiBP, noninvasive measured blood pressure; PetCO₂, end-tidal carbon dioxide partial pressure; P_{plat} , plateau pressure; RR, respiratory rate; SpO₂, oxygen saturation; TT, Tritube; VCV, volume-controlled ventilation.

Limitations of the study

The primary endpoint was chosen because it allows for objective and standardised measurements. One could argue that enhanced laryngeal visibility due to a smaller tracheal tube diameter is a rather obvious consequence, but it is not the only factor influencing laryngeal visibility,

and seeking an objective measurement seemed an appropriate approach.

The apparent differences in the tubes did preclude a blinded analysis of the laryngoscopic photographs. Hence, a bias due to nonblinding cannot be excluded.

Some clinicians may prefer a smaller MLT or jet ventilation for laryngeal surgery and interventions.^{20,21} However, in our institution jet ventilation is available for special cases and the local standard for anaesthesia is conventional ventilation via an MLT 6.0. Our findings concerning laryngeal visibility and surgical conditions may be less pronounced if an MLT with a smaller diameter was used.

The level of neuromuscular blockade may also affect the rating of surgical conditions during laryngeal surgery.¹² Since we did not quantify the level of neuromuscular blockade, we cannot exclude this influencing our observations. However, with respect to the individual dosing based on the predicted body weight (Table 1) and the pharmacokinetics of cis-atracurium with an organ-independent metabolism, we think it justified to assume there were comparable levels of neuromuscular blockade for both study groups.

There are differences between FCV and conventional ventilation, which are described in detail elsewhere.¹⁰ Prominent among these is the tracheal pressure measurement during FCV, whereas for conventional ventilation, the measured airway pressure represents the pressure at the Y-piece. However, during zero flow conditions, the pressure is equal throughout the whole respiratory system including the ventilator circuit. For this reason, P_{plat} was determined after an end-inspiratory occlusion during zero flow conditions for both groups to enable a correct determination of the semi-static C_{RS} . With regard to the expiratory phase of FCV, PEEP might be underestimated because there is no end-expiratory occlusion for the correct determination.²² However, based on the known (end-) expiratory flow and the assumption of a normal mean airway resistance of the bronchial tree,²³ the error can be approximated as 0.3 cmH₂O, which seems clinically irrelevant. In addition, an underestimated PEEP would mathematically imply an even higher C_{RS} , as ΔP would then be even lower. When the published work on ventilation with a linear decline in airway pressure is taken into account, this study is in agreement with previous results.^{15,16} Furthermore, the risk of developing intrinsic PEEP was lower when using an active expiratory support system (as with FCV) compared with conventional ventilation via a MLT in a lung model study.²⁴ However, since intrinsic PEEP was not assessed in this study, we cannot completely exclude some potential influence of intrinsic PEEP on the results.

We noticed comparable PetCO₂ combined with a lower minute volume due to a lower respiratory rate in the

Tritube-FCV group. According to the study protocol, respiratory rate was continuously adjusted to the PetCO₂. Due to the small ID of Tritube, artificial dead space is substantial lower compared with the MLT. During mechanical ventilation with a steady state CO₂, reduced dead space ventilation will increase alveolar ventilation which in turn leads to improved CO₂ clearance. However, for an unequivocal interpretation of gas exchange, arterial blood samples for determination of the partial pressures of O₂ and CO₂ would be necessary. A previous study in an animal model demonstrated improvements concerning gas exchange during FCV and several underlying mechanisms were proposed.¹¹ Since arterial blood gases were not determined for this study, the interpretation of gas exchange is limited. In addition, the lower respiratory rate will necessarily lead to differences of the inspiratory and expiratory times, which again will lead to differences in the inspiratory and expiratory flow. For our study it is possible that these differences will have influenced the results. However, the suspected underlying mechanism for the observed improvements is the constant expiratory flow. The reduced respiratory rate might have additionally emphasised the already existing differences of the expiratory flow.

One patient in the Tritube-FCV group was excluded due to a software malfunction and failure of the ventilator. The Tritube was removed, the patient was reintubated and ventilated with standard equipment. The study was interrupted until a software update for the ventilator solved this issue. However, the Evone ventilator is still a new device on the market and judgement on ventilator performance and potential complications might be too early.

Another patient in the Tritube-FCV group was excluded following a tube displacement due to coughing. In a previous study, this specific risk of the Tritube was addressed.¹⁰ The high artificial flow resistance of the Tritube may lead to a disproportionate build-up of pressure in the trachea after a thoracic contraction which in turn might cause a tube to displace. Anaesthetists who employ the Tritube should be aware of this increased risk, especially for prolonged procedures with COPD patients in whom substantial secretions might add to the airway resistance.

Finally, specific clinical trials are needed to determine any possible benefits of a Tritube over a jet ventilation catheter.

Conclusion

The combination of a Tritube and FCV poses a new option for anaesthesia for laryngeal procedures. Although there are benefits in better visualisation of the surgical field, conditions for surgery are not improved in patients with an easy airway. The ventilation mode FCV enhances lung aeration and consequently improves C_{RS} .

Acknowledgements relating to this article

Assistance with the study: we would like to thank Dietmar Enk, inventor of FCV and Tritube for sharing his ideas on small lumen ventilation with us.

Financial support and sponsorship: the project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement no 691519.

Conflicts of interest: SS reports a consulting contract with Gründler medical and grants from Deutsche Forschungsgemeinschaft, outside the submitted work.

Presentation: preliminary data for this study were presented as a poster at the Euroanaesthesia meeting, 1 to 3 June 2019, Vienna.

References

- 1 Anesthesia and Airway Management for Laryngeal Surgery. *Operative techniques in laryngology*. Berlin, Heidelberg: Springer; 2008; 53–59.
- 2 English J, Norris A, Bedforth N. Anaesthesia for airway surgery. *BJA Educ* 2006; **6**:28–31.
- 3 McRae K. Anesthesia for airway surgery. *Anesthesiol Clin North Am* 2001; **19**:497–541.
- 4 Nekhendzy V, Kristensen MS, Claire RE. Anesthetic and airway management of microlaryngeal surgery and upper airway endoscopy. *Benumof and Hagberg's airway management*. Amsterdam: Elsevier; 2013; 785–812.e7.
- 5 Charters P, Ahmad I, Patel A, et al. Anaesthesia for head and neck surgery: United Kingdom National Multidisciplinary Guidelines. *J Laryngol Otol* 2016; **130** (S2):S23–S27.
- 6 Jaquet Y, Monnier P, van Melle G, et al. Complications of different ventilation strategies in endoscopic laryngeal surgery: a 10-year review. *Anesthesiology* 2006; **104**:52–59.
- 7 Cook TM, Alexander R. Major complications during anaesthesia for elective laryngeal surgery in the UK: a national survey of the use of high-pressure source ventilation. *Br J Anaesth* 2008; **101**:266–272.
- 8 Kristensen MS, de Wolf MWP, Rasmussen LS. Ventilation via the 2.4 mm internal diameter Tritube® with cuff – new possibilities in airway management. *Acta Anaesthesiol Scand* 2017; **61**:580–589.
- 9 Hamaekers AEW, Götz T, Borg PAJ, et al. Achieving an adequate minute volume through a 2 mm transtracheal catheter in simulated upper airway obstruction using a modified industrial ejector. *Br J Anaesth* 2010; **104**:382–386.
- 10 Schmidt J, Günther F, Weber J, et al. Flow-controlled ventilation during ear, nose and throat surgery: a prospective observational study. *Eur J Anaesthesiol* 2019; **36**:327–334.
- 11 Schmidt J, Wenzel C, Mahn M, et al. Improved lung recruitment and oxygenation during mandatory ventilation with a new expiratory ventilation assistance device: a controlled interventional trial in healthy pigs. *Eur J Anaesthesiol* 2018; **35**:736–744.
- 12 Kim HJ, Lee K, Park WK, et al. Deep neuromuscular block improves the surgical conditions for laryngeal microsurgery. *Br J Anaesth* 2015; **115**:867–872.
- 13 Grivans C, Lundin S, Stenqvist O, et al. Positive end-expiratory pressure-induced changes in end-expiratory lung volume measured by spirometry and electric impedance tomography. *Acta Anaesthesiol Scand* 2011; **55**:1068–1077.
- 14 Lehmann EL, D'Abbrera HJM. *Nonparametrics: statistical methods based on ranks*, 1st ed. New York, NY: Springer; 2006.
- 15 Goebel U, Haberstroh J, Foerster K, et al. Flow-controlled expiration: a novel ventilation mode to attenuate experimental porcine lung injury. *Br J Anaesth* 2014; **113**:474–483.
- 16 Wirth S, Springer S, Spaeth J, et al. Application of the novel ventilation mode flow-controlled expiration (FLEX): a crossover proof-of-principle study in lung-healthy patients. *Anesth Analg* 2017; **125**:1246–1252.
- 17 Schmidt J, Wenzel C, Spassov S, et al. Expiratory ventilation assistance during mandatory ventilation in porcine ARDS improves arterial oxygenation – a randomised controlled animal study [Abstract]. *Eur J Anaesthesiol* 2018; **35** (e-Supplement 56):7.
- 18 O'Gara B, Talmor D. Perioperative lung protective ventilation. *BMJ* 2018; **362**:k3030.
- 19 Serpa Neto A, Schultz MJ, Gama de Abreu M. Intraoperative ventilation strategies to prevent postoperative pulmonary complications: systematic review, meta-analysis, and trial sequential analysis. *Best Pract Res Clin Anaesthesiol* 2015; **29**:331–340.
- 20 Davies JM, Hillel AD, Maronian NC, et al. The Hunsaker Mon-Jet tube with jet ventilation is effective for microlaryngeal surgery. *Can J Anaesth* 2009; **56**:284–290.
- 21 Barakate M, Maver E, Wotherspoon G, et al. Anaesthesia for microlaryngeal and laser laryngeal surgery: impact of subglottic jet ventilation. *J Laryngol Otol* 2010; **124**:641–645.
- 22 Blanch L, Bernabé F, Lucangelo U. Measurement of air trapping, intrinsic positive end-expiratory pressure, and dynamic hyperinflation in mechanically ventilated patients. *Respir Care* 2005; **50**:110–124.
- 23 Kaczka DW, Ingenito EP, Suki B, et al. Partitioning airway and lung tissue resistances in humans: effects of bronchoconstriction. *J Appl Physiol* 1997; **82**:1531–1541.
- 24 Wirth S, Seywert L, Spaeth J, et al. Compensating artificial airway resistance via active expiration assistance. *Respir Care* 2016; **61**:1597–1604.