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ORIGINAL RESEARCH

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# Airway management during unusual tracheal stenosis: A clinical feasibility trial

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## Abstract

**Objectives:** Prolonged intubation is a known risk factor of LTS. LTS related to COVID-19 may result in a different phenotype: pronation affects the location of stenosis and COVID-19 pneumonia can decline lung mechanics. Therefore, airway management in these patients may carry unique challenges for both anesthesiologists and surgeons.

This prospective observational feasibility trial aims to evaluate the use of a novel thin, cuffed, endotracheal tube (Tritube) in combination with flow-controlled ventilation (FCV) in the management of patients with COVID-19-related LTS undergoing laryngeal surgery.

**Methods:** 20 patients suffering from COVID-19-related LTS, as diagnosed by CT, requiring endolaryngeal surgery, with or without $CO_2$ laser, were included. Ultrathin endotracheal tube Tritube, together with FCV was used for airway management and ventilation. Feasibility, ventilation efficiency, and surgical exposure were evaluated.

**Results:** Median duration of mechanical ventilation during their ICU stay was 17 days, (range, 7–27), and all patients had been pronated. In 18/20 patients, endoscopic diagnosis confirmed the initial CT diagnosis: posterior subglottic stenosis. Surgeons' satisfaction on the view was rated 9 out of 10 (range 7–10), where 0 was the worst view and 10 was the best view. Hemodynamic and respiratory variables were within the normal clinical range during the surgical procedure. One patient that had a SpO2 of 90% before induction of anesthesia, a temporal drop to 89%, caused meeting the predefined requirement of "respiratory complication."

**Conclusion:** This study demonstrates the feasibility of using Tritube with FCV in patients with relatively unusual subglottic posterior location tracheal stenosis, undergoing laryngotracheal surgery. Tritube provides a good surgical field and FCV provides highly adequate ventilation especially in patients with compromised lung mechanics.

**Level of Evidence:** IV, non-comparitive prospective clinical trial with 20 patients.

KEYWORDS

COVID-19 pnemonia, flow-controlled ventilation, tracheal stenosis, Tritube

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## 1 | INTRODUCTION

Laryngotracheal stenosis (LTS) may occur as an uncommon but important long-term outcome of endotracheal intubation or tracheostomy.[1,2] The subglottic area is a common region of local mucosal ischemia, which is a key factor in the development of postintubation LTS. In these patients, unique challenges are generated to the anesthesiologist for securing an effective airway and to the surgeon for adequate surgical exposure.[1]

The Coronavirus disease 2019 (COVID-19) globally has led to a significant increase in endotracheal intubation and tracheostomy in patients suffering from respiratory failure. Because of high patient mortality and virus aerosolization apprehension, globally hospital COVID-19 protocols often included delaying tracheostomy for more than 2 weeks in favor of endotracheal intubation. In addition, prone positioning was frequently performed to improve gas exchange in these patients.[3] Prone position and prolonged intubation carry the risk of laryngotracheal complications. As such, LTS has been recognized as a late complication in patients recovered from COVID-19 disease.[4,5] The location of stenosis may differ from the location usually observed before. This can relate to the fact that patients were longer intubated than usual and because of the relatively frequent pronation. Though, the sole effect of proning on the larynx is unclear. This rather "unusual" location of stenosis, being posterior, brings the need for new airway management approaches during laryngotracheal surgery. The current armamentarium to manage the stenotic airway includes several strategies like intermittent apnea, jet ventilation (HFJV), and ventilation with small ETTs: the so-called "microlaryngeal endotracheal tubes." Though the used methods are subjected to the preference of the surgical-anesthetic team.[6]

Recently, a new tool was described as an option to manage the difficult or shared airway: Tritube (Ventinova Medical B.V., Eindhoven, The Netherlands; Figure 1), an ultra-thin cuffed endotracheal tube with an outer diameter of 4.4 mm. It needs to be used in combination with a novel, highly efficient, ventilation mode Flow Controlled Ventilation (FCV) and promises an improved glottic view in the compromised airway.[7]

In this current prospective study, we investigated the feasibility of using this novel tube Tritube in combination with FCV in the airway management of patients with unusual, posterior, location of laryngotracheal stenosis, relating to prolonged intubation due to COVID-19 pneumonia, undergoing laryngotracheal surgery. We report on the visualization of the operation field and on the safety profile of this tube and ventilation mode in the context of intraoperative and post-operative hemodynamic and respiratory parameters.

## 2 | MATERIALS AND METHODS

Ethics approval for this prospective feasibility study [local institutional ethics committee approval (2021/1958)] was provided by the Ethical Committee of Istanbul University Istanbul Faculty of Medicine, Istanbul, Turkey. This study has been perfromed in accordance with the Declaration of Helsinki. Clinical trial registration was done prospectively (NCT05317923 on 08/04/2022). Written informed consent was taken from all participants. Procedures were performed by the same experienced anesthesiologist and same surgeon who is experienced in head and neck surgeries.

### 2.1 | Patients

Patients 18–80 years of age, with an American Society of Anesthesiology (ASA) status of I-III status, scheduled for an elective laryngeal procedure due to subglottic stenosis were included in our study. Furthermore, the stenosis needed to be located at the "unusual" posterior position and secondary to prolonged intubation and/or percutaneous tracheostomy due to COVID-19 pneumonia. The location of stenosis was determined in our Ear-Nose-Throat Surgery Department using a three-dimensional computed tomography (3D CT) scan of the neck.

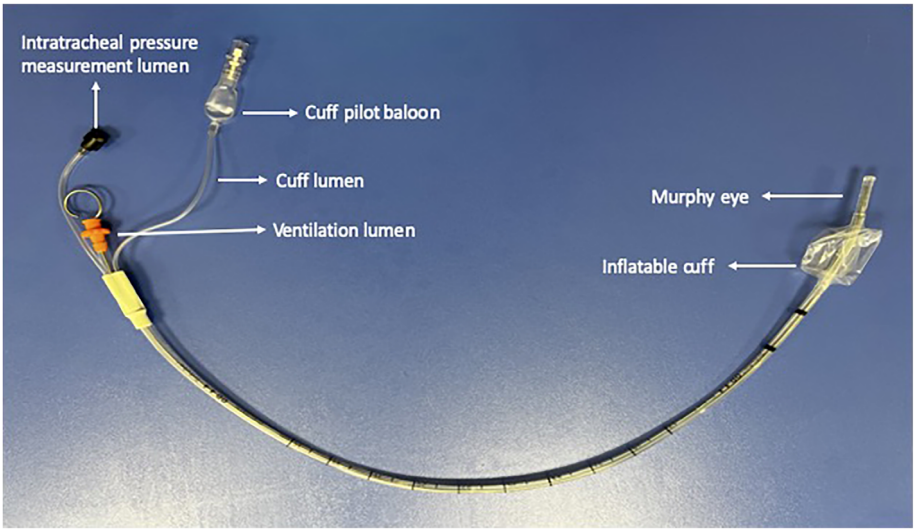



**FIGURE 1** External view of the Tritube.

Exclusion criteria were comorbidities such as congestive heart failure and emergency laryngeal procedures.

## 2.2 | Anesthetic protocol

Following standardized monitoring (electrocardiogram, pulse oximetry, non-invasive blood pressure) adequate preoxygenation (expired fraction of oxygen >0.9) was performed. Intravenous anesthesia was induced (0.05 mg. $kg^{-1}$ midazolam, 2 µg. $kg^{-1}$ fentanyl, 2.5 mg. $kg^{-1}$, propofol, 0.6 mg. $kg^{-1}$ rocuronium) and maintained using propofol and remifentanil. Additionally, iv ranitidine 50 mg, granisetron 3 mg, dexamethasone 8 mg and prednisolone 1 mg. $kg^{-1}$ were administered to all patients. FCV relies on a constant inspiratory and expiratory flow, the latter is generated by suctioning. Therefore it can be considered to administer glycopyrronium,[8,9] to reduce secretions and reduce the risk of tube obstructions by these secretions.

## 2.3 | Tritube and Flow-controlled Ventilation (FCV)

Tritube (Ventinova Medical B.V., Eindhoven, the Netherlands; Figure 1) is a cuffed endotracheal tube with a 4. 4-mm-outer diameter and a length of 45-cm-long and three lumens: one for cuff inflation and deflation, second for ventilation of the patient, and one lumen for the measurement of the airway pressure. The combination of a cuff sealing the airway and a narrow inner diameter creates a highly resistant airway and therewith prevents passive expiration. Therefore, the use of Tritube requires expiration to be actively generated through suctioning. FCV is a ventilatory mode where both inspiratory and expiratory flow rates are maintained stable and low, that is, <20 L/min, throughout the respiratory cycle by regulating tracheal pressure, as measured through Tritube's pressure measurement lumen. FCV aims for linear increases and decreases in intratracheal pressure between a chosen end-expiratory pressure (EEP) and peak pressure. During FCV, the inspiratory flow rate, inspiratory to expiratory (I:E) ratio, peak inspiratory pressure, EEP, and $FiO_2$ are set by the user, whereas tidal volume and respiratory rate vary depending on ventilator settings and the mechanical properties of the patient's respiratory system. The differences between FCV and conventional mechanical modes, that is, volume-controlled ventilation (VCV) and pressure-controlled ventilation (PCV), regarding the gas flow, tidal volume, and airway pressure waveforms are illustrated in Figure 2.

## 2.4 | Intubation and ventilation

Intubation was performed using a laryngoscope. Then, the site and degree of stenotic region were assessed by the surgeon, using a 0°-angled rigid bronchoscope. Also, 4% lidocaine spray was utilized to avoid laryngospasm and coughing. After intubation, the cuff of the Tritube was inflated to 25–30 $cmH_2O$. Then, the Tritube was connected to the FCV-ventilator [Evone (Ventinova Medical, B.V., The Netherlands)] with the following initial settings: inspiration: expiration (I:E) ratio of 1:1.0 $FiO_2$: 0.8 with end-expiratory pressure (EEP): 4–5 mbar to acquire the highest compliance, Peak inspiratory pressure (Peak): 14–18 mbar to achieve tidal volume (TV) (6 mL. $kg^{-1}$) and respiratory rate (RR): 12–14 $min^{-1}$, by adjusting the flow, to maintain PetCO2 between 35 and 45 $cmH_2O$ values (Figure 3). The $FiO_2$ was then reduced from 80% to maintain the $SpO_2$ value above % 90.

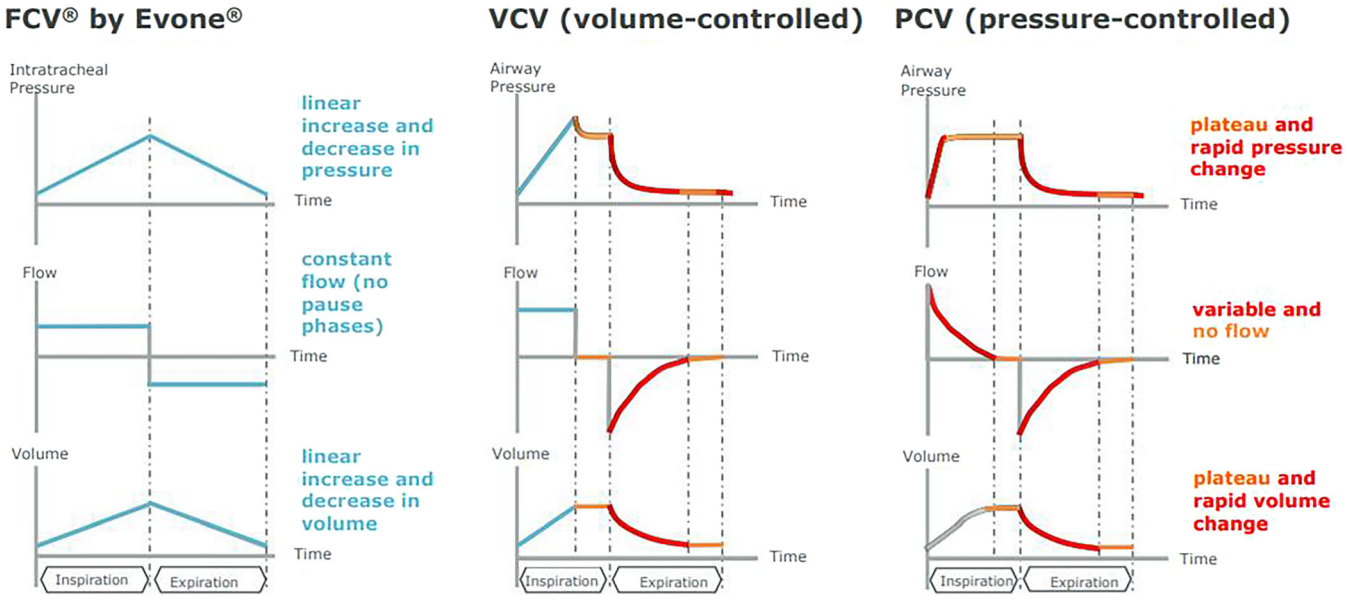



**FIGURE 2** Flow-controlled ventilation (FCV) compared to volume-controlled ventilation (VCV) and pressure-controlled ventilation (PCV). FCV relies on a high resistant breathing circuit to enable a full control of ventilation. FCV is a fully dynamic ventilation providing stable gas flow into and out of the patient's lungs. FCV aims for linear increases and decreases in intratracheal pressures and a constant flow during inspiration and expiration.

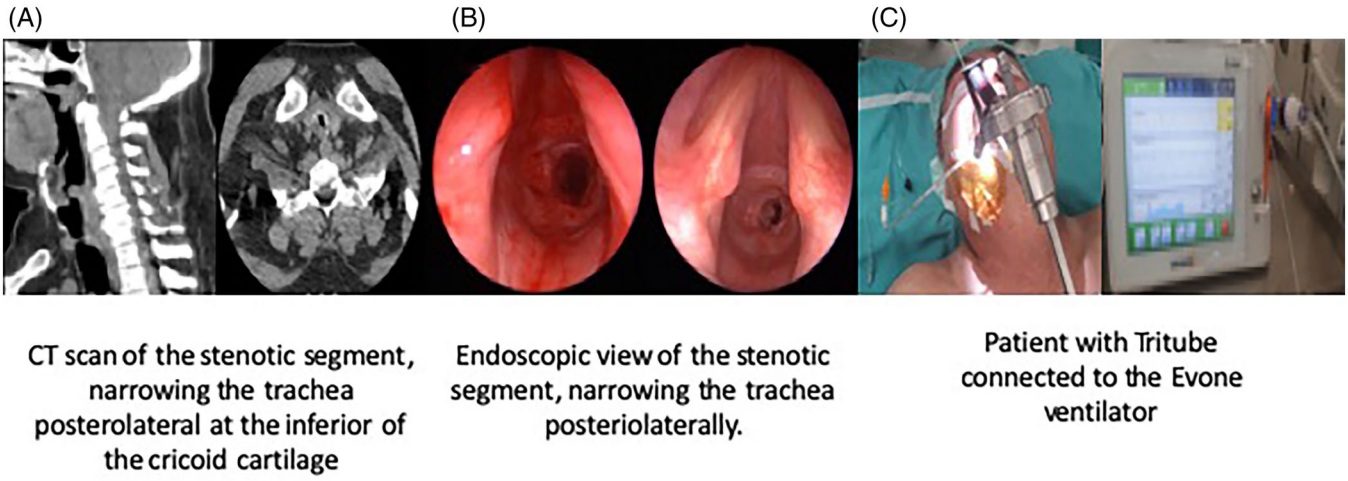



**FIGURE 3** CT scan, endoscopic view of stenosis, and Tritube with Evone ventilator. (A) CT scan of the stenotic segment, narrowing the trachea posterolateral at the inferior of the cricoid cartilage. (B) Endoscopic view of the stenotic segment, narrowing the trachea posterolaterally. (C) Patient with Tritube connected to the Evone ventilator.

## 2.5 | Airway management during procedure

Tritube is made of polyurethane and not laser certified. Therefore, when the carbon dioxide laser was in use, general laser-safety protocols such as inflating the tube cuff with water, covering the surrounding tissues with wet pads and reducing the $FiO_2$ levels to 0.40 were employed.[8,9] Following $CO_2$ laser incision, the Tritube was removed to perform balloon dilation during apnea.

## 2.6 | Extubation

At the end of the procedure, sugammadex was applied to reverse neuromuscular blockade. Then, the cuff was deflated and the Tritube was used as a subglottic insufflation catheter to provide efficient apneic oxygenation, to facilitate spontaneous breathing, and to ensure soft and awake extubation. In case this was not sufficient, Evone ventilator was switched from FCV mode to jet ventilation mode using $FiO_2$ of 1.0. Alternatively, in case jet ventilation did not result in $SpO_2 > 90\%$ and $etCO_2 < 45$ mmHg, the patient was kept under FCV mode, with Tritube's cuff inflated, until extubation. A cuff leak test was performed to confirm the absence of edema just before extubation. Patients were transferred to the recovery room and observed for the possibility of airway obstruction and emergent tracheostomy, then discharged to the ward once they fulfilled a modified Aldrete score = 10.[10]

## 2.7 | Data sampling

At inclusion the following data was collected: demographic characteristics (age, gender, Body Mass Index (BMI) (kg. $m^{-2}$), American Society of Anesthesiology (ASA) status, Mallampati classification (MP), Cormack–Lehane score (CL), comorbidities such as respiratory and cardiovascular disease), duration of intubation/tracheostomy length due to COVID-19 pneumonia, tracheostomy status, need for prone position, mechanical ventilation (MV) duration.

Primary outcome measures were PCO2 and PO2, that were collected at baseline (just before intubation), and perioperatively at 5, 15, 30, and 45 min after induction and just before extubation.

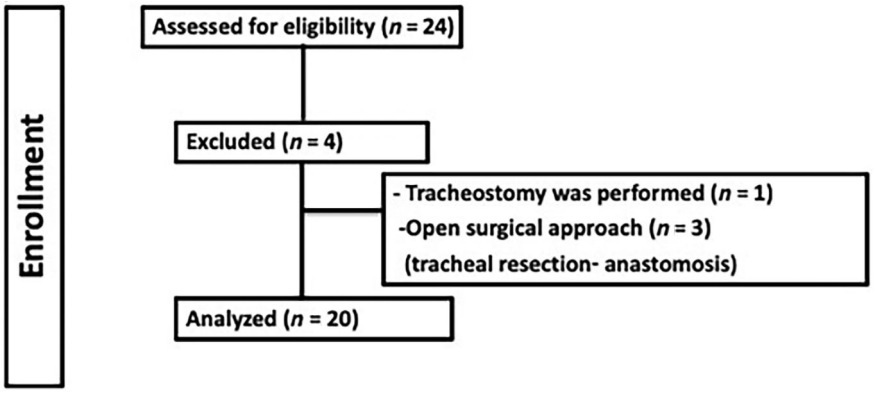
During the procedure respiratory and hemodynamic data were collected: $PetCO_2$, resistance (R), dynamic compliance ($C_{dyn}$), Peak pressure, EEP, tidal volume, respiratory rate and minute volume (at 5th, 15th, 30th, and 45th min and at the end of the surgery); heart rate (HR), mean arterial pressure (MAP), peripheral oxygen saturation ($SpO_2$) before induction, 5th, 15th, 30th, and 45th min and at the end of the surgery.

Surgical data were collected: surgical procedure, duration of surgery, Cotton–Myer classification used for grade of airway stenosis,[11] laparoscopy findings (location of stenosis), and laryngeal diagnosis. At the end of the surgery, surgeons' satisfaction was assessed with Visualization of the Operation Field score (VAS 0 = the worst view, 10 = the best view).

## 2.8 | Adverse events

Adverse events, potentially related to the use of Tritube and/or FCV ventilation were collected: hypoxia (SPO2 < 90%), hypercarbia (PCO2 > 50 mmHg), laryngospasm, bronchospasm, bradycardia (HR < 50 beats. $min^{-1}$), tachycardia (HR > 100 beats. $min^{-1}$), hypertension (Mean Arterial Pressure (MAP) >100 mmHg for at least 1 minute), hypotension (MAP<65 mmHg for at least 1 min). Furthermore, the extubation strategy was recorded (FCV until extubation, placement of LMA, jet ventilation) and urgent need for tracheostomy.

FIGURE 4 Study flow diagram.




### 2.9 | Statistical analyses

For the sample size analysis, consecutive sampling technique was chosen throughout the study period. Data are presented as median, (min–max) or n, %. Descriptive analysis was used to evaluate the data.

## 3 | RESULTS

24 patients were assessed for enrollment. Four were excluded, leaving 20 patients for analyses. Of the four excluded patients, in three the surgical procedure was decided to continue as an open surgical approach such as tracheal resection-anastomosis in another session. In one patient due to severe dyspnea and stridor, tracheostomy was performed prior to the procedure (flow chart Figure 4). General patient characteristics, history of ICU stay, diagnosis, and surgical data are summarized in Table 1.

### 3.1 | ICU stay and Airway diagnosis

During the Intensive Care Unit (ICU) stay, the median duration of MV was 17 days, [range 7–27], and the prone position was used in all COVID-19 patients ($n = 20$, 100%) who underwent orotracheal intubation. A tracheostomy had been placed in 8 patients (40%). The patients were included based on the initial 3D CT analyses indicating a posterior subglottic stenosis. In 18 patients (90%), the posterior subglottic location could be confirmed, while in 2 patients (10%), the lesion appeared to be in the glottis and located unilaterally.

### 3.2 | Procedure, respiratory, and hemodynamic data

The surgical procedure involved only tracheal dilatation in nine patients (45%), and only $CO_2$ laser surgery in one (5%) patient. In 10 patients (50%) both techniques were used. The mean duration of surgery was 80 min (55–130 min); see Table 1.

Primary outcome parameters $PO_2$ and $PaCO_2$ (Table 2), showed a stable and adequate gas exchange throughout the procedure. Before induction $PO_2$ levels were 126 mmHg [96–142 mmHg] and gradually increased to 150 mmHg [108–160 mmHg] at the end of the surgery. Underlining adequate ventilation, the $PaCO_2$ gradually decreased from 56 mmHg [51–60] to 46 [39–51].

In line with the blood gas analyses, $PetCO_2$ was within the normal range in all patients throughout the procedure (Table 3) and showed a stable but slow decline (from 53 [48–58] mmHg after induction to 42.5 [36–48] mmHg at the end of surgery) indicating adequate ventilation with FCV. $SpO_2$ was stable in all patients starting at 95 [90–97] % and slowly increasing to 98 [94–100] % at the end of surgery. In the one patient with a $SpO_2$ of 90% before induction, the $SpO_2$ dropped to 89% at timepoint 5th and 15th after induction, meeting our criteria for respiratory complication ($SpO_2$ < 90%). At the later timepoints, the $SpO_2$ in this patient was 93% or higher.

Respiratory variables were stable and within the normal range with dynamic compliance of 66 [40–72] mL. $cmH_2O^{-1}$ and total resistance of 5 [5–7] $cmH_2O$. $L^{-1}$. $s^{-1}$. With a set EEP of 5 [4–5] $cmH_2O$ a driving pressure of 9.5 [8–12] $cmH_2O$ was used to obtain the aimed tidal volume of approximately 6 mL. $kg^{-1}$. A minute volume of 4.5 [4. 3–5.2] L. $min^{-1}$ was required to maintain normocapnia.

Hemodynamic values were stable and within normal ranges and no other adverse event than one described above occurred during FCV ventilation.

The median VAS score determined by the surgeon, to indicate surgeon's satisfaction on the view, was 9 (range 7–10; Table 1).

The main extubation strategy was using FCV until extubation ($n = 13$; 65%, Table 1).

## 4 | DISCUSSION

This observational study is the first trial to report and evaluate the airway management and ventilation performance in patients with rather unusual localization of LTS caused by long-term intubation for COVID-19 pneumonia. Our study shows that using Tritube and FCV is feasible and safe and creates a good surgical exposure.

**TABLE 1** General patient characteristics, history of ICU stay, diagnosis and surgical data.

| Sample size ($n = 20$) | | Median [range] or n (percentage) |
|---|---|---|
| General patient characteristics | Age (years) | 61.5 [36–76] |
| | Female | 12 (60%) |
| | BMI (kg/m$^2$) | 28.4 [25.3–35.2] |
| | ASA status | |
| | ASA II | 8 (40%) |
| | ASA III | 12 (60%) |
| | The Mallampati score | |
| | Grade 2 | 18 (90%) |
| | Grade 3 | 2 (10%) |
| | Comorbidities | |
| | Smoking status | 15 (75%) |
| | Hypertension | 8 (40%) |
| | Asthma/COPD | 10 (50%) |
| | Diabetes Mellitus | 8 (40%) |
| | Obstructive Sleep Apnea | 4 (20%) |
| History | ICU stay | |
| | Intubation duration (COVID-19) (days) | 12 [7–22] |
| | Tracheostomy placed | 8 (40%) |
| | Mechanical Ventilation duration (days) | 17 [7–27] |
| | Prone position | 20 (100%) |
| Diagnosis | The Myer-Cotton classification | |
| | Grade 2 | 14 (70%) |
| | Grade 3 | 6 (30%) |
| | Laryngeal diagnosis | |
| | Posterior subglottic stenosis | 18 (90%) |
| | Unilateral glottic stenosis | 2 (10%) |
| Surgical data | Surgical procedure | |
| | Tracheal dilatation | 9 (45%) |
| | Laser surgery | 1 (5%) |
| | Both | 10 (50%) |
| | Duration of surgery (min) | 80 [55–130] |
| | Respiratory complication | 1 (5%) |
| | Hemodynamic complication | 0 (0%) |
| | Extubation strategy | |
| | FCV until extubation | 13 (65%) |
| | Placement of LMA | 1 (5%) |
| | Jet ventilation | 6 (30%) |
| | Placement of tracheostomy tube | 0 (0%) |
| | VAS score | 9 [7–10] |

Abbreviations: BMI: body mass ındex; COPD: chronic obstructive pulmonary disease; COVID-19: Coronavirus disease 2019; FCV: flow-controlled ventilation; LMA: laryngeal mask airway; VAS: visualization of the operation field score.

The COVID-19 pandemic is expected to trigger a significant increase in laryngeal complications, related to prolonged intubation.[12–14] While actual figures as still unclear, emergent data support this.[4,5,13,15,16] Our study does not provide data on the incidence of LTS after prolonged intubation during COVID-19, as COVID-19-related LTS was an inclusion criterium. In our study population, consisting of both intubated and tracheostomized patients, we observed that the median of mechanical ventilation was 17 days (range, 7–27 days).

**TABLE 2** Primary outcome data of $PO_2$ and $PaCO_2$ throughout the procedure.

| Variable ($n = 20$) | Median [range] |
|---|---|
| $PO_2$ (mmHg) | |
| Before induction | 126 [96–142] |
| 5th min (after induction) | 138 [87–151] |
| 15th min | 141 [126–155] |
| 30th min | 142 [129–155] |
| 45th min | 145 [129–161] |
| End of surgery | 150 [108–160] |
| $PaCO_2$ (mmHg) | |
| After induction (0 min) | 56 [51–60] |
| 5th min | 51 [47–56] |
| 15th min | 49 [44–53] |
| 30th min | 48 [44–53] |
| 45th min | 48 [43–51] |
| End of the surgery | 46 [39–51] |

**TABLE 3** Intraoperative respiratory and hemodynamic variables during flow-controlled ventilation.

| Variable ($n = 20$) | Median [range] |
|---|---|
| Pulse saturation (SpO2) (%) | |
| Before induction | 95 [90–97] |
| 5th min (after induction) | 96 [89–99] |
| 15th min | 96 [89–100] |
| 30th min | 97 [93–100] |
| 45th min | 97 [94–99] |
| End of surgery | 98 [94–100] |
| Minimum value | 95 [90–97] |
| $PEtCO_2$ (mmHg) | |
| After induction (0 min) | 53 [48–48] |
| 5th min | 48 [44–52] |
| 15th min | 46 [41–50] |
| 30th min | 45 [41–50] |
| 45th min | 44 [39–52] |
| End of the surgery | 43 [36–48] |
| Respiratory data | |
| CRS (mL/cm$H_2O$) | 66 [40–72] |
| R (cm$H_2O$/L/s) | 5 [5–7] |
| Peak pressure (cm$H_2O$) | 14 [13–17] |
| EEP (cm$H_2O$) | 5 [4–5] |
| ΔP (cm$H_2O$) | 10 [8–12] |
| Inspiratory Flow (L/min) | 11 [9–14] |
| MV (L/min) | 5.5 [4.5–7] |
| RR (1/min) | 10 [8–13] |
| Heart rate (1/min) | |
| Before induction | 88 [71–98] |
| 5th min (after induction) | 72 [57–81] |
| 15th min | 68 [56–73] |
| 30th min | 63 [58–73] |
| 45th min | 66 [61–71] |
| End of the surgery | 65 [60–70] |
| Minimum value | 62 [56–68] |
| Maximum value | 88 [61–98] |
| Mean arterial pressure (mmHg) | |
| Before induction | 110 [97–124] |
| 5th min (after induction) | 86 [81–103] |
| 15th min | 81 [78–87] |
| 30th min | 86 [74–98] |
| 45th min | 85 [72–88] |
| End of the surgery | 85 [71–91] |
| Minimum value | 80 [72–85] |
| Maximum value | 110 [97–124] |

Median intubation duration was 12 days (7–22 days) in line with earlier reports on LTS in COVID-19 patients.[17–19] Common risk factors for developing LTS,[20,21] Diabetes Mellitus (eight patients), and BMI >30 kg. $m^{-2}$ (5 patients) were present in our study population. As aimed, all patients were ventilated in prone position, being a key factor for the unusual localization of the stenosis.[4]

In 90% of the cases, preoperative radiological images provided correct localization of the stenosis. In two patients (10%; both with tracheostomy status), the stenosis appeared to be unilaterally in the glottis instead of posterior subglottic. This underlines the need for endoscopic assessment to determine appropriate anesthetic and surgical strategies,[22] especially in patients who had a tracheostomy. Importantly, we observed that the posterior subglottic stenosis is located distally from the common stenotic site. Moreover, the stenosis is limited to only one subsite depending on the localization of the tracheal tube, which also presents unique challenges for airway management and surgical procedure.

Surgical treatments including endoscopic dilatation and laser or open surgery are often essential to improve airway patency[23] In 90% of our cases, endoscopic treatments such as dilatation with intralesional corticosteroid injection were performed due to the low-grade and one-sided stenosis, similarly as earlier described.[22,24,25] But, due to the repeated dilatational procedures by balloon, bougies, or rigid endoscopic instrumentations, anesthetic armamentarium is much more challenging in these patients. Therefore, although the anesthetic management in stenosis is well known, post-COVID LTS requires novel approaches. Previously reported airway management strategies in patients with LTS consist of ventilation via a small-sized endotracheal tube beyond the stenotic region, HFJV technique, or intermittent apneic ventilation.[26–28] In the current study we used in our cases was Tritube in combination with FCV ventilation. The benefits of Tritube in upper airway surgery, a.o. improving surgical exposure and working conditions, have been described.[7–9,29–35] We confirm the great surgical exposure as the VAS was ranked 9 out of 10 (7–10). Concealment of laryngeal structures was hardly observed, facilitating

a relatively easy dilatational process. Note that, in our study, three patients were excluded because it was decided to perform tracheal resection-anastomosis. Recently, Kuut and colleagues[34] described the value of using Tritube in that procedure.

Stenotic patients with hypoxemic respiratory failure have also limited pulmonary function[36] as also observed in our cohort. In cases of severe adhesions of the stenosis to the surrounding connective tissue, a prolonged dilatational process may be demanded. In our study, 19 patients required prolonged apneic ventilation of approximately 10 min. In case traditional small-sized tubes would have been used, the tube may well have been too short to pass the stenotic lesion site and even if it had been long enough, the dilatational process ordinarily involves repetitive extubating and apneic intervals, likely would have led to hypoxia and hypercarbia.[37] Alternatively, HFJV could have been used in the narrowed airway providing maximal exposure of the surgical field.[38] But, the respiratory impairment of our patient group adds a significant risk of hypercapnia, rapid desaturation, and hypoxia to the established HFJV risks, being aspiration (uncuffed catheter) and barotrauma (stenotic airway). To avoid barotrauma in a stenotic airway HFJV may need to be interrupted (frequently) to enable adequate passive gas egress. Furthermore, using HFJV in respiratory impaired patients, rapid desaturation and/ or hypoxia may demand an intermittent increase of FiO2 to 100%, which limits the use of a laser.

We show that FCV ventilation via cuffed Tritube ensures an efficient ventilation in the narrowed airway. Moreover, the highly efficient ventilation, as described before in various patients, allowed an extended apneic period for the surgical procedure.[35,39–42] Our respiratory and hemodynamic data show that FCV was able to maintain stable respiratory and hemodynamic levels for almost 80 min, without having to accept periods of hypercapnia. Another benefit of using Tritube with FCV is the continuous $PetCO_2$ monitoring, while only intermittent capnometry is possible with HFJV.

We observed that oxygenation ($PO_2$ and $SpO_2$) and respiratory system compliance gradually improved throughout the procedure without an increase in inspiratory plateau pressure. Also, we experienced that, leaving narrowed tube with deflated cuff in situ facilitated the extubation of high-risk patients while avoiding the need for reintubation or tracheostomy in Tritube with FCV.

In one patient with a history of mild chronic obstructive pulmonary disease, reflected by the low lung compliance as measured by Evone, a brief period of desaturation occurred. We defined a $SpO_2$ <90 as desaturation. Upon induction, this patient had a $SpO_2$ declined to 89%. We paused surgical manipulation, adjusted ventilator settings, and $SpO_2$ increased.

However, this technique has some drawbacks (1) stenosis with a lumen diameter of less than <4 mm will not allow the pass the Tritube, (2) the patient needs to be anesthetized using TIVA and (3) spontaneous breathing is not possible.

Also, Tritube is not laser certified. After discussing this with the surgical team, we were comfortable using the tube during $CO_2$ laser procedures while applying general laser-safety protocols as described above. We never experienced any safety issues to laser use in combination with the Tritube when these strict safety measures are taken.

Further, it should be emphasized that this was an observational study without a control group. Furthermore, randomized studies with a larger number of patients are needed to evaluate any possible risks or benefits of a Tritube with FCV over a conventional or jet ventilation technique in a narrowed airway in patients with a compromised respiratory function.

## 5 | CONCLUSION

The large number of patients worldwide suffering from long duration of mechanical ventilatory support due to COVID-19 pneumonia will presumably increase the incidence of LTS in the near future. Anesthesiologists should be aware that the location of this stenosis may be at an unusual position, being posterior, and more difficult to manage than commonly localized stenosis. Careful planning should be taken into consideration to manage the acute airway. As demonstrated in our cases, ventilation with Tritube in FCV mode by Evone contributes to the armamentarium for airway management providing safe and highly efficient ventilation, also in the lungs compromised by COVID-19 pneumonia, by generating consistent and controllable flow rate during inspiration and expiration. Furthermore, it improves surgical conditions without interruption. This approach must be studied by prospective randomized controlled trials with larger sample sizes to evaluate its benefits and disadvantages.

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### CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

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