

Complications of Different Ventilation Strategies in Endoscopic Laryngeal Surgery

A 10-year Review

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Background: Spontaneous ventilation, mechanical controlled ventilation, apneic intermittent ventilation, and jet ventilation are commonly used during interventional suspension microlaryngoscopy. The aim of this study was to investigate specific complications of each technique, with special emphasis on transtracheal and transglottal jet ventilation.

Methods: The authors performed a retrospective single-institution analysis of a case series of 1,093 microlaryngoscopies performed in 661 patients between January 1994 and January 2004. Data were collected from two separate prospective databases. Feasibility and complications encountered with each technique of ventilation were analyzed as main outcome measures.

Results: During 1,093 suspension microlaryngoscopies, ventilation was supplied by mechanical controlled ventilation *via* small endotracheal tubes ($n = 200$), intermittent apneic ventilation ($n = 159$), transtracheal jet ventilation ($n = 265$), or transglottal jet ventilation ($n = 469$). Twenty-nine minor and 4 major complications occurred. Seventy-five percent of the patients with major events had an American Society of Anesthesiologists physical status classification of III. Five laryngospasms were observed with apneic intermittent ventilation. All other 24 complications (including 7 barotrauma) occurred during jet ventilation. Transtracheal jet ventilation was associated with a significantly higher complication rate than transglottal jet ventilation ($P < 0.0001$; odds ratio, 4.3 [95% confidence interval, 1.9–10.0]). All severe complications were related to barotraumas resulting from airway outflow obstruction during jet ventilation, most often laryngospasms.

Conclusions: The use of a transtracheal cannula was the major independent risk factor for complications during jet ventilation for interventional microlaryngoscopy. The anesthetist's vigilance in clinically detecting and preventing outflow airway obstruction remains the best prevention of barotrauma during subglottic jet ventilation.

FOUR methods have been used to secure the airway and deliver ventilation to patients undergoing suspension microlaryngoscopy for the management of laryngeal pathologies.

1. Controlled mechanical ventilation *via* a small endo-

tracheal tube offers adequate airway protection and gas exchange, but the endotracheal tube prevents optimal vision and access to the larynx. Furthermore, endotracheal fire¹⁻⁴ may still be encountered with the use of carbon dioxide laser despite the development of nonflammable endotracheal tubes.⁵⁻⁷

2. *Spontaneous ventilation* offers a free access to the larynx, but with a moving surgical field and a risk of inhalation of anesthetic gases and laser fumes by the patient and the medical staff. For these reasons, this technique is not used at our institution.
3. *Subglottic jet ventilation* allows normocapnic ventilation through transglottal or transtracheal cannulas as small as 1.5 mm ID, thereby improving visibility and access to the operative field. Transtracheal high-frequency jet ventilation is a widely used technique for elective laryngeal surgery and management of the difficult airway.⁸⁻¹⁰ At our institution, Ravussin *et al.*¹¹⁻¹³ developed a transtracheal polyurethane cannula that has been used during the past two decades for elective laryngeal procedures. There are few reports about the exact incidence of barotraumas during jet ventilation,¹⁴⁻¹⁷ and comparison between transtracheal and transglottal jet ventilation with regard to their specific rate of complications are largely lacking.
4. *Apneic anesthesia with intermittent ventilation* offers an ideal view for the surgeon,¹⁸ but only for short procedures in patients supporting some minutes of apnea.¹⁹ The incidence of the main complication, laryngospasm, is not known.

The aim of this study was to determine the incidence of complications related to the different ventilation strategies and to estimate whether transtracheal access for jet ventilation may increase the risk of barotrauma or other related complications compared with transglottal access.

Materials and Methods

This data analysis was approved by Commission d'Ethique de la Recherche Clinique de la Faculté de Biologie et de Médecine de l'Université de Lausanne (Lausanne, Switzerland). From January 1994 to January 2004, the 1,093 interventional suspension microlaryngoscopies performed in the Department of Otolaryngology, Head and Neck Surgery of our tertiary care institution were retrospectively reviewed and included in this study.

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Data were collected from two prospective databases of the Department of Anesthesiology and the Department of Otolaryngology, Head and Neck Surgery. They included patient age, sex, diagnosis of laryngeal disease and indication for suspension microlaryngoscopy, American Society of Anesthesiologists (ASA) physical status classification, surgical interventions, ventilation strategies, and intraoperative and postoperative complications or unexpected events. To avoid any underestimation of complications, we used a crossed-research design in reviewing the computerized medical records with operative and diagnostic codes or key words. In all cases with complications, the complete patient's chart was thoroughly reviewed.

Four groups of patients were formed according to the strategy of ventilation: transtracheal jet ventilation (group 1), transglottal jet ventilation (group 2), apneic intermittent ventilation (group 3), and mechanical controlled ventilation (group 4). Complications were analyzed as the main outcome measure. Only the most severe complication that occurred during each procedure was taken into account to estimate the complication rates. Complications were classified into minor (not life-threatening) or major, according to their degree of severity. Emphysema of the neck was assessed by palpation, standard lateral soft tissue imaging, or both. Emphysema of the mediastinum and pneumothorax were diagnosed on radiographs of the thorax. Hemodynamic instability was defined by the ASA criteria: hypertension ($> 30\%$ of the preoperative value), hypotension ($< 30\%$), bradycardia (< 50 beats/min), and arrhythmias.

Anesthesiologic Procedure

Anesthetic Technique. Anesthesia was induced with intravenous propofol (1.5 mg/kg). Inhalation of sevoflurane was used for children or adult patients expected to be difficult to ventilate or intubate. Total intravenous anesthesia was maintained with propofol ($100\text{--}200\ \mu\text{g} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$) and alfentanil (10 $\mu\text{g}/\text{kg}$) or remifentanyl. Vecuronium (0.1 mg/kg) or succinylcholine (1 mg/kg) was used for muscle relaxation at anesthesia induction. Boluses of vecuronium (0.01 mg/kg) were given to maintain one or two responses on the train-of-four monitoring throughout the procedure. Cardiorespiratory monitoring included noninvasive blood pressure, electrocardiogram, peripheral oxygen saturation, and expiratory carbon dioxide. Measurement of the transcutaneous carbon dioxide (Tosca Sensor[®]; Linde Medical Sensors AG, Basel, Switzerland) has been routinely applied during jet ventilation since January 2001. Morphine (0.1 mg/kg) was given 30 min before the end of the procedure in cases of remifentanyl anesthesia.

Choice of Ventilatory Mode. Four main strategies were used to ventilate the patients during suspension microlaryngoscopy: subglottic jet ventilation (transtracheal or transglottal), apneic intermittent ventilation or

mechanical controlled ventilation through orotracheal/nasotracheal tubes. The choice of the ventilatory mode and type of airway access depended mainly on three parameters: type of laryngeal disease (nature, size, location, extension), patient's characteristics (anatomy, cardiac and respiratory impairments), duration of the procedure, and the surgeon's experience.

1. *Type of laryngeal disease.* Laryngeal pathologies of the anterior commissure were approached using a transglottal jet cannula positioned at the posterior commissure of the larynx. Lesions situated at the posterior commissure of the larynx were exposed after insertion of a transtracheal jet cannula¹¹ through the cricothyroid membrane or lower through the upper trachea. Transtracheal cannula insertion was not indicated if the subglottic area, upper trachea, or both were involved by the pathology, whatever its nature (malignant, viral, or vascular).
2. *Patient characteristics.* Jet ventilation was contraindicated in patients with marked emphysema (increased risk of barotrauma) or in the presence of pulmonary hypertension (risk of right heart failure). Patients with restrictive or obstructive pulmonary diseases or rigid thoracic walls are poor candidates for jet ventilation and were ventilated through small endotracheal tubes. In cases of upper airway obstruction treated with jet ventilation, particular care was taken to enable the complete exhalation of the injected gas to avoid barotrauma.
3. *Procedures of long duration* (1 h or longer) performed by inexperienced surgeons were considered as an indication to secure the airway with jet ventilation or mechanical controlled ventilation. However, for shorter procedures with experienced surgeons, apneic intermittent ventilation was used.

Technique of Ventilation.

Jet Ventilation. At our institution, three different devices are commonly used to apply jet ventilation during suspension microlaryngoscopy:

1. A transglottal polyurethane jet cannula, 2 mm ID (Acutronic Medical Systems AG, Baar, Switzerland).
2. A metallic cannula, 2 mm ID, inserted through a specific channel of the suspension microlaryngoscopic blade.
3. A transtracheal polyurethane jet cannula (Ravussin cannula⁸; VBM Medizintechnik GmbH, Sulze a.N., Germany), available in three different sizes (13, 14, or 18 gauge).

The transglottal jet cannula was inserted into the subglottic area during direct visual control just before positioning the laryngoscope. For the insertion of the transtracheal cannula, the patient was intubated with the rigid bronchoscope, with the bevel turned posteriorly. The bronchoscope thereby stents the larynx and pro-

protects the posterior part of the trachea from laceration. The jet ventilator (Universal Jet Ventilator; Acutronic Medical Systems AG, Hirzel, Switzerland) was set on manual mode at a low frequency until the laryngoscope was secured and whenever there was a consistent risk of obstruction of the airway. Automatic high-frequency jet ventilation was used during the procedure as long as there was no risk of obstruction of the outflow tract. The following high-frequency jet ventilation settings were used: frequency of 150–300/min; inspiratory pressure drive of 1–3 bar, measured at the end of the injection tube; inspiration:expiration time ratio of 1:1 to 1:2.

Apneic Intermittent Ventilation. The patient was ventilated by mask until the larynx was exposed and then through the smallest possible orotracheal uncuffed tube inserted through the laryngoscope. The tube was withdrawn and reinserted as frequently as necessary to maintain an oxygen arterial saturation of 90% or greater and a carbon dioxide end-tidal pressure between 40 and 60 mmHg. According to the tolerance of the patient, periods of apnea up to 5 min were allowed for surgical interventions.

Mechanical Controlled Ventilation. Mechanical controlled ventilation was performed through either standard or laser-safe orotracheal/nasotracheal tubes or, for patients with a tracheostoma, through cuffed tracheostomy tubes.

Surgical Procedure

The larynx was exposed with different types of laryngoscope: Linholm, Weerda, Kleinsasser, or Vaughan. When a satisfying exposure was achieved, the microscope was positioned and focused. During jet ventilation, the surgeon carefully avoided any obstruction of the airway. This could mainly occur when cotton swabs were used to stop bleeding. If necessary, the anesthesiologist had to stop air insufflation as long as it was required to control an episode of bleeding. Adequate teamwork between the anesthesiologist and surgeon was crucial.

The laser beam was used according to standard safety rules: eye protection for the patient and the whole medical staff working in the endoscopy room, wet towels applied over the patient's face and chest, reduction to 30% inspired oxygen or lower during periods of laser firing, and avoidance of a polyurethane cannula directly in the field of the laser beam.

Statistical Analysis

Univariate analyses were performed using Pearson chi-square or Fisher exact tests. The heterogeneity of the groups prevented any further comparison among the four groups. We thus restricted all further tests to the two jet ventilation groups, where multivariate analyses were performed by a stepwise logistic regression to identify factors having a predictive role for the occur-

rence of complications, adjusting for the type of intervention, indications, and ASA physical status. A *P* value of 0.05 was regarded as the level of significance. The package STATA 8.2 (StataCorp LP, College Station, TX) was used for all statistical analyses.

Results

We reviewed 1,093 interventional microlaryngoscopy procedures undertaken in 661 patients. Anesthesia was conducted with four different ventilation strategies (table 1). Sixty-seven percent of the interventional suspension microlaryngoscopies were performed during jet ventilation (734 of 1,093 interventions), 18% were performed during mechanical controlled ventilation (200 of 1,093), and 14% were performed during apneic intermittent ventilation (159 of 1,093). Jet ventilation was applied through either a transtracheal cannula (265 of 734) or a transglottal cannula (469 of 734). In the mechanical controlled ventilation group, the majority of the patients were ventilated through a long-standing tracheostoma (141 of 200), and the remaining 38 patients were ventilated through a laser-safe oroendotracheal tube. The distribution of ages (table 1) showed a mixed sample in all groups, except for the apneic intermittent ventilation group, which was essentially composed of children, one third of whom were infants.

The indications for suspension microlaryngoscopy (table 1) varied significantly among the groups. Phonosurgery encompasses a broad spectrum of pathologies and thus constituted a frequent indication (20.2%). Apneic anesthesia with intermittent ventilation was most often associated with pediatric indications such as subglottic stenosis, laryngomalacia, and laryngeal scars or webs. Patients with early squamous cell carcinoma were more often considered for transtracheal jet ventilation, whereas patients treated for papillomatosis frequently underwent transglottal jet ventilation.

Among the patients with a preoperatively assessed severe laryngeal obstruction (> 75% of the lumen), who were equally distributed among all four groups, no complication was encountered.

Univariate analysis demonstrated significant differences among the four groups with regard to patient age, year of intervention, ASA physical status classification, indications to treat, and specific interventions (listed in table 2). Heterogeneity of the groups prevented further comparison.

Descriptive analysis of complications considered minor and major events separately. However, for statistical purposes (low occurrence of separate events), we studied the occurrence of minor or major complication as a single item.

Table 1. Patient Distribution and Characteristics

	TTJV	TGJV	AIV	MCV	Total
Patients	265	469	159	200	1,093
Age, yr	52.1 ± 19.0	48.3 ± 21.6	17.6 ± 23.8	31.5 ± 27.1	41.7 ± 25.5
< 1 (n)	0	4	50	8	62
1–16 (n)	18	56	61	84	219
> 16 (n)	247	409	48	108	812
ASA physical status					
I	57 (21.5)	159 (33.8)	66 (41.5)	76 (38.0)	358 (32.7)
II	161 (60.8)	239 (51.1)	82 (51.6)	93 (46.5)	575 (52.7)
III	47 (17.7)	71 (15.2)	11 (6.9)	31 (15.5)	160 (14.7)
IV	0	0	0	0	0
Indications*					
Phonosurgery†	80 (30.2)	106 (22.6)	8 (5.0)	27 (13.5)	221 (20.2)
Vocal cord paralysis	21 (7.9)	133 (28.4)	15 (9.4)	16 (8.0)	185 (16.9)
Papillomatosis	34 (12.8)	91 (19.4)	14 (8.8)	22 (11.0)	161 (14.7)
Early SCC	85 (32.1)	59 (12.6)	1 (0.6)	10 (5.0)	155 (14.2)
Subglottic stenosis	9 (3.4)	26 (5.5)	56 (35.2)	59 (29.5)	150 (13.7)
Webs/scars	13 (4.9)	24 (5.1)	16 (10.6)	36 (18.0)	89 (8.1)
Laryngomalacia	1 (0.4)	4 (0.9)	38 (23.9)	4 (2.0)	47 (4.3)
Others	22 (8.3)	26 (5.5)	11 (6.9)	26 (13.0)	85 (7.8)
Severe laryngeal obstruction‡	8 (3.0)	12 (2.6)	2 (1.3)	4 (2.0)	26 (2.4)

Data are presented as mean ± SD or n (%).

* The three most frequent indications for suspension microlaryngoscopy with each type of ventilation are indicated in bold. † *Phonosurgery* describes benign pathologies of the larynx and includes the following indications: vocal fold nodule, cyst, polyp, angiomatous polyp, granuloma, telangiectatic granuloma, Reincke edema, pachylaryngitis, sulcus glottides, spasmodic dysphonia, arytenoid luxation, postsurgical dysphonia. ‡ Preoperatively recognized severe laryngeal obstruction (> 75% of the lumen).

AIV = apneic intermittent ventilation; ASA = American Society of Anesthesiologists; MCV = mechanical controlled ventilation; SCC = squamous cell carcinoma; TGJV = transglottal jet ventilation; TTJV = transtracheal jet ventilation.

Minor Complications

Minor complications are listed in table 3. They occurred in 29 of 1,093 procedures (2.7%). Jet ventilation was associated with 24 of 29 minor complications, whereas the other 5 cases were uncomplicated laryngeal spasms that occurred during apneic intermittent ventilation (3.1%). Thirty-eight percent of the patients with minor events had an ASA physical status classification of III, compared with 14.7% for the whole set of patients.

Minor Complications during Jet Ventilation

Episodes of hemodynamic instability were the most frequently encountered events. Mainly associated with

transtracheal jet ventilation (six of eight cases), they were never caused by barotrauma and had no adverse effect on the patient. Emphysema limited to the neck was seen in three patients undergoing transtracheal jet ventilation. In one patient, cervical emphysema was caused by an episode of cough with the transtracheal cannula still in place. The cannula was probably poorly fixed to the neck and displaced into the cervical soft tissue during the cough. In the second case, there was accidental air inflation during the placement of the transtracheal cannula, and in the third case, no definite explanation was found, but the cannula probably also displaced into the paratracheal soft tissues during the

Table 2. Specific Interventions Performed during 1,093 Suspension Microlaryngoscopies

Intervention	Overall	TTJV	TGJV	AIV	MCV
Laser surgery	763 (70)	238 (73.2)	283 (71.6)	114 (56)	128 (72.5)
Vocal fold injection*	160 (16.6)	11 (19.1)	122 (13.2)	15 (20.7)	12 (14.5)
Mitomycin application	130 (12.0)	20 (16.2)	39 (10.7)	27 (6.9)	44 (13.5)
Surgery without laser	105 (10.1)	13 (9.4)	47 (11.3)	20 (11.3)	25 (7)
Cidofovir injection	92 (8.6)	12 (7.9)	60 (7.2)	10 (3.1)	10 (17)
Stent insertion/removal	75 (8.2)	6 (8.3)	24 (8.1)	6 (11.9)	39 (5.5)
Others†	67	5	16	19	27
Total (100%)	1,392	305	591	211	285

Data are presented as n (%). For each suspension microlaryngoscopy procedure, the first (n = 1,093), second (n = 267), or third (n = 32) interventions were recorded. The three most frequent intervention performed during suspension microlaryngoscopy within each group are indicated in bold.

* The following materials were injected: fat, collagen, Gelfoam (Pharmacia & Upjohn Comp., Puurs, Belgium), Zyplast (Collagen Aesthetics Ltd, Arklow, county Wicklow, Ireland), Teflon (DuPont, Wilmington, DE), Vox implant (Uroplasty BV Comp., Geelen, Netherlands). † *Others* includes granulation tissue removal, botulinum toxin injection, dilatations.

AIV = apneic intermittent ventilation; MCV = mechanical controlled ventilation; TGJV = transglottal jet ventilation; TTJV = transtracheal jet ventilation.

Table 3. Incidence of Complications

Event	TTJV	TGJV	AIV	MCV
Minor complications				
Failure*†	3	4	0	0
Mucosal damage*	1	0	0	0
Laryngospasm*	1	0	5	0
Hemodynamic instability	6	2	0	0
Hypoxemia	2	1	0	0
Myocardial ischemia	1	0	0	0
Cervical emphysema*	3	0	0	0
Major complications				
Cervicomedialastinal emphysema*	1	0	0	0
Pneumothorax*	1	1	0	0
Tension pneumothorax*	1	0	0	0
Total	20/265 (7.5%)	8/469 (1.7%)	5/359 (1.4%)	0/200 (0%)

* Complications directly related to the ventilation procedure. † Failure of insertion of the cannula and failure of ventilation through the cannula.

AIV = apneic intermittent ventilation; MCV = mechanical controlled ventilation; TGJV = transglottal jet ventilation; TTJV: transtracheal jet ventilation.

procedure. These three patients presented no respiratory symptoms and required no treatment for their emphysema, which resolved spontaneously.

In one patient, a posterior tracheal mucosal tear with slight bleeding was observed after placement of a transtracheal cannula, but without deleterious consequences.

Seven technical failures were recorded. In four patients, the transglottal cannula could not be placed in the subglottic space. A transtracheal cannula was successfully placed in two of these patients. The third patient was successfully treated with apneic intermittent ventilation, and the fourth one underwent intubation with a rigid bronchoscope. In three patients, the transtracheal cannula folded during insertion, leading to total inflow obstruction. These three situations were dealt with by inserting another cannula through the same puncture site (first case), by using a transglottal cannula (second case), and by applying apneic intermittent ventilation (third case). Despite these events, all of the seven surgical procedures were fully performed as planned.

Minor Complications during Apneic Intermittent Ventilation

Of the five cases of laryngeal spasms that occurred (incidence: 3.1%), two of them were encountered in children, none were complicated by significant hypoxemia, and a favorable outcome was observed in all cases. In three patients, laryngeal spasm could be explained by an insufficient level of anesthesia at the end of the procedure.

Major Complications

The overall incidence of major complications was 0.37% (4 of 1,093). No deaths occurred during the procedures or were related to them. All major events occurred during subglottic jet ventilation (table 3). Transtracheal jet ventilation was involved in three out of four

cases (1.1%), and the remaining case occurred during transglottal jet ventilation (0.2%).

One unilateral pneumothorax with cervicomedialastinal emphysema occurred in a patient undergoing a debulking procedure of the glottis with the carbon dioxide laser for a tumor obstructing more than half of the lumen. Acute intraoperative bleeding developed and was managed by immediate application of a cotton swab soaked in adrenalin that temporarily sealed the airway.

The most severe complication observed in this series was a bilateral tension pneumothorax with cervicomedialastinal emphysema. It occurred by reventilating a patient through the transtracheal jet cannula when mask ventilation was no longer feasible at the end of anesthesia, most probably because of laryngeal spasm. Ventilation became rapidly impossible, and the patient required immediate bilateral thoracic drainage.

The sole major complication observed with transglottal jet ventilation was a left-sided pneumothorax with cervicomedialastinal emphysema. A severe laryngospasm occurred at the end of the procedure and caused a complete obstruction of the air outflow tract, as described in the precedent case.

One patient had development of cervicomedialastinal emphysema after an episode of cough when the transtracheal cannula was still in place at the end of the procedure. Extensive palpable emphysema of the anterior neck and upper thoracic wall rapidly developed, and cervicomedialastinal emphysema was confirmed by chest radiographs. However, the patient did not show desaturation or hemodynamic instability. The mechanism involved was probably a slight displacement of the cannula into the paratracheal soft tissues. No particular treatment was applied.

Transglottal jet ventilation was not significantly associated with fewer major events than was transtracheal jet ventilation ($P = 0.137$). However, the risk ratio (transtracheal:transglottal) of these two methods was 5.4.

Table 4. Jet Ventilation: Observed Complications Correlated to ASA Physical Status and Ventilation Mode

Ventilation*	ASA Physical Status†	Complications			
		No	Minor	Major	Total
TGJV	I	159			0/159
	II	235	4		4/239 (1.7%)
	III	67	3	1	4/71 (5.6%)
TTJV	I	56	1		1/57 (1.8%)
	II	148	12	1	13/161 (8.1%)
	III	41	4	2	6/47 (12.8%)

* Odds ratio for transtracheal jet ventilation (TTJV) vs. transglottal jet ventilation (TGJV) was 4.3 (95% confidence interval, 1.9–10.0). † Odds ratio for the increase of one grade of American Society of Anesthesiologists (ASA) physical status was 2.9 (95% confidence interval, 1.5–5.4).

The four major complications recorded in this series accounted for 82 additional days of hospital stay because all four cases were planned as ambulatory procedures. No major complications were observed among the pediatric patients during this 10-yr period. Seventy-five percent of the patients with major events had an ASA physical status classification of III. It is interesting to note that we did not experience any airway fire in 763 carbon dioxide laser procedures.

Jet Ventilation Group Analysis

Among the specific interventions performed during suspension microlaryngoscopy, the use of the laser was not associated with an increased number of complications ($P > 0.25$). A high ASA physical status classification and transtracheal jet ventilation were highly associated with an increased occurrence of complications ($P < 0.001$; table 4). The odds ratio of complications from transtracheal/transglottal jet ventilation was 4.3 (95% confidence interval, 1.9–10.0). The odds ratio of an increase of one ASA physical status grade was 2.9 (95% confidence interval, 1.5–5.4). There was no interaction between ASA physical status classification and type of ventilation ($P > 0.25$).

Discussion

Interventional suspension microlaryngoscopy is a commonly performed procedure in otolaryngology and head and neck surgery for the diagnosis and treatment of laryngeal pathologies. Sharing the same anatomical site, only a close collaboration between the anesthesiologist and the surgeon guarantees an adequate ventilation combined with a good surgical exposure.

No complications occurred during mechanical controlled ventilation, and only minor complications occurred during apneic intermittent ventilation. The majority of complications occurred during subglottic jet ventilation.

Barotrauma

The four major complications were all barotrauma due to the pursuit of jet ventilation despite an obstructed airway. One was related to a failure of coordination between surgeon and anesthesiologist, and two were the consequence of jetting during a laryngospasm. These cases should thus be considered as “pilot errors” rather than a failure of the technique. Misplacement or displacement of the transtracheal cannula, sometimes after an episode of cough, is the cause of one major and three minor cases of emphysema in our series. Air can penetrate into the paratracheal space under three circumstances: (1) Air is insufflated through a misplaced cannula²⁰; (2) the cannula migrates in the paratracheal space during an episode of cough, for example; and (3) hollow channels are created from the trachea by more than one puncture to place the transtracheal cannula. To prevent this problem, we recommend avoiding multiple punctures during insertion of the transtracheal cannula, fixing firmly the transtracheal cannula with a ribbon, and waking the patient up during mask ventilation with the transtracheal cannula still in place at the end of the surgical intervention.

There are numerous case reports of barotrauma associated with jet ventilation, ranging from noncomplicated cervical emphysema to tension pneumothorax with consecutive heart failure,^{20–24} particularly at the beginning of desobstruction procedures.¹⁹ Recently, Bourgain *et al.*¹⁵ reported their experience with transtracheal jet ventilation in 643 cases. They mentioned a high incidence of subcutaneous emphysema (8.4%) and pneumomediastinum (2.5%). In contrast, pneumothoraces rarely occurred (1%), and no tension pneumothorax was reported.¹⁵ The occurrence of pneumothorax has been estimated at approximately 0.04% during mechanical controlled ventilation with tracheal intubation and at approximately 0.2% with transglottal jet ventilation.¹⁶ The incidence of pneumothorax (2 of 734, 0.27%) in our series is comparable. This is remarkable because at our institution, all interventional suspension microlaryngoscopy procedures are performed by experienced head and neck surgeons with anesthesiology residents in training. Nevertheless, these residents were closely supervised by board-certified anesthesiologists.

Our experience highlights the risks of jet ventilation with a closed glottis as, for example, in case of laryngospasm, which happened twice in our complex cases. This underlines the necessity of identifying laryngospasm when a previously clear airway becomes obstructed. In fact, pressure monitoring at the end of the injector offers only relative safety¹⁵ because it cannot detect resistance to gas delivery before supplying the first tidal volume.²⁵

Recent progress in transcutaneous carbon dioxide²⁶ and inspiratory pressure²⁷ monitoring did not improve the safety of jet ventilation. The clinical monitoring of

the patient still remains, in our opinion, the standard method to prevent barotrauma: The anesthetist must keep his or her eyes and his hands on the thorax and listen to each outflow sound to verify the unobstructed outflow of air after each inspiration. Furthermore, assuring an adequate level of anesthesia, analgesia and muscle relaxation constitute the best prevention of laryngospasm.

Interestingly, if a relation between the risk of barotrauma and the preoperative degree of airway obstruction was expected,¹⁵ this was not observed in this study.

Transtracheal versus Transglottal Jet Ventilation

In our series of 734 cases of subglottal jet ventilation, we found more complications with the transtracheal (7.5%) than with the transglottal (1.7%) approach. This was a retrospective analysis, and thus the conclusions should be interpreted with caution. Although the stepwise logistic regression allowed adjustment for differences among the groups, such as the type of intervention, indications, and ASA physical status classification, it cannot be excluded that other parameters not contained in the data base might be, in part, responsible for the observed difference. Nevertheless, we recommend using a transglottal instead of a transtracheal jet cannula whenever possible.

Failure to introduce the cannula or to ventilate the patient through it was encountered in three cases with the transtracheal technique and four cases with the transglottal technique. These patients were all successfully ventilated with another technique, highlighting the fact that transtracheal ventilation can be used in place of the transglottal approach and *vice versa*. The insertion of the transtracheal cannula is facilitated when the bronchoscope is in place because the anterior-posterior dimension of the trachea is maintained by the rigid tube, and the risk of damage to the posterior tracheal wall is decreased.

Some authors reject the use of transtracheal jet ventilation except for emergency cases with significant airway compromise.²⁸ More and more, however, national anesthesia societies recognize the necessity to train anesthesiologists in rescue techniques of airway management.⁸ According to our two decades of experience, performing elective transtracheal jet ventilation in the endoscopy suite offers the best way for the anesthesiologist to acquire this potentially lifesaving technique of ventilation.

Apneic Intermittent Ventilation

The laryngospasms (3.1%) observed during apneic intermittent ventilation occurred mainly (three of five) at the end of the surgical procedure because of an insufficient level of anesthesia. They had no deleterious consequences for the patient as described elsewhere.^{18,19}

ASA Physical Status Classification: A Predictive Factor of Complications

A high ASA physical status classification significantly correlated with an increased risk for complications in the two groups of jet ventilation. Nevertheless, ASA physical status classification is not predictive of the risk of barotrauma.

Conclusion

In this series of more than 1,000 cases of interventional suspension microlaryngoscopy, subglottic jet ventilation through a transtracheal cannula was the major independent risk factor for complications as opposed to the transglottal approach. The anesthetist's vigilance in clinically detecting and preventing outflow airway obstruction remains the best prevention of barotrauma during subglottic jet ventilation. Hence, risk of complications and benefit of an expected improved surgical outcome must be carefully weighed when choosing transtracheal as opposed to transglottal approach for jet ventilation. This technique should be taught at highly specialized centers with a high case load and extensive experience during close supervision.

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