Superimposed high-frequency jet ventilation (SHFJV) for endoscopic laryngotracheal surgery in more than 1500 patients

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Background. Superimposed high-frequency jet ventilation (SHFJV), which does not require any tracheal tubes or catheters, was developed specifically for use in laryngotracheal surgery. SHFJV uses two jet streams with different frequencies simultaneously and is applied in the supraglottic space using a jet laryngoscope and jet ventilator.

Methods. Between 1990 and 2004, SHFJV was studied in 1515 consecutive patients (including 158 children requiring laryngotracheal surgery) prospectively. Ventilation was performed with an air/oxygen mixture and anaesthesia was administered i.v.

Results. Adequate oxygenation and ventilation was achieved in 1512 patients. Arterial blood gas analyses (BGA) were performed between 1990 and 1994; thereafter BGA was only performed in patients with high-grade stenosis of the larynx/trachea or high-risk patients \( n = 623 \), mean \( P_{aO_2} \) 133.8 (39.4) mm Hg and mean \( P_{aCO_2} \) 42.3 (10.1) mm Hg. There were no significant changes in \( P_{aO_2} \) or \( P_{aCO_2} \) during the entire period of SHFJV. No complications secondary to the ventilation technique were observed; in particular, no barotrauma occurred. Three patients required tracheal intubation. SHFJV was also successfully used for laser surgery \( (n = 312) \). It proved to be a safe mode of ventilation without any complications such as airway fire, major haemorrhage, or aspiration of debris.

Conclusion. SHFJV is an advanced ventilation mode playing a pivotal role in the (open) ventilatory support/ventilation of patients with laryngotracheal stenosis. It is particularly indicated in cases of severe stenosis and offers optimal conditions for laryngotracheal surgery, including laser surgery and stent implantation techniques.
translaryngeal Hunsaker MonJet Ventilation catheter, and its successor, the LaserJet® catheter.

Both techniques use small tubes and hence do not impede the surgical access, while providing a better view of the structures of the larynx. The translaryngeal approach using the LaserJet® catheter provides excellent ventilation and is not associated with vocal cord movement. Owing to the stiffness of the catheter there is no risk of kinking, but barotrauma may result in cases of proximal obstruction. The Ravussin needle must be attached tightly to avoid displacement from the tracheal lumen. Obstruction of the trachea as a result of tumours, inflammatory tissue might be aggravated by catheters leading to hypoxia or bleeding, and necessitate the use of alternative ventilation methods. Currently the Ravussin needle is given preference for emergency treatment of hypoxic, difficult-to-intubate patients.

The use of jet techniques in patients with high-grade laryngeal or subglottic stenoses is still challenging for the anaesthesiologist, but is controversially discussed in the published literature.

Despite the availability of several types of devices for safe performance of gas exchange during laser surgical procedures, such as tubes made from polytetrafluoroethylene (Teflon®) (LaserJet® catheter), wrapped tubes or metal tubes, the hazards of microlaryngeal surgery performed with CO₂ laser persist; these include (airway) fires resulting from ignition of surgical drapes, and combustion of tracheal tubes. Superimposed high-frequency jet ventilation (SHFJV) was developed in 1990 and used in clinical trials. The nozzles were integrated into special laryngoscopes with two metal cannulas, and a jet ventilator facilitated combined simultaneous supraglottic low- and high-frequency jet ventilation. The procedure allowed free access to the surgical field.

The present report summarizes our experience with this technology over a long period, used in a large number of patients, in combination with different surgical procedures. The feasibility of the technique, CO₂ elimination, gas exchange and the limits of the jet technique in cases of severe laryngeal or tracheal stenosis were investigated in the clinical setting. Furthermore, the aspect of safety in the administration of anaesthesia during laser surgery was evaluated.

### Methods

**Jet technique**

**Ventilation technique**

SHFJV was performed as described previously. Briefly, two jet streams with different frequencies were applied.

![Typical pressure (A) and flow (B) curves during SHFJV with continuous high-frequency (HF) and two cycles of a simultaneous low-frequency (LF) jet stream, using a mechanical adult test lung (Metron QA-VT Adult Ventilator Tester, Michigan Instruments Inc., USA), and connected to a jet laryngoscope. The peak airway pressure provides the tidal volume, and the PEEP correlates with the volume of gas remaining in the lungs at the end of expiration, equivalent to the functional residual capacity. The second portion of the figure below demonstrates the flow. Respirator settings: LF unit: \( f=0.2 \text{ Hz} \) (12 bpm), \( I:E=1:1 \), driving pressure=1.1 bar; HF unit: \( f=6 \text{ Hz} \) (360 bpm), \( I:E=1:1 \), driving pressure=0.5 bar, peak airway pressure 14 cm H₂O; PEEP 6 cm H₂O; test lung compliance \( C=0.05 \text{ litre per cm H₂O} \).]
simultaneously (Fig. 1). The continuous high-frequency jet stream was superimposed during the inspiratory and expiratory phases of the low-frequency jet ventilation. The low-frequency jet stream resulted in phased airway pressure changes analogous to conventional ventilation with 12–20 bpm (0.2–0.3 Hz), and provided the upper pressure level. The high-frequency jet stream with a frequency of 100–900 cycles min$^{-1}$ (1.6–15 Hz) generated the lower pressure level (i.e. the PEEP).

Jet laryngoscope
Figure 2 shows the laryngoscope used for SHFJV: a steel tube equipped with two nozzles integrated in the body for simultaneous administration of high-frequency and low-frequency jet ventilation. A third nozzle is placed close to the distal tip, allowing pressure monitoring. The driving pressure varies between 1 and 3 bar. The jet laryngoscope is positioned by the surgeon.

Ventilators
Two prototypes of jet ventilators capable of the SHFJV technique were developed and used. The Bronchotron respirator (Percussionaire Corp., Idaho, USA) is a pneumatically operated ventilator independent of any electrical supply. The second is the Laryngojet (Acutronic Medical Systems, Hirzel, Switzerland), which is equipped with electromagnetic valves controlled by a microcomputer. Both jet ventilators are capable of providing two separate jet streams simultaneously, and are provided with an integrated alarm system with an inspiratory peak pressure limit. The following ventilation settings were used in all patients: inspiration/expiration (I:E) time ratio=1:1, $F_{\text{IO}_2}$ between 40 and 60%, low-frequency (LF): 0.2–0.3 Hz, high-frequency (HF): 10 Hz. Driving pressures were set at 0.7–3.5 bar for high-frequency, and 1.0–3.5 bar for low-frequency jet ventilation.

Clinical study
Patients
After obtaining approval from the ethics committee and informed patient or parents’ consent, 1515 patients (650 females and 865 males, including 158 children) with ASA physical status I–III underwent SHFJV for elective surgery of the larynx/trachea from January 1990 to December 2004. Patient characteristics and diagnoses are listed in Tables 1 and 2.

ECG, heart rate (HR), blood pressure and oxygen saturation were monitored in all patients. To register the exact values of arterial blood gases in all patients from 1990 to 1994, an arterial cannula was introduced for the determination of $P_{\text{AO}_2}$, $P_{\text{ACO}_2}$ and arterial blood pressure ($n=500$). After 1994, an arterial cannula was only inserted in patients...
with high-grade laryngeal/tracheal stenosis, high-risk patients with peripheral oxygenation below 92%, and an anticipated operating time of more than 30 min (n=132). Arterial blood gas analysis was performed every 5 min. Applied oxygen concentration was monitored using the Oxycheck (Datex-Oscan Oxy, Helsinki, Finland). Ventilation pressure was continuously measured at the tip of the jet laryngoscope.

**Anaesthesia technique**

Total i.v. anaesthesia was used in all cases because SHFJV using the jet laryngoscope is an open system. All patients were pre-medicated with 7.5 mg oral midazolam approximately 60 min before the start of anaesthesia. Anaesthesia was induced with fentanyl 3–5 μg kg⁻¹ i.v., propofol 1.5–3 mg kg⁻¹ i.v. and vecuronium 0.1 mg kg⁻¹ i.v. A radial artery cannula was inserted and invasive blood pressure was recorded. Anaesthesia was maintained with a continuous infusion of propofol 6 mg kg⁻¹ h⁻¹ i.v. Fentanyl 2 μg kg⁻¹ i.v. and vecuronium 0.03 mg kg⁻¹ i.v. were supplemented as required.

**Laser surgery**

Two CO₂ lasers were used (Hercules 5040; Heraeus Laser Sonics Inc., Milpitas, CA, USA, and Sharplan 1050; Laser Industries Ltd, Vörösmarty, Israel). No laser protective measures were required in the field of operation. The patients’ eyes were shielded with saline-soaked pads. In laser patients, \( F_{O_2} \) ranged from 40 to 60%.

**Study design**

In a prospective study, SHFJV was used consecutively in all patients undergoing laryngotracheal surgery. Exclusion criteria were acute bleeding in the area of the larynx and the trachea, infectious lung disease (e.g. tuberculosis), highly contagious disease (hepatitis, HIV, etc.), inability to perform retroflexion of the head (in this case the laryngoscope cannot be positioned properly), and high-grade stenosis of the larynx (grade IV according to Cotton). Complications were defined as dental damage, aspiration of gastric contents, pneumothorax, skin emphysema, gross mucosal damage, bradycardia (HR <45 bpm), triggering of dysrhythmia, airway fire and death.

**Statistical analysis**

Data are presented as means (SD) if not otherwise specified. Group comparisons between the different time points were performed using a paired t-test. Statistical analyses were performed with a commercially available computer program (Stat View; SAS Institute Inc., Cary, NC, USA). A P-value <0.05 was considered to indicate statistical significance.

### Results

SHFJV was performed successfully in 1512 patients (99.8%). Endotracheal intubation was required in three patients (0.2%): one obese patient weighing 121 kg and presenting with massive stenosis attributable to laryngeal carcinoma, one patient with COPD suffering from massive laryngeal stenosis because of papillomatosis, and one patient with pulmonary metastasis after partial resection of the larynx. The longest duration of surgery using SHFJV was 180 min in a 2-yr-old girl with 90% stenosis of the larynx (grade IV according to Cotton). Complications were defined as dental damage, aspiration of gastric contents, pneumothorax, skin emphysema, gross mucosal damage, bradycardia (HR <45 bpm), triggering of dysrhythmia, airway fire and death.

### Table 1 Patient characteristic data and the SHFJV technique. Values are mean (SD)

<table>
<thead>
<tr>
<th>Patients</th>
<th>n</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>1515</td>
<td>100</td>
</tr>
<tr>
<td>Male</td>
<td>865</td>
<td>57.1</td>
</tr>
<tr>
<td>Female</td>
<td>650</td>
<td>42.9</td>
</tr>
<tr>
<td>Children</td>
<td>158</td>
<td>10.4</td>
</tr>
</tbody>
</table>

Age
- Adults (yr) 48.5 (20)
- Children (yr) Newborns to 14

Body weight
- Adults (kg) 70 (22)
- Children Neonates with a birthweight of 1750 g and above

Blood pressure (mm Hg)
- 100 (16)

Heart rate (beats min⁻¹)
- 75 (18)

Oxygen saturation (%)
- 99 (1)

SHFJV working pressure
- Low frequency (bar) 1.6 (0.6)
- High frequency (bar) 1.3 (0.5)

Airway pressure
- Average (cm H₂O) 1.1 (0.6)
- PEEP (cm H₂O) 0.4 (0.2)

### Table 2 Diagnoses of patients undergoing microlaryngeal/tracheal surgery under SHFJV

<table>
<thead>
<tr>
<th>Diagnoses</th>
<th>Total (n=1515)</th>
<th>Percent (100%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carcinoma of larynx and vocal fold</td>
<td>318</td>
<td>21.0</td>
</tr>
<tr>
<td>Polyps on a vocal cord</td>
<td>239</td>
<td>15.8</td>
</tr>
<tr>
<td>Reinke’s oedema</td>
<td>199</td>
<td>13.1</td>
</tr>
<tr>
<td>Chronic laryngitis</td>
<td>86</td>
<td>5.7</td>
</tr>
<tr>
<td>Leucoplasia of the vocal fold</td>
<td>83</td>
<td>5.5</td>
</tr>
<tr>
<td>Laryngeal or tracheal stenosis</td>
<td>139</td>
<td>9.2</td>
</tr>
<tr>
<td>Bilateral vocal fold paralysis</td>
<td>180</td>
<td>11.9</td>
</tr>
<tr>
<td>Vocal fold nodule</td>
<td>43</td>
<td>2.8</td>
</tr>
<tr>
<td>Laryngeal granuloma</td>
<td>52</td>
<td>3.4</td>
</tr>
<tr>
<td>Laryngeal cysts</td>
<td>78</td>
<td>5.2</td>
</tr>
<tr>
<td>Synechia of vocal fold</td>
<td>38</td>
<td>2.5</td>
</tr>
<tr>
<td>Phonosurgery</td>
<td>22</td>
<td>1.5</td>
</tr>
<tr>
<td>Others</td>
<td>38</td>
<td>2.4</td>
</tr>
</tbody>
</table>
to provide the lowest $F_{\text{IO}_2}$ possible equivalent to pulse oxymetric oxygen saturation. There were no significant differences between $P_{\text{aO}_2}$ measured at the different time points during SHFJV, as shown in Figure 3.

The measured mean $P_{\text{aCO}_2}$ values ranged between 42 and 46 mm Hg (Fig. 3b). However, in patients with acute dyspnoea and signs of respiratory insufficiency (e.g. higher $P_{\text{aCO}_2}$) secondary to laryngeal or subglottic stenosis, hypercapnia was already present before the operation. To obtain normocapnia, ventilation pressures were enhanced or lowered during the intervention, depending on whether the patient had elevated or reduced levels of CO$_2$.

We measured the course of pressures in the jet laryngoscope and intratracheally ($n=13$). The airway pres-
Airway pressures measured along the jet laryngoscope and in the trachea in patients undergoing SHFJV (n=13). Measured pressures at the distal tip of the jet laryngoscope (15 cm) correlated well with intratracheal values (30 cm). Pressures in the middle of the jet laryngoscope (10 cm) reflect the effect of air-entainment. Values of individual patients (grid lines) and median values (bold line) are shown in distances from the proximal end (entrance) of the jet laryngoscope.

Complications resulting from ventilation with SHFJV, such as barotrauma or subcutaneous emphysema were not observed in any patient.

All patients had stable haemodynamics at all times during the operation and in the recovery room (Table 1).

One hundred and thirty-nine patients had a severe laryngeal or tracheal stenosis. The jet laryngoscope could be positioned correctly and jet ventilation performed properly even when the aperture of the glottis measured no more than 2 or 3 mm.

CO₂ laser was used in 312 patients. We performed 101 laser interventions in 77 children. No complications related to the laser procedure were encountered. There were no cases of airway fire/explosion; no aspiration of debris into the trachea or lungs, and no bronchial airway irritation secondary to laser smoke inhalation. Other complications such as pneumothorax, fistula formation or perforation were also not observed.

Intratracheal stent application was performed in 45 patients. The surgeons adapted 35 silicone stents and 10 expandable Polyflex stents to the local anatomical situation and inserted these into the trachea/bronchi under continuous SHFJV; the apnoea technique was not required during any stenting procedure.

**Discussion**

In recent years, several effective jet techniques have been established for microlaryngeal surgery, each with its characteristic advantages and disadvantages.

**Interference with surgery**

Needle cricothyroidotomy facilitates infraglottic single-frequency jet ventilation in patients without considerable glottic stenosis. It offers an excellent surgical view of the larynx, and the possibility to ventilate patients in emergency cases. However, tracheal stent application is not possible because of the jet catheter in the trachea.

The Hunsaker catheter (HMJT), and its successor LaserJet®, with the jet applied transl South, and positioned infraglottically, are well suited for surgical procedures in the normal-sized glottis and trachea. It offers good surgical view and access. Subglottic jetting causes minimal vocal fold motion. A further advantage of the translaryngeal technique is the fact that it does not depend on the positioning of the suspension laryngoscope. Thus, infraglottic jet ventilation offers greater comfort and safety for the patient. Another advantage is the constant gas egress, directed outwards, which precludes intrusion of fluid or solid material. The technique can be used in patients without considerable stenosis in the glottis, and in cases of supraglottic upper airway obstruction. Moreover, it is useful in phonosurgery because it ensures that the vocal folds remain motionless. However, tracheal stenting is difficult when this technique is used.

SHFJV offers a completely free access as compared with the two infraglottic jet ventilation techniques. It also permits better inspection of the ventricles and the subglottic space, avoids damage resulting from intubation in cases of severe stenosis (a characteristic of translaryngeal techniques), and allows tracheal stent application during continuous SHFJV.

**Oxygenation and ventilation**

Most jet ventilation techniques such as infraglottic needle or translaryngeal catheter jet ventilation facilitate sufficient oxygenation in patients with normal lung function. A disadvantage of the SHFJV is the reduction of the inspiratory oxygen fraction as a result of entrainment at the jet nozzles. Therefore, the real $F_{\text{IO}_2}$ in the lung is lower than the adjusted $F_{\text{IO}_2}$ at the respirator. However, we were able to achieve sufficient oxygenation even in high-risk patients.

**Ventilation**

In patients with reduced respiratory reserves, for example decreased lung compliance or increased resistance, massive obesity, or massive obstructive pulmonary disease, the time for high-frequency jet ventilation and adequate gas exchange is limited. This may lead to CO₂ retention. When the transtracheal or translaryngeal access is used, CO₂ elimination usually occurs because a lower jet frequency and increased volumes of the single jet gas impulses are used. In the case of SHFJV, superimposition of the low-frequency jet induces additional gas, resulting in thoracic inspiratory and expiratory movements, similar to those during conventional ventilation. Recently published results showed that CO₂ elimination can be maintained better with
supraglottic SHFJV than with infraglottic single-frequency jet ventilation.\textsuperscript{22} Thus SHFJV offers hitherto unknown possibilities. Ventilation at two arbitrary pressure levels similar to biphasic positive airway pressure allows adequate ventilation over a longer period even in patients with reduced pulmonary reserves.

Within this open ventilation system, the level of intrinsic PEEP is defined by the driving pressure, the I:E ratio of jet gas impulses, and the frequency of the high-frequency jet stream. The risk of over-distension of small airways or barotrauma attributable to inadvertent high peak pressures or increased intrinsic PEEP should be considered, particularly in lungs with obstructive or restrictive disease. In this investigation, we observed no acute increase in peak pressures or total PEEP in any patient with obstructive lung disease. Nevertheless, in patients with a prolonged peripheral expiratory time (e.g. COPD), the I:E ratio should be adjusted.

While inadequate warming and humidification during HFJV pose a difficulty for long-term application of HFJV and may lead to tracheobronchitis or deterioration of the mucociliary transport system, several humidification systems for HFJV\textsuperscript{23–26} have been developed. Although unconditioned jet ventilation dessicates the airway mucosa because of the high jet gas flow and leads to temperature loss because of the proximity to the large blood vessels in the mediastinum, our patients ventilated with SHFJV for up to 180 min experienced no persistent or clinically relevant mucosal damage.

### Complications

Bourgain and colleagues\textsuperscript{27} reported complications following transtracheal HFJV in 643 patients who had undergone laryngoscopy. The authors observed subcutaneous emphysema in the neck in 8.4%, extension of the emphysema to the face in 2% (14 patients), pneumomediastinum in 2.5% (16 patients), and pneumothorax in 1.1% (7 patients).

Russel and colleagues\textsuperscript{28} performed 90 selected microlaryngeal interventions with needle cricothyroidotomy. The authors encountered about 12 complications. One half of them were caused by the applied ventilation technique [surgical emphysema (n=2), bleeding (n=3), kinking (n=1)]. Further complications published as case reports include barotrauma,\textsuperscript{29} subcutaneous emphysema,\textsuperscript{30} pneumoperitoneum and others, such as puncture of the oesophagus leading to over-distension of the gastrointestinal tract and haematoma. Spread of virus particles, smoke or debris during any supraglottic jet ventilation has not been reported in any study; we also encountered no such complications in our patients.

SHFJV may be accompanied by dental damage resulting from inadvertent malpositioning of the jet laryngoscope (as in conventional laryngoscopy), the inability to position the laryngoscope correctly because of the pathological anatomy of the larynx, displacement of the laryngoscope during the surgical procedure, or vibrations of the vocal fold attributable to jet ventilation. However, while using SHFJV we did not encounter any major problems related to positioning or dislocation of the laryngoscope. The higher the frequency of the jet stream, the more likely it is that vibrations of the vocal fold will not occur. In very rare cases these motions disturb the procedure. We increased the frequency of the jet stream in order to create a nearly continuous gas stream, or switched it off and ventilated the patient with the low-frequency jet stream alone. Supraglottic jet ventilation was used in 1515 cases and was not associated with the complications described for other techniques. Only three patients had to be intubated because of severe co-existing airway disease.

### Airway pressure monitoring

Jet ventilation via a transtracheal needle does not facilitate simultaneous continuous measurement of the airway pressure unless a second catheter is placed inside the airway; the latter approach appears to be more invasive. However, when the application of jet gas and airway pressure is determined with one catheter, the subsequent end-expiratory pause and the resulting pressure decrease can be used for pressure monitoring.\textsuperscript{31} However, peak pressures in the inspiratory phase might be higher. The LaserJet\textsuperscript{c} facilitates pressure monitoring proximal to the jet outlet. Intratracheal pressure measurement during jet ventilation is generally not very accurate. However, this is not of clinical relevance, as the safety feature of automatic ventilator shutdown in case of inadvertent pressure elevation remains unaffected by this circumstance. Similarly, the SHFJV ventilators allow measurement of continuous peak pressure and PEEP at the distal tip of the jet laryngoscope.

High ventilatory frequencies with short expiratory times predispose to air trapping and inadvertent high PEEP, and may result in barotrauma. We examined applied pressures in a large group of ENT patients (n=134) undergoing SHFJV with an I:E=1:1 for the high-frequency jet stream.\textsuperscript{32} SHFJV facilitated proper gas exchange even in patients with increased body weight, did not necessitate the use of maximum airway pressures, and did not result in barotrauma.

As supraglottic jet ventilation is an open ventilation system, the applied tidal volume results from the applied jet gas, the entrained air, and the backflow of gas around the glottis (leak). Optimal positioning of the jet laryngoscope will minimize this leak volume. Measuring pressure in a system with a leak is very cumbersome, and the results may be unreliable. In a small group of adults (n=13) we determined pressure distal to the jet laryngoscope during SHFJV in the trachea, and registered good correlation between the pressures measured at the tip of the jet laryngoscope and intratracheal values (Fig. 4).

### Capnography and continuous CO\textsubscript{2} measurement

Maintaining normocarbia is one of the essential goals of modern anaesthesia. During the last few decades, several
new non-invasive approaches have been introduced to monitor the efficacy of gas exchange during HFJV. These include end-tidal capnography and oxygraphy using a specially designed rigid bronchoscope with an additional small suction channel and a port for gas sampling. Another procedure is transcutaneous monitoring of \( PCO_2 \) and \( PO_2 \), which was first proposed for general use in the 1970s.

Today, both end-tidal and transcutaneous respiratory monitoring are used in clinical practice during HFJV. The transcutaneous monitoring technique is generally accepted for use in infants and children and has been successfully applied in adults for adjusting jet ventilation settings. Transcutaneous \( CO_2 \) measurement is an accepted and effective method. Despite a delay of approximately 1 min in the determination of \( CO_2 \) values, the results correlate well with changes in \( CO_2 \) over time. Ventilator settings can be adapted accordingly.

**Stenosis**

Patients with laryngeal or tracheal stenosis require special consideration. If intubation is rendered impossible by the grade of the stenosis, a tracheotomy has to be performed first. The application of jet ventilation was deemed inappropriate for many years, as evidenced by several textbooks on the subject. However, recent developments and improvements of jet techniques have proved that jets can be applied in these cases as well.

*Transtracheal jet ventilation (TTJV)* is performed distal to the stenosis. Unobstructed expiratory gas flow always has to be maintained to avoid barotraumas. These interventions are associated with a higher risk of complications. Monnier and colleagues described 65 cases of TTJV in 12 patients with subglottic stenoses. One complication occurred as a result of cervico-mediastinal emphysema. Depierraz and colleagues described the use of TTJV in 16 children with stenotic processes. In 28 laser procedures, complications were encountered in three children, namely skin emphysema, bilateral pneumothorax and cardiovascular depression. In these studies the authors noted that TTJV was used as an alternative technique to prevent tracheotomy. They recommended low jet frequency, a short inspiration time, a long expiration time and low driving pressure.

The LaserJet can be used only if the catheter does not obliterate the remaining lumen of the Airways. This situation occurs in patients with high-grade stenoses, where no residual lumen is available for the expiratory gas flow because of the size of the jet catheter. There are no studies concerning the use of this tube in stenosis.

**Supraglottic SHFJV may be used as an alternative to infraglottic jet ventilation in this setting**

In our study, 139 patients had a severe laryngeal or tracheal stenosis. However, all interventions could be completed without any complications related to the technical ventilation procedure. The pressure below the stenosis cannot be higher than the pressure above the stenosis with any supraglottic technology. Stenosis will reduce the inflow of jet gas, and the resulting distal airway pressure behind the stenosis will be reduced as well. This also applies to the insertion of surgical instruments that reduce the airway diameter. In retrospect, our results show that supraglottic SHFJV reduces the risk of barotrauma. We also agree with other authors that the use of jet ventilation can prevent tracheotomy in patients with (laryngeal) stenosis.

As shown by our previous experiments and clinical results, the risk of a ventilatory complication when using supraglottic SHFJV in laryngeal stenosis may be considered low.

**Laser surgery**

For endoscopic laser surgery, SHFJV offers unobstructed conditions for surgery. Complications were encountered when laser surgery was used in conjunction with jet ventilation, but the complications may not have been a result of the application of laser. Fires caused by interaction between the jet catheter and laser have not been described. Only one case report concerning airway ignition described the use of two Teflon catheters which were bonded with a non-laser-proof layer.

**Application of SHFJV in children**

SHFJV appears to be particularly useful in children because of its minor invasiveness and its ability to provide supraglottic access to the surgical field. Accordingly, we encountered no complications in children. Even premature babies with a body weight less than 2 kg, presenting with tracheal stenosis, were ventilated safely. Children with papillomas of the larynx were treated repeatedly by laser surgery. Follow-up endoscopies did not show spread of papillomas in the subglottic or the tracheal surgical field in children ventilated by SHFJV.

**Application of the SHFJV for stent application**

SHFJV was also used with excellent results for implantation of tracheal and bronchial stents, as it allows continuous ventilation without restricting the surgeon’s freedom of manipulation. Thus, the surgical procedure is also safer for the patient.

An alternative for stent insertion is conventional jet ventilation with a rigid bronchoscope and an integrated jet nozzle. Other jet ventilation catheters such as infraglottic or transcutaneous jet catheters interfere during stent placement and should not be used.

Extreme obesity is a contraindication for supraglottic jet ventilation because of limited ventilation pressure, especially in combination with pulmonary obstructive disease. Moreover, severe haemorrhage and anatomic anomalies...
hinder exact placement of the jet endoscope and also appear to be contraindicated.

With regard to handling the technique, the SHFJV technology was explained to the medical personnel who then underwent a brief introductory phase of application, and were able to implement the technique without any difficulties.

Conclusion

Our method offers an excellent surgical view of the larynx/trachea and adequate oxygenation and ventilation of treated patients, especially for laser surgery. The technique may be used in the presence of stenoses in adults and children because it is minimally invasive and avoids tracheotomy. Compared with other techniques, the likelihood of baro-trauma with SHFJV is very low, provided it is used correctly and continuous pressure monitoring is performed.

In conclusion, our experience in 1515 patients shows that SHFJV is a safe and highly effective method.

Acknowledgement

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References

24 Chatburn RL, McClellan LD. A heat and humidification system for high frequency jet ventilation. Respir Care 1982; 27: 1386–91