Superimposed High-Frequency Jet Ventilation for Laryngeal and Tracheal Surgery

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Objective: To describe our experience with superimposed high-frequency jet ventilation (SHFJV), which does not require any endotracheal tubes or catheters, for performing laryngeal and tracheal surgery.

Design: A case series of 500 patients.

Setting: A university medical center.

Patients: Four hundred sixty adult patients and 40 children in a consecutive sample who required laryngeal or tracheal surgery under SHFJV.

Interventions: The SHFJV uses 2 jet streams with different frequencies simultaneously and is applied using a jet laryngoscope. Ventilation was performed with an air-oxygen mixture, and intravenous agents were used for anesthesia. Arterial blood gas values were analyzed.

Main Outcome Measures: Reported values of oxygenation and ventilation during the application of SHFJV and laryngotracheal surgery.

Results: In 497 patients, adequate oxygenation with a mean ± SD PaO2 of 91.8 ± 22.9 mm Hg and ventilation with a PaCO2 of 29.7 ± 5.5 mm Hg were achieved using SHFJV. The average duration of the application of ventilation was 27 minutes, and the longest duration was 118 minutes. No complications due to the ventilation technique were observed. Laser surgery was performed in 150 patients.

Conclusions: The use of SHFJV in combination with the jet laryngoscope provides patients with sufficient ventilation during laryngotracheal surgery. Even in patients at high risk because of pulmonary or cardiac disease, this technique can be applied safely. In patients with stenosis, the ventilation is applied from above the stenosis, reducing the risk of barotrauma. The SHFJV can be used for tracheobronchial stent insertion, and laser can be used without any additional protective measures.

Arch Otolaryngol Head Neck Surg. 2000;126:40-44
PATIENTS AND METHODS

PATIENTS

Starting in 1990, we analyzed the outcomes of the first 500 patients in whom SHFJV was applied. Of the 500 patients, 193 were female, 307 were male, and 40 were children ranging from neonate to 14 years of age. The age of the patients (mean ± SD) was 48.3 ± 19.4 years, the oldest being 92 years. The body weight ranged from 2.5 kg in a neonate to 123 kg in an obese adult (70.2 ± 21.7 kg). The patients’ diagnoses are listed in the Table. One hundred eighty-eight patients (37.6%) were considered at high risk for the following reasons: chronic obstructive pulmonary disease or emphysema (n = 36 [7.2%]), bronchial asthma (n = 14 [2.8%]), pulmonary metastases (n = 6 [1.2%]), extreme obesity (body mass index, >35) (n = 42 [8.4%]), cardiac disease (American Society of Anesthesiology classification, 3-4) (n = 52 [10.4%]), and laryngeal stenosis (degree II and III of obstruction according to Cotton4) (n = 38 [7.6%]). In 12 patients with increasing hypoxemia and peripheral oxygen saturation of less than 90%, emergency surgical procedures were performed using SHFJV.

MONITORING

In all patients, electrocardiography, arterial oxygen saturation (Sao2) using a pulse oximeter, and arterial blood pressure using an arterial catheter were monitored simultaneously each datum by an automated device (Merlin, model 685; Hewlett-Packard Co, Waltham, Mass). The ventilation pressure was measured continuously at the tip of the jet laryngoscope, and arterial blood gas analysis was performed every 5 minutes. The applied oxygen concentration was monitored by an anesthesia monitoring system (Datex Devision Instrumentarium Corp; Helsinki, Finland). The fraction of inspired oxygen (FiO₂) values are those adjusted at the respirator, but the actual FiO₂ concentrations are lower because of the Venturi effect.3

ANESTHESIA TECHNIQUE

Intravenous anesthesia was used in all patients because SHFJV using the jet laryngoscope is an open system. As premedication, all adult patients received oral diazepam (0.15 mg/kg of body weight), and children received midazolam hydrochloride (1 mg/kg of body weight) given rectally. Preoxygenation was performed by mask ventilation with 100% oxygen. Anesthesia induction consisted of the administration of propofol (2 mg/kg) and sufentanil citrate (0.3 µg/kg), with vecuronium bromide (0.08 mg/kg) given for a muscle relaxant. For anesthesia maintenance, propofol (4–7 mg/kg per hour) was administered as a continuous intravenous infusion. Sufentanil and vecuronium were given as needed.

The administration of mask ventilation with 100% oxygen was continued during induction. After 2 minutes, the jet laryngoscope was inserted using a protection for the teeth. The tubing for both jet streams and the pressure monitor were connected to the jet laryngoscope, and SHFJV was started.

At the end of the surgical procedure and after the patient regained protective reflexes, the jet laryngoscope was removed. Mask ventilation was administered until the patient emerged from anesthesia. Neuromuscular blockade was reversed by administering neostigmine methylsulfate and atropine sulfate.

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In 12 patients with severe hypoxemia due to extensive laryngeal stenosis, intubation was considered impossible. With assisted mask ventilation in which 100% oxygen was administered, the Sao2 was 90% or less. The SHFJV was applied, and all 12 patients received adequate ventilation (Figure 3) during the entire surgical procedure. Postoperatively, all patients had sufficient spontaneous respiration.

For endoscopic procedures of the larynx and the trachea, different jet ventilation techniques can be applied.2 These methods, however, are limited for 1 or more reasons: an increased risk of barotrauma, insufficient carbon dioxide elimination, the risk of catheter dislocation or kinking, or impaired visibility.

Subglottic jet techniques applied through the larynx6–8 or percutaneously through the trachea9 with thin papillomatosis, and 1 patient had pulmonary metastasis after partial resection of the larynx. The mean ± SD time of SHFJV was 27.2 ± 16.1 minutes. The longest duration of SHFJV was 118 minutes in a 2-year-old girl. Laser surgery was performed in 150 patients, of whom 28 were children. Complications due to ventilation with SHFJV, such as barotrauma, were not observed in any of the patients.

The measured FiO₂ values are presented in Figure 2. The Sao2 values determined by pulse oximetry, was between 96.9 ± 3.1% and 98.4 ± 1.6%. Except in the 3 patients mentioned earlier, the Sao2 was always more than 92.1% during surgery and in the recovery room. The mean values of the PaO2 were 92.1 ± 22.9 mm Hg and of the PaCO2 were 29.7 ± 5.5 mm Hg. All patients were hemodynamically stable at all times (mean arterial pressure between 73.8 ± 15.2 mm Hg and 78.8 ± 15.3 mm Hg, and mean heart rate between 75.3 ± 18.3 and 83.4 ± 23.1 beats/min).

The inspiratory pressures measured at the tip of the jet laryngoscope were 5.7 ± 2.2 millibar, and the observed positive end-expiratory pressures were 2.1 ± 0.8 millibar.

We have never experienced combustion when using SHFJV for laser surgical procedures. Among the 500 patients in whom ventilation was given by SHFJV, 150 procedures were performed using laser. No complications related to the ventilation technique occurred. Because of the high gas flow, smoke is removed instantaneously from the operating area, and devices for smoke suctioning are not necessary.

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Ventilation Technique

With the SHFJV technique, 2 jet streams with different frequencies are applied simultaneously. The low-frequency jet stream provides 8 to 20 breaths per minute and serves primarily to remove carbon dioxide. The high-frequency jet stream, which provides 400 to 800 breaths per minute, causes a delay of the expiration of gas and prevents the lungs from being totally exhausted at the end of respiration. The inspiratory-expiratory ratio is 1:1 in both frequency settings. Because of this gas dynamic property, it is possible to achieve larger tidal volumes than with single-frequency jet ventilation techniques and to build up a positive end-expiratory pressure in an open system.

Jet Laryngoscope

The jet laryngoscope (C. Reiner Corp, Vienna, Austria), a diagram of which is shown in Figure 1, is a conical endoscope tube used by otorhinolaryngology surgeons for laryngeal procedures that has been modified by Aloy et al. Two metal cannulas with 1.5-mm internal diameters are welded to the proximal third of the jet laryngoscope. The openings of the cannulas into the jet laryngoscope have an 18° angle but do not protrude into the lumen of the jet laryngoscope. The 2 jet nozzles are placed apart, one beside the other toward the distal end of the jet laryngoscope. The low-frequency jet stream goes through the distal cannula, and the high-frequency jet stream passes through the proximal cannula, maximizing the air entrainment (Venturi effect). As a result of the design of the angle of insertion of the cannulas, the entering gas streams do not hit the opposite wall of the jet laryngoscope but are directed toward the center of the distal end of the jet laryngoscope. A third cannula for continuous measurement of the ventilation pressure is inserted at the tip of the jet laryngoscope. Distinctive connectors prevent incorrect line connections to the jet respirator. The jet laryngoscope is available in 3 sizes for adults and 2 sizes for children.

Ventilators

Two generations of jet ventilators were used with the SHFJV technique. One (Bronchotron; Percussionaire Corp, Sandpoint, Idaho) is a pneumatically operated ventilator. The other (Larynojet; Acutronic Corp, Jona-Rapperswil, Switzerland) has electromagnetic valves and is controlled by a microcomputer. Both jet ventilators are capable of providing 2 separate jet streams with 2 different frequencies simultaneously, and both have an integrated alarm system with an inspiratory peak pressure limit. If the adjusted pressure limits are exceeded, the gas supply is cut off and an alarm sounds. Ventilation is resumed once the inspiratory peak pressure drops below the adjusted threshold and the alarm has been reset. Both ventilators work with an oxygen-air mixture, and both have integrated manometers for displaying the inspiratory pressure.

Laser Surgical Procedures

Two carbon dioxide lasers were used (Hercules 5040; Heraeus Laser Sonic Inc, Milpitas, Calif, and Sharplan 1050; Laser Industries Ltd, Tel Aviv, Israel). No combustible materials or gases are used with the SHFJV. Intravenous anesthetic is given, and air and oxygen are used for ventilation. The FiO2 usually ranges between 0.3 and 0.4. Due to the Venturi effect, the oxygen concentration in the operating area is diluted by room air and does not reach critical concentrations.

catheters provide safe ventilation during endolaryngeal surgery, if no major narrowing of the glottic space exists. If, however, the patient has laryngeal or tracheal stenosis or is a child with stenotic alterations, eg, papillomatosis, these techniques are associated with increased respiratory risks, and in these patients, even narrow-caliber endolaryngeal tubes and catheters present a handicap to the surgical technique.

Compared with all forms of single-frequency jet ventilation, the simultaneous application of 2 jet streams with different frequencies in SHFJV presents entirely new possibilities. The SHFJV leads to better inflation of the lungs than the single-frequency ventilation techniques and to better filling of the lungs during expiration. Because carbon dioxide is removed by the low-frequency jet ventilation, the frequency of the high-frequency jet can be adjusted as desired (up to 1200 breaths per minute). Movements of the vocal cords due to the low-frequency jet stream are diminished to a great extent by the high-frequency jet stream, which prevents a complete closure of the vocal cords, and only a slight movement of the peripheral parts of the vocal cords is observed. If no movement at all is required, the low-frequency jet stream can be shut off for a short time. Figure 4 shows the positioned jet laryngoscope during SHFJV and the free airway in a patient with squamous cell carcinoma of the right anterior vocal cord.

A misplacement of the jet nozzles is not possible because the jet nozzles are integrated into the jet laryngoscope. The net gas flow at the vocal cords is close to 0, and therefore, blood and tissue particles are not blown into the lungs or environment.

In several patients with papillomatosis, endoscopic examinations at monthly intervals were performed after surgery using SHFJV, and in all patients the trachea was normal. That the patients with papillomatosis received ventilation using SHFJV had the further advantage that tracheotomy, which is a major problem in patients with laryngeal papillomatosis, was not necessary.

The third cannula at the tip of the jet laryngoscope enables continuous inspiratory pressure monitoring. Because the gas pressures are already low in the plane of the operating field and further decrease toward the trachea, no adverse hemodynamic effects are observed when using the SHFJV.

As with all jet ventilation techniques, an entrainment of room air occurs due to the Venturi effect of the gas stream leaving the nozzle. This further enhances the tidal volume but also results in a decreased applied oxygen concentration, as noted by the adjusted FiO2 at the
respirator. Passing through the jet nozzles, the gas stream undergoes changes. It changes from a high pressure (1-2 millibar) and a low flow (20 L/min) to a low pressure (6-10 millibar) and a high flow (up to 200 L/min, depending on the working pressures). This pressure drop and the placement of the jet nozzles in the proximal part of the endoscope ensure that no high pressures occur in the distal part of the endoscopy tube. Therefore, the risk of damage to the mucosa of the larynx or the trachea due to the jet streams is unlikely.

Although the pressures are low (6-10 millibar), the possibility of barotrauma cannot be eliminated entirely, but none of our patients experienced barotrauma due to SHFJV with the jet laryngoscope.

LARYNGEAL AND TRACHEAL STENOSIS

In patients with laryngeal stenosis (Cotton II and III), respiration might be impaired to such a degree that even surgical procedures using local anesthesia might not be possible. Attempts to improve oxygenation in these patients by applying high-frequency jet ventilation have been made using small translaryngeal or transtracheal catheters.

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The SHFJV is superior to the single-frequency jet ventilation technique for use in obese patients and patients with pulmonary diseases. This is because SHFJV delivers a larger tidal volume than single-frequency ventilation techniques. The SHFJV has even been used in patients with disease states—such as chronic obstructive pulmonary disease, restrictive pulmonary disease, coronary artery disease, and extreme obesity—that were regarded as relative or even absolute contraindications to single-frequency jet ventilation.

**HIGH-RISK PATIENTS AND JET VENTILATION**

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**LARYNGOTRACHEAL SURGERY IN CHILDREN**

Because of the development of pediatric jet laryngoscopes, SHFJV is also applicable for laryngeal procedures in children. This ventilation technique is suitable for removing aspirated intratracheal or intrabronchial foreign bodies because ventilation is not a handicap in the operating area.

**TRACHEOBRONCHIAL STENT INSERTION**

The experience acquired with SHFJV using the jet laryngoscope in otorhinolaryngology surgery has led to the use of the SHFJV for tracheobronchial stent insertion. Aloy et al demonstrated in 15 patients with high anesthesia risk of 4 to 5 (the American Society of Anesthesiology scale) that continuous ventilation of a patient during stent insertion is possible. If the jet laryngoscope is inserted correctly, the carina can be seen. Even large silicon or metal stents can be inserted without any problem. With the use of the SHFJV and the jet laryngoscope, the procedure time is distinctly shorter because of the good visibility and because multiple switches between an endotracheal tube and bronchoscope are not necessary. A patient can be given ventilation up to when the stent is placed in its final position. At this point, ventilation of the patient is not possible with any current ventilation technique. This ensures that the patient is well oxygenated throughout the procedure.

Contraindications for SHFJV using the jet laryngoscope are acute bleeding in the tracheobronchial system and inability of the patient to hyperextend the neck. Hyperextension of the neck is necessary to correctly place the jet laryngoscope to direct the gas stream into the trachea. In patients in whom the glottis cannot be visualized through the jet laryngoscope, transtracheal high-frequency ventilation is the technique of choice.

Accepted for publication June 18, 1999.

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**REFERENCES**