Supralaryngeal tubeless combined high-frequency jet ventilation for laser surgery of the larynx and trachea

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We have developed a new technique of combined high-frequency jet ventilation (HFJV), characterized by simultaneous application of a low-frequency (LF) and a high-frequency (HF) jet stream. Tubeless supralaryngeal jet ventilation was delivered via a modified Kleinsasser laryngoscope. We studied 44 adults undergoing 45 elective surgical procedures of the larynx and trachea using a carbon dioxide laser during HFJV. Applied inspiratory oxygen ratios ranged from 0.4 to 1.0. Mean driving pressures of the HF and LF jet streams were 1.5 bar and 1.8 bar in adults, respectively. Mean duration of HFJV was 41 (range 10–180) min. HFJV resulted in mean PaO₂ and PaCO₂ values of 16.6 (range 9.8–26.9) kPa and 5.7 (3.0–7.6) kPa, respectively. Tubeless supralaryngeal HFJV was safe and effective in maintaining gas exchange in the presence of laryngeal or tracheal stenoses, providing optimal visibility of anatomical structures, offering maximum space for surgical manipulation, and avoiding the use of combustible material inside the larynx or trachea.

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Since its first description by Klain and Smith, high-frequency jet ventilation (HFJV) has been used successfully for the respiratory management of patients during laryngeal and tracheal surgery, in the presence of bronchopleural fistulae or for the treatment of pulmonary insufficiency. Jet ventilation techniques use the principle of Venturi to augment ventilation produced by a narrow stream of gas applied with high speed originating from a high-pressure source. We recently developed a new jet ventilation technique and reported its clinical use in patients requiring microsurgical interventions of the larynx. These patients sometimes present with considerable obstruction of the upper airways caused by stenoses arising from benign and malignant processes. They confront the anaesthetist and surgeon with the problem of limited space to position the tracheal tube to ensure sufficient ventilation and to carry out the surgical procedure. However, the tracheal tube further restricts the view and access to the larynx, and may shift anatomical structures, rendering assessment of pathologies more difficult.

In the presence of massive stenosis, conventional ventilation may sometimes be difficult or has been associated with severe complications as a result of interference with the laser, such as damage to the tube or its cuff or formation of toxic vapours; even fire and explosions have been reported. Despite the use of protective foils and the development of laser resistant tracheal tubes, the use of lasers in surgery presents an increased risk of fire resulting from application of high energy focused on small areas. Supraglottic and subglottic HFJV using small-bore tubes to deliver inspiratory gas have been used in patients with airway stenoses, and even percutaneous applications have been described. As a further development, we studied tubeless combined supralaryngeal HFJV to offer optimal visibility and unrestricted access for surgery and to reduce the risk of complications during laser surgery.

We report our clinical experience using two jet streams to ventilate the lungs of patients via a modified Kleinsasser laryngoscope during laser surgery of the larynx and trachea.

Methods and results

After obtaining approval from our Institutional Review Board and informed patient consent, we studied 44 ASA I–III patients (aged 16–89 yr, weight 45–94 kg) undergoing supralaryngeal combined HFJV for elective laser surgery of the larynx or trachea. Diagnoses included squamous cell carcinoma, papilloma, vocal cord paralysis, haemangioma and granuloma. Extreme obesity and bleeding lesions of the larynx were considered contraindications for HFJV.
The continuous HF jet stream was applied during the inspiratory and expiratory phases of LF jet ventilation. The LF jet stream resulted in phasic airway pressure changes from the high-pressure source to the inspiratory lines of solenoid valves (Fig. 1). Austria) was connected to the central gas supply; gas flow electronic jet respirator (Alexander 1, Fa. Festo, Vienna, The distal end of the jet laryngoscope was open to air. The direct both jet streams along the centre of the laryngoscope cannulae openings in the proximal half were designed to (superimposed) via two separate metal cannulae (id 1.5 mm) welded to the left side of the jet laryngoscope. The jet laryngoscope is attached safely to the patient’s head and chest in a stable supralaryngeal position to allow supraglottic HFJV.

A radial artery catheter was inserted for intraoperative blood-gas analysis. During induction of total i.v. anaesthesia (propofol, sufentanil, vecuronium) respiration was assisted with a face mask and 100% oxygen. Airway assessment was performed laryngoscopically before relaxation was achieved, and the jet laryngoscope (Fa. C. Reiner, Vienna, Austria), directed at the glottis, was positioned to facilitate an unrestricted view of the vocal cords. Non-compliant Teflon tubing connects the ventilator outputs with the injectors. A pressure monitoring cannula enables monitoring at the tip of the laryngoscope. The jet laryngoscope is safely attached to the patient’s head and chest in a stable supralaryngeal position to allow supraglottic HFJV.

After initiation of HFJV, ventilation was examined clinically by observing thoracic excursions and auscultation of the lungs. Mean HF and LF driving pressures during the surgical procedure were 1.5 (range 0.7-3.5) bar and 1.8 (1.0-3.5) bar, respectively. The maximum pressures generated by the jet streams measured at the tip of the jet laryngoscope ranged from 15 to 30 cm H₂O. The rate of the HF jet stream was set at 180-900 bpm (3-15 Hz) and the rate of the LF jet stream to 6-30 bpm, according to arterial analogous to conventional ventilation. To avoid barotrauma from gas trapping caused by short expiratory phases at high ventilatory frequencies, the inspiratory to expiratory time ratios were set to 1:2. The air-oxygen mixture of both jet streams was adjusted to provide the lowest fraction of inspiratory oxygen (F\textsubscript{O\textsubscript{2}}) possible according to pulse oximetry and arterial blood-gas values, which were determined every 5 min. The ventilator allowed adjustment of driving pressures of both jet streams (0-3.5 bar) according to chest expansion, resulting in total flow rates of 50 litre min\textsuperscript{-1} maximum.

Gradual increases in the driving pressures of the HF and LF jet streams served to increase applied tidal volume and airway pressures. Tidal volume provided by the jet ventilator was augmented by the amount of gas entrained around the cannulae as a result of the Venturi effect. Thus the resulting F\textsubscript{O\textsubscript{2}} of inspiratory gases in the patients’ lungs was lower than that delivered by the respirator because of dilution with surrounding entrained air. In this open ventilation system, generation of PEEP was based on application of the HF jet stream and its driving pressure and did not include the use of a PEEP valve. Thus moderate intrinsic PEEP was intended to increase residual capacity and secure oxygenation in the presence of the lowest F\textsubscript{O\textsubscript{2}} possible.

In addition to the respiratory’s manometer, an alarm system and shut down device were integrated to limit peak supralaryngeal airway pressure, which was measured at the tip of the laryngoscope immediately in front of the glottic opening, using a separate line integrated into the laryngoscope. Using this jet equipment, tubeless combined HFJV was a pressure-controlled, pressure-limited and time-cycled open ventilation technique. In the event of increases in arterial pressure and heart rate >20% of baseline values on initiation of HFJV, anaesthesia was deepened by administering repeated doses of sufentanil and propofol.

To protect patients from corneal injury, the eyes were covered with saline-soaked eye pads. Laser surgery was performed with a carbon dioxide laser (Hercules 5040, Haereus, Germany; or Sharplan 1050, Vörösmarty, Israel). At the end of the surgical procedure, jet ventilation was discontinued and the jet laryngoscope removed. Patients’ lungs were ventilated by mask until awakening. Patient data, arterial blood-gas values (P\textsubscript{aO\textsubscript{2}} and P\textsubscript{aCO\textsubscript{2}}), arterial oxygen saturation (S\textsubscript{aO\textsubscript{2}}), ventilator settings and duration of HFJV were evaluated. Statistical analysis of the data was performed, including determination of mean (SD and range) values.

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$P_{aCO_2}$ values, using inspiratory to expiratory time (i:E) ratios of 1:2. $FIO_2$ of the jet streams was set initially to 1.0 and reduced subsequently to the lowest possible value with a mean of 0.6 (0.4–1.0), according to pulse oximetry and blood-gas analysis. Mean duration of HFJV was 41 (10–180) min, resulting in mean $PaO_2$ and $PaCO_2$ values of 16.6 (9.9–26.9) kPa and 5.7 (3.0–7.6) kPa, respectively. To estimate the diluting effect of gas entrainment caused by the Venturi effect, $FIO_2$ was measured immediately in front of the glottic opening at three different oxygen concentrations in 20 patients before surgery. Mean oxygen concentrations at $FIO_2$ values of 0.5, 0.7 and 1.0 were 32 (SD 4.1)%, 40 (7.1)% and 52 (10.7)%, respectively. There were no complications related to the laser or HFJV.

Comment

We have described the use of combined HFJV produced by simultaneous application of a low-frequency and a high-frequency supralaryngeal jet stream. We have demonstrated that the use of this new technique produced good operating conditions for laser laryngeal surgery with adequate gas exchange in 44 patients. By obviating the need for a tracheal tube, it reduced the risk of complications during laser surgery arising from combustible endolaryngeal material. No serious side effects were observed. However, limitations such as the absence of a monitoring device for distal airway pressures, difficulty in determining end-tidal carbon dioxide concentration and applied tidal volume, and incorrect alignment of the jet streams leading to gastric insufflation have been discussed.

Without the possibility of monitoring distal airway pressure, the complication rate in a series of 942 cases was 0.42%, comprising four paediatric patients with pneumothoraces during subglottic jet ventilation. Although additional catheters to measure distal pressure may be used in a punctual manner, permanent placement during laser surgery is contradictory to the presented approach of unrestricted access to the operating field and avoidance of endolaryngeal material. As barotrauma is the major concern in HFJV, it is essential to ensure adequate expiratory airflow during HFJV, especially in patients presenting with severe airway stenoses.

References