CLINICAL USES OF HIGH FREQUENCY JET VENTILATION IN ANAESTHESIA

F. GIUNTA, M. CHIARANDA, G. MANANI AND G. P. GIRON

Experimental data have demonstrated the potential usefulness of high frequency ventilation in producing gaseous exchange with a reduced risk of pulmonary barotrauma [1-3]. HFPPV and HFJV have been used during general anaesthesia for endoscopy and surgery of the airways and have been shown to provide adequate gaseous exchange and improved operating conditions in comparison with conventional respiratory support methods. High frequency ventilation using the Sander's jet technique [4—6] has been used for prolonged periods without interrupting endoscopic or surgical procedures. HFVJ has also been administered through a thin catheter. This provides good exposure of the operating field during endoscopy and laryngeal surgery [7, 8] and overcomes the difficulties associated with the use of a standard tracheal tube, during operations for correcting tracheal stenosis [9, 10] and in tracheobronchial angle surgery [11]. It has also been suggested that the relatively small changes in intrathoracic pressure and lung volume might be useful in thoracic surgery [12, 13] and neurosurgery [14], but clinical experience in these areas is limited.

This report describes our personal experience in the use of HFJV, since 1981, in approximately 300 patients undergoing surgery.

MATERIALS AND METHODS

HFJV equipment

The HFJV apparatus (Polyfunction Jet Ventilator, AAT Cravera, Padova, Italy) comprised: a blender—reducer receiving compressed air and oxygen at 300–400 kPa which regulates the air—oxygen mix and driving pressure; a solenoid valve controlling the passage of the gas mixture to the injector device; a timer controlling the valve opening time (i.e. insufflation period from 1% to 100% of the respiratory cycle) and the ventilatory rate (1-480 b.p.m.); the injector system.

Endoscopy and surgery of the proximal airways. HFJV was administered through a narrow injection catheter inserted in the airway, with a second rigid catheter positioned distally to the injector in the airway for gas sampling and measurement of airway pressure. In all subjects gas exchange was satisfactory, even during tracheoplasty and bronchoplasty.

SUMMARY

Since 1981, high frequency jet ventilation (HFJV) has been used in 300 patients undergoing surgery, most commonly during i.v. general anaesthesia for endoscopy and surgery of the airways: laryngoscopy, bronchoscopy, laryngeal microsurgery and laser surgery (more than 230 patients); repair of tracheal stenosis, tracheal sleeve pneumonectomy and tracheal sleeve lobectomy. HFJV was administered through a narrow injection catheter inserted in the airway, with a second rigid catheter positioned distally to the injector in the airway for gas sampling and measurement of airway pressure. In all subjects gas exchange was satisfactory, even during tracheoplasty and bronchoplasty.
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Jet flow

Monitoring

Flow, P, CO₂

Entrained
gases

A

B

FIG. 1. A: Diagram of the injector system and source of entrained gas. The jet is delivered coaxially, through the tracheal tube. B: Diagram of the injection system inside the airways. With this system, gases are entrained from the operating site.

shaped tracheal tube connector. Standard (Portex) or triple-lumen (Hi-Lo, National Catheter Co.) tracheal tubes were used. The injector system (nozzle + entrainment circuit) was similar to that described first by Carlon and colleagues [15].

The minute volume delivered by the nozzle during continuous flow proved to be: 23 litre min⁻¹ at 100 kPa, 39 litre min⁻¹ at 200 kPa and 54 litre min⁻¹ at 300 kPa. Gas entrainment varied according to the respiratory resistive load opposed to the jet flow. Ventilatory frequencies varied from 100 to 250 b.p.m., with inspiratory times from 33% to 50% and driving pressures between 100 and 200 kPa.

Patients and technique

HFJV was used with i.v. general anaesthesia for endoscopy and surgery of the airways as follows:
(a) Laryngoscopy and laryngeal microsurgery (228 adults; ASA I–III).
(b) Surgical repair of tracheal stenosis (caused by prolonged tracheal intubation in 11 adults, subsequent to thyroidectomy in two; ASA III and IV).
(c) Surgery of the carina (41 adults; ASA III, IV): tracheal sleeve pneumonectomy (TSP) (23 patients) and tracheal sleeve lobectomy (TSL) (12 patients) for adenocarcinoma of the right tracheobronchial angle; surgical repair of traumatic rupture of the carina (two patients) and left main bronchus close to the carina (one patient); surgical repair of postoperative fistula after removal of the oesophagus (low tracheal lesion) (one patient) and right tracheobronchial suture with removal of the carina and left bronchial stump by sternotomy (repeat surgery after non-radical left pneumonectomy on the bronchus) (one patient).
(d) Laser surgery for a congenital diaphragm linking the vocal cords ventrally (14-yr-old male) and for tracheal stenosis produced by a tracheostomy cannula at the level of the sixth ring (50-yr-old male).
(e) Pulmonary surgery in 16 adult patients (ASA III) undergoing thoracotomy for intrathoracic oesophageo-gastric plastic surgery.

All patients were informed in advance that a high frequency ventilation technique would be used. Hypnosis and analgesia during HFJV were obtained by i.v. administration of a hypnotic agent (Althesin until 1985, then thiopentone and, more recently, propofol) and an analgesic (fentanyl) given in divided doses.

The methods for using the HFJV varied according to the type of operation.

Laryngeal endoscopy and microsurgery and laser surgery. The injector catheter was placed 2–3 cm beyond the rima of the false vocal cords, after inducing anaesthesia. HFJV was continued until spontaneous breathing was restored.

Tracheal stenosis surgery. The patient's lungs were ventilated initially with intermittent positive pressure ventilation (IPPV) through a standard
tracheal tube of a size compatible with the stenosis. On tracheal section, the injector catheter was passed through the tracheal tube and positioned with its tip below the rim of the tracheal section (fig. 2). HFJV lasted throughout the anastomosis, at the end of which the catheter was used as a guide for re-insertion of the larger-gauge tracheal tube.

Lung surgery. HFJV was compared with one lung ventilation (OLV) using jet ventilation only during the thoracotomy stage of oesophageal surgery in 16 patients, whereas a similar group was treated with OLV through a double-lumen tracheal tube. The measurements for comparison were taken after thoracotomy, when all the patients were receiving ventilation with IPPV through a standard tracheal tube.

The alveolar–arterial oxygen gradient ($P_{A,\text{O}_2} - P_{A,\text{O}_2}$) was calculated using standard equations. Direct data were obtained by taking simultaneous mixed arterial (radial artery) and pulmonary arterial blood samples. Thoraco-pulmonary compliance ($C_{rs}$) was measured with the patient supine and paralysed, taking the mean value of series of measurements obtained at known volumes.

Monitoring

ECG, arterial pressure (AP) (invasive or non-invasive methods) and heart rate were monitored continuously in all patients; central venous pressure (CVP), pulmonary arterial pressure (PAP), pulmonary capillary wedge pressure (PCWP) and cardiac output (CO) were measured in selected subjects. Blood samples were taken as necessary. During rHFJV for endoscopy and airway surgery a thin, rigid nylon catheter (i.d. 1 mm) was positioned approximately 6 cm beyond the injector catheter to monitor airway pressure ($P_{aw}$) (Statham ± 2.5 PSI D transducer; Honeywell amplifier). At approximately 5-min intervals, the thin catheter was connected to a side-stream capnograph (IL 200, Instrumentation Laboratories) and the fraction of carbon dioxide exhaled ($F_{ECO_2}$) was measured during a brief period of interruption of the HFJV (approximately 5 s) in order to obtain a plateau on the capnogram (fig. 3). Special care was taken to keep
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the catheter patent by periodically flushing it with air. A similar procedure was followed in the case of HFJV in patients with a tracheal tube, inserting a catheter (i.d. 1 mm) through this as far as the carina and alternating measurement of Paw with $FE_{CO_2}$; in other subjects, monitoring was performed with the triple-lumen tracheal tube.

RESULTS

For surgery and instrumental investigations of the upper airways, the duration of HFJV was generally short (20 min), but in 40 patients it lasted more than 1 h. For surgical repair of tracheal stenosis, HFJV was used only at the time of the end-to-end anastomosis (usually approximately 35 min). In tracheal sleeve pneumonectomy (TSP) and tracheal sleeve lobectomy (TSL), jet ventilation was limited also to the stage of reconstruction of the airways; it was used for 30–40 min for tracheobronchial suture (TSP) and approximately 65 min for the two TSL sutures.

In cases of fistula and rupture of the airways, HFJV was maintained from induction of anaesthesia until closure of the airways (range 75–145 min).

All surgery was completed without needing to change the ventilation technique; there was no mortality during surgery.

Blood samples demonstrated a considerable variability in $Pa_O_2$ (range 20–48 kPa); in three patients, $Pa_{CO_2}$ was low (2.2, 2.7 and 2.4 kPa, range 2.2–7.1 kPa). Hyperventilation was corrected by reducing operating pressure. In one of these patients ventricular tachycardia developed, but normal rhythm was established within 5 min, by which time the $Pa_{CO_2}$ values also had returned to normal.

DISCUSSION

The high frequency insufflation of small volumes of gas through a thin injector catheter has proved capable of maintaining gaseous homeostasis. This method involves potential risks in relation to the high pressure of the gases and the danger of barotrauma. The “open” feature of the ventilating system also makes it impossible to measure tidal volume. In the early years of our experience, monitoring during HFJV proved difficult as it was necessary to perform repeated blood-gas analysis. The introduction of a second catheter, placed distally in the airways with respect to the injector, facilitated monitoring of Paw and $FE_{CO_2}$. A lung simulator was used to verify that Paw at the end of inspiration, measured 6 cm beyond the injector, generally equalled Paw at the end of inspiration in the “alveolar” compartment, in various conditions of compliance and resistance of the airways [unpublished observations]. The most recent model of ventilator (used from 1985) automatically shuts off the jet flow if the preset maximum pressure is exceeded.

Brief periods of apnoea (5–6 s) enabled an end-tidal sample of gas to be taken from the airways for measurement of $FE_{CO_2}$ during HFJV. These measurements correlated well with $Pa_{CO_2}$ values (fig. 3b). Since this technique for analysing carbon dioxide was introduced into clinical practice (1985), intraoperative monitoring has become simpler and blood sampling less frequent. When HFJV was provided by means of an injector catheter inside the airways, $Pa_{O_2}$ and $Pa_{CO_2}$ were very variable because of differing amounts of gas entrainment, caused by manipulation of the injector catheter by the surgeon. However, the ventilation was always adequate and in some patients hyperventilation occurred. Another advantage was that the anaesthetist could adjust solenoid valve opening time from 33 to 55% to minimize the risk of aspiration of blood or secretions.

In the laryngeal surgery, there were four cases of severe bleeding. This problem was overcome by protecting the airways downstream by passing a tracheal tube guided by the injector catheter itself. This technique enabled the source of bleeding to be separated from the airways, until the haemorrhage could be stemmed. There were no cases of macroscopic inhalation of blood during surgery of the juxta-carinal trachea and main bronchi. There were no differences in the duration of recovery time between pneumonectomized and TSP patients, or between lobectomized and TSL patients. In our view, the additional risk involved in the method of ventilation is negligible if sufficient care is taken during surgery to avoid inhalation.

Another danger which was always taken into account was that of direct trauma caused by the rigid injector catheter. In tracheal stenosis, this catheter should not cause lesions because it is free, coaxial to the trachea and introduced under direct visual control. In TSP and TSL, its positioning calls for the use of a double-lumen tracheal tube of
size sufficient to allow the injector catheter (o.d. 3.2 mm) to slide without too much friction. The catheter is pre-shaped with a curvature in the final 5 cm similar to that of Carlens' tube for the left bronchial lumen. The jet produces a particular sound when in the correct position for optimum entrainment and the anaesthetist should always manipulate the injector catheter to maintain this sound during surgical manipulation. The risk of puncture of the bronchus by the catheter must always be borne in mind. In the present series, no lesions resulting from direct trauma were observed by fibreoptic bronchoscopy after surgery.

In conclusion, HFJV proved to be a useful technique because of the very small gauge of the jet cannula and the possibility of maintaining adequate ventilation during open-airways conditions.

In patients with stenosis of the airways, HFJV could not solve the ventilation problem. It was, therefore, used only after surgical section downstream from the stenosis, when the small dimensions of the injector catheter facilitated surgical reconstruction of the airways.

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