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Transtracheal high frequency jet ventilation for endoscopic airway surgery: a multicentre study

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Serious complications during high frequency jet ventilation (HFJV) are rare and have been documented in animals and in case reports or short series of patients with a difficult airway. We report complications of transtracheal HFFJV in a prospective multicentre study of 643 patients having laryngoscopy or laryngeal laser surgery. A transtracheal catheter could not be inserted in two patients (0.3%). Subcutaneous emphysema (8.4%) was more frequent after multiple tracheal punctures. There were seven pneumothoraces (1%), two after laser damage to the injector, one after difficult laryngoscopy, four with no clear cause. Arterial desaturation of oxygen was more frequent during laser surgery and in overweight patients. Transtracheal ventilation from a ventilator with an automatic cut-off device is a reliable method for experienced users. Control of airway pressure does not prevent a low frequency of pneumothorax.

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Diagnostic or surgical laryngoscopy requires a method that can give good exposure of the larynx, continuous control of airway patency, and immobility of the vocal cords. Techniques suggested include spontaneous ventilation under light anaesthesia in adults or deep anaesthesia in children,[1] an apnoeic technique, especially in children,[2] intermittent positive pressure ventilation *via* a small microlaryngeal tube,[3] manual jet ventilation at a normal ventilatory frequency[4] or high frequency jet ventilation (HFJV).[5] Most require specific skills and equipment, which is why none have gained general acceptance. Jet ventilation has been an established anaesthetic technique of ventilation for surgical laryngoscopy for over 20 yr;[5] its main advantage is good access to the surgical field because of the small diameter of the transtracheal catheter, and the ability to maintain adequate ventilation throughout the procedure.[6] The method uses a metallic tube or a cannula placed either supraglottically (which may be attached to the endoscope) or subglottically (after intubation *via* the nasal or the oral route or after puncture of the cricothyroid membrane) at a normal rate or at high frequency. Transtracheal jet ventilation allows endoscopic surgical access to the larynx[7] and can be used for patients with acute airway problems.[8] Laryngoscopy and intubation are not needed, no apparatus is placed in the upper airway, and adequate gas exchange is obtained.[7] Serious complications during HFJV are rare. There are case reports or series of patients with complications[8] such as transtracheal catheter dysfunction[9] and barotrauma.[10] Expiratory obstruction and pulmonary hyperinflation may cause subcutaneous emphysema, pneumomediastinum and pneumothorax.[8] To avoid this problem, modern jet ventilators now have safety systems to stop inflation if tracheal pressure is too great.[11]

We assessed transtracheal jet ventilation (TTJV) during laryngoscopic and laser surgery procedures in a prospective multicentre study.

Methods

Three hospitals were studied over a 1-yr period after local ethical approval. After obtaining informed consent, patients about to undergo upper airway endoscopy were studied. We noted: age, weight, height, previous cervical radiotherapy, if skin fibrosis was present, chronic obstructive pulmonary disease (COPD) defined as asthma or productive cough over 3 consecutive months for at least 2 yr, and radiological evidence of pulmonary emphysema. Exclusion criteria were infection at the puncture site and coagulation disorders. Anaesthesia was induced with propofol (2 mg kg^{-1} i.v.) and alfentanil (15 μg kg^{-1}) and maintained with propofol infusion and intermittent doses of alfentanil. Muscle relaxation was achieved with either succinylcholine infusion or vecuronium bromide (0.05 mg kg^{-1}) antagonized with neostigmine and atropine, and monitored by nerve stimulator.

After induction of anaesthesia, a catheter was introduced through the cricothyroid membrane into the trachea, 13 or 14 gauge for adult patients and 18 gauge for children aged less than 3 yr. Two types of tracheal catheters were used: a Teflon 14-gauge, 10 cm length, arterial catheter (Seldicath® Plastimed, France) introduced using the Seldinger method[11] or a Ravussin 13-gauge catheter directly introduced into the trachea under endoscopic control by the surgeon (VBM Laboratory, Germany).[12] The number of punctures and the experience of the anaesthetist (consultant or resident) were recorded. In all cases, 2 ml of 2% lidocaine were injected through the injector. Taking into account the usual tracheal length, the distal tip of the injector was expected to be located between 2 and 4 cm above the carina. After induction, HFJV was started using the following settings: rate 2 Hz, inspiratory/expiratory ratio 0.5, driving pressure 2.8–4 bar according to age, weight and chest expansion, $F\text{I}_{O_2}$=1 except during laser surgery. The patients were not intubated and passive expiration was facilitated by manually lifting the jaw before and after laryngoscopy. Two HFJVs were used: the GR300 (LSSA, Fontenay sous bois, France) or the AMS 1000 (Acutronic medical systems, Hirzel, Switzerland). Both were equipped with a fail-safe system allowing the measurement of expiratory airway pressure through the transtracheal catheter.[11] Each end-expiratory pressure value was recorded by a microprocessor located in the ventilator. This microprocessor allowed the next inflation only when end-expiratory pressure was less than a preset value (usually 4 cm H_2O). This feature detects overinflation during laryngoscopy. Driving pressure was progressively decreased during emergence and HFJV was stopped when patients became conscious. Mechanical ventilation was restarted if breathing was inadequate. The tracheal catheter was withdrawn in the recovery room.

Duration of laryngoscopy, upper airway disease (benign or cancer), use of laser and episodes of desaturation (<90% for >1 min) were recorded. After the procedure, the surgeon graded the extent of upper airway obstruction by allocating a numerical score for each of the following features: tumour position, tumour infiltration, the severity of tumour vegetation, oedema, and fibrosis (Table 1). To summarize these values, two final scores were calculated, by addition and also by multiplication of the individual component values. Each of these values was used for comparisons.[7]

In the recovery room, Sp_{O_2} was measured and the use of supplementary oxygen, intubation or tracheotomy was recorded. If serious postoperative breathing difficulty was present, HFJV was added to spontaneous breathing until complete recovery or resolution of the obstruction.[13]

Cervical subcutaneous emphysema was sought systematically by neck examination; when present, a chest x-ray was performed to diagnose pneumomediastinum or pneumothorax.

Results are expressed as mean (SD). Predictive factors were determined only in adult patients. Children were included in the assessment of complications but were excluded from statistical analysis because of the small number of patients and the different clinical context. Univariate non-parametric tests were first used, followed by stepwise multiple logistic regression which was used to examine the relationships between complications and perioperative data. The results were considered significant if $P<0.05$.

Results

There were 643 patients, 523 males and 120 females, and comprising 632 adults and 11 children (Table 2). A Seldicath® catheter was used in 579 cases and a Ravussin catheter in 64 cases. The complication rate was similar with both transtracheal catheters and did not depend on the experience of the anaesthetist.

The catheters were successfully inserted in 641 patients (99.7%) and could not be inserted in two patients (0.3%). Ninety-two per cent of insertions were successful at the first attempt, 6% at the second, 1.4% at the third and 0.6% at the fourth attempt. No catheter was misplaced or displaced and no bleeding was observed. Multiple punctures were more frequent (13%) in patients with previous cervical radiotherapy compared with 7% in patients without cervical radiotherapy ($P<0.05$). No complication was observed during laryngoscopy in children.

Table 1 Scoring of upper airway obstruction. Two final scores were calculated by adding and multiplying each value. A value of 1 was given to 'no tumour' when the score was calculated by multiplication

Category	Scoring value
Cancer localization	
No tumour	0
Tongue	1
Oropharynx	2
Base of tongue	3
Hypopharynx	4
Larynx	5
Infiltration	
No	1
Yes	2
Vegetations	
No	1
Mild	2
Major	3
Oedema	
No	1
Yes	2
Fibrosis	
No	1
Yes	2

Table 2 Patient details. Mean (SD) [range]

	All patients (adults and children) (*n*=643)	**Children (*n*=11)**	**Adults (*n*=632)**
Age	54 (13) yr [1 month to 86 yr]	5.4 (5.0) yr [1 month to 13 yr]	55 (12) yr [17–86 yr]
Sex ratio M/F	523/120	3/8	520/112
Weight (kg)	66 (15) [3–120]	16.7 (13.5)	67 (14) [30–120]
Height (cm)			169 (8) [143–192]
COPD	15%	0%	16%
Radiological emphysema	8%	0%	8%
Cervical radiotherapy	21%	0%	21%
Cervical skin fibrosis	11%	0%	11%

Table 3 Factors associated with subcutaneous emphysema. * Fisher exact *t*-test

	Without subcutaneous emphysema	**With subcutaneous emphysema**	
Duration (min)	21.5 (23.9)	26.6 (28.7)	NS
Obstruction score (additive)	0.16 (0.37)	0.21 (0.43)	NS
Obstruction score (multiplication)	10.5 (13.8)	13.9 (16.7)	NS
Weight (kg)	67.3 (13.5)	70.7 (18.5)	NS
Age (yr)	55.0 (14.8)	61.9 (14.4)	NS
Puncture attempts >2	10/581; 1.7%	4/49; 8.1%	*P*=0.02*

Subcutaneous emphysema was limited to the neck in 53 of 643 patients (8.4%) and extended to the face or the thorax in 14 patients(2%). Subcutaneous emphysema was more frequent after multiple tracheal punctures (2% after a single tracheal puncture and 8% after multiple punctures) (Table 3). Pneumomediastinum was diagnosed in 16 patients (2.5%) and was always associated with subcutaneous emphysema.

Seven pneumothoraces occurred in the first 24 h (Table 4). Because of the small number of patients, risk factors for a pneumothorax could not be determined by a stepwise analysis. In three patients, the pneumothorax was small and unilateral and did not necessitate any treatment before resolving spontaneously; no obvious cause was found. In four cases, pleural drainage was needed for 24–72 h. In three of these cases, the pneumothorax occurred during prolonged endoscopy for obstructive cancer; two were related to laser damage to the transtracheal catheter during laryngeal disobstruction in patients with tumours; the third pneumothorax occurred after a long and difficult laryngoscopy in a patient with a large tumour. The last pneumothorax occurred without any explanation.

Oxygen desaturation was more frequent when delivered oxygen concentration was less than 100% and during laser surgical procedures (*n*=25) (Table 5). Other factors predicting low Sp_{O_2} were multiple tracheal punctures and obesity. In one case, desaturation was caused by the tracheal catheter tip being located in a bronchus, recognized by chest auscultation. Urgent tracheotomy was never required.

Discussion

We found that HFJV, *via* a catheter placed through the cricothyroid membrane, is an easy and safe way to ventilate patients about to undergo ENT laryngoscopy, microlaryngoscopic, and laser surgery. The method offers the following advantages: no intubation, excellent surgical view of the larynx, and adequate oxygenation in most patients. Ventilation, or at least oxygenation, can be maintained throughout the procedure. HFJV overcomes the disadvantage of an anaesthetic technique using a tracheal tube which can hide the posterior part of the glottis and which carries the risk of fire in the airway.[14] Finally, HFJV is useful during recovery; at the end of the procedure, HFJV was tolerated by patients recovering from muscle paralysis and was continued until the patients fully recovered from anaesthesia. Leaving the catheter in the trachea during the early recovery period allows adequate emergency oxygenation at a time when re-intubation may be difficult or contraindicated.[6]

TTJV has been used routinely in our institutions for more than 10 yr and we have a large experience in this field. Transtracheal ventilation can be unsafe in unexperienced hands.[6] In a retrospective study of 58 hospitals, complications were more frequent when experience of jet ventilation was limited.[14] Potential problems exist and a good understanding of the technique is necessary.[8] Even when used for resuscitation, the anaesthetist should carry out transtracheal ventilation under supervision in a more controlled situation.[15]

The cricothyroid membrane is the route of choice for transtracheal ventilation as it has no blood vessels, with a low risk of bleeding.[16] The puncture can be done with general or local anaesthesia, or directly in emergency situations. It must be strictly in the midline to avoid misplacement. Passing a catheter through the infracricoid membrane should be avoided because of potential bleeding but can be done when the cricothyroid membrane cannot be punctured, for example if a surgical scar or subglottic tumour are present. Mucosal lesions related to laryngoscopy and intubation and inadvertent placement or migration of an injection catheter into the oesophagus can be avoided.[17] In patients with an abnormality of the upper airway, such as in cases of head and neck cancer, it can be valuable. In these

Table 4 Data for the seven pneumothorax cases

Time	Age (yr)	Weight (kg)	Puncture attempts	Obstruction score	Duration (min)	Associated complications	Mechanism	Treatment
Preoperative	55	80	4	40	90	Low Sa_{O_2}	Section catheter	Drainage
Preoperative	62	61	2	60	80	Low Sa_{O_2}	Section catheter	Drainage
Preoperative	43	61	1	20	120	0	Difficult laryngoscopy Airway obstruction	Drainage
Postoperative	66	70	1	1	7	0	Unknown	Drainage
Postoperative	31	80	1	1	10	0	Unknown	0
Postoperative	61	62	2	8	21	0	Unknown	0
Postoperative	64	71	1	12	15	0	Unknown	0

Table 5 Factors associated with oxygen desaturation (Mean (SD)). *Fisher exact *t*-test. Using multiple logistic regression, episodes of low-oxygen desaturation were more frequent during laser surgery when $F_{I_{O_2}}$ was less than 1. Complications (pneumothorax, subcutaneous emphysema and low-oxygen saturation) were more frequent after difficult transtracheal puncture. A history of chronic bronchitis did not predict complications

	Without desaturation	With desaturation	
Duration (min)	20.8 (23.4)	42.9 (30.4)	NS
Obstruction score (multiplication)	10.5 (13.7)	13.9 (18.5)	NS
Weight (kg)	67.1 (13.6)	73.4 (12.2)	P=0.03
Age (yr)	54.9 (0.1–86)	58.8 (3–83)	NS
Puncture attempts >2	17/526; 3.2%	8/40; 20%	P=0.0001*
Laser surgery	15/526; 2.8%	10/75; 13.3%	P=0.0001*
$F_{I_{O_2}}$=1	505/517; 97.6%	12/83; 14.5%	P=0.0008*
COPD	19/504; 3.8%	6/91; 6.6%	NS

patients, a TTJV catheter allows rapid induction and adequate control of the airway.[8]

Adverse events were infrequent and complications were mainly related to (1) the puncture itself, (2) mechanical problems (subcutaneous emphysema, pneumomediastinum and pneumothorax, (3) episodes of low-oxygen saturation, and (4) recovery.

The puncture

The failure rate of cricothyroid membrane puncture was small (0.3%). The number of complications was not influenced by the experience of the anaesthetist (junior *vs* senior) or the type of transtracheal catheter (Seldicath® or Ravussin catheter). Most of the puncture difficulties were related to abnormal anatomy, which is previous radiotherapy, and should be identifiable preoperatively. Conventional i.v. catheters are not safe for jet ventilation because they are short, thin-walled, and easily kinked. The use of metallic needles has been proposed but the risk of tracheal perforation during patient movements seems high.[18 19]

Mechanical problems

The major concern during jet ventilation is the risk of subcutaneous emphysema, pneumomediastinum, pneumothorax, and even pneumoperitoneum. Such complications have been reported after endotracheal intubation (0.04%), but with less incidence than after jet ventilation (0.2%).[14] They are related either to barotrauma or tracheal mucoseal trauma and have been reported in adults and children, using orotracheal, nasotracheal, or transtracheal catheters.[19] Subcutaneous cervical emphysema is more frequent after difficult tracheal puncture, especially in patients with previous cervical radiotherapy. The gas mixture enters the subcutaneous space around the puncture site. This is of no major clinical consequence, but patients, anaesthetist, and surgeon should be aware of this potential complication. Pneumomediastium may be related to the extension of the subcutaneous emphysema or to some damage to the tracheal mucosa. The Seldicath® catheter is relatively rigid and may hit the tracheal wall at the end of each insufflation, allowing a high-pressure gas mixture to penetrate the submucosal space. We report a 1% incidence of pneumothorax which is similar to normal rate jet ventilation.[4] Pneumothorax can occur despite the use of ventilators equipped with a system to control end-expiratory tracheal pressure. Few prospective studies have quantified this risk when using jet ventilation: two pneumothoraces were reported in a series of 318 patients using the jet insufflation technique via a foil wrapped catheter.[4] In our study, two bilateral pneumothoraces followed a laser impact on the catheter during laryngeal dis-obstruction. In this condition, transtracheal ventilation should be used very cautiously, and HFJV through a nasotracheal catheter could be a better method. In any case, the anaesthetist must check the position of the catheter endoscopically. A laser resistant tracheal tube may be an alternative method. This is less convenient for the surgeons, does not prevent the occurrence of pneumothorax completely and exposes the patient to the risk of tracheal tube fire.[14] In the remaining five cases, the pneumothoraces were small and were recognized in the recovery room. They were always associated with subcutaneous emphysema with no evidence of upper airway obstruction. Disruption of the perivisceral fascia can follow cricothyroid membrane puncture or a lesion to the tracheal wall at the injector tip. As we did not inspect the tracheal wall at the end of the laryngoscopy, we cannot be sure of this. Finally, a pneumothorax may be related to high-airway pressure during recovery (cough or active expiration). This could explain some complications diagnosed after endoscopy. End-expiratory pressure monitoring has been found to indicate tracheal pressure measured with a separate catheter in model lung studies and relate to change in pulmonary volume in patients during laryngoscopy.[11] Although barotrauma may be related to excessive peak airway pressure, we used end-expiratory pressure because of technical constraints. As pressure changes are small during TTJV,[20] this difference was neglected.

Episodes of low-oxygen saturation

During HFJV, oxygenation depends upon several factors:[21] the injected oxygen concentration, the ratio of entrained gas, and the increase in functional respiratory capacity (PEEP effect). Inspired gas is a mixture of injected gas and entrained air. Entrained air is limited during transtracheal HFJV,[22 23] so FI_{O_2} was high and oxygenation was always adequate during laryngoscopic and microsurgical procedures. Episodes of oxygen desaturation were more frequent during laser surgery when FI_{O_2} was decreased (the use of FI_{O_2} greater than 0.4 is contraindicated during laser surgery[24 25]). In most of these patients, it was necessary to stop laser surgery during short periods of time in order to increase FI_{O_2}. In two patients, hypoxic episodes were related to bilateral pneumothorax, and tracheal intubation was required before pleural drainage. One case of oxygen desaturation was caused by the cricothyroid catheter lying in the right main bronchus; this complication should be detected by systematic pulmonary auscultation. Carbon dioxide retention can occur during jet ventilation, particularly in COPD and obese patients. Blood gas analysis was not performed in our study but it is likely that some patients were hypercapnic. To provide non-invasive ventilation monitoring during laryngoscopy, tracheal gas can be aspirated through the injector after stopping the ventilator. This allows the diagnosis of hypo- or hyperventilation.[26] Obesity is considered a risk factor for hypoxaemia during conventional ventilation and HFJV[7] and our data support this. A low Pa_{O_2} has also been reported in COPD patients under HFJV,[7] but we did not confirm this observation.

Recovery

Upper airway obstruction is common after direct laryngoscopy. This complication was not quantified in our study because of the difficulty in assessing the level of obstruction. Emergency tracheotomy or reintubation was never indicated in this large group of patients partially because of the use of short-acting anaesthetics and reversal of neuromuscular blocking agents. The catheter was left in place and withdrawn before the patient returned to the ward, so that immediate reventilation and/or oxygenation were possible. As patients were not intubated, weaning from the ventilator was easy to achieve by decreasing the driving pressure before stopping jet ventilation. Low-pressure (<2 bar) HFJV may be restarted and superimposed on spontaneous breathing in a conscious or semi-conscious patient; if expiration is easy, the risk of barotrauma is limited and this method can be used even in patients with severe upper airway obstruction.[13] TTJV is an attractive alternative to tracheotomy in this difficult situation.[27]

Specific methods have been developed to prevent fire, such as foil-tape and saline-soaked pledgets protected tubes or special tubes designed to resist a laser beam.[24–30] A transtracheal catheter can be touched by the laser beam but its low flammability (Teflon) reduces the risk of fire with this technique.[28] Its cost is less than that of the special tubes designed to resist a laser. Finally, perfect surgical conditions need an immobile field, with no vocal cord movement. In case of abnormal forced movements of vocal folds or any other cause of obstruction, jet ventilation can be stopped transiently during laser treatment (apneic oxygenation).

As vapourisers are not available on jet ventilators, total i.v. anaesthesia was used in all cases. Propofol provides satisfactory conditions[31] and muscle relaxation was added to prevent any movement of the vocal cords. Awareness was not encountered in our study, probably because propofol was supplemented with opiates.[32]

Conclusion

HFJV delivered by a ventilator with an automatic cut-off device is a reliable technique in the hands of trained personnel, used for laryngoscopy and laser surgery in a large series of patients. The risk of subcutaneous emphysema and pneumothorax, despite automatic control of airway pressure, is present. Anaesthesia and ventilation may be achieved despite the lesion and the surgical manoeuvres. Return to spontaneous breathing is particularly easy to control.

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