MECHANICAL VENTILATION DURING LARYNGEAL SURGERY: AN EVALUATION OF THE CARDEN TUBE

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ABSTRACT

The effectiveness and safety of the Carden tube-oxygen injector system for ventilation was studied in 18 high-risk patients with obstructive airways disease during microlaryngeal surgery. Blood gas studies during operation demonstrated a mean PaO_2 of 65.6 kPa (493 torr) and a mean PaCO_2 of 4.5 kPa (34 torr) during mechanical ventilation. No serious complications were noted during operation. Fifty per cent of the patients had postoperative hypercapnia and in two the trachea was re-intubated.

Airway maintenance and ventilation are discussed in detail and it is concluded that the Carden tube-oxygen injector system is a safe and convenient method for ventilating the lungs of patients with pulmonary disease who require microlaryngeal surgery.

MECHANICAL VENTILATION of patients undergoing microlaryngoscopy or laryngeal micro-surgery under general anaesthesia poses special problems for both anaesthetist and surgeon. Effective airway control, adequate ventilation and prevention of aspiration compete for primacy with good visibility and surgical access. Many techniques have been devised to meet anaesthetic and surgical requirements. These include reinforced tracheal tubes¹⁻³ and high-pressure gas injection through ventilating attachments to laryngoscopes or bronchoscopes^{4,5} through small bore catheters^{6,7} through trans-tracheal catheters or cricothyroid needles^{8,9} or through the Carden tube¹⁰ and modifications.¹¹ In many centres these "venturi" or "injector" methods are replacing conventional spontaneous ventilation techniques for airway endoscopy. The Carden tube, first described in 1973,¹⁰ has many desirable properties and, since becoming commercially available, is now in widespread use. It allows for unimpeded surgical access while providing excellent airway and ventilation control when used with a high-pressure gas source.

Some difficulties remain even when using the Carden tube. It has been claimed that the tube is difficult to insert.¹² Many of the patients requiring laryngeal surgery are heavy smokers with significant pulmonary disease. It has never been shown that ventilation with this system is

adequate in these patients. The incidence of other possible complications such as accidental extubation, failure to extubate, postoperative laryngospasm and complications involving the two small tubes attached to the tracheal tube (the oxygen insufflation line and the cuff inflation line) similarly remains unknown. This study reports on a series of patients with known obstructive pulmonary disease who had laryngoscopy or laryngeal operations and whose lungs were ventilated through a Carden tube.

METHODS AND MATERIALS

Patients booked for elective microlaryngoscopy or laryngeal micro-surgery who had clinical evidence of obstructive airways disease were further evaluated with chest roentgenograms, pulmonary function tests, and arterial blood gases. Patients with proven airway obstruction were admitted into the study after informed consent had been obtained (Table I). Patients were divided into "mild" and "severe" lower airway obstruction groups on the basis of pulmonary function studies (Table II).

Patients were premedicated with a narcotic and atropine or scopolamine. On arrival in the operating room a 20-gauge plastic cannula was placed in a radial artery, shown by the Allen test to have good collateral circulation. The anaesthetists assigned to the case then induced anaesthesia with intravenous thiopentone. Following muscle relaxation with succinylcholine a Carden tube (size 8.0 or 9.0) was inserted using a laryngoscope and Magill forcep. The cuff was then inflated and ventilation started with 100 per cent oxygen by connecting the insufflation catheter to

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TABLE I

POPULATION CHARACTERISTICS

Number of patients studied	18
Male	15
Female	3
Age	range: 34-77 Mean: 57
Number of patients	18
Normal airway anatomy	7
Carcinoma of vocal cord	1
Carcinoma of pyriform fossa	1
Carcinoma of hypopharynx	2
Carcinoma of tonsil	1
Post-radiation laryngeal oedema	3
Vocal cord scarring	1
Benign epiglottic ulcers	1
Anterior commissure synechiae	1
Number of patients with:	
Chronic obstructive airways disease	18
alone	10
with emphysema	5
with upper airway obstruction	1
with sarcoidosis (restrictive defect)	2

a Bird Mark 2 Oxygen Injector. Inspiratory time, expiratory pause and pressure-flow controls were adjusted by the anaesthetist to his satisfaction, based on clinical assessment of ventilation. Anaesthesia was maintained with fentanyl citrate and intermittent thiopentone. Muscle relaxation was maintained by succinylcholine infusion. Arterial blood gas samples were drawn at frequent intervals throughout the procedure to assess the effect of surgical and anaesthetic manipulations. Further samples were obtained in the recovery room. Operations lasted from ten minutes to ninety minutes. At the end and upon return to neuromuscular function the trachea was extubated by gentle traction on the cuff inflation catheter. Oxygen 40 per cent was administered by face mask in the recovery room. To assess the accuracy of the anaesthetists' clinical judgment regarding ventilation he was asked to record a guess as to the patient's Pa_{CO_2} during steady state ventilation in the operating room. The anaesthetist and the attending surgeon were also asked to grade their over-all objective satisfaction with the use of the Carden tube in the particular case on an arbitrary scale from one to five, one being completely unsatisfactory and five ideal. Intubation attempts and all complications were recorded, as were any criticisms by surgical or anaesthetic staff. Preoperative and postoperative chest X-rays were compared for evidence of aspiration.

RESULTS

Eighteen patients with laryngeal pathology and pulmonary findings as outlined in Tables I and II were studied.

Ease of insertion of Carden tube

All anaesthetists used standard Magill forceps to insert the tube and no serious difficulties were encountered (Table II). All felt that with a small amount of practice the tube was as easy to insert as a regular tracheal tube and in some difficult airways had distinct advantages over full-length tubes. In general, those experienced in the method were faster and encountered fewer difficulties.

Complications during operation

In two instances the tube became accidentally dislodged during the operation. In both cases it was easily re-inserted without removing the suspension laryngoscope. In three other instances the Carden tube gradually "rode up" between the cords. In these cases the surgeon simply pushed it back down and the cuff volume was increased to hold the tube more firmly in place. In one case the oxygen catheter became obstructed by pressure from the suspension laryngoscope and this produced a loud rude noise. This situation was rapidly corrected by a slight adjustment of the position of the laryngoscope. One tube was difficult to remove on extubation and the anaesthetist removed it under direct vision with the Magill forceps. None of these complications produced significant blood gas changes or posed a threat to the patient's safety.

Intraoperative ventilation and oxygenation during operation

Results of blood gas studies are detailed in Table V. Preoperatively the patients showed variable degrees of mild hypoxaemia or hypercapnia while breathing room air. During induction of anaesthesia and intubation there was a rise in Pa_{O_2} and Pa_{CO_2} in most patients. No patient was significantly hypercarbic, acidotic, or hypoxic. With the start of artificial ventilation the blood gases in all cases showed marked hyperoxia and normocapnia or hypocapnia. No patient had hypoxia, hypercarbia, or acidosis at any stage during the period of ventilation. Manipulations such as suctioning, movement of the laryngoscope, and removal of all instruments and air-

TABLE II
PULMONARY FUNCTION TEST RESULTS IN PATIENTS CLASSIFIED AS HAVING "SEVERE"
OR "MILD" AIRWAYS OBSTRUCTIVE DISEASE

Pulmonary function test (per cent predicted value)	Mild	Severe	Significance*
Total lung capacity	mean 112.0 S.D. 10.0	126.4 28.5	P < 0.10 (N.S.)
Forced expiratory volume at 1 second	mean 110.1 S.D. 19.7	75.6 21.1	P < 0.01
Residual volume	mean 112.0 S.D. 21.0	168.0 59.9	P < 0.02
Flow at 50% vital capacity	mean 33.8 S.D. 11.9	19.9 6.3	P < 0.01
Flow at 25% vital capacity	mean 54.4 S.D. 13.3	27.6 12.8	P < 0.01
Calculated airways resistance	mean 151.8 S.D. 49.6	415.0 53.4	P < 0.01
Number of patients	8	10	

*By Student's t-test for unpaired means.

TABLE III
EASE OF INSERTION OF CARDEN TUBE

Number of cases studied	18
No difficulties encountered during intubation	13
Difficult intubation due to patient airway anatomy	4
Difficult intubation due to Carden tube design	1
Intubation on first attempt	15
Intubation after two to three attempts	3
Intubation after more than three attempts	0
Failure to intubate with Carden tube	0
Significant hypoxia ($\text{Pa}_{\text{O}_2} < 9.98 \text{ kPa}$ [75 torr]) during intubation	0
Significant hypercarbia ($\text{Pa}_{\text{CO}_2} > 7.98 \text{ kPa}$ [60 torr]) during intubation	2
Significant acidosis ($\text{cH}^+ > 50.12 \text{ nmol/l}$ [pH < 7.30]) during intubation	2

ways from the oropharynx did not produce any changes in arterial gas tensions.

Ventilation and oxygenation were assessed by the anaesthetists without knowledge of blood gas results. In 11 out of 18 cases ventilation, as measured by Pa_{CO_2} was underestimated by a mean of 1.2 kPa (9 torr) with a range of 0.3–3 kPa (2–23 torr). In five cases the adequacy of ventilation was overestimated by a mean of 0.4 kPa (3 torr) with a range of 0.4–0.9 kPa (1–7 torr). Two estimates of Pa_{CO_2} were correct. Similarly, the adjustment of the Bird Mark 2 Oxygen Injector (Inflation pressure and inspiratory/expiratory times) was done by the anaesthetists using only clinical judgement. The settings chosen, as measured by the investigator at the end of each case,

showed no appreciable differences between patients with "mild" and "severe" airways obstruction (Table IV).

Postoperative complications

Nine out of eighteen patients had significant hypercarbia with respiratory acidosis in the recovery room (Pa_{CO_2} more than 50). Six of these patients had clinically evident laryngospasm with high-pitched stridor and indrawing. Two patients required re-intubation of the trachea and one of these went on to tracheostomy. Pa_{CO_2} was significantly higher in the patients with laryngospasm (Table VI). Other factors that may have contributed to postoperative hypoventilation were analyzed (Table V). Hypoventilation was

TABLE IV
VENTILATOR SETTINGS USED TO MAINTAIN CLINICALLY
ADEQUATE VENTILATION IN PATIENTS WITH MILD AND
SEVERE AIRWAYS OBSTRUCTION

	Mild	Severe
Inflation Pressure* (cm of water)	mean 18.5 range 12.0-32.0	18.8 12.0-27.0
Volume Product† (litres/minute)	mean 23.0 range 16.0-29.0	23.7 15.0-42.0

*Ventilator output as measured against infinite resistance i.e. a Bourdon gauge.

†Ventilator output as measured against zero resistance, i.e. a pneumotachograph. Both measurements reflect only ventilator adjustment, not pressures or minute volumes delivered to patients.

not significantly different in patients who had severe compared to mild airways obstruction. The presence or absence of airway pathology or surgical intervention did not correlate with recovery room Pa_{CO_2} nor did the use of excessive oxygen, as evidenced by Pa_{O_2} of more than 13 kPa (100 torr) contribute significantly to the post-operative hypercarbia. The only other factor that approached statistical significance was the use of preoperative local anaesthetic spray applied to the larynx. Patients with anaesthetized cords tended to have lower recovery room Pa_{CO_2} ($p < 0.10$).

No patient had complications related to the insertion of the arterial line. No patient had post-operative X-ray changes or clinical evidence of aspiration.

TABLE V
BLOOD GASES BEFORE, DURING, AND AFTER CARDEN TUBE JET VENTILATION

Time Sample Drawn	Group	Pa_{O_2} mean $\pm$ S.D.		Pa_{CO_2} $\pm$ S.D.		Significance
		kPa	(mm Hg)	kPa	(mm Hg)	
Preoperatively	Total	10.1 $\pm$ 1.6	(73.6 $\pm$ 12.2)	5.3 $\pm$ 0.7	(40.0 $\pm$ 5.4)	N.S./N.S.
	Mild	9.9 $\pm$ 1.6	(74.6 $\pm$ 12.3)	5.1 $\pm$ 0.5	(38.5 $\pm$ 4.0)	
	Severe	10.2 $\pm$ 1.7	(76.4 $\pm$ 12.9)	5.5 $\pm$ 0.8	(41.4 $\pm$ 6.3)	
Intraoperatively	Total	65.6 $\pm$ 15.4	(493.0 $\pm$ 115.9)	4.6 $\pm$ 1.0	(34.6 $\pm$ 7.7)	N.S./N.S.
	Mild	59.7 $\pm$ 18.5	(449.1 $\pm$ 139.9)	4.8 $\pm$ 1.2	(35.8 $\pm$ 8.8)	
	Severe	70.4 $\pm$ 11.1	(529.3 $\pm$ 83.6)	4.5 $\pm$ 0.9	(33.7 $\pm$ 7.0)	
Postoperatively (Recovery room)	Total	19.6 $\pm$ 10.4	(147.0 $\pm$ 78.5)	7.0 $\pm$ 2.0	(52.9 $\pm$ 15.1)	N.S./N.S.†
	Mild	22.1 $\pm$ 10.1	(166.5 $\pm$ 75.8)	6.5 $\pm$ 1.6	(49.1 $\pm$ 12.2)	
	Severe	17.6 $\pm$ 10.8	(132.7 $\pm$ 81.2)	7.4 $\pm$ 2.2	(56.0 $\pm$ 16.9)	

*Significance comparing Pa_{O_2} and Pa_{CO_2} in mild and severe groups by Student's t-test for unpaired means.

†All N.S. values are $p > 0.10$.

TABLE VI
FACTORS CONTRIBUTING TO POSTOPERATIVE HYPERCAPNIA

Factor	N	Pa_{CO_2} mean $\pm$ S.D.		Significance*
		kPa	(mm Hg)	
Clinically evident laryngospasm	6	8.8 $\pm$ 2.0	(66.5 $\pm$ 15.1)	$P < 0.05$
No laryngospasm apparent	12	6.9 $\pm$ 1.8	(51.7 $\pm$ 13.3)	
Cords sprayed with cocaine 5%	8	6.3 $\pm$ 1.3	(47.2 $\pm$ 10.0)	$P < 0.10$
Cords not sprayed	10	7.6 $\pm$ 1.3	(57.0 $\pm$ 9.8)	
Recovery room hyperoxia (100)	12	6.7 $\pm$ 1.2	(50.4 $\pm$ 9.2)	$P < 0.05$
Recovery room hypoxia	6	9.0 $\pm$ 1.6	(68.0 $\pm$ 12.0)	
Biopsies or manipulation	9	6.8 $\pm$ 1.5	(51.3 $\pm$ 11.2)	$P < 0.10$
Inspection only	9	7.2 $\pm$ 1.6	(54.4 $\pm$ 12.4)	
Normal airway anatomy	7	6.6 $\pm$ 1.2	(49.7 $\pm$ 8.7)	$P < 0.10$
Airway pathology present	11	7.3 $\pm$ 1.5	(54.9 $\pm$ 11.1)	
"Severe" group	10	7.4 $\pm$ 2.2	(56.0 $\pm$ 16.9)	$P > 0.10$
"Mild" group	8	6.5 $\pm$ 1.6	(49.1 $\pm$ 12.2)	

*By Student's t-test for unpaired means.

SUBJECTIVE EVALUATION

In general, both anaesthetists and surgeons were highly satisfied with the ventilatory technique. Eleven staff anaesthetists assigned an overall mean satisfaction score of 4.2/5.0 (range 2–5). Eight surgeons rated their satisfaction with a mean score of 4.7/5.0 (range 4–5).

DISCUSSION

The single most important conclusion to be drawn from our data is that the Carden tube oxygen injector system provided adequate ventilation and oxygenation for patients with mild to severe obstructive disease of the airway. This is important because a large proportion of patients requiring laryngeal surgery have abnormal pulmonary function and are high-risk patients for any kind of mechanical ventilation. The high degree of reliability of the clinical parameters used by anaesthetists to judge ventilation and to adjust the oxygen injection is also encouraging. Patients in the study were more than adequately ventilated and oxygenated throughout each case.

The Carden tube proved to be fairly easy to insert and remarkably free of technical difficulties during all the study cases. Airways were well maintained and the steady back pressure up through the cords prevented aspiration of surgical debris as evidenced by the unchanged chest X-rays in all patients and by the direct observations of the surgeons that debris tended to be jetted up into the pharynx. Movement of the tube during the operation was uncommon and easily remedied when it did occur. The Carden tube was easily removed in all but one case.

In contrast, the high rate of postoperative hypoventilation in this study was alarming. Most of the hypercapnic patients had marked laryngospasm with upper airway obstruction as opposed to central hypoventilation as the cause for their ventilatory failure. None of the factors that might logically be expected to provoke laryngospasm correlated statistically with recovery room PaCO_2 , however, and we must conclude that some factor common to all patients in the study is responsible for the tendency to laryngospasm. This may be related to either the anaesthetic or surgical technique, though further studies would be required to ascertain whether other methods of

ventilation would produce a lower incidence of laryngospasm. It seems doubtful to us that the use of Carden tube itself is the irritant factor. Nevertheless, it would seem prudent to observe and monitor post-laryngoscopy patients carefully, to determine blood gases in doubtful cases, and to keep facilities and personnel available for establishment of an artificial airway in the immediate postoperative period.

Further studies to determine the relative merits of the great variety of proposed methods for ventilation during laryngeal surgery are required. In this study we have shown that the Carden tube is one method which is safe, convenient, and effectively meets the requirements of modern micro-laryngeal surgery.

REFERENCES

1. WESTHUES, M. Ueber die Intubationsnarkose bei mikrochirurgischen Eingriffen am Kehlkopf. *Anaesthetist* 14: 309 (1966).
2. POLLARD, BRIAN J. Anaesthesia for Laryngeal Microsurgery. *Anaesthesia* 23: 534 (1968).
3. JACOBSEN, E., SKOVSTED, P. & THOMSEN, K.A. General anaesthesia for microlaryngoscopy using small bore endotracheal tubes. *Acta Otolaryng.* 74: 346 (1972).
4. SANDERS, R.D. Two ventilating attachments for bronchoscopes. *Delaware Medical Journal* 39: 170 (1967).
5. BARR, N.L., ITSCHOLTZ, S. & CHAN, C. Oxygen injection in suspension laryngoscopy. *Arch. Otolaryng.* 93: 606 (1971).
6. SPOEREL, W.E. & GREENWAY, R.E. Technique of ventilation during endolaryngeal surgery under general anaesthesia. *Canad. Anaesth. Soc. J.* 20: 369 (1973).
7. EL-NAGGAR, M., KEH, E., STEMMERS, A. & COLLINS, V. Jet ventilation for microlaryngoscopic procedures: a further simplified technique. *Brit. J. Anaesth.* 47: 390 (1975).
8. SPOEREL, W.E., NARAYANAN, P.S. SINGH, N.P. Transtracheal ventilation. *Brit. J. Anaesth.* 43: 932 (1971).
9. SMITH, R.B., SCHAEER, W.B., & PFAEFFLE, H. Percutaneous transtracheal ventilation for anaesthesia and resuscitation, a review and report of complications. *Canad. Anaesth. Soc. J.* 22: 607 (1975).
10. CARDEN, E. & CRUTCHFIELD, W. Anaesthesia for microsurgery of the larynx (a new method). *Canad. Anaesth. Soc. J.* 20: 378 (1973).
11. DAGHLIAN, B.D. A useful tube for anaesthesia during laryngeal microsurgery. *Brit. J. Anaesth.* 48: 607 (1976).

RÉSUMÉ

L'efficacité et la sécurité du tube de Carden utilisé avec un injecteur à oxygène pour la ventilation des patients soumis à une microchirurgie du larynx ont fait l'objet d'une évaluation

chez 18 malades à risque élevé, c'est-à-dire présentant un syndrome pulmonaire obstructif. Les gazométries effectuées en cours de chirurgie ont montré des Pa_{O_2} moyennes de 65.6 kPa (493 torr) et des Pa_{CO_2} moyennes de 4.5 kPa (34 torr). On n'a relevé aucune complication grave. Une hypercapnée a été observée en période post-opératoire chez 50 pour cent des opérés et dans deux cas, les malades ont dû être intubés pour assistance respiratoire.

Les auteurs discutent du maintien des voies aériennes et de la ventilation de ces malades. Ils concluent que le tube de Carden utilisé avec un injecteur à oxygène représente une méthode pratique et sécuritaire pour la ventilation des malades présentant un syndrome obstructif et soumis à une microchirurgie du larynx.