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Reconstruction of the Trachea in Children with Tracheal Stenosis by Using Jet Ventilation

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Tracheal stenosis is a life-threatening childhood disease. Airway management of children during tracheal resection and reconstruction presents several clinical problems. During surgery, adequate ventilation and oxygenation must be provided, despite an open trachea, and the surgeon must be provided with an unobstructed field.

Various techniques have been described to ensure ventilation during such procedures. High-frequency jet ventilation can provide adequate oxygenation and good surgical access in adult patients[1–3] and children.[4] This paper reports the use of low-frequency jet ventilation in four infants during resection of tracheal stenosis.

CASE REPORTS

The clinical features of four patients are summarized in table 1. The procedure of jet ventilation was explained to the parents and informed consent obtained.

Atropine (0.02 mg/kg) im was given preoperatively. Anesthesia was induced with fentanyl 20 μg/kg iv and nitrous oxide 50% with oxygen. Skeletal muscle paralysis was maintained with pancuronium bromide (0.1 mg/kg) iv. A radial artery catheter was inserted for continuous measurement of systemic arterial blood pressure and intermittent analysis of arterial blood gases. Transcutaneous P_{CO_2} (tcP_{CO_2}) was measured continuously. The trachea was intubated orally with a 14-cm long, 2.5–3.5 mm ID, uncuffed polyvinyl chloride tube, placing the tip above the stenotic segment. A 40-cm 5-French polyethylene tube with a single distal orifice was used to provide jet ventilation. This was passed through the endotracheal tube and placed just above the stenosis. The distal airway pressure was monitored *via* a 130-cm 3-French polyvinyl chloride catheter inserted with the tip below the stenosis. During jet ventilation, the proximal end of the endotracheal tube was left open to the atmosphere to provide an exit for the continuous outflow of gas. The jet ventilator used (Mera® HFO Jet Ventilator, Senko Medical Industrial Co., Tokyo, Japan) has a pneumatic valve system. Oxygen concentration during jet ventilation was adjusted with an oxygen-nitrous oxide blender. Humidification was provided by the intermittent infusion of 0.45% saline directly into the jet stream every 10–15 min.

Ventilation was initiated manually *via* the endotracheal tube, then switched to high-frequency jet ventilation *via* the 5-Fr catheter using a frequency of 180 breaths/min with an inspiratory to expiratory ratio of 1:1. This setting of the jet ventilator was followed by an increase in Pa_{CO_2} in cases 1 and 2. Consequently, the frequency was changed to less than 40 breaths/min with an inspiratory to expiratory ratio of 1:3. This resulted in a decrease in the Pa_{CO_2}. In cases 3 and 4, low-frequency ventilation was used throughout. Surgical repair was carried out *via* a cervical approach in case 3 and a median sternotomy in cases 1, 2, and 4. Immediately after resection of the stenotic area, the jet ventilation catheter and the airway pressure monitoring catheter were advanced into the open distal trachea. The catheter measuring airway pressure was always placed distal beyond the insufflation catheter (fig. 1). Figures 2 and 3 show the intraoperative patterns of airway pressure and tcP_{CO_2}. The pattern of airway pressure provided useful early information regarding the adequacy of ventilation. For example, the decrease of the peak airway pressure movement in the third tracing in figure 2 indicated inadequate ventilation and resulted in an increase of tcP_{CO_2}. The elevated peak airway pressures, especially those with a stepwise pattern, as shown in figure 3, indicate obstruction of the outflow of gas due to surgical manipulation.

After anastomosis of the trachea, the endotracheal tube was advanced into the distal trachea and manual ventilation was reinstituted.

Postoperatively, children were transferred to the surgical intensive care unit without the reversal of neuromuscular blockade, and conventional mechanical ventilation (CMV) was performed using a constant-flow, time-cycled Sechrist® ventilator to ensure immobilization of the neck. CMV, with a frequency of 15–20 breaths/min and a peak airway pressure of 15–20 cm H_2O, was continued from 10 days to 2 weeks. In cases 3 and 4, the subsequent course was uncomplicated, and the patients were discharged from the hospital. Although the postoperative course was uneventful in case 1, she died suddenly at 6 months after surgery. In case 2, respiratory distress with inspiratory stridor and chest wall retraction recurred 1 month after surgery. Diagnostic tracheoscopic examination revealed proliferation of granulation tissue at the anastomotic site in the trachea. He underwent an endoscopic resection of this granulation tissue with satisfactory results.

DISCUSSION

Jet ventilation during anesthesia for major airway surgery has various advantages over CMV. During the resection and reconstruction, the use of CMV impairs surgical exposure, and requires repeated endobronchial intubation and extubation. Jet ventilation *via* a thin in-

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TABLE 1. Characteristics of Patients Receiving Jet Ventilation during Operation

Patient #	Age	Sex	Body Weight (kg)	Diagnosis	Size of Endotracheal Tube (ID mm)	Type of Operation	Duration of Jet Ventilation (Min)
1	1Y2M	F	7.0	Acquired tracheal stenosis due to prolonged endotracheal intubation	3.0	Tracheal resection	150
2	2M	M	5.4	Congenital tracheal stenosis	2.5	Tracheal resection; implantation of cartilage graft	140
3	1.5M	M	5.0	Subglottic web; infectious granuloma	3.0	Debridement; anterior cricoid splitting	60
4	2Y	F	7.5	Congenital tracheal stenosis	2.5	Tracheal resection; implantation of cartilage graft	90

sufflation catheter inserted through the endotracheal tube into the distal portion of the trachea provides adequate ventilation and oxygenation with unobstructed vision and access to the circumference of the trachea.

Although Neuman *et al.* used jet ventilation at 100 breaths/min for tracheal resection in a child,[4] we found frequencies of less than 40 breaths/min to be more satisfactory. However, we did also change the I/E ratio from 1:1 during the high-frequency ventilation to 1:3 during low-frequency ventilation, and this may also have influenced the adequacy of ventilation. Direct comparison between Neuman's technique and ours is

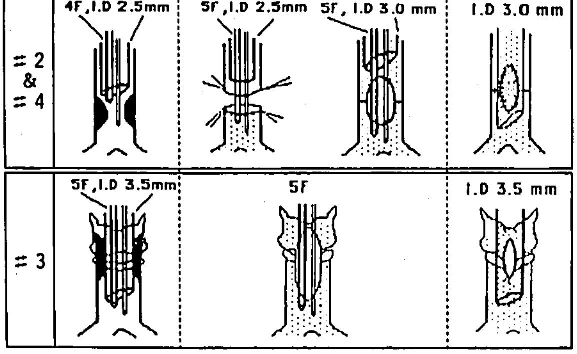

FIG. 1. Schematic representation of airway management during tracheal resection and reconstruction.

also difficult in view of the different sizes and ages of the patients involved, and, hence, differing endotracheal tube sizes and mechanical properties of the lungs.

Banner *et al.* suggest that, during jet ventilation, the major determinant of tidal volume and CO_2 elimination is inspiratory time, rather than I/E ratio or frequency.[6] In addition, Weisberger *et al.*[7] suggest that the absolute expiratory time, rather than I/E ratio or frequency, is also important as the determinant of any increase in functional residual capacity or the development of air trapping. In our cases, the Pa_{CO_2} was lower when a frequency of less than 40 breaths/min with an I/E ratio of 1:3 was used than with a frequency of 180 breaths/min with an I/E ratio of 1:1. The increase in Pa_{CO_2} at the higher frequency was probably caused by both the decrease of the tidal volume due to the short inspiratory time and to air trapping due to the short expiratory time.[8,9] Therefore, we recommend low-frequency jet ventilation during anesthesia for airway surgery, such as tracheoplasty or bronchoplasty, in all patients.

During resection and reconstruction, surgical manipulations frequently produce mechanical obstruction by compression of the trachea. This causes gas trapping due to obstruction of the expiratory flow, and may lead to barotrauma. To prevent this, we continuously monitored the airway pressure by a small catheter inserted into the distal trachea. This immediately detected both elevated pressures due to gas trapping (fig. 3) and inadequate ventilation, which would result in an increased tcP_{CO_2} (fig. 2).

In conclusion, we found that low-frequency jet ventilation during tracheal reconstruction was an alternative to conventional ventilation, and that normocarbia was easily maintained. To assess the adequacy of jet ventilation, to detect elevated airway pressure, and to prevent

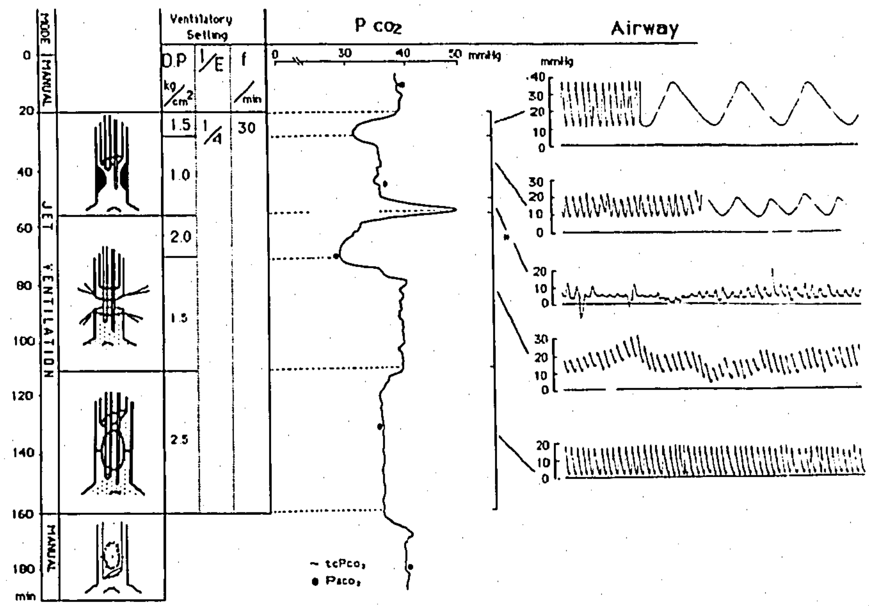

FIG. 2. Recording of airway pressure and transcutaneous P_{CO_2} during anesthesia in case 4. The decrease in the peak airway pressure fluctuation and an increase of tcP_{CO_2} indicates inadequate ventilation (*). F = frequency; DP = driving pressure; I/E = inspiratory:expiratory ratio; tcP_{CO_2} = transcutaneous P_{CO_2}.

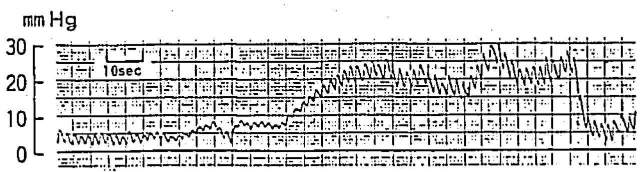

FIG. 3. Recording of airway pressure. Elevated peak airway pressure swing (step pattern) indicates the obstruction of the outflow of gas due to surgical manipulation.

pulmonary barotrauma, we found it necessary to monitor the distal airway pressure and transcutaneous P_{CO_2} continuously.

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