In the treatment of vascular ring, repair of the trachea and esophagus or aortopexy is often necessary in addition to resection of the vessels. Although the decision is made mainly on the basis of the preoperative computed tomographic or magnetic resonance images or intraoperative bronchoscopic findings, the anatomic information may be insufficient.

We report here the usefulness of expiratory airway resistance (Raw) and the flow-volume (FV) curve in a patient with vascular ring for the assessment of the immediate surgical effect during the operation and for deciding the timing of extubation.

Method

Patients were anesthetized with fentanyl and pancuronium bromide. After intubation, measurement of pressure and flow was started and maintained by manual ventilation during the operation. The sensor was placed between the tracheal tube and the anesthesia equipment in the operating room or the respirator in the intensive care unit. Pressure and flow were measured simultaneously with a CO2SMO Plus! monitor (Novametrix Medical Systems Inc, Wallingford, Conn), and Raw was calculated as driving pressure divided by maximum expiratory flow. Raw and the FV curve were displayed in real time on a personal computer connected to the CO2SMO Plus! monitor. All digital data were stored. FV curves were sampled over a 5-minute period every 15 minutes, and all data were stored.

Ten consecutive FV curves in which the tidal volume was between 50 and 60 mL were reproduced from the data, and the mean tidal volume and the mean minimum volume were calculated. The expiratory flow at the midpoint between the mean tidal volume and the mean minimum volume was measured, and the ratio to the maximum expiratory flow (V50) was calculated (Figure 1, A and B). V50 was determined preoperatively, immediately after intubation, after the tracheal tube was placed below the stenotic sites, before and after resection of the vascular ring, after withdrawal of the tracheal tube above the stenotic sites, and several times in the intensive care unit.

For control values, after the induction of anesthesia, V50 was measured in the same way, and mean Raw was determined from continuous measurements over 60 minutes (Figure 2) in 26 patients with congenital heart disease without airway obstruction (body weight 3.3-23.6 kg, mean 9.1 kg, SD 5.5 kg).

Statistical Analysis

The correlations between body weight and Raw and between body weight and V50 were examined in control subjects, and the correlation between the data was tested by the F test.

Clinical Summary

A 7-month-old girl with a previous diagnosis of corrected transposition of the great arteries, pulmonary stenosis, ventricular septal defect, and right aortic arch was admitted to our hospital for cardiac catheterization. Increased wheezing since birth had been noted, and
angiograms and computed tomographic scans showed a right aortic arch and aberrant left subclavian artery behind the trachea and the esophagus, which formed a vascular ring. The wheezing was considered to be due to tracheal constriction by the pulmonary artery, aorta, left subclavian artery, and left ligamentum arteriosum. The patient's condition deteriorated and she was intubated. Bronchoscopic examination revealed that the anterior and posterior walls of the trachea were compressed just above the carina, but the size of the trachea was almost normal (Figure 3, A). Preoperative measurement of Raw and the FV curve was performed during respiratory assistance with positive-pressure support (Figure 4).

Intraoperatively, the measurement of Raw and the FV curve was started (Figure 4) after the induction of general anesthesia. The tracheal tube was threaded past the stenotic site in the trachea with a fiberoptic bronchoscope. Because it was considered to be safer for ventilation, the tracheal tube was fixed at this site during the operation. The left ligamentum arteriosum and the left subclavian artery were resected via a left posterolateral thoracotomy. Neither aortoectomy nor reconstruction of the trachea or esophagus was performed. By means of the fiberoptic bronchoscope, the tracheal tube was withdrawn just above the stenotic site, and bronchoscopic examination showed that the slit-like stenotic sites in the trachea had slightly widened (Figure 3, B). Measurements were resumed after the patient returned to the intensive care unit (Figure 4).

Results

In control subjects, Raw decreases as body weight increases ($y = 547.37x^{-1.2997}$, $r = -0.93$, $P < .01$, Figure 5, A), and Raw also decreases as body weight increases with the same tracheal tube size (Figure 5, B). $V_{50}$ gradually decreases linearly as body weight increases ($y = -0.0026x + 0.7452$, $r = -0.33$, $P < .05$, Figure 6), but the values are in the narrow range between 0.6 and 0.8 (mean: 0.72, SD: 0.04).

In the case reported here, Raw was measured as 60 to 80 cm H$_2$O · L$^{-1}$ · s$^{-1}$ and $V_{50}$ as 0.56 during respiratory support with positive airway pressure before the operation (Figure 4). Intraoperatively, after the induction of anesthesia, Raw was 98 cm H$_2$O · L$^{-1}$ · s and $V_{50}$ was derived as 0.37 from the FV curve,
showing an obstructive pattern during manual ventilation (Figure 1, A), compared with 39 cm H$_2$O · L$^{-1}$ · s and 0.73 in controls with the same body weight (Figures 5, A, and 6). Prolongation of expiratory time was also indicated (Figure 7, A).

Immediately after resection of the vascular ring, Raw remained high but $V_{50}$ increased to around 0.60 (Figure 4) and the FV curve returned to a convex shape. The tracheal tube was withdrawn with a bronchoscope, and the slit between the anterior and posterior walls of the trachea was noted to be slightly wider (Figure 3, B). Raw and $V_{50}$ remained at the same values after the depth of the tracheal tube was changed (Figure 4 and Figure 1, B), and the expiratory time was shortened (Figure 7, B).

In the intensive care unit, Raw gradually decreased to within normal ranges, 40 to 50 cm H$_2$O · L$^{-1}$ · s, and $V_{50}$ increased to 0.78.
Brief Communications

The tube was removed successfully 24 hours after the operation.

Discussion

Surgical management is essential for relieving tracheal stenosis caused by a vascular ring, and reconstruction of the trachea and esophagus is sometimes required. Chest radiography, computed tomography, magnetic resonance imaging, angiography, barium esophagography, and bronchoscopy provide useful anatomic information about the trachea, but sometimes this is insufficient to determine the condition of the trachea. Our investigation indicates that the continuous measurement of Raw and V<sub>50</sub> can provide physiologic real-time information about the condition of the trachea. This method may be useful for intraoperative assessment.
of the tracheal condition and for deciding the timing of extubation in the intensive care unit in patients with vascular ring.

The FV curve becomes abnormal at maximum respiratory effort in patients with airway obstruction. Abramson and associates showed that the FV curve was abnormal in neonates and infants with airway obstruction, even during spontaneous tidal breathing, by using a facial mask and pneumotachograph; they further showed that this curve normalized a few months after the operation. The FV curve was more sensitive for detecting airway obstruction during manual ventilation than during mechanical ventilation, because airway obstruction was reduced as a result of positive airway pressure support. In this case, the abnormal FV curves (Figure 1, A) were slightly different preoperatively from those of other reports, which were relatively constant low flow. This discrepancy probably comes from the methodologic difference. We performed the measurement during manual ventilation with muscle relaxant, which was different from measurements obtained during spontaneous breathing. The abnormal FV curve pattern changed to a near normal convex shape immediately after resection of the vascular ring. On the basis of this finding, we believed that no surgical reconstruction of the trachea or esophagus was required. The FV curve was more sensitive in revealing the condition of the trachea immediately after surgery, whereas Raw remained markedly high and gradually normalized 12 hours postoperatively.

In control subjects, Raw values were dependent on the patients' body weights. This tendency was also seen in the same size of tracheal tube (Figure 5, B). The normal value in the patients with congenital heart disease without airway obstruction weighing less than 4 kg was over 70 cm H2O · L–1 · s. This value was different from a previous study in which Raw was reported to be around 40 cm H2O · L–1 · s in patients under 4 kg with no respiratory failure. V50 weakly correlated to body weight but, interestingly, most of the values were between 0.68 and 0.78.

Extubation is often difficult after surgery for respiratory obstruction and depends on the degree of improvement in the stenotic part of the respiratory tract. Raw and V50 are useful for assessing the condition of the proximal respiratory tract. We consider that extubation can be successfully performed if both these values are normalized after surgery, as seen in the present case.

Further study of a larger number of patients with various types of vascular rings is required.

Limitation

We calculated the control values from various types of congenital heart diseases on the assumption that heart defects such as ventricular septal defect, atrial septal defect, patent ductus arteriosus, transposition of the great arteries, complete arteriovenous canal, truncus arteriosus, pulmonary atresia with ventricular septal defect, and tetralogy of Fallot would not affect the central respiratory condition. There might be some effect of the anesthesia on the Raw and the FV curve.

References


Figure 7. A, Flow curve indicated the duration of expiratory time before the operation. B, The expiratory time was lessened after the operation.