CONTINUOUS SPIROMETRY FOR DETECTION OF DOUBLE-LUMEN ENDOBRONCHIAL TUBE DISPLACEMENT

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SUMMARY
Flow-volume and pressure-volume loops were measured with continuous spirometry in 49 patients in whom the trachea was intubated "blindly" with a double-lumen endobronchial tube for thoracic surgery. Nineteen endobronchial tubes were malpositioned by fibreoptic bronchoscopic criteria; 63% of these were suspected because of the configuration of the spirometric loops. During positioning of the patient and during operation, 34.7% of the endobronchial tubes migrated from the initially correct or corrected position. The secondary displacements were identified by abnormal loop configurations and confirmed with fibreoptic bronchoscopy. Continuous spirometric monitoring is helpful in detecting endobronchial tube displacement during intubation and surgery.

KEY WORDS
Anaesthetic techniques; fibreoptic bronchscopy, one-lung ventilation; Intubation; endobronchial; Monitoring; spirometry.

The position of double-lumen endobronchial tubes (DLT) which have been inserted blindly frequently requires correction after fibreoptic bronchoscopic examination [1, 2]. The precisely positioned DLT can be dislocated when the patient is moved to the lateral position [3] and may be dislodged during intraoperative manipulation of the pulmonary hilum. Malposition or displacement of the DLT, with subsequent impaired gas exchange, is one of the most difficult situations the anaesthetist may encounter during one-lung ventilation. During operation, the position can be corrected with fibreoptic bronchoscopic or the surgeon can replace the tube manually when the chest is opened. Both procedures are time consuming. Estimation of the dependent lung ventilation is possible [4, 5] by watching mediastinal movements and by monitoring inspiratory airway pressure changes, end-tidal concentration of carbon dioxide and pulse oximetry.

The spirometer of the Ultima SV (Datex Instr. Corp. Helsinki, Finland) provides continuous data on adequacy of ventilation and oxygenation. It incorporates inspiratory airway pressure, volume, flow and end-tidal carbon dioxide measurements at the tracheal tube. The in-line respiratory monitor is supplied with flow-volume and pressure-volume loop displays providing information about the compliance and flow characteristics of the ventilatory system [6, 7]. Changes in compliance and the expiratory flow characteristics are continuously and visually illustrated by the changing form of each loop and can be compared with the baseline curves stored in memory. The visual display of the numeric information may be especially helpful during thoracic surgery. Therefore, the present study was designed to investigate the change in configuration of the displayed loops resulting from malposition or migration of the DLT.

PATIENTS AND METHODS
The study was approved by our hospital's Ethics Committee and informed consent was obtained during a 5-month period from 49 consecutive adult patients undergoing elective right or left thoracotomy requiring one-lung ventilation.

Three-lead ECG, invasive radial arterial pressure and arterial oxygen saturation were monitored continuously. The respiratory variables were observed with the flow sensor and gas sampling probe of the Ultima. Anaesthesia was induced and maintained with a variable rate continuous infusion of propofol; pancuronium was used for neuromuscular block. In all patients, the bronchus of the dependent lung was intubated in a "blind" fashion with a double-lumen endobronchial tube of appropriate size (Broncho-Cath, Mallinckrodt Laboratories, Athlone, Ireland). After intubation, the tracheal and bronchial cuffs were inflated with air and the common connector of the DLT was attached to the flow sensor. Pressure-volume and flow-volume loops were recorded with the two lungs ventilated with 10 ml kg\(^{-1}\) tidal volume at a rate of 10–12 b.p.m. To keep the volume constant, the ventilator settings were the same throughout the procedure.

The ability to isolate each lung was assessed by alternately clamping the tracheal and bronchial limbs. The apical, anterior and axillary area of each hemithorax were auscultated, and both limbs were examined for leaks. Pressure-volume and flow-volume loops were recorded again, with the tracheal lumen clamped and judgement was made about the position of the DLT based on the configuration of the displayed loops resulting from malposition or migration of the DLT.
the loops. Fibreoptic bronchoscopy was then performed to determine if the bronchoscopic findings confirmed the impressions based on the flow- and pressure-volume loops. When the position was not adequate according to the criteria described by Smith, Hirsch and Ehrenwerth [1], it was corrected under direct bronchoscopic examination.

After the patient was placed in the lateral position, the tracheal lumen of the DLT was clamped, flow-volume and pressure-volume loops were recorded and interpreted. Fibreoptic bronchoscopy was repeated and correction of the DLT position was made when required.

During operation and during the period of one-lung ventilation, the flow-volume and pressure-volume loops were monitored continuously. When alteration of the configuration of the curve was noted, recordings were made and fibreoptic bronchoscopy performed. When secondary migration was seen by fibreoptic bronchoscopy, the position of the DLT was corrected.

## RESULTS

The mean age of the patients was 57.3 yr (range 14-74 yr), mean height 167 cm (range 151-183 cm) and mean weight was 66.8 kg (range 38-103 kg). In the 49 patients studied, 19 right-sided and 30 left-sided DLT were positioned; 19 (38.7%) proved to be placed inaccurately during blind intubation (table I). Based on the flow-volume/pressure-volume loop configurations alone, 12 DLT were judged not to be in the satisfactory position after intubation (confirmed by fibreoptic bronchoscopy), and seven other malpositions were recognized by fibreoptic bronchoscopy. From all of the initially correct, or corrected positions, 17 DLT (34.7%) migrated subsequently: five (10.2% of all cases) during change to the lateral position and 12 (24.5%) during surgical manipulation. Sixteen of the 17 secondary displacements were identified by the aberrant pressure-volume and flow-volume curves.

The configuration of the pressure-volume PV loop did not change significantly during one-lung ventilation compared with two-lung ventilation when the DLT was positioned correctly. Only the slope of the curve shifted slightly to the right (fig. 1). When the DLT was placed incorrectly, the form of the pressure-volume curve altered, the inspiratory and expiratory limb becoming distorted and the area of the curve enlarged abnormally (fig. 1).

Of the initially malpositioned DLT, seven were advanced too far, six were not advanced sufficiently and two left-sided tubes were twisted to the right. From the six initially malpositioned right-sided DLT, obstruction of the right upper lobe orifice was noted with fibreoptic bronchoscopy in five instances. Only one patient exhibited $Sp_\text{O}_2 < 90\%$ during one-lung ventilation. Eleven patients had airway pressures > 40 cm H$_2$O and, on nine occasions,
Intrinsic PEEP up to +9 + 11 cm H₂O or persistent expiratory flow was noted on the flow-volume loops during one-lung ventilation.

**DISCUSSION**

Of the 49 DLT, 19 (38.7%) were malpositioned and then repositioned with fibreoptic bronchoscopy during initial placement. Of the 19 initial malpositions, 12 (63%) were suspected because of the configuration of the pressure- and flow-volume loops. The smaller proportion of loop-recognized initial malpositions is likely to be the result of individual variations in the characteristics of the pressure-volume and flow-volume loops in a population with altered lung function. For this reason, a baseline curve has to be established for each patient in the dorsal position during two-lung ventilation. This curve can be stored in the memory of the monitor and compared with those obtained after positioning of the patient and during surgery. We have not found data in the literature concerning the incidence of secondary displacements. In our study, with continuous spirometric evaluation, 92% of secondary migrations were identified because of the altered configuration of pressure- and flow-volume curves and confirmed subsequently by fibreoptic bronchoscopy.

The pattern of the flow-volume loop is determined by the mechanical properties of the total respiratory system (the lung and thorax of the patient, the endobronchial tube and the ventilator), but it is reproducible for that given patient. The curve is not very different during two- or one-lung ventilation when the DLT is positioned accurately (fig. 1).

Malposition of a DLT can result in expiratory flow limitation, increased inspiratory or expiratory resistance, or both, because of lumen obstruction and delayed deflation or incomplete emptying of the lung. This results in "cut-off" of the high flow rates and a flat, horizontal expiratory limb (fig. 1). Surgical manipulation around the lung hilum during dissection also changes the pattern of the flow-volume loops, especially the expiratory limb. It becomes ragged or serrated and the expiratory limb may reach the volume axis at a volume greater than zero (fig. 2). Depending on the degree of obstruction caused by the malposition of the endobronchial tube, or by the surgical manipulation of the non-dependent lung, the configuration of the flow-volume loop may be distorted or even grotesque. These loops may illustrate visually the phenomenon of persistent expiratory flow described by Larsson, Malmkvist and Werner [8] (fig. 3). In nine patients, we demonstrated increased end-expiratory pressures during one-lung ventilation, occasionally without increased inspiratory airway pressure. With continuous spirometric monitoring of flow- and pressure-volume loops, large numbers of initial and intraoperative DLT displacements were detected by the altered configuration of either the pressure-volume or the flow-volume loop. As the change of DLT position can be seen immediately from the displayed curves, appropriate action can be initiated, and the harmful effects of increased airway pressure, hyperinflation, hypoventilation and hypoxaemia can be avoided.

In conclusion, continuous spirometry is a promising method of monitoring ventilation during anaesthesia for lung surgery. The margin of safety of the correct position for the DLT is narrow:

movement of the patient and manipulation can easily displace or dislodge the tube from the correct position. Comparison of the displayed loops with those recorded and considered normal for individual patients is highly desirable, as the curves are slightly different in each patient. Small deviations from baseline can signify a position-related problem, but the exact site and nature of obstruction cannot be diagnosed and corrected based on the altered loop configuration alone. Fibreoptic bronchoscopy is necessary to correct the problem.

REFERENCES


