On-line expiratory flow-volume curves during thoracic surgery: occurrence of auto-PEEP

G. BARDOCZKY, A. d'HOLLANDER, J.-C. YERNAULT, A. VAN MEUYLEM, J.-M. MOURES and P. ROCMANS

SUMMARY
Flow-volume loops were monitored continuously in 39 patients undergoing thoracic surgery requiring one-lung ventilation. In 26 of the 39 patients (67%), auto-positive end-expiratory pressure (auto-PEEP) was seen on the flow-volume curves during both two-lung and one-lung ventilation. Eighty-seven percent of the patients whose trachea was intubated with a smaller size (35- and 37-French gauge) double-lumen tracheal tube exhibited auto-PEEP, compared with patients in whom the tube used was larger (39- or 41-French gauge: 54% and 50%, respectively). Before operation, mean airway resistance was significantly greater in patients who exhibited auto-PEEP during anaesthesia (2.4 cm H₂O litre⁻¹ s⁻¹) than in patients without auto-PEEP (1.7 cm H₂O litre⁻¹ s⁻¹). (Br. J. Anaesth. 1994; 72: 25-28)

KEY WORDS

During mechanical ventilation, patients with chronic airflow obstruction are prone to the development of inadvertent positive end-expiratory pressure which has been termed occult, intrinsic or auto-PEEP [1, 2]. It may occur also in patients without chronic obstructive airways disease, if expiratory time is too short to allow complete expiration [2]. Patients undergoing lung surgery may be susceptible to develop auto-PEEP because of pre-existing obstructive airway disease and because intra-operative circumstances (lateral decubitus position, use of a double-lumen tracheal tube (DLT), one-lung ventilation (OLV)) may impede expiration [3, 4].

Conventionally, auto-PEEP may be assessed by occluding the ventilator expiratory valve at end-expiration [5] and measuring airway pressure after equilibrium has been achieved—a pressure greater than atmosphere indicating auto-peep [6]. However, this interferes with the ventilation of the lungs.

The Ultima SV (Datex Instr. Corp. Helsinki, Finland) respiratory monitor measures inspiratory and expiratory airway pressure, air flow and volume [7, 8]. Its flow sensor is a bi-directional, pressure-based flow sensor with two fixed resistances interposed in the airflow. The sensor is placed close to the patient, at the tracheal tube. A continuous flow-volume loop may be displayed (fig. 1) and changes in the dynamic characteristics of the respiratory system deduced from the changing shape of the loop.

This study was designed to determine the likelihood and magnitude of auto-PEEP during anaesthesia in patients undergoing lung surgery.

PATIENTS AND METHODS
The investigation was approved by the local Ethics Committee and informed consent was obtained from 39 consecutive adult patients undergoing elective thoractomy requiring one-lung ventilation (OLV).

Three-lead ECG, invasive radial arterial pressure and arterial oxygen saturation were monitored continuously. 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 with a DLT (Broncho-Cath, Mallinckrodt Laboratories, Athlone, Ireland) of a size determined by a staff anaesthetist not participating in the study. The correct position of the DLT was ascertained in the usual manner (auscultation, alternate clamping for leak detection and fiberoptic bronchoscopy). The patients' lungs were ventilated with 50% oxygen in air with a Siemens Servo 900 C constant inspiratory flow ventilator (Siemens Elema, Solna, Sweden), at a constant tidal volume of 10 ml kg⁻¹ and a ventilatory frequency of 10–12 b.p.m. Ventilator settings were kept the same throughout the procedure, including the period of OLV. Inspired and expired tidal volumes (V₁, Vₑ), peak and end-inspiratory pressures (P₁,peak; P₁,end), PEEP, inspiratory: expiratory ratio (I:E), total dynamic compliance (Crs), percentage of tidal volume exhaled passively in 1 s (PEV₁) and ventilatory frequency (f) were monitored continuously with the flow sensor of the Ultima SV attached to the common connector of the
DLT. Before each study, the ventilator and the breathing system were inspected carefully for leaks. The accuracy of the ventilator and the flow sensor was ascertained before use in each patient, using the Bio-Tek Ventilator Tester (Winooski, VT U.S.A.).

Data collection and flow-volume loop recordings were made with the patient in the lateral decubitus position with the chest closed when both lungs were ventilated, and during the period of OLV. On the recorded flow-volume curves, auto-PEEP was defined as failure of the descending limb of the expiratory flow curve to reach the volume axis at the zero point—a gap in the continuity of the flow-volume curve (fig. 2).

In order to approximate the influence of the size of the DLT on the presence or absence of auto-PEEP, in vitro resistance of the double-lumen endobronchial tubes was determined in our laboratory with the same ventilator and ventilator tubing, using a Fleisch pneumotachograph and a differential pressure transducer. A constant inspiratory flow of 0.35 litre s\(^{-1}\) was used with ventilatory settings similar to that used during anaesthesia. Three measurements were made with each size of DLT and the means used for calculation.

Student's \(t\) test and Fisher's exact test were performed on the results. All data are expressed as mean (SD). \(P < 0.05\) was considered significant.

### RESULTS

The mean age of the patients was 60.5 yr (range 19–78 yr); mean weight and height were 70.9 (SD 15) kg and 167 (8) cm, respectively. We performed 29 right-sided and 10 left-sided thoracotomies. The DLT was inserted into the contralateral (dependent) lung in all patients. Quantitative tests of pulmonary function were available before operation for all patients (table I). There were no significant differences between patients with and without auto-PEEP in ventilatory variables during operation.

According to the criteria described, 26 (67%) patients exhibited auto-PEEP during anaesthesia and in 13 auto-PEEP was not seen. When present, auto-PEEP persisted throughout the procedure, including the periods of two-lung ventilation. When OLV was initiated, the auto-PEEP persisted and did not change significantly as judged from the size of the gap on the flow-volume curve.

Patients in the auto-PEEP group had significantly greater airway resistance (\(R_{aw}\)) (2.4 cm H\(_2\)O litre\(^{-1}\) s\(^{-1}\)) in the preoperative pulmonary function studies compared with patients without auto-PEEP (\(R_{aw}\) 1.7 cm H\(_2\)O litre\(^{-1}\) s\(^{-1}\)) \((P < 0.05)\). The sizes of DLT used and their in vitro resistance are shown in table II. Of the 21 patients in whom the trachea was intubated with large (39- and 41-French gauge) DLT, auto-PEEP was observed in 11 (52%).

---

**TABLE I. Preoperative pulmonary function tests (mean (SD)) in 39 patients scheduled to undergo lung surgery who subsequently exhibited (AP) or did not exhibit (No AP) auto-positive end-expiratory pressure.**

<table>
<thead>
<tr>
<th>Pulmonary function test</th>
<th>AP (n = 26)</th>
<th>No AP (n = 13)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FEV(_1) (litre)</td>
<td>2.1 (0.8)</td>
<td>2.1 (0.9)</td>
</tr>
<tr>
<td>FEV(_1)/FVC%</td>
<td>59.6 (9.8)</td>
<td>61.6 (15.3)</td>
</tr>
<tr>
<td>Raw (cm H(_2)O litre(^{-1}) s(^{-1}))</td>
<td>2.4 (1.1) *</td>
<td>1.7 (0.9)</td>
</tr>
<tr>
<td>FRC (rel%)</td>
<td>141.0 (31.2)</td>
<td>143.8 (60.5)</td>
</tr>
<tr>
<td>RV (rel%)</td>
<td>157.5 (50.1)</td>
<td>162.5 (72.5)</td>
</tr>
</tbody>
</table>

*P < 0.05 between groups*
MONITORING FLOW-VOLUME CURVES

Table II. Characteristics of the double-lumen endobronchial tubes (DLT) and the theoretical combined resistance of the patient's airways (Raw) and the double-lumen endobronchial tubes (RDLT) in the presence (AP) or absence (No AP) of auto-PEEP during anesthesia for lung surgery (mean (SD)). I.d. = Internal diameter; R = resistance; AP = auto-positive end-expiratory pressure.

<table>
<thead>
<tr>
<th>DLT size</th>
<th>I.d. (mm)</th>
<th>Raw (cm H2O litre^-1 s)</th>
<th>RDLT (cm H2O litre^-1 s)</th>
<th>Raw + RDLT (cm H2O litre^-1 s)</th>
<th>AP (n)</th>
<th>No AP (n)</th>
</tr>
</thead>
<tbody>
<tr>
<td>41 F</td>
<td>6.5</td>
<td>3.3 (0.5)</td>
<td>2.2 (1.3)</td>
<td>5.5 (0.2)</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>39 F</td>
<td>6.0</td>
<td>3.6 (0.0)</td>
<td>1.8 (0.7)</td>
<td>5.2 (0.1)</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>37 F</td>
<td>5.5</td>
<td>4.3 (0.3)</td>
<td>2.2 (1.0)</td>
<td>6.5 (0.3)</td>
<td>14</td>
<td>2</td>
</tr>
<tr>
<td>35 F</td>
<td>5.0</td>
<td>4.3 (0.5)</td>
<td>3.8 (1.8)</td>
<td>8.1 (0.5)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>26</td>
<td>13</td>
</tr>
</tbody>
</table>

Smaller endobronchial tubes (35- and 37-French gauge) were used in 18 patients, 15 (83%) of whom had auto-PEEP (P > 0.05). The combined, theoretical total resistance (preoperative Raw plus in vitro resistance of the DLT) was significantly greater (P < 0.05) in the auto-PEEP group.

DISCUSSION

The flow-volume curve has a smoothly curved inspiratory limb influenced largely by the inspiratory flow of the ventilator, and a triangular expiratory limb, with the apex of the triangle representing peak expiratory flow, followed by an exponentially decreasing descending limb, joining the volume axis at the zero flow-volume point [8] (fig. 1). The expiratory part of the flow-volume curve is determined by the rate of passive lung deflation, which is in turn determined by elastic recoil of the lung and chest wall and by the total flow resistance offered by the bronchial tree, tracheal tube, expiratory limb of the ventilator, and any additional equipment [6]. The presence of auto-PEEP is apparent as a gap in the curve between the starting inspiratory and the end-expiratory points of the loop (fig. 2), showing that expiratory flow persisted when inspiration commenced.

Our results indicate that auto-PEEP can be demonstrated during anaesthesia for thoracic surgery in a large proportion of patients, particularly those with an increased Raw before operation. Most patients undergoing lung surgery have pre-existing pulmonary disease with airflow limitation [9], and during mechanical ventilation they demonstrate dynamic hyperinflation [2].

Besides the airflow limitation of the diseased lung, auto-PEEP may be likely to occur during mechanical ventilation either because there is not enough time for lung deflation or because additional equipment (tracheal tube, filters, expiratory valve) is interposed in the system increases expiratory resistance significantly [2, 10].

Tracheal tubes make an important contribution to expiratory resistance, and even in the absence of obstructive disease may provide sufficient resistance to result in auto-PEEP [11]. Double-lumen endobronchial tubes are used routinely to separate the two lungs during anaesthesia for thoracic surgery. The low airflow resistance attributed to these tubes has been identified by in vitro studies [12, 13] and the values may not correspond to in situ resistance because of changes in configuration, kinking and impingement on the tracheal or bronchial wall [14]. The internal diameter of the DLT is particularly important, as each 1-mm decrease in diameter is accompanied by an increase in airflow resistance, in the range 25-100% [15].

We found an increased airflow resistance between the larger (39- and 41-French gauge) and the smaller (35- and 37-French gauge) DLT (table II). The difference was not statistically significant, but may have clinical relevance. In our study, 14 of 16 patients whose trachea was intubated with a 37-French gauge (5.5 mm.i.d.) DLT showed the presence of auto-PEEP, while only five of 10 patients in whom the 6.0-mm i.d. (39-French gauge) DLT was inserted exhibited auto-PEEP. These results indicate that the DLT itself may provide sufficient resistance to result in auto-PEEP, even in patients with normal Raw, and highlight the importance of selecting for use the largest possible DLT [16].

The degree of auto-PEEP cannot be determined with this monitoring technology at the present time, but its presence or absence and its proportion may be displayed readily. Flow-volume monitoring may provide useful guidelines for the management of ventilation during thoracic surgery.

REFERENCES


