Variation in the arterial to end-tidal $P_{CO_2}$ difference during one-lung thoracic anaesthesia†

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SUMMARY

We have measured the arterial to end-tidal $P_{CO_2}$ difference ($P_{a_{CO_2}} - P_{E_{CO_2}}$) in 22 patients undergoing pulmonary resection in the lateral thoracotomy position during two-lung ventilation (TLV) and after transition to one-lung ventilation (OLV). With OLV for each patient, the practice of correcting the estimate by an initial measurement of ($P_{a_{CO_2}} - P_{E_{CO_2}}$) was evaluated by subtracting the initial ($P_{a_{CO_2}} - P_{E_{CO_2}}$) from subsequent values measured at 10-min intervals. Net (uncorrected) and corrected differences during OLV were analysed using ANOVA. ($P_{a_{CO_2}} - P_{E_{CO_2}}$) values during TLV and OLV were similar: mean (SD) 1.3 (0.6) kPa and 1.2 (0.7) kPa, respectively (ns). Mean ($P_{a_{CO_2}} - P_{E_{CO_2}}$) varied in the range 0.2-2.5 kPa, while maximum ($P_{a_{CO_2}} - P_{E_{CO_2}}$) was 0.3-2.8 kPa. The mean (SD) of 133 pairs of measurements with OLV was 1.1 (0.7) kPa. Even after correction, mean ($P_{a_{CO_2}} - P_{E_{CO_2}}$) varied in the range −0.7 to 0.8 kPa; individual extreme values were from −1.3 to 1.7 kPa. Variation between patients was found to be greater than variation within patients for both net and corrected differences (F ratio = 37.0 and 10.9, respectively), although calculating a corrected difference did reduce variation between patients from a mean square value of 2.44 to 0.61. The wide variation in ($P_{a_{CO_2}} - P_{E_{CO_2}}$) suggests that the accuracy of estimation of $P_{a_{CO_2}}$ by monitoring $P_{E_{CO_2}}$, although improved by the use of a corrected difference, remains questionable during OLV. (Br. J. Anaesth. 1994; 72: 21–24)

KEY WORDS


During one-lung anaesthesia, close monitoring of oxygenation is essential [1]. Maintenance of normal arterial carbon dioxide partial pressure ($P_{a_{CO_2}}$) is not generally a problem if the same tidal volume can be maintained when changing from two-lung (TLV) to one-lung ventilation (OLV) [2]. Possibly because of this, there have been few studies on the use of capnography in monitoring the adequacy of ventilation during one-lung anaesthesia [3].

Capnography has been shown to be useful in detecting endobronchial intubation and incorrect placement of double-lumen endobronchial tubes [4]. Dual end-tidal $P_{CO_2}$ ($P_{E_{CO_2}}$) monitoring of both lumens of an endobronchial tube provides continuous assessment of ventilation from each lung during positioning and can verify isolation [5]. Fletcher has reviewed the subject of the arterial to end-tidal $P_{CO_2}$ difference ($P_{a_{CO_2}} - P_{E_{CO_2}}$) during cardiothoracic surgery [6]. The most common indication for thoracotomy in adults is bronchial carcinoma. Patients with this condition are almost exclusively smokers with resultant airways disease; their ($P_{a_{CO_2}} - P_{E_{CO_2}}$) during anaesthesia has been shown to be increased even when they were in the supine position [7]. The lateral position is known to impair ventilation-perfusion relationships in anasthesitized patients [8, 9]. Pansard and colleagues, in a study of 35 patients anaesthetized in the “kidney rest” position, found a significant increase in ($P_{a_{CO_2}} - P_{E_{CO_2}}$) after patients were placed in the lateral decubitus position [10]. Heneghan, Scallan and Branthwaite found mean (SD) values of 1.3 (0.16) kPa and 1.2 (0.12) kPa during TLV and OLV, respectively, in six patients undergoing thoracotomy in the lateral position [11]. We have therefore studied how closely end-tidal $P_{E_{CO_2}}$ values reflect changes in arterial $P_{a_{CO_2}}$ in patients undergoing thoracotomy for pulmonary resection during OLV.

PATIENTS AND METHODS

After obtaining Ethics Committee approval and informed written consent, we studied 22 patients undergoing elective pulmonary resection during one-lung anaesthesia. We excluded patients suffering from symptomatic cardiac disease, the elderly and poor risk patients (ASA > III). A radiologically clear field in the dependent lung was another prerequisite for inclusion. Lung function tests (FEV1, FVC) were performed before operation.

Patients were premedicated with diazepam 10 mg orally 90 min before induction of anaesthesia with...
fentanyl 3 μg kg⁻¹ and propofol 2–3 mg kg⁻¹. Vecuronium 0.1 mg kg⁻¹ was administered to produce neuromuscular block. Anaesthesia was maintained using 100% oxygen supplemented by 1.3% inspired isoflurane and fentanyl as necessary. Intraoperative monitoring consisted of continuous ECG, pulse oximetry, direct arterial pressure via a radial artery cannula, train-of-four and oesophageal temperature. Arterial pressure and heart rate were maintained within 20% of baseline. In each patient, one-lung anaesthesia was produced using a plastic, double-lumen endobronchial tube (Bronchocath) sited using a fibreoptic bronchoscope. Endobronchial tube position was checked with the patient in the lateral position. Ventilation using a Carden ventilator at a rate of 10 b.p.m. was standardized to a tidal volume of 10 ml kg⁻¹ measured by Wright respirometer. These ventilatory settings were chosen to ensure efficient distribution of ventilation to minimize the arterial to end-tidal PCO₂ difference [12] and to allow comparison with previous work [13].

PACO₂ was measured from gas sampled between the double-lumen catheter mount and the Y-piece of the ventilator tubing using a sidestream infra-red capnometer (Datex Capnomac) calibrated according to the manufacturer’s instructions before use in each patient [14]. The capnograph trace was displayed continuously (Datex Cardiocap II). The mean value of PACO₂ from five consecutive breaths was recorded before blood was sampled from the radial artery cannula for analysis using an automatic gas analyser (ABL4, Radiometer, Copenhagen); calibration was checked daily [15]. Values of PACO₂, PACO₂ and PACO₂ were corrected to body temperature and atmospheric pressure as appropriate [16]. Initial measurements were made after 20 min with TLV with the patient in the lateral position. After transition to OLV with the pleura open, measurements were repeated after an additional 20 min; thereafter, repeated estimates of (PACO₂ — PACO₂) were made at approximately 10-min intervals during OLV.

Analysis

Values of (PACO₂ — PACO₂) were computed at each sample point. The presence of a relationship between (PACO₂ — PACO₂) during TLV and OLV, and FEV₁ and FVC (expressed as percentages of predicted values) was investigated using scatter plots and linear regression analysis using the method of least squares. (PACO₂ — PACO₂) during TLV in the lateral position was compared with the first reading during OLV using Student’s paired t test.

To assess the usefulness of the initial (PACO₂ — PACO₂) reading during OLV as an offsetting factor to improve estimates of PACO₂ from PACO₂ as suggested previously [11], we subtracted the initial (PACO₂ — PACO₂) from subsequent values to obtain a corrected difference. We plotted mean (SD) (PACO₂ — PACO₂) and the mean corrected difference for each patient. Net (uncorrected) and corrected differences were analysed using one-way analysis of variance with repeated measures.

One-lung (PACO₂ — PACO₂) values were plotted on the ordinate axis for each patient against PACO₂. Linear regression was carried out and the significance of resultant correlation coefficients was determined using two-tailed levels of significance.

RESULTS

We studied 22 adult patients presenting consecutively for pulmonary resection for bronchial carcinoma (table I). Left sided procedures were performed in 12 patients; five patients underwent pneumonectomy, three had wedge resections and the remainder had lobectomies.

Variation in (PACO₂ — PACO₂) at similar indices of preoperative lung function was large, resulting in no demonstrable significant relationship between (PACO₂ — PACO₂) and FEV₁ and FVC. There was no difference in (PACO₂ — PACO₂) between TLV and OLV, mean 1.3 (SD 0.6) kPa compared with 1.2 (0.7) kPa, respectively. During OLV, the mean number of repeated estimates per patient was six (minimum five, maximum seven), mean (PACO₂ — PACO₂) varied from 0.2 to 2.5 kPa and maximum values were in the range 0.3–2.8 kPa (fig. 1). The mean of 133 pairs of (PACO₂ — PACO₂) measurements on OLV was 1.1 (0.7) kPa (range 0.1–2.8 kPa). Even after correction, mean (PACO₂ — PACO₂) varied from −0.7 to 0.8 kPa; individual extreme values ranged from −1.3 to

| TABLE I. Patient characteristics and preoperative spirometry (mean (SD) [range]) |
|-----------------------------|-----------------------------|
| Age (yr)                    | 58.5 (39–70)                |
| Height (cm)                 | 166 (7.7) [152–180]         |
| Weight (kg)                 | 67.8 (10.7) [60–77]         |
| Sex (M:F)                   | 15:7                        |
| ASA (II:III)                | 14:8                        |
| FEV₁(%)                     | 0.78 (0.21) [0.42–1.1]      |
| FVC (%)                     | 0.91 (0.22) [0.53–1.31]     |

![Fig. 1. Mean (SD) (PACO₂ — PACO₂) values during OLV for each patient, plotted in ascending order of means. Vertical line indicates mean value ((PACO₂ — PACO₂) = 1.1 kPa) for 133 repeated estimates of the net difference.](image-url)
pulmonary resection would be expected to be 0.3-0.6 kPa, depending on ventilator settings [18].

anaesthesia, PE'Pa^ generally underestimates PE'CO.) (Paco, — PE'CO.) for a group of patients presenting for pulmonary resection, has been recommended [12, 18], with a median (Paco, — PE'CO.) value of 0.3 to 0.6 kPa, depending on ventilator settings [18]. (Paco, — PE'CO.) in a group of patients presenting for pulmonary resection would be expected to be increased. Werner and colleagues [13] studied 17 such patients: mean (Paco, — PE'CO.) supine was approximately 0.6 kPa at Paco, 3.7 kPa and a ventilatory frequency of 10 b.p.m. PE'CO was measured from each lung in the lateral position: (Paco, — PE'CO.) was zero from the dependent lung and 1.4 kPa from the upper lung. If combined (Paco, — PE'CO.) had been measured, it is likely that it would have been large, as the upper lung would make the greater contribution to late expiration [6]. This was confirmed by the findings of Heneghan, Scallon and Branthwaite [11] and in the present study: mean (Paco, — PE'CO.) was 1.3 (0.16) kPa and 1.3 (0.6) kPa, respectively.

During OLV, the presence of the right-to-left shunt through the upper lung results in an increased measured physiological deadspace and may be expected to lead to an increased (Paco, — PE'CO.) but this (Paco, — PE'CO.) may not be greater than the original two-lung value [6]. This is confirmed by both our findings and those of Heneghan’s group [11]. During OLV, in the absence of any confounding or inhibiting factors to the hypoxic vasoconstriction response (HPV), the non-dependent: dependent lung blood flow ratio is estimated to be about 20:80 [19, 20]. The addition of 1 MAC isoflurane anaesthesia may be expected to cause a 21% decrease in the HPV response [20], with an increase in total shunt to about 24% [21]. In children with right-to-left shunt, there is a strong relationship between Paco, (Paco, — PE'CO.) at Paco, less than 10 kPa [22]. In the present study, in which oxygenation was well maintained, there was no significant relationship between Paco, and (Paco, — PE'CO.) in each patient, thus implying that the shunt fraction was of insufficient size to result in a significantly increased arterial to end-tidal gradient. That (Paco, — PE'CO.) decreased in three of four patients after pulmonary artery clamping (table II) suggests the intrapulmonary shunt may contribute to the gradient during OLV, although this could be just a reflection of the wide within-patient variation in (Paco, — PE'CO.).

The range of values of (Paco, — PE'CO.) during TLV and OLV in the 22 patients in this study was wider than that in the smaller study by Heneghan, Scallon and Branthwaite [11]. We were unable to demonstrate any significant correlation between preoperative lung function tests (FEV1 and FVC) and (Paco, — PE'CO.) which may have helped in identifying those patients with a significant discrepancy between Paco, and PE'CO.

Intraoperative variation in (Paco, — PE'CO.) values reflects changes in ventilation-perfusion relationships in the dependent lung. Impairment of gas exchange can be demonstrated with prolongation of anaesthesia [23]. Gunnarsson and colleagues noted significant increases in shunt and large increases in atelectasis between 30 and 90 min after induction [24]. In addition to this loss of dependent lung volume with anaesthesia, there is circumferential compression of the dependent lung by the mediastinum, abdominal contents and surgical manoeuvres [9]. Secretions may accumulate and there may be transudation of fluid in the dependent lung (which

<table>
<thead>
<tr>
<th>Patient</th>
<th>Paco (kPa)</th>
<th>(Paco — PE'CO) (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A: Before CC</td>
<td>16.7</td>
<td>1.6</td>
</tr>
<tr>
<td>After CC</td>
<td>55.5</td>
<td>1.3</td>
</tr>
<tr>
<td>B: Before CC</td>
<td>54.6</td>
<td>1.6</td>
</tr>
<tr>
<td>After CC</td>
<td>69.1</td>
<td>1.5</td>
</tr>
<tr>
<td>C: Before CC</td>
<td>39.8</td>
<td>0.7</td>
</tr>
<tr>
<td>After CC</td>
<td>58.6</td>
<td>0.8</td>
</tr>
<tr>
<td>D: Before CC</td>
<td>15.1</td>
<td>1.6</td>
</tr>
<tr>
<td>After CC</td>
<td>27.3</td>
<td>1.3</td>
</tr>
</tbody>
</table>

1.7 kPa (fig. 2). Variation between patients was greater than that within patients for both net and corrected differences (F ratio 37.0; df 21, 111; P < 0.001 and F ratio 10.9; df 21, 89; P < 0.001, respectively), although calculating a corrected difference did reduce variation between patients from a mean square value of 2.44 to 0.61.

There was no significant relationship between (Paco, — PE'CO.) and Paco, in each patient. In three of four patients undergoing pneumonectomy, (Paco, — PE'CO.) was reduced after pulmonary artery clamping (table II).

**DISCUSSION**

The measurement of PE'CO has been recommended for non-invasive estimation of Paco, [17]. During anaesthesia, PE'CO generally underestimates Paco, [12, 18], with a median (Paco, — PE'CO.) value of 0.3-0.6 kPa, depending on ventilator settings [18]. (Paco, — PE'CO.) in a group of patients presenting for pulmonary resection would be expected to be

![Fig. 2. Mean (SD) of corrected (Paco — PE'CO) (obtained by subtracting the initial value from subsequent values) for the same patients as in figure 1, plotted in the same order. If a corrected estimate was of significant value in improving the accuracy of our estimation of Paco, from PE'CO monitoring, one would expect the mean corrected (Paco — PE'CO) to be close to 0 and the error bars indicating to overlap and cross the corrected (Paco — PE'CO) = 0 in both directions.](image-url)

**TABLE II. Changes in (Paco — PE'CO) in four patients after pulmonary artery cross-clamping (CC)**
may be vertically below the left atrium), leading to airway closure [25]. Pulmonary vascular resistance in the dependent lung determines the ability of the ventilated lung to accept redistributed blood flow from the hypoxic lung. The increased airway pressures that may be needed to ventilate the dependent lung would, by increasing dependent lung vascular resistance, cause diversion of right ventricular outflow to the non-dependent lung [26]. Hence, the use of capnography combined with continuous spirometry [27] may prove more useful in reducing the variation in \((P_{a}CO_2 - P_{e}CO_2)\) by identifying changes in compliance and expiratory flow characteristics. By varying dependent lung ventilation and perfusion, these combined factors are the most likely sources of variation in \((P_{a}CO_2 - P_{e}CO_2)\) during OLV.

In the supine position, the variation in \((P_{a}CO_2 - P_{e}CO_2)\) within patients has been shown to be comparable to or greater than between patients [28]. This is at variance with our own findings during OLV, when variation between patients was found to be greater than within patients for both net and corrected differences. The use of a corrected estimate obtained by subtracting the initial value of \((P_{a}CO_2 - P_{e}CO_2)\) did reduce variation between patients from a mean square value of 2.44 to 0.61. However, even after correction, mean \((P_{a}CO_2 - P_{e}CO_2)\) varied in the range -0.7 to 0.8 kPa (fig. 2). This suggests that the accuracy of estimation of \(P_{a}CO_2\) from \(P_{e}CO_2\) monitoring, although improved by the use of a corrected difference, remains questionable during OLV.

REFERENCES