THE EFFECT OF UPPER ABDOMINAL SURGERY ON THE RELATIONSHIP OF AIRWAY CLOSING POINT TO END TIDAL POSITION


University Department of Anaesthesia, Western Infirmary, and Department of Clinical Physics and Bio-Engineering, Western Regional Hospital Board, Glasgow

(Received 24 February 1972)

SUMMARY

1. The relationship between end tidal position (ETP) and the point of lung emptying at which there is significant airways closure (CP) has been investigated before and after upper abdominal surgery in thirty-one patients.

2. A significant negative correlation between the index (ETP-CP) and the alveolar-arterial $P_{O_2}$ difference ($A-aP_{O_2}$) was found.

3. Nineteen of these patients had a vagotomy and drainage operation and, in this group, there was a greater fall in ETP than in CP in the first and second postoperative days.

4. It is suggested that airway closure is a contributory factor to the known hypoxaemia following abdominal surgery.

Key words: airway closure, alveolar-arterial oxygen difference, end tidal position, gastric surgery.

Dollfuss, Milic-Emili & Bates (1967) produced evidence to suggest that, during expiration from total lung capacity to residual volume, a point is reached at which a significant number of small airways in dependent regions of lung are closed with consequent alveolar gas trapping. This is termed the closing volume (CV). Its size depends on many factors, the most important of which is the trans-pulmonary pressure. In young subjects, CV lies in the expiratory reserve volume (ERV), but it increases with age.

It is to be expected that airway closure will cause ventilation/perfusion (V/Q) inequality within the lung and Anthonisen, Danson, Robertson & Ross (1969) have ascribed the fall in $P_{a_o_2}$ with age to this phenomenon. It seems reasonable to suggest that the relationship of the point of airway closure (CP) to the end tidal position (ETP) will be important in determining the extent of the V/Q disturbance. Thus a young patient with his CP in the ERV will have less disturbance than an older patient whose CP is within the tidal breathing range.

In a situation where there is temporary external compression of the chest wall or spasm

Correspondence: Dr A. A. Spence, University Department of Anaesthesia, Western Infirmary, Glasgow.
of the expiratory muscles, the functional residual capacity (FRC) will be reduced and the resting ventilation will take place at a lower lung volume and higher trans-pulmonary pressure. Airway closure will therefore occur earlier during expiration than previously and the CP will approach or precede the ETP. Cohen, Bell, Saltzman & Kylstra (1971) have shown that immersion of human volunteers up to their necks in water causes an increase in the alveolar-arterial $P_{O_2}$ difference ($A-aD_{O_2}$). Spence & Alexander (1972) have postulated that airway closure might be an important factor in producing the well-known reduction in $P_{a,O_2}$ after abdominal surgery. Their hypothesis was based on the following observations.

1. Postoperative hypoxaemia is known to be the result of ventilation/perfusion disturbance (Troell, 1951).
2. FRC and ETP fall after abdominal surgery (Beecher, 1933).
3. Abdominal wound pain and consequent muscle spasm causes a rise in pleural surface pressure (Bromage, 1967).

This fall in functional residual capacity and rise in trans-pulmonary pressure might cause a shift in the relationship of CP to ETP. The present study was designed to investigate this relationship before and after upper abdominal surgery and to relate the findings to the measured hypoxaemia induced by operation.

**MATERIALS AND METHODS**

Thirty-one patients having various types of upper abdominal surgery through a right para-median incision were studied before and on the first, second and fifth day after operation. Of these, nineteen had a vagotomy and drainage operation. The remainder did not constitute such a homogeneous group and included patients having cholecystectomy and other types of gastric surgery. During anaesthesia the inspired oxygen concentration did not exceed 35%. After anaesthesia the patients breathed room air. At all times during the studies the patients were in bed in the laboratory and lay in a standard semi-recumbent position. All the procedures were fully explained to the patients who freely gave their consent.

Arterial blood from the radial artery was collected in heparinized plastic syringes and analysed immediately for $P_{O_2}$, $P_{CO_2}$ and pH with the appropriate Radiometer electrodes. The $P_{O_2}$ electrode cathode was covered with a 25 $\mu$m teflon membrane. A factor of 1.065 was applied to the measured $P_{O_2}$ of blood to allow for the different response of the electrode to air, which was used for calibration, and to blood. Where appropriate, the blood gases were corrected for temperature by using the Severinghaus slide rule (Severinghaus, 1966).

The alveolar–arterial $P_{O_2}$ difference was calculated as follows:

$$A-aD_{O_2} = P_{A,O_2} - P_{a,O_2}$$

where $P_{A,O_2} = P_{1,O_2} - (P_{a,CO_2}/R)$ and $P_{A,O_2} = alveolar$ $P_{O_2}$; $P_{a,CO_2} = arterial$ $P_{CO_2}$; $P_{1,O_2} = inspired$ $P_{O_2}$; $R = respiratory$ quotient (assumed to be 0.8).

The method of Dollfuss et al. (1967) was used to measure CP. The patient breathed from a closed-circuit spirometer fitted with an oxygen stabilizer. The spirogram was recorded on the conventional moving paper chart and also on the $X$ axis of a Bryans 24000 $XY$ recorder. After four or five tidal breaths the lungs were emptied to residual volume and a bolus of about 2 ml of air containing $^{133}$Xe was injected into the mouthpiece. The patient then inspired to total lung capacity and re-expired slowly to residual volume. The $^{133}$Xe concentration of the expired
gas was monitored with a sodium iodide scintillation counter, set at 90° into a lead-shielded cuvette between the mouthpiece and the circuit. The scintillation counter was connected to a pulse-height analyser and an analogue rate meter. The output of the rate meter was recorded on the Y axis of the XY recorder.

The expired $^{133}$Xe concentration pattern has distinctive zones consisting of a steep rise (alveolar and dead space gas) to an 'alveolar' plateau. A 'knee' or steep increase in concentration at the end of the alveolar plateau has been shown to denote CP (Dollfuss et al., 1967). For each study the difference between ETP and CP was calculated: (ETP - CP). A positive value signifies that CP lies in the expiratory reserve volume. Where CP is greater than ETP, a negative value results. All gas volumes were corrected to B.T.P.S.

RESULTS

Fig. 1 shows A-a$\Delta$O$_2$ plotted against (ETP - CP) for all studies both before and after operation. There is a significant negative correlation between these indices ($r = 0.6; P < 0.001$).

Table 1 lists the change in (ETP - CP) and A-a$\Delta$O$_2$ on the first, second and fifth days after operation in the nineteen patients undergoing vagotomy and drainage. This has been calculated as the difference between each postoperative value and the corresponding pre-operative value. Thus a patient with (ETP - CP) of 0.3 litre before operation and -0.1 litre on the first postoperative day (i.e. CP now precedes ETP) would have a value: $0.3 - (-0.1) = 0.4$ litre entered in the column for day 1.
In thirteen out of sixteen patients, CP came nearer to, or preceded ETP, on day 1. The mean difference between the pre-operative and postoperative values for (ETP - CP) was 0.35 litre (SEM 0.021). This was accompanied by a mean increase in the A-aDo\textsubscript{2} of 18.4 mmHg (SEM 1.90). A similar pattern was obtained on the second day, but by the fifth day the CP had returned to its pre-operative relationship to the ETP and this was associated with an improved A-aDo\textsubscript{2}.

**TABLE 1.** Sex, age, (ETP - CP) and A-aDo\textsubscript{2} for nineteen patients convalescing after upper abdominal surgery

<table>
<thead>
<tr>
<th>Sex</th>
<th>Age</th>
<th>Δ (ETP - CP) (l)</th>
<th>Δ A-aDo\textsubscript{2} (mmHg)</th>
<th>Sex</th>
<th>Age</th>
<th>Δ (ETP - CP) (l)</th>
<th>Δ A-aDo\textsubscript{2} (mmHg)</th>
<th>Sex</th>
<th>Age</th>
<th>Δ (ETP - CP) (l)</th>
<th>Δ A-aDo\textsubscript{2} (mmHg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M</td>
<td>46</td>
<td>+1.58</td>
<td>17</td>
<td>M</td>
<td>47</td>
<td>-0.17</td>
<td>9</td>
<td>M</td>
<td>44</td>
<td>-0.01</td>
<td>16</td>
</tr>
<tr>
<td>M</td>
<td>48</td>
<td>-0.31</td>
<td>12*</td>
<td>M</td>
<td>50</td>
<td>+0.41</td>
<td>23</td>
<td>M</td>
<td>40</td>
<td>+0.15</td>
<td>21</td>
</tr>
<tr>
<td>M</td>
<td>42</td>
<td>+0.05</td>
<td>21</td>
<td>M</td>
<td>29</td>
<td></td>
<td></td>
<td>M</td>
<td>30</td>
<td>+0.11</td>
<td>18</td>
</tr>
<tr>
<td>M</td>
<td>68</td>
<td>+0.36</td>
<td>10</td>
<td>M</td>
<td>44</td>
<td>+0.24</td>
<td>24</td>
<td>M</td>
<td>27</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>40</td>
<td>+0.03</td>
<td>17</td>
<td>M</td>
<td>36</td>
<td>+0.18</td>
<td>25</td>
<td>M</td>
<td>43</td>
<td>+1.47</td>
<td>25</td>
</tr>
<tr>
<td>M</td>
<td>60</td>
<td>+0.08</td>
<td>1</td>
<td>M</td>
<td>60</td>
<td>-0.02</td>
<td>-5</td>
<td>M</td>
<td>43</td>
<td>+0.71</td>
<td>32</td>
</tr>
<tr>
<td>F</td>
<td>49</td>
<td>+0.66</td>
<td>23</td>
<td>M</td>
<td>31</td>
<td></td>
<td></td>
<td>M</td>
<td>43</td>
<td>+0.71</td>
<td>32</td>
</tr>
</tbody>
</table>

Mean 43.0
SEM 2.34
n 19

Significance of difference from pre-operative mean

<table>
<thead>
<tr>
<th>P</th>
<th>P</th>
<th>P</th>
<th>P</th>
<th>NS</th>
<th>NS</th>
</tr>
</thead>
</table>

* *Pyrexia on days 1 and 2. Radiologically detectable bilateral basal collapse on day 2.

**DISCUSSION**

These findings demonstrate a relationship between the index (ETP - CP) and the A-aDo\textsubscript{2}, and would support the hypothesis that small airway closure may be a factor in the causation of intrapulmonary shunting of blood. Although there may be dispute as to whether, in fact, small airways do close or whether they are only narrowed, there would be a significant mechanical effect in either case leading to maldistribution of inspired gas.
Airway closure after upper abdominal surgery

It is also clear that the difference in relationship between ETP and CP in the postoperative period appears to be a factor in the production of the hypoxaemia which results from an upper abdominal wound. It is important to note that, although the group trends are as stated, we have been unable to demonstrate a significant correlation between the individual changes of A–aD02 and the individual changes in (ETP – CP). There are several explanations for this. It may be that (ETP – CP) is not the best index and that CV/FRC\% is better. This requires measurement of FRC which is difficult to achieve in ill patients. In addition, it should be remembered that in some patients, at least, there may be areas of lung collapse. Under these circumstances, the forces acting on small airways may operate towards reducing CV. Once again, the measurement of FRC may throw some additional light on this matter. It is interesting that the patient who had the largest negative value for change in (ETP – CP) on day 1 had radiologically obvious basal collapse on day 2 and presented clinically as a typical postoperative pneumonia.

ACKNOWLEDGMENTS

This work was supported by a grant from the Secretary of State for Scotland. We are grateful to the Board of Management for Glasgow Western and Gartnavel Hospitals for help with the purchase of equipment. We thank Mr Hugh Gorman for technical assistance and our surgical and nursing colleagues for co-operation.

REFERENCES