DIFFERENTIAL LUNG VENTILATION

R. F. Seed and M. K. Sykes

SUMMARY
The respiratory gas exchange of each lung was measured in dogs using a tracheal divider positioned with the aid of a bronchoscopic telescope. The proportions of tidal volume ($V_t$), oxygen consumption ($V_{O_2}$) and carbon dioxide output ($V_{CO_2}$) contributed by each lung were similar in the supine and lateral positions during spontaneous ventilation. During controlled ventilation the proportions were unchanged in the supine position but there was an increase in the proportion of $V_t$, $V_{O_2}$ and $V_{CO_2}$ contributed by the upper lung in the lateral position. When ventilation to the lower lung was increased to produce equal end-tidal $CO_2$ concentrations in both lungs the proportion of $V_t$, $V_{O_2}$ and $V_{CO_2}$ contributed by each lung returned to values found in the supine position.

In 1950 Rothstein, Landis and Narodick showed that the oxygen uptake of the lower lung exceeds that of the upper lung during spontaneous ventilation in the lateral position in man. This suggested that pulmonary blood flow was greater in the dependent lung, probably because of a gravitational redistribution of flow. Some years later Svanberg (1957) demonstrated in man that the lower lung is always better ventilated, regardless of the side on which the subject is lying. Thus it would seem that during spontaneous ventilation in the lateral position the increased perfusion of the lower lung is matched by increased ventilation so that the ventilation/perfusion ratios of the two lungs are not greatly altered.

However, when controlled ventilation is instituted in the lateral position these relationships are disturbed. Perfusion is still greater in the lower lung but ventilation is not increased as the high diaphragm of the lower side no longer confers any mechanical advantage (Barth et al., 1957; Doerfel, 1959). Furthermore the weight of the mediastinal contents on the lower lung limits its ability to expand during controlled ventilation so that a larger proportion of the total ventilation enters the upper lung (Rehder, Theye and Fowler, 1964). Potgieter (1959) demonstrated that there was a considerable reduction in the total compliance of the lower lung and chest wall in patients in the lateral nephrectomy position and that the volume of the dependent lung and thoracic cavity was smaller (as judged by radiological studies). He postulated that since the lower lung could not be adequately ventilated during controlled ventilation, there might be a higher incidence of postoperative chest complications affecting the lung which had been dependent during the surgical procedure. Browne and associates (1970) have subsequently shown that the substitution of a nitrogen-containing mixture for nitrous oxide in the inspired gases throughout operation for repair of hiatus hernia is associated with a highly significant reduction in the incidence of postoperative atelectasis in the dependent lung. This suggests that the collapse of alveoli distal to closed airways is delayed by the use of the relatively insoluble nitrogen.

The aim of the present work was to determine whether the altered gas exchange during controlled ventilation in the lateral position could be restored to normal by increasing the ventilation to the lower lung.

METHODS
Six adult greyhounds were anaesthetized with an intravenous injection of 5 per cent sodium thiopentone (25–30 mg/kg). An endotracheal tube was then passed and anaesthesia maintained with 0.5–1 per cent halothane in air with spontaneous ventilation until the surgical preparations had been completed. Anaesthesia was then continued with intermittent intravenous injections of chloralose 40–80 mg/kg, the dogs breathing air throughout the remainder of the experiment.
Differential Lung Ventilation

After induction of anaesthesia a catheter was passed into the pulmonary artery via the external jugular vein by the method of Fife and Lee (1965) and the abdominal aorta was cannulated via the femoral artery. Both these catheters were connected to pressure transducers (Consolidated Electrodynamics) and their outputs were recorded on a heated stylus recorder (Devices Ltd.). Body temperature was measured with a mercury in glass thermometer placed in the rectum. A slow intravenous infusion of normal saline was continued during the experiment.

Following these preparations a low tracheostomy was performed and the airway examined with a bronchoscope to determine the positions of the orifices of the right and left upper lobe bronchi. A specially constructed metal, double lumen tracheal divider (fig. 1) was then inserted and the trachea ligated around it. The divider was constructed from two straight steel tubes each of 0.8 cm internal diameter and length 33 cm brazed together in parallel. At the proximal end of each there was a side arm for connection to the non-rebreathing valve systems. The distal ends were cut obliquely and angled at 10° away from the mid-line and grooved circumferentially. A child's toy balloon was pulled over the ends of the two endobronchial outlets, tied down with linen thread to the grooves on the endobronchial ends of the tube and the rubber cut away to expose the orifices. Another thread secured the neck of the balloon to the main shafts of the tubes. The balloon could be inflated by a metal tube (2 mm I.D.) running down between the two main tubes. When the balloon was inflated an airtight seal was provided both around the main tube and also between the endobronchial outlets at the carinal notch.

The double-lumen tube was inserted with a fore-oblique bronchoscopic telescope inside one tube so that the division between the ends of the endobronchial tubes could be placed astride the carina under direct vision. The cuff was inflated, again under direct vision, and care taken to ensure that none of the bronchial openings were occluded on either the right or left sides. To check that the right and left sides were effectively separated, one tube was connected to an underwater seal of 1 cm H₂O resistance while the other was connected to a source of oxygen and inflated to a pressure of 35–40 cm H₂O. There was an initial flow of bubbles through the underwater seal due to mediastinal displacement but bubbling then ceased. If it continued it was considered that separation was not adequate: the tube was therefore repositioned and the cuff readjusted until no “blow-over” occurred. When the position of the double-lumen tube was satisfactory both lungs were inflated three times from a common source to a pressure of 30 cm H₂O to centralize the mediastinum. This checking procedure was repeated on each side to confirm the position of the tube whenever the animal was turned to a new position.

Measurements of the function of each lung were first made during spontaneous ventilation in the supine and right lung dependent positions using matched Dräger non-rebreathing valves to separate inspired and expired gas streams. The dogs were then ventilated with a Cape ventilator, the Dräger valves being exchanged for collect valves with carefully matched characteristics (Sykes, 1969). Measurements of lung function in the supine and lateral positions were repeated.

When these measurements had been completed the dog was maintained in the right lung dependent position. Ventilation to the lower lung was then increased by partially occluding the tube leading to the upper lung by means of a screw-clip. The expired gas from the upper lung was allowed to escape freely via a bypass tube containing a low resistance one-way flap-valve (fig. 2). By gradually increasing the proportion of the total ventilation diverted to the lower lung it was possible to achieve a state in which the end-tidal carbon dioxide concentrations from the two lungs became equal. (It was felt that this provided the best guide to the matching of ventilation to perfusion on each side.) Measurements of the function of each lung were then repeated. A period of 45 min was allowed to elapse after conditions were changed to ensure that a reasonably steady state existed during each set of measurements.

Measurements.

Expired gas from the Dräger or collect valves on each side was passed through twin gas collection systems consisting of a mixing unit (Sykes, 1968).
and a calibrated dry gas meter. Gas volumes were measured over periods of 3–5 min and the gas temperature was noted. Respiratory rate was counted during spontaneous ventilation and set at 15–20 b.p.m. during artificial ventilation. Mixed expired gas concentrations were determined on two paramagnetic oxygen analysers (Servomex Model OA 101 Mk II) calibrated on “white spot” nitrogen, air and oxygen whilst end-tidal and mixed expired CO₂ concentrations were determined on an infra-red CO₂ analyser (Hartmann-Braun URAS 4) calibrated with air and CO₂ and air mixtures. Mixed expired gas samples were checked on the O₂ and CO₂ electrodes. Duplicate blood samples from the femoral and pulmonary artery catheters were collected slowly in heparinized 5 ml plastic syringes during the period of expired gas sample collection and a blood sample was also taken for haemoglobin estimation. Blood samples were analysed immediately for Po₂, PCO₂ and pH using duplicate electrode systems consisting of a Radiometer E5046 oxygen electrode, a Severinghaus carbon dioxide electrode and a Radiometer capillary glass electrode standardized against precision buffer solutions. The output from the oxygen and pH electrodes was read on a Radiometer pH 27 meter whilst the output from the carbon dioxide electrode was read on a Vibron electrometer model C33B (Electronic Instruments Ltd., Richmond, Surrey). The oxygen, carbon dioxide and pH electrode systems were calibrated and checked as has been described previously (Sykes and Lumley, 1969). A blood-gas factor of 1.04 was applied to the measured blood oxygen tensions (Adams and Morgan-Hughes, 1967) and temperature corrections were applied to the blood gas tensions measured at 37°C (Kelman and Nunn, 1966).

Calculations.
All calculations, apart from compliance, were performed on an Elliott 4100 computer, utilizing a programme written by Adams (1970). The respiratory exchange ratio used in the alveolar air equation for calculation of total venous admixture in these experiments was calculated from the sum of the CO₂ outputs and O₂ consumptions from each lung. All the other calculations were based on standard equations. The data obtained were submitted to statistical analysis using Student’s paired t test.

Effective compliance of the lung plus chest wall in the three sets of circumstances (supine, right lateral and right lateral with equal end-tidal CO₂) during controlled ventilation was calculated from each tidal volume divided by the relevant airway pressure at the end of inspiration for both the right and left lung of each dog. The mean effective compliance for each lung of the six dogs is expressed in table II in ml/cm H₂O.

RESULTS
When the gas exchange data for both lungs were summed there were no statistically significant differences in tidal volume (VT), oxygen consumption (VO₂) or CO₂ output (VCO₂) between any of the five phases of the study. There were no significant differences in arterial CO₂ tension (PaCO₂), arterial O₂ tension (PaO₂), total venous admixture (Qva/Qt) or mean pulmonary artery pressures (table I).

During spontaneous ventilation in both the supine and right lung dependent positions there were significant differences in VT, VO₂ and VCO₂ between the right and left lungs (P<0.05), the ratios of the measurements between right and left lungs being approximately 60:40 (table II).
Differential Lung Ventilation

TABLE I. Mean values for respiratory data summed from both lungs. (\(=PE'\text{CO}_2\) indicates ventilation to lower lung increased until end-tidal \(\text{CO}_2\) concentrations were equal)

<table>
<thead>
<tr>
<th></th>
<th>Spontaneous ventilation</th>
<th>Controlled ventilation</th>
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<tr>
<td></td>
<td>Supine R.lung dependent</td>
<td>Supine R.lung dependent = (PE'\text{CO}_2)</td>
</tr>
<tr>
<td>(V_t) (mlBTPS)</td>
<td>m (SD) 590 (262)</td>
<td>m (SD) 450 (76)</td>
</tr>
<tr>
<td>(V_{\text{CO}_2}) (ml/min STPD)</td>
<td>189 (14) 224 (47)</td>
<td>179 (39) 200 (18) 189 (14)</td>
</tr>
<tr>
<td>(V_{\text{O}_2}) (ml/min STPD)</td>
<td>197 (20) 234 (58)</td>
<td>193 (36) 207 (31) 196 (27)</td>
</tr>
<tr>
<td>(P_{\text{aCO}_2}) (mm Hg)</td>
<td>47.1 (3.8) 46.0 (4.8)</td>
<td>44.0 (8.6) 45.5 (8.9) 42.5 (4.7)</td>
</tr>
<tr>
<td>(P_{\text{aO}_2}) (mm Hg)</td>
<td>88.5 (5.8) 83.5 (8.6)</td>
<td>89.6 (8.7) 87.2 (8.0) 90.0 (4.5)</td>
</tr>
<tr>
<td>(Q_{\text{va}}/Q_t) (%)</td>
<td>13.5 (4.4) 17.7 (8.5)</td>
<td>11.5 (5.3) 13.0 (6.0) 11.2 (4.6)</td>
</tr>
<tr>
<td>PAP (m)</td>
<td>14.7 (3.8) 16.7 (7.2)</td>
<td>16.0 (5.8) 16.2 (3.9) 18.7 (5.2)</td>
</tr>
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There were no statistically significant differences between any of the five conditions.

\(\text{PAP (m)} = \text{mean pulmonary artery pressure.}\)

TABLE II. Mean values and standard deviations for right and left lungs during spontaneous and controlled ventilation.

<table>
<thead>
<tr>
<th></th>
<th>Spontaneous ventilation</th>
<th>Controlled ventilation</th>
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<tbody>
<tr>
<td></td>
<td>Supine Right lung dependent</td>
<td>Supine Right lung dependent = (PE'\text{CO}_2)</td>
</tr>
<tr>
<td></td>
<td>Right lung (lower) Left lung</td>
<td>Right lung (lower) Left lung</td>
</tr>
<tr>
<td>(V_t) (ml)</td>
<td>mean 275.2 195.7 352.4 237.6 237.3* 212.2† 193.5** 254.9†† 229.9*** 211.8†††</td>
<td></td>
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<tr>
<td></td>
<td>SD 78.5 36.2 96.0 96.4 36.7 40.0 30.0 36.7 28.2 34.9</td>
<td></td>
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<tr>
<td>(V_{\text{O}_2}) (ml/min)</td>
<td>mean 121.9 75.2 147.2 87.2 115.9* 77.4† 108.1** 98.7†† 116.1*** 80.0†††</td>
<td></td>
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<tr>
<td></td>
<td>SD 17.2 6.7 31.3 40.6 17.9 19.0 13.7 20.9 14.3 21.5</td>
<td></td>
</tr>
<tr>
<td>(V_{\text{CO}_2}) (ml/min)</td>
<td>mean 115.2 73.6 134.7 87.7 107.7* 71.6† 94.7** 105.0†† 110.7*** 78.6†††</td>
<td></td>
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<tr>
<td></td>
<td>SD 12.9 6.7 35.4 40.6 13.5 21.0 10.8 14.5 11.2 14.9</td>
<td></td>
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<tr>
<td>Compliance (ml/cmH(_2)O)</td>
<td>mean - - - 29 25 21 28 21 23 23</td>
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<td>SD 5 6 4 6 3 3 3 8 8</td>
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\(\text{Statistical Comparisons (t-test).}\)

- Left lung († to †† P<0.05)
- Right lung * to ** P<0.05
- †† to ††† P>0.05
- ** to *** P>0.05
During controlled ventilation in the supine position the distribution of ventilation became more even although the ratios of \( V_{CO_2} \) and \( V_O_2 \) remained at approximately 60:40 (right: left). However, when the animals were turned into the right lung dependent position there was a reduction of ventilation to the lower lung and an increase in ventilation to the upper lung, the changes in each lung being significant \((P<0.05)\). The changes in \( V_{CO_2} \) and \( V_O_2 \) were similar in direction and were also significant at the \( P<0.05 \) level but the change in \( V_{CO_2} \) was more marked than the change in \( V_O_2 \).

When ventilation was adjusted so that end-tidal \( CO_2 \) concentrations were equal in the right lung dependent position it was found that \( V_T \), \( V_{CO_2} \), and \( V_O_2 \) returned to values which were not significantly different from those existing during controlled ventilation in the supine position.

Effective compliance was lower in the left lung than the right during controlled ventilation in the supine position but was lower in the right lung in the right lung dependent position. The difference in effective compliance was reduced when ventilation to the lower lung was increased to make end-tidal \( CO_2 \) concentrations equal.

**DISCUSSION**

A major problem in this study was to separate the right and left lungs from each other and to ensure that they remained effectively separated regardless of position. Small Carlens and left-sided Robertshaw endobronchial tubes were initially used in a pilot study on two dogs. However, with these tubes it was not possible to guarantee that effective separation of the two gas streams had been achieved and that all the segments of each lung were being ventilated. A study of the bronchial anatomy in a number of greyhounds (fig. 3) indicated that conventional double-lumen tubes were not suitable for this species. The angle between the bronchi is less than in the human and the carina is narrow. Furthermore the right upper lobe bronchus commonly originates either at the level of the carina or just below this point. In the greyhound even the left upper lobe bronchus has a high origin so that the endobronchial cuffed portion of a conventional left-sided double-lumen tube tends to occlude this orifice.

The construction of a special tracheal divider with the endobronchial ends diverging only \( 10^\circ \) from each other ensured that the tube straddled the sharp carina. A further advantage of two straight tubes was that a fore-oblique telescope could be passed down each tube so that the airway on each side could be carefully inspected after inflation of the balloon. This ensured that no lobar orifice was obstructed by the tube or by the inflated cuff.

Several authors have described techniques for differential pulmonary function studies using conventional double-lumen tubes or modifications thereof. The “George Wright” tracheal divider (Rahn and Bahnson, 1953) is very similar to that described here. It was modified by Lategola and Schilling (1958) to avoid the theoretical possibility of a rigid tube exerting leverage against the right pulmonary artery as it crosses the carina, thus interfering with the true evaluation of differential pulmonary function. Benfield, Coon and Gee (1966) described a silastic tube based on the Carlens design with a short left sided cuffed endobronchial portion and a cuff 2–3 cm from the carinal bifurcation of the tube.

The correct positioning of these tubes has also presented problems. Most authors have positioned the tube under fluoroscopic control. Benfield, Coon and Gee (1966) utilized a metal guide to find the carina during fluoroscopy and then passed the bronchospirometry tube over it. The use of a fore-oblique telescope inside one or other lumen of the tube offers a technique whereby the patency of the airway can be ensured and would seem to confer a
practical advantage in determining effective separation and function of the two lungs. The position of the inflatable cuff can be accurately ascertained and hyper-inflation of the cuff with resultant bronchial occlusion can be avoided.

Methods of testing the separation of the gas streams to each lung include auscultation of each side with the other occluded, a leak test whereby the two tubes are connected to a double spirometer with successive weighting of each bell and observation of the spirometer tracing (Gee, Benfield and Rasmussen, 1968), and the introduction of helium into one side of the tube with helium analysis of the air from the opposite lung (Benfield, Coon and Gee, 1966). A high positive pressure applied to one side with the other connected to an underwater seal is also an effective way of testing for leakage of gas from one side to the other. It must be emphasized, however, that the position of the tracheal divider must be rechecked whenever the position of the preparation is changed.

If the tracheal divider were to be used for the study of bilateral lung function in experimental studies of lung transplantation, the length of the divider would have to be increased to permit oral intubation. A longer fore-oblique telescope would then be required.

Gas exchange.

The efficiency with which gas is exchanged in the lung depends on the matching of ventilation to perfusion. At first sight it would appear that \( \text{CO}_2 \) elimination would be primarily dependent on ventilation whilst oxygen consumption would be mainly related to pulmonary blood flow. In fact both \( \text{VCO}_2 \) and \( \text{Vo}_2 \) are affected by both ventilation and perfusion.

If blood flow is held constant and tissue \( \text{CO}_2 \) production is constant, \( \text{VCO}_2 \) will depend on the reduction in blood \( \text{PCO}_2 \) as it passes through the lungs and on the \( \text{CO}_2 \) dissociation curve. Under these conditions \( \text{VCO}_2 \) is ventilation-dependent. However, as West (1969) has shown, changes in blood flow will cause surprisingly large changes in \( \text{VCO}_2 \), a doubling of pulmonary blood flow causing changes in \( \text{VCO}_2 \) of similar magnitude if arterial \( \text{PCO}_2 \) is kept constant by increasing ventilation. Hence \( \text{VCO}_2 \) is both ventilation and blood flow dependent.

As would be predicted from the Fick equation, changes in pulmonary blood flow in the presence of a constant tissue oxygen utilization produce proportional changes in \( \text{Vo}_2 \), providing full saturation of the end-pulmonary capillary blood is maintained. However ventilation may also affect \( \text{Vo}_2 \), there being two possible mechanisms. In the first place \( \text{Vo}_2 \) depends on blood flow and the arterio-venous oxygen content difference. If the inspired oxygen concentration is below about 30 per cent changes in alveolar \( \text{PO}_2 \) resulting from changes in ventilation will produce changes in end-pulmonary capillary oxygen content and so in \( \text{Vo}_2 \). The second mechanism depends on the effect of ventilation on intrapulmonary shunts. It is now believed that, in addition to the anatomical right-to-left shunts in the lungs, there are intra-pulmonary shunts due to airway closure. Airway closure appears to occur in the dependent portions of the lungs and the number of airways closed is related to age and to the functional residual capacity. An increase in ventilation might intermittently open these airways or might alter FRC thereby reducing the proportion of intra-pulmonary shunt and increasing the \( \text{Vo}_2 \) for a given lung blood flow. Although these ventilatory effects on \( \text{Vo}_2 \) are probably small compared with the effects of changes in blood flow, the presence of shunts does lead to errors in the calculation of lung blood flow. Thus 4 of our dogs had a total venous admixture of approximately 20 per cent when breathing air spontaneously in the lateral position. If this shunt was situated entirely in the lower lung and if the total blood flow to each lung was the same, then the \( \text{Vo}_2 \) of the lower lung would have been four-fifths of the \( \text{Vo}_2 \) of the upper lung. For this reason no attempt has been made to calculate lung blood flow in these studies and all the results are discussed in terms of \( \text{VT} \), \( \text{VCO}_2 \) and \( \text{Vo}_2 \), firstly for the whole animal and secondly for individual lungs.

Although there were increases in the total \( \text{VT} \), \( \text{VCO}_2 \) and \( \text{Vo}_2 \) from both lungs in 3 of the dogs associated with light anaesthesia and stimulation from the tube in the lateral position during spontaneous ventilation, there were no significant differences between meaned results from each of the phases of the study (table I). The overall respiratory exchange ratio was within normal limits in all measurements, confirming that a reasonably steady state existed at the time of sampling.

In both positions during spontaneous ventilation the right lung contributed about 60 per cent of the total ventilation and this was matched by the oxygen uptake and carbon dioxide elimination. During controlled ventilation in the supine position the \( \text{Vo}_2 \) and \( \text{VCO}_2 \) contributed by each lung was unchanged but the ventilation was distributed more
a shift of blood flow to that lung. This might have been due to an increase in pulmonary vascular resistance from the upper lung could have been due to both the increased oxygen uptake and CO₂ elimination in the upper lung in our experiments, but it is not clear why ventilation should be distributed more evenly in our dogs but it is possible that this results from the different anatomical configuration of the greyhound and its highly mobile mediastinum.

During controlled ventilation in the lateral position Rehder, Theye and Fowler (1964) found that ventilation and VCO₂ in the lower lung were decreased whilst blood flow was slightly increased. In our own studies ventilation was decreased but so also were VCO₂ and VO₂. However it is of interest that VCO₂ was decreased proportionately more than VO₂. Rehder and his colleagues utilized the Fick principle and calculated blood flow from the VO₂ of each lung and the measured oxygen content of mixed venous and arterial blood. They ventilated the lungs with 65 per cent O₂ to minimize the effects of ventilation/perfusion inequalities and pointed out that the calculated blood flow included blood flowing through intrapulmonary shunts. They assumed that these shunts were evenly distributed throughout the lungs and therefore claimed that the blood flow would be proportional to VO₂. As mentioned earlier, it is now known that shunts are not evenly distributed throughout the lungs and Katori and his colleagues (1966) have shown that blood in the pulmonary veins draining dependent parts of the lungs has a lower oxygen content than blood from the upper parts of the lungs. For this reason the use of the measured arteriovenous O₂ content difference in the Fick equation would tend to underestimate flow in the lower lung and overestimate flow in the upper lung. These errors would tend to be larger in animals breathing air because of the difference in end-pulmonary capillary PO₂. This would cause blood in the pulmonary veins draining a poorly ventilated lung to have a lower PO₂ than blood from a well-ventilated lung. This again would tend to produce an underestimate of flow in the dependent lung.

It is difficult to explain why VO₂ should have increased in the upper lung in our experiments, but both the increased oxygen uptake and CO₂ elimination from the upper lung could have been due to a shift of blood flow to that lung. This might have been due to an increase in pulmonary vascular resistance in the dependent lung caused by a decrease in alveolar PO₂ or increase in alveolar PCO₂ secondary to alveolar hypoventilation (Barer, Howard and Shaw, 1970). Alternatively the increase in resistance might have been associated with a fall in functional residual capacity in the dependent lung. However, an increase in oxygen uptake and CO₂ elimination of the upper lung could also have occurred without any redistribution of blood flow purely as a result of increasing ventilation to that lung. An increase in ventilation would have tended to lower alveolar PCO₂ and so to lower the CO₂ content of blood leaving the lung. Thus more CO₂ would be eliminated even if blood flow were to remain the same. The increase in alveolar PO₂ which resulted from this hyperventilation would have increased the end-pulmonary capillary O₂ content and so increased the oxygen uptake for any given blood flow. Hyper-ventilation of the upper lung would also have tended to minimize intrapulmonary shunt so that more blood was exposed to the oxygen in the alveoli. This could have increased oxygen consumption in the upper lung whereas an increase in shunt in the lower lung (due to a reduction in functional residual capacity) might have reduced the lower lung oxygen uptake. Whatever the explanation it is evident that the extreme narrowness of the greyhound's thorax must tend to minimize the gravitational effects on the distribution of blood flow.

The technique of diverting more of the total ventilation to the lower lung (and yet allowing the upper lung to expire freely) until the end-tidal CO₂ concentration was the same on both sides resulted in the volumes of ventilation, oxygen uptake and CO₂ elimination reverting to values similar to those found in the supine position. There is no evidence of any increase in arterial PO₂ or reduction in PCO₂ which would indicate an improvement in the efficiency of gas exchange but the technique may well be of value in some patients undergoing surgery in the lateral position. Its use during thoracotomy would be of most value when it was desired to maintain partial ventilation of the upper exposed lung (e.g., in patients with minimal respiratory reserve). In other circumstances the lung is usually either totally deflated or else partially compressed by retractor so that its effective ventilation is reduced. Thus a greater proportion of the total ventilation automatically passes to the lower lung where it matches the gravitational perfusion. However, during protracted renal, or other, surgery in the lateral position a consideration of the relation-
ships of ventilation to perfusion in the dependent lung and an attempt to match them more efficiently by the technique described may be of value in reducing the possibilities of pulmonary collapse in the compressed lung. It must be remembered, however, that the excessive application of pressure to the lower lung may produce marked increases in pulmonary vascular resistance and mediastinal shift. Furthermore, the diversion of blood from the lower lung to a collapsed area of upper lung (as in thoracotomy) may well cause severe arterial hypoxaemia (Tarhan and Lundborg, 1970).

REFERENCES


VENTILATION PULMONAIRE DIFFERENTIELLE

Sommaire
L’echange gazeux respiratoire de chaque poumon a été mesure chez des chiens en utilisant un diviseur trachéal, mis en place à l’aided’un télescope bronchoscopique. Les proportions de volume respiratoire (Vr), consomma-
tion d’oxygene (Vo,) et debit d’anhydride carbonique (Vco,) contribuee par chaque poumon etaient similaires durant la ventilation spontanee en position couchée sur le dos et en position latérale. Les proportions demeureraient inchangées durant la ventilation contrôlée en position couchée, mais il y eut une augmentation de la proportion Vr, Vo et Vco. contribuee par le poumon superieure en position latérale. Lorsque la ventilation dans le poumon inférieur etait augmentee afin de produire des concentrations CO2-fin d’inspiration egales dans les deux poumons, les proportions de Vr, Vo et Vco contribuee par chaque poumon retournaient aux valeurs trouvées en position couchée.

UNTERSCHIEDLICHE LUNGEN-VENTILATION

Zusammenfassung
Der respiratorische Gasausstausch jeder Lunge wurde bei Hunden gemessen, indem man einen trachealen “Teller” verwandte, der mit Hilfe eines bronchoskopischen Tele-
skops in die richtige Lage gebracht wurde. Strömungs-
volumen (Vr), Sauerstoffverbrauch (Vo,) und CO2-
Austoss (Vco,) waren bei Spontanatmung in jeder Lunge gleich, wenn sich der Patient in Rücken- oder Seitenlage befand. Wenn kontrolliert beatmet wurde, ergaben sich die gleichen Werte bei Rückenlage, aber bei Seitenlage war ein Anstieg der Werte Vr, Vo, zu vermerken, der der oberen Lunge zuzu schreiben war. Bei verstärkerter Ventilation der unteren Lunge zum Zwecke der Erreichung gleicher Endströmungs-konzentrationen von CO2 in beiden Lungen gingen die Werte Vr, Vo und Vco jeder Lunge auf Werte zurück, wie sie in Rückenlage gefunden wurden.
VENTILACIÓN PULMONAR DIFERENCIAL

RESUMEN

El intercambio respiratorio de gases de cada pulmón fue medido en perros utilizando un divisor traqueal colocado con auxilio de un telescopio broncoscópico. Las proporciones de volumen respiratorio (VT), consumo de oxígeno (VO₂) y gasto de anhídrido carbónico (VCO₂) contribuidas por cada pulmón fueron similares en las posiciones lateral y supina durante la ventilación espontánea. Durante la ventilación controlada las proporciones siguieron iguales en la posición supina, pero hubo un incremento en la proporción de VT, VO₂ y VCO₂ contribuida por el pulmón superior en la posición lateral. Cuando la ventilación para el pulmón inferior fue aumentada para producir concentraciones respiratorias finales iguales de CO₂ en ambos pulmones, la proporción de VT, VO₂ y VCO₂ contribuida por cada pulmón volvió a los valores encontrados en la posición supina.

BOOK REVIEW


This short book of just over 100 pages deals adequately with the pathophysiology and treatment of drowning and near-drowning. The author does not ignore the classical distinctions between sea-water and fresh-water drowning but points out that in victims who are resuscitated these differences are often blurred and that too much emphasis should not be placed on them. It is rightly stressed that in the treatment of patients apparently drowned the main requirement is to relieve the hypoxia and that the correction of electrolyte disturbances is of secondary rather than of primary importance.

The material is well presented, informative and suitably documented. The illustrations have been carefully selected and add to the value of the text. At first sight the bibliography is extensive but closer inspection reveals that many references are repeated from chapter to chapter. In this connection the reader’s time and patience would have been saved had the references been collected at the end of the book rather than listed after each chapter. It is possible also that his pocket might have been spared because at $9.50 this volume is expensive by any standard.

It is claimed in the foreword that this is the only available book that deals with the problem of drowning in its entirety; unfortunately this is just what it fails to do. For more than 200 years active positive steps have been taken to reduce the mortality of drowning as witnessed by the many interesting papers on the subject contained in the European scientific literature of the 18th century. In particular John Hunter’s “Proposals for the recovery of People apparently drowned” published in the Philosophical Transactions of the Royal Society in 1776 make remarkable reading even today. This aspect of the subject is almost completely ignored by the author as is the wider public interest manifested as early as 1767 by the foundation of a Dutch Society in Amsterdam to provide instruction in life-saving measures in cases of drowning. Seven years later the Humane Society was founded in London for the same purpose. Had the author chosen to extend his brief almost certainly he could have produced a standard source of reference for many years to come. As it is this is a useful book which puts the practical aspects of treatment in perspective.

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