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Effect of body position on gas exchange after thoracotomy

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ABSTRACT To determine the effect of change in body position on gas exchange after thoracotomy, 12 patients with potentially resectable lung tumours were studied before and 24 hours after operation. Measurements of arterial blood gas tension (PaO_2, $PaCO_2$), alveolar-arterial oxygen difference (A–adO_2), venous admixture effect ($\dot{Q}s/\dot{Q}t$ percent), and physiological dead space to tidal volume ratio (Vd/Vt), were made in the supine, and left and right lateral decubitus positions. Preoperatively, altering position did not affect gas exchange significantly. After thoracotomy in the lateral position with the unoperated side dependent, PaO_2 was significantly higher, and A–adO_2 and $\dot{Q}s/\dot{Q}t$ percent significantly lower than in the supine position. Postoperatively, the lateral position with the side of thoracotomy dependent was usually associated with the worst gas exchange. Only three patients achieved their best postoperative gas exchange in this position. In two this may have resulted from dependent small airway closure during tidal breathing, due to airways obstruction and old age, and in the third from postoperative atelectasis in the unoperated lung. No significant changes in mean $PaCO_2$, Vd/Vt, or minute ventilation ($\dot{V}E$) occurred with different positioning.

Early bronchospirometric studies in lateral positions suggested that the upper lung had a higher ventilation to perfusion ($\dot{V}/\dot{Q}$) ratio than the lower (Vaccarezza *et al*, 1943; Inada *et al*, 1954). Bryan *et al* (1964) confirmed the presence of $\dot{V}/\dot{Q}$ gradients with ^{133}xenon, showing that they increased in a vertical direction irrespective of the posture chosen. Kaneko *et al* (1966) confirmed these findings in normal subjects in different decubitus postures, concluding that a better total match of ventilation and perfusion occurred in these positions than in upright postures. Zack *et al* (1974) examined the effect of body position on PaO_2 in 13 patients with predominantly unilateral lung disease, and they observed that the lateral position in which the diseased lung was dependent produced a significantly lower PaO_2 than the opposite position.

We wished to investigate whether the position in which patients were nursed after thoracotomy would influence gas exchange and hence postoperative management.

Methods

Twelve consecutive referrals who had potentially resectable lung tumours were studied (table 1). None had preoperative radiographic evidence of asymmetrical lung disease, other than tumour. All were cigarette smokers and had chronic bronchitis (MRC, 1966). Five had moderate airways obstruction (Gaensler and Wright, 1966).

One hour before operation each subject rested for 15 minutes in three successive positions: supine, and left and right lateral decubitus, the order being randomised. They breathed room air through an open circuit consisting of a mouth-piece, two-way valve (Collins, P320), and connections so that expired gas could be collected in a balloon during the last three minutes in each position. During the last 20 seconds of gas collection, arterial blood was obtained with a glass syringe through a radial artery cannula. During anaesthesia a Swan-Ganz catheter (Edwards, 93–117–5F) was placed in the main pulmonary artery trunk, to allow postoperative mixed venous sampling.

The same procedure was followed 24 hours after operation during spontaneous breathing, after the following criteria had been observed: (*a*) that the open circuit delivery system was connected to a Venturi device, which provided an inspired O_2 concentration (FIO_2) of $0{\cdot}40 \pm 0{\cdot}02$; (*b*) that the supine PaO_2 had been stable on an FIO_2 of 0·4 during the hour preceding measurements; and (*c*) that the pulmonary artery cannula was correctly positioned.

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Table 1 *Details of 12 consecutive referrals who had potentially resectable lung tumours*

Patient	*Age*	*Sex*	*FVC% pred*	*FEV_1% pred*	*FEV_1/FVC%*	*Operative procedure*
1	52	M	76	74	72	Left lower lobectomy
2	58	F	120	81	51	Left upper lobectomy
3	59	F	80	78	72	Left "open and shut" thoracotomy
4	63	M	112	106	66	Right upper lobectomy
5	45	F	74	64	67	Left lower lobectomy
6	70	M	88	56	46	Right upper lobectomy
7	56	F	93	83	67	Right upper lobectomy
8	56	M	94	59	42	Right lower lobectomy
9	58	F	99	98	74	Right upper lobectomy
10	48	F	80	85	82	Right upper lobectomy
11	64	M	72	56	54	Left lower lobectomy
12	53	F	106	74	53	Right lower lobectomy
Mean	56·83	(5M)	91·16	76·18	62·17	
SD	6·93	(7F)	15·70	15·91	12·55	

Arterial and mixed venous samples were taken simultaneously during gas collection. No additional analgesia was required during the manoeuvres.

Duplicate measurements of Pa_{O_2} and Pa_{CO_2} were obtained using a blood gas analyser (Instrumentation Lab, 113–04). Expired gas was analysed using an infrared CO_2 analyser (Beckman, LB–2) and a polarographic O_2 analyser (Beckman, OM–11). $\dot{V}E$ (STPD) was obtained by emptying the balloon into a Tissot spirometer. Haemoglobin was measured pre- and post-operatively. A–aD_{O_2} was calculated using the ideal alveolar air equation (Riley and Cournand, 1948/49). $\dot{Q}s/\dot{Q}t$ was calculated using the equation:

$$\dot{Q}s/\dot{Q}t = \frac{C\acute{c}_{O_2} - Ca_{O_2}}{C\acute{c}_{O_2} - C\bar{v}_{O_2}}$$

where $C\acute{c}_{O_2}$ = end capillary O_2 content, Ca_{O_2} = arterial O_2 content, and $C\bar{v}_{O_2}$ = mixed venous O_2 content. O_2 content was estimated using the measured oxygen tensions, the haemoglobin concentration, the oxyhaemoglobin dissociation curve, correction for pH (Severinghaus, 1958), and the solubility of O_2 in the blood (Sendroy *et al*, 1934). It was assumed that $P\acute{c}_{O_2}$ equalled $PA_{O_2} - 1$ mmHg, and that the preoperative arteriovenous O_2 content difference was 4·5 ml/100 ml. Vd/Vt was calculated using Bohr's equation.

Results

Table 2 shows the effect of pre- and post-operative change on mean Pa_{O_2}, Pa_{CO_2}, $\dot{Q}s/\dot{Q}t$ percent, and Vd/Vt.

Effect of preoperative change in body position—No consistent changes in mean values occurred between any of the three positions. Intra-subject variations occurred in random fashion irrespective of the

Table 2 *Gas exchange pre- and post-operatively*

Mean (SD in parentheses)	Preoperative FI_{O_2}:0·21 D	S	U	Postoperative FI_{O_2}:0·40 D	S	U
Pa_{O_2}	69·01 (5·18)	68·92 (4·24)	67·98 (3·96)	105·56* (5·50)	100·42* (13·89)	97·68 (15·07)
Pa_{CO_2}	35·79 (2·58)	35·65 (1·21)	35·93 (2·28)	40·05 (2·83)	38·76 (2·83)	39·54 (1·88)
A–aD_{O_2}	30·38 (5·71)	30·92 (3·03)	30·92 (5·96)	120·58* (6·58)	127·07* (14·69)	129·41 (15·87)
$\dot{Q}s/\dot{Q}t$%	12·19 (3·26)	12·15 (2·34)	12·57 (2·87)	7·57* (2·08)	8·91* (3·47)	9·58 (4·50)
Vd/Vt	0·34 (0·06)	0·33 (0·05)	0·34 (0·08)	0·51 (0·04)	0·49 (0·04)	0·50 (0·03)

Where S: supine, D: lateral decubitus with tumour-free or unoperated lung dependent, U: lateral decubitus with tumour-free or unoperated lung uppermost.
* = Mean difference D–S statistically significant.
(Pa_{O_2}, Pa_{CO_2} and A–aD_{O_2} are given in mmHg. Conversion factor: 1 mmHg=7·5kPa).

position of the tumour-bearing lung in relation to the opposite lung. No significant change in $\dot{V}E$ occurred between preoperative positions.

Effect of postoperative change in body position—In the lateral position with the unoperated side dependent (D) Pa_{O_2} was significantly higher ($P<0.01$), and $A\text{-}aD_{O_2}$ and $\dot{Q}s/\dot{Q}t$ percent were significantly lower ($P<0.01$ and $P<0.05$ respectively) than in the supine position (S). Comparing unoperated side dependent (D) with unoperated side uppermost (U), the mean results did not differ significantly because in three subjects gas exchange improved rather than worsened with the thoracotomy dependent. Vd/Vt, Pa_{CO_2}, and $\dot{V}E$ showed no significant change with postoperative positioning.

Comparison of pre- and post-operative values—While breathing an FI_{O_2} of 0·4, Pa_{O_2} fell in only one subject (9), who also had the highest postoperative $\dot{Q}s/\dot{Q}t$ percent. Mean Pa_{CO_2} values for each position postoperatively were significantly higher than the preoperative values for the corresponding postures ($P<0.05$ for each position). Mean Vd/Vt also increased for each postoperative posture ($P<0.001$ for all positions). $A\text{-}aD_{O_2}$ was increased postoperatively ($P<0.001$ for all positions). As expected $\dot{Q}s/\dot{Q}t$ percent postoperatively was lower on 40% oxygen. This fall was only significant for the lateral position with the tumour-free/unopened hemithorax dependent ($P<0.05$). $\dot{V}E$ for each preoperative posture ranged between 5·30 and 5·50 l and increased significantly postoperatively, to between 6·43 and 6·84 l ($P<0.001$ for lateral and <0.02 for supine postures).

Discussion

Preoperatively our subjects did not behave differently from young controls (Zack *et al*, 1974), in that gas exchange was not influenced by change in decubitus posture. There are no published data of this nature for older controls.

The postoperative finding of improved gas exchange in the lateral position with the unopened hemithorax dependent, compared with the supine posture, implies (in the absence of a change in Pa_{CO_2} or $\dot{V}E$ between positions) that the former posture resulted in better overall matching of ventilation and perfusion in the lungs.

Apart from having reduced surface area of lung available for gas exchange as a result of resection, possibly in our postoperative supine patients the side on which the operation had been performed was relatively hypoventilated as a result of areas of incomplete postoperative lung re-expansion, or of splinting of the affected hemithorax because of pain. Were this the case an abnormally high venous admixture effect would apply to that lung, assuming that pulmonary arterial perfusion to remaining lung tissue was little changed. If such a patient was then placed in a lateral position, thoracotomy uppermost, perfusion to this poorly ventilated lung would be reduced as an effect of gravity (West and Dollery, 1960), and this in turn would reduce the venous admixture occurring in the uppermost lung. Such a positional change might also further augment the efficiency of gas exchange in that patient, by placing as large a volume of "good lung"—that is lung that had not been subjected to surgical resection or handling—in the dependent position, in which ventilation and perfusion are normally better matched (Kaneko *et al*, 1966). If this hypothesis is correct it would account for our observation of significantly increased Pa_{O_2} and significantly reduced $A\text{-}aD_{O_2}$ and $\dot{Q}s/\dot{Q}t$ percent in the lateral decubitus position with the unoperated side dependent.

The relationship of gas exchange to position in these subjects may also have been influenced by small airway closure during tidal breathing. All of our subjects were smokers, and this is associated with raised closing volume (McCarthy *et al*, 1972). Closing volume also increases linearly with age (LeBlanc *et al*, 1970), and as functional residual capacity (FRC) falls when a seated subject becomes supine, it has been estimated that in normal supine subjects airway closure occurs during tidal breathing by the age of 44 years (LeBlanc *et al*, 1970). No regression equations for closing volume against age for subjects in the lateral decubitus postures have been published. It has, however, been shown that a fall in FRC from the seated to either lateral decubitus position is only about half as great as that from the sitting to supine positions (Blair and Hickam, 1955). Accordingly, small airway closure per unit lung volume in our patients was probably less in the lateral than in the supine positions, and this may have contributed to the improvement in gas exchange on changing from the supine position to lateral decubitus with unoperated side dependent. Presumably any potential benefit from turning to the opposite decubitus position was outweighed by the factors stated in the preceding paragraph.

Three subjects (6–8) had better gas exchange in the lateral decubitus posture with the operated-upon hemithorax dependent. In one (7) the postoperative chest radiograph showed shadowing consistent with areas of atelectasis in the left lower lobe on the *unoperated* side. The degree of $\dot{V}/\dot{Q}$ mismatching in this atelectatic, dependent left lung was probably therefore greater than that occurring in the surgically manipulated but radiographically fully expanded right lung when it was dependent. The other two subjects who behaved paradoxically had more severe airways obstruction than the remainder, and possibly their diseased dependent airways closed at a higher volume on expiration, so that during tidal breathing the number of small airways closing per unit volume of dependent lung exceeded that of the other patients. Were the closing volumes of these subjects sufficiently large, then the potential of the unoperated lung as a better gas exchanger would be wasted, by placing it in the more dependent position. This explanation would be particularly applicable to one subject (6) who as the oldest member of the group would, on the criterion of age alone, have the highest closing volume.

A comparison of measurements between the same position pre- and post-operatively shows that despite increased $\dot{V}E$ after surgery, $Paco_2$ rose indicating overall alveolar hypoventilation. The observed increased Vd/Vt is also consistent with less efficient co_2 clearance. An increase in $A\text{–}adO_2$ is a normal consequence of raising FIo_2; however, Cole and Bishop (1963) in a group of normal subjects of comparable age to our subjects, obtained a smaller mean increase in $A\text{–}adO_2$ for a greater increase in FIo_2, suggesting that the increased $A\text{–}adO_2$ in our patients was consistent with worsened postoperative gas exchange, and not entirely explainable by the change in FIo_2 alone. The reduction of mean $\dot{Q}s/\dot{Q}t$ percent observed postoperatively is a consequence of increased FIo_2, and does not indicate a reduced physiological shunt. Breathing 100% oxygen has been shown to produce increased perfusion of dependent lung in the lateral decubitus position in normal subjects (Arborelius *et al*, 1974), but it is uncertain to what extent 40% oxygen would alter $\dot{V}/\dot{Q}$ relations in the positions studied by us.

The findings of this study clearly have a bearing on the postoperative management of subjects who have undergone thoracotomy. For the most part the results are in accord with what one might predict from previous investigations, carried out in normal subjects, in which regional ventilation and perfusion have been shown to be influenced by body position. Our study shows that the effects of changes in position on gas exchange in post-thoracotomy subjects were generally of limited magnitude except in one subject (3) whose Pao_2 fell 35 mm when the operated side was in the dependent position. Were this patient to have had his blood gases analysed before and after he had been turned, such a change might well have been assumed to represent a grave deterioration in his condition. In three instances, however, change of position produced an anomalous and unexpected effect on gas exchange, though in general an adequate explanation for the anomaly was present. We conclude that in the management of subjects who have undergone thoracotomy, consideration should be given to the effects of position on pulmonary gas exchange, which in the absence of evidence to the contrary is usually better when the "good" lung is dependent.

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