LOBAR ALVEOLAR GAS CONCENTRATION AFTER PNEUMONECTOMY[1]

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We have recently shown that end-expiratory lobar alveolar gas concentrations vary with body position (1). Erect man has higher oxygen and lower carbon dioxide concentrations and a higher R.Q. in the right upper lobe than in the right lower lobe. Supine man has no significant difference between these lobes in R.Q. but the oxygen concentration is lower and the carbon dioxide higher in the upper lobe than in the lower lobe.

Changes in lobar gas values in moving from the erect to the recumbent posture may be due to changes in pulmonary ventilation or perfusion. Pulmonary ventilation as a factor has been studied in subjects with pneumoperitoneum (2). With an increased tidal air-functional residual air ratio (3) there is supposedly more uniform ventilation (4, 5) but lobar differences in gas values are similar to those found in normal subjects. Thus a change in pulmonary ventilation with a change of body position does not appear to be the major factor.

To examine the role of pulmonary circulation, we have studied subjects following pneumonectomy. With total cardiac output passing through one lung, a more uniform pulmonary perfusion might be expected than in the normal subject.

METHOD

Five patients were selected who had a pneumonectomy three to twenty-four months before the experiment. All were women between the ages of 23 and 41 years. Four had undergone left pneumonectomy and one right. Four of the subjects had minimal disease or less in the remaining lung. The fifth (I. L.) is thought to have had no more than a minimal lesion in the remaining lung, but this cannot be positively ascertained. By X-ray there was no evidence of emphysematous bullae, but in all there was some scoliosis and over-distention of the remaining lung. All subjects had a thoracoplasty of 7 to 9 ribs on the pneumonectomy side. In three, a thoracoplasty had been unsuccessful in controlling the disease and a pneumonectomy followed. In two, the thoracoplasty followed the pneumonectomy to fill space. None had dyspnea on moderate effort; all felt in good health.

By the method previously described (1) small radiopaque plastic catheters (2 mm. o.d., 1 mm. i.d. 70 cm. long) were introduced into the upper lobe and lower lobe bronchus or a segmental division of these bronchi. Simultaneous end-expiratory gas samples were obtained from each lobe when the subject was erect and when recumbent. Gas samples were taken in pre-evacuated mercury sampling tubes and analyzed in a Scholander 0.5 cc. gas analyzer. At termination of the procedure a small bronchogram identified the position of the catheter tip.

Lung volume studies were completed on four subjects. The fifth was unavailable for this study. The Darling open circuit method (6) was used to determine the residual lung volume with the subject semi-recumbent.

RESULTS

Results in the remaining lung of five subjects with contralateral pneumonectomy are presented in Table I. Simultaneous end-expiratory oxygen and carbon dioxide values are shown for the upper and the lower lobe in each position. Respiratory exchange ratios were calculated for each lobe in both the supine and upright postures. All values are for the right side except in the one case whose remaining lung was on the left (I. L.). The paired samples method was used for all statistical analysis.

For the upright position nine paired samples on five subjects are shown. One of these was observed to be contaminated by inspiration. Upon elimination of this sample the oxygen concentration is higher in the upper lobe than in the lower lobe by a mean of 1.49 vol. per cent. This is statistically significant ($P = .01$). Carbon dioxide was lower in the upper lobe than in the lower lobe by 0.71 vol. per cent ($P < .01$). There is a mean difference between lobes in respiratory exchange ratio of 0.06, being higher in the upper lobe ($P < .01$).

For the supine position, Table I shows ten paired samples on five subjects. There was no

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TABLE I

Simultaneous upper and lower lobe alveolar air values in subjects with one lung (post-pneumonectomy) in the erect and supine positions

Subject	Barometer	Catheter	Upright				Horizontal				N_2 index	$\frac{RA}{TC} \times 100$
			Volume %			Minutes upright before sample	Volume %			Minutes supine before sample		
			O_2	CO_2	R.Q.		O_2	CO_2	R.Q.			
A. T.	756.0	RUL	14.27	5.24	0.75		12.19	5.84	0.62		2.6	53
		RLL	13.96	5.36	0.73	10	12.63	5.79	0.65	40	†	†
E. C.	760.0	RUL	18.60*	1.89	0.79		14.62	3.50	0.50			
		RLL	19.55*	1.09	0.77	5	14.84	5.12	0.81	20		
		RUL	15.74	4.26	0.79		†					
		RLL	15.23	4.50	0.75	10						
F. I.	757.1	RUL	16.95	2.90	0.69		16.48	4.01	0.89		2.2	52
		RLL	14.82	4.25	0.65	11	17.46	3.83	1.15	8		
		RUL	18.49	2.12	0.85		14.18	3.93	0.53			
		RLL	17.11	3.10	0.78	13	12.29	3.86	0.39	10		
I. L.	740.8	LUL	14.69	5.28	0.82		11.93	3.33	0.32		2.4	55
		LLL	12.96	5.87	0.69	5	14.67	4.92	0.75	7		
		LUL	16.78	3.39	0.79		12.81	5.56	0.64			
		LLL	13.00	5.86	0.69	10	13.80	5.51	0.73	11		
		LUL	†				12.87	5.79	0.67			
		LLL					13.01	5.78	0.68	45		
E. S.	752.9	RUL	16.15	4.15	0.85		15.23	4.90	0.84		2.3	46
		RLL	15.29	4.54	0.77	5	15.96	4.94	1.00	20		
		RUL	17.43*	2.91	0.80		13.76	5.16	0.67			
		RLL	14.94	4.78	0.76	9	14.49	5.17	0.77	27		
		RUL	14.12	5.13	0.71		16.04	4.50	0.91			
		RLL	12.90	5.64	0.65	15	16.27	4.80	1.05	5		

* Known contamination with inspired air.
† No samples taken.

observed contamination in this group but one sample is suspicious from its values. Using all values the oxygen concentration was lower in the upper lobe by a mean of 0.53 vol. per cent ($P < .05$). The carbon dioxide was lower in the upper lobe by a mean of 0.31 vol. per cent ($P > .10$). The R.Q. was lower in the upper lobe by 0.14 ($P = .02$).

Table I also shows the nitrogen index and residual air/total capacity ratios in four of the five subjects. All show high nitrogen indices for subjects with total ventilation in one lung and all show moderately elevated residual air total capacity ratios indicating pulmonary distention.

Table II shows a comparison of mean differences in gas concentration between upper and lower lobes for normals and subjects with but one lung. In the erect position, the subject with a pneumonectomy does not differ significantly from the normal in oxygen and carbon dioxide lobar differences. However, the mean difference between lobes in R.Q. is significantly smaller in the pneumonectomy case than in the normal subject ($P < .001$). When supine the mean lobar carbon dioxide difference in the pneumonectomy case is significantly smaller than in the normal subject, but the mean lobar oxygen difference is not significant. The lobar R.Q. differences for the supine pneumonectomy sub-

TABLE II

Comparison of mean differences between upper and lower lobe gas values in normal subjects and patients with but one lung *

	Upright			Supine		
	Volume %			Volume %		
	O_2	CO_2	R.Q.	O_2	CO_2	R.Q.
Normal	+2.14	−0.63	+0.18	−1.11	+0.42	−0.05
Subject with pneumonectomy	+1.49	−0.71	+0.06	−0.53	−0.31	−0.14

* Lower lobe values were subtracted from upper lobe values.

ject are not significantly different from values found in normal supine subjects.

The ventilation-perfusion equation (7) may be used to compare the two lobes where

$$\frac{V_A}{Q_c} = \frac{0.864\,R(Cc_{O_2} - C\bar{v}_{O_2})}{P_{A_{CO_2}}}$$

$(Cc_{O_2} - C\bar{v}_{O_2})$ is the arteriovenous oxygen difference in cc. per liter and should be sufficiently similar between lobes to regard it as a constant. The factor 0.864 is a constant and is the same for both lobes. For purposes of comparison between lobes, the variables are R and $P_{A_{CO_2}}$. The numerical values are of use only in comparing the lobes and are not included in the tables. In the erect pneumonectomy subject, the V_A/Q_c ratio is significantly higher in the upper lobe than in the lower lobe ($P < 0.01$). The same subject when supine shows a higher V_A/Q_c ratio in the lower lobe ($P = .05$).

Using the same equation, we have recalculated our original studies (1) in a similar manner. This has shown the V_A/Q_c ratio to be higher in the upper lobe than in the lower lobe ($P < .001$) when normal man is erect. When supine the lower lobe has the higher ventilation to perfusion ratio ($P < .02$). Comparison of normal and pneumonectomy subjects has shown no statistically significant difference in their mean lobar V_A/Q_c differences for the erect or supine position.

DISCUSSION

Lobar end-expiratory alveolar air studies in normal man (1) have shown the lower lobe to have a higher ventilation-perfusion ratio in the supine position. In contrast, erect man has a higher ventilation-perfusion ratio in the upper lobe. The difference between lobes may result from unequal ventilation or perfusion.

The object of the present study has been to determine the effect of altered pulmonary perfusion upon lobar alveolar air values. Subjects with but one lung might be expected to have more uniform pulmonary perfusion with total cardiac output flowing through one-half the normal vascular bed. More effective ventilation results from an increased tidal air functional residual air ratio in a single lung (5, 8). The present series of pneumonectomy subjects have both over-distention and high nitrogen indices with less effective ventilation than in a normal single lung. These subjects show alveolar gas R.Q. values to be higher in the upper lobe when erect. The lower lobe has higher R.Q. values when the subject is supine. The lobar difference in gas R.Q. when erect is significantly smaller in the pneumonectomy subject (0.06) than in the normal subject (0.17). Calculation of the V_A/Q_c ratio reveals the erect pneumonectomy subject to have a significantly higher value in the upper lobe than in the lower lobe. The supine subject has a higher ventilation to perfusion ratio in the lower lobe. These are not significantly different from values found in normal subjects, though total ventilation and blood flow are confined to one lung.

Considerable evidence has accumulated that total pulmonary ventilation is uneven (4, 6, 9, 10) in normal man. Little evidence exists that any division of the lung, such as a lobe, has more effective ventilation than other parts. Subjects with pneumoperitoneum (3) or post-pneumonectomy (5, 8) have increased tidal air/functional residual air ratios and more effective ventilation than normal man. They have similar lobar ventilation-perfusion differences. The part played by lobar ventilation in changing V_A/Q_c ratios with body position must await direct measurement, but the more important factor would seem to be perfusion.

Evidence that unequal perfusion exists is scant. Roelsen (9) believed unequal pulmonary perfusion exists in normal man, and others (11, 12) have assumed its existence in describing ventilation-perfusion relationships. In erect man, gravity could affect the low pulmonary arterial pressure to reduce blood flow through upper lobe. This would explain the high V_A/Q_c ratio in upper lobe when erect. Explanation of the higher lower lobe value when supine is not so apparent.

The relative prominence of either ventilation or perfusion in producing these results is not proven. Both factors may change in opposite directions from one position to another and present measurements are but net results.

Use of the V_A/Q_c equation in the manner above may be an approximation for lobes. In its use are assumptions that may apply more closely for the whole lung than for the individual lobe. Thus the lung is assumed to inspire gas

which it expired or of a homogeneous concentration from the dead space, which may not be true for the individual lobe. This problem is being further investigated.

CONCLUSIONS

Subjects with but one lung have higher ventilation-perfusion ratios in the upper lobe than in the lower lobe when erect. When supine the ventilation-perfusion ratio is higher in the lower lobe than in the upper. These values are not statistically different from those found in normals. The lobar gas R.Q. differences are significantly smaller in the pneumonectomy subject than in the normal subject in the erect position.

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