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INSPIRATORY FLOW RATE AND VENTILATION DISTRIBUTION

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INTRODUCTION

The regional distribution of small quantities of a radioactive gas given at the mouth and inhaled from functional residual capacity (FRC), depends on the inspiratory flow rate (Robertson et al, 1969; Hughes et al, 1972). In those studies only the extremes of flow rate were examined. This report is concerned with the distribution of boli of xenon^{133} gas used to label different portions of tidal volume over a range of inspiratory flow rates.

METHODS

Twelve normal volunteers were studied, seated upright. After a period of normal tidal breathing the subjects stopped at FRC while a 5 ml bolus of the marker gas was introduced into the trachea through a catheter, at the mouth or 500 ml from the mouth (figure 1). The flow rate of the subsequent inspiration was controlled by a regulating valve (Jonson, 1969). At high flow rates a pneumotachograph was used. When total lung capacity was achieved, the lungs were scanned from bottom to top with a pair of detectors over each lung. All the scans were corrected for regional lung volume found by scanning after equilibration with xenon^{133}/air mixture.

RESULTS AND DISCUSSION

The results are discussed in terms of the intrinsic mechanical properties of the lung. For this purpose a single compartment model of the lung at FRC will suffice; similar though more complex equations are required for analysis of two compartments (Pedley et al, 1972). The equation for airflow ignoring the inertial effects (Otis et al, 1972) is

$$\Delta P = \Delta V/C + \dot{V}R$$

ΔV is the change in lung volume occurring from the onset of inspiration until the bolus reaches the site at which distribution is determined, ΔP is the change in transpulmonary pressure, C is compliance, R is lower airways resistance and $\dot{V}$ is a constant inspiratory flow rate. $\Delta V/C$ is the elastic component and $\dot{V}R$ is the resistive component. For slow inspirations, $\dot{V}$ and the resistive pressure drop is low so the majority of ΔP is spent in overcoming the elastic elements of the lung, i.e. the alveoli. It has been suggested that the resulting increased basal ventilation occurs because the basal alveoli are smaller and more compliant, associated with lower distending pressure in the dependent zones of the vertical lung (Milic-Emili et al, 1966). At higher flow rates, $\dot{V}$ and the resistive pressure drop is higher so distribution becomes more dependent on the resistive elements of the lung, i.e. the airways (Robertson et al, 1969). If the airways are smaller in the basal regions there may be a reduction of basal ventilation. This analysis assumes ΔP is the same in all lung regions, an assumption which at high flow rates generated by maximal respiratory effort is probably not correct.

For mouth boli increasing flow rate reduces relative basal ventilation (figure 2). At 1.0 litre/sec. there is some reduction of basal ventilation but it is uniform over the rest of the lung. At higher flow rates 3 litres/sec. there is a further reduction of basal ventilation. If this distribution reflects the distribution of regional airways conductance (I/R), there appears to be a poor correlation with the distribution of regional lung expansion (figure 3).

When boli are inhaled 500 ml. from the mouth ΔV is increased and the bolus is distributed at a slightly higher lung volume so that both R and C are reduced. The net result is to increase the influence of the elastic components of the lung. In fact, at all three flow rates basal ventilation exceeds apical (figure 4). At a flow rate of 0.4 litre/sec. similar to that achieved during normal tidal breathing, the distribution of boli inhaled from the trachea differs from boli inhaled 500 ml. from the mouth. The tracheal bolus representing expired alveolar gas is preferentially distributed to the upper regions where blood flow is less in the upright position. Boli inhaled 500 ml. from the mouth representing fresh inspired air is preferentially distributed to the basal regions where blood flow is greater (figure 5).

CONCLUSION

In normal erect subjects inspiring from FRC, it would appear that the effect of flow rate on ventilation distribution is predominantly in the early stages of inspiration. During tidal breathing, this suggests that the distribution of expired alveolar gas in the trachea and upper airways differs from the air inspired subsequently. The change in gas distribution at higher flow rates may reflect the increasing importance of regional airways conductances, on the other hand regional inequalities of ΔP are probably also playing a part. Measurements of both these parameters, in man, will be required to further elucidate the matter.

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LEGENDS

Figure 1. Experiment arrangement showing the sites and the procedure of bolus injection at FRC either into the trachea or into the mouth or 500 ml. from the mouth at the end of an added dead space.

Figure 2. Distribution of boli inhaled from the mouth at 0.1, 0.25, 0.4 and 1.0 litre/sec. plotting ventilation per unit regional lung volume at TLC against lung distance. All the curves have been normalized.

Figure 3. Distribution of boli inhaled from the mouth at flow rates greater than 3 litres/sec. compared with the distribution of regional FRC as a proportion of regional lung volume at TLC. Both distribution curves have been normalized.

Figure 4. Distribution of boli inhaled through the added dead space 500 ml. from the mouth at 0.1, 0.4 and 1.0 litre/sec. All the curves have been normalized.

Figure 5 Distribution of boli at 0.4 litre/sec inhaled from the trachea or through the added dead space. Note that the tracheal bolus representing dead space gas is distributed preferentially to the apex of the lung.

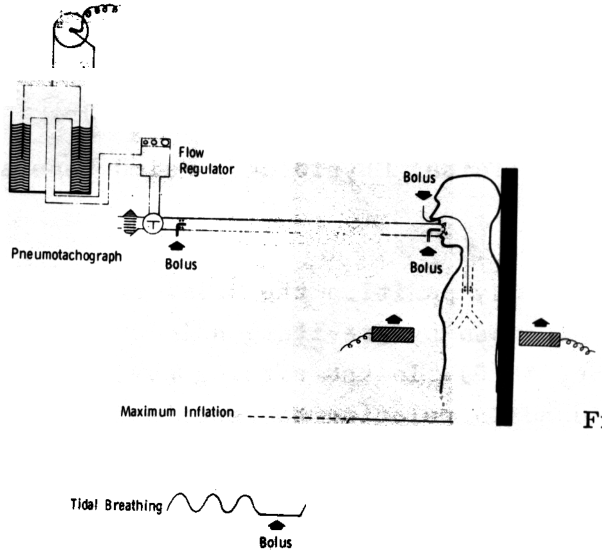


Fig. 1.

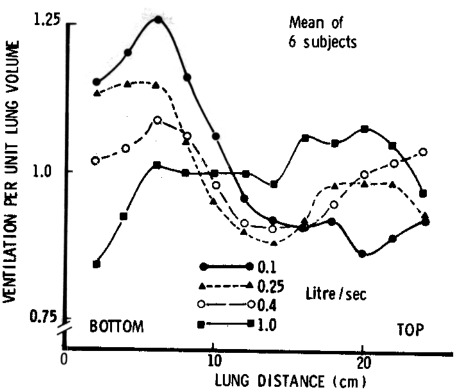


Fig. 2.

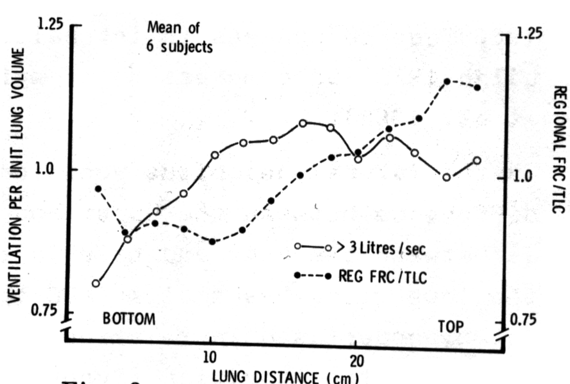
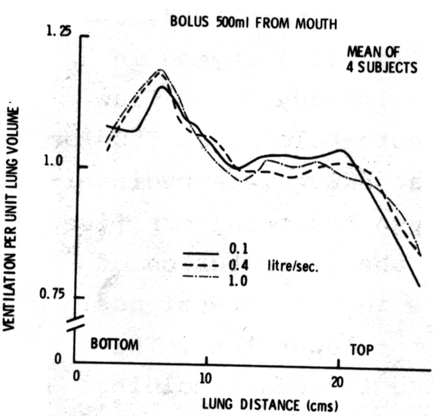


Fig. 3.



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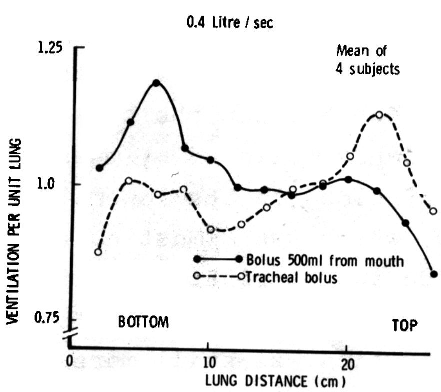

Fig 5.