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RELATIONSHIP BETWEEN BLOOD FLOW AND ALVEOLAR GAS TENSIONS IN LUNG LOBULES

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INTRODUCTION

In 1946 von Euler and Liljestrand reported that in cats the breathing of pure oxygen lowered pulmonary artery pressure and oxygen-lack raised it. Because these effects were not influenced by vagotomy they reasoned that regulation of pulmonary blood flow was mainly mediated by a local action of blood and alveolar gases. Evidence supporting this suggestion was obtained by several workers who confined the oxygen-lack to one lung (Dirken & Heemstra 1948; Rahn & Bahnson 1953) or one lobe (Barer et al. 1970); in animals and in man (Defares et al. 1960; Arborelius 1960) local hypoxia increased vascular resistance and diverted blood flow elsewhere in the lung.

METHODS AND RESULTS

Our recent work was designed to reinvestigate relations between blood flow and alveolar oxygen tension in much greater detail. First, we used an experimental animal from South America, the Coati mundi (Nasua nasua) whose lungs lack the communications which in most other mammals permit collateral airflow between the subsegments of a lobe. By wedging a bronchial catheter in an airway subtending a group of lobules whose tidal volume comprised only 1% of the lung tidal volume, local hypoxia or hyperoxia could be produced without any changes in the mixed arterial blood composition or overall ventilation. The animals were anaesthetized with 1% chloralose and 10% urethane and were breathing spontaneously. Secondly, we used a mass spectrometer to make frequent analyses of the mixed expired gas (see figure 1); we also measured intermittently, the mixed venous blood PO_2 and PCO_2. From the O_2 - CO_2 diagram (Rahn 1949; Riley & Cournand 1949) and Fick equation we calculated continuously the lobule alveolar ventilation ($\dot{V}A$) blood flow ($\dot{Q}$) ventilation-perfusion ratio ($\dot{V}A/\dot{Q}$) alveolar oxygen (PAO_2) and carbon dioxide ($PACO_2$) tensions. In figure 2 we have plotted the response of the lobule in terms of ventilation-perfusion ratio as

alveolar ventilation was systematically increased or decreased by altering the instrumental dead space of the lobules. During this time, there were no significant changes in lung or lobule tidal volume, minute ventilation, arterial or mixed venous PO_2 and PCO_2. Continuous monitoring of lobule $\dot{V}A$, $\dot{Q}$ and PAO_2 (for clarity, only values at 0.5, 8 and 14 minutes have been tabulated) show that changes of PAO_2 in response to increases or decreases in $\dot{V}A$ were accompanied by substantial and rapid changes in blood flow. Had there been no change of perfusion from the control value (3.22 ml/min) $\dot{V}A/\dot{Q}$ ratio would have increased to 1.4 and later decreased to 0.19; similarly PAO_2 would have increased to 122 mm Hg (instead of 109.5) and fallen to 66 mm Hg (instead of 83.5).

These results suggest a local control system of great sensitivity by which perfusion is matched to ventilation so that a reasonably constant alveolar PO_2 is maintained and the oxygenation of local capillary blood optimized. The stimulus for the changes of local blood flow is presumably local PAO_2 since, in these experiments, alveolar PCO_2 remained almost constant. It is also remarkable that such changes of lobule blood flow occur in response to changes of PO_2 in the so-called 'normal' or 'physiological' range (85-110 mm Hg). Figure 3 summarizes the effects of changing PAO_2 on lobule blood flow in 5 experiments. In the PO_2 range 60-115 mm Hg blood flow changes by about 20% per 10 mm Hg PAO_2. Lobule blood flow was only slightly affected by changes in $PACO_2$ at constant PAO_2 - high PCO_2 caused some vasoconstriction; lobule tidal volume was not affected by changes in local alveolar gas tensions, even with PAO_2 and $PACO_2 < 10$ mm Hg, presumably because of the interdependence of expansion within a lobe.

It is difficult to say how far these results apply to man. Hypoxic vasoconstriction has been well documented in man and the Coati mundi lung, apart from lacking interlobular collateral communications, is similar in its fine structure to the lungs of dog and man. Pulmonary vascular resistance in man seems much less sensitive to changes of PAO_2 in the 'normal' range (85-110 mm Hg) although responsiveness at a sublobar level has never been tested. If a local mechanism exists in man of similar sensitivity, it would prove a valuable homoeostatic mechanism

in terms of gas exchange in the face of inhomogeneities of ventilation and blood flow produced by gravity or disease.

CONCLUSIONS

In the Coati mundi comparatively small changes of alveolar PO_2 confined to subsegments of a lobe provoke significant changes in blood flow.

We suggest that these changes in lobule perfusion reflect a control mechanism operating at a local level which matches ventilation to perfusion so as to maintain reasonably constant regional alveolar gas tensions.

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LEGENDS

Figure 1. Reproduction of computer output of mass spectrometer analysis of mixed expired gas from lobules of Coati mundi lung. REF (reference) gives the oxygen and carbon dioxide concentrations of lobule inspired gas. RUN shows analysis of mixed expired oxygen (FEO_2) and carbon dioxide ($FECO_2$) fractions with calculation of respiratory exchange ratio (R). Values are averaged over 6 second periods. Note the decrease in R, brought about by increasing instrumental dead space.

Figure 2. Plot of lobule ventilation/perfusion (VA/Q) ratio against time. At 1.8 and 9.0 minutes a step-change in alveolar ventilation was made by decreasing and increasing instrumental dead space respectively. Values of alveolar ventilation ($\dot{V}A$), perfusion ($\dot{Q}$) and alveolar PO_2 for the lobule are given above at 1.0, 8.0 and 14 minutes when steady values had been reached. The horizontal bars represent $\dot{V}A/\dot{Q}$ ratios which would have occurred if $\dot{Q}$ had remained at its initial level (3.22 ml/min) while $\frac{\text{predicted } PAO_2}{\dot{V}A/\dot{Q}}$ is the oxygen tension appropriate for that $\dot{V}A/\dot{Q}$.

Figure 3. Plot of lobule blood flow (as percent of that at PAO_2 100 mm Hg) against alveolar oxygen tension showing mean curve from 9 runs in 5 experiments. Note linear increase of flow as PAO_2 rises from 60 to 115 mm Hg.

O_2	CO_2	
21.04	0.03	REF.
21.03	0.01	REF.
21.06	0.01	REF.
21.10	0.00	REF.
21.14	0.00	REF.

RUN

FEO_2	$FECO_2$	R	MIN.	SEC.
18.70	1.82	0.755	40	31
18.70	1.82	0.755	40	37
18.62	1.89	0.761	40	43
18.54	1.99	0.776	40	50
18.43	2.06	0.766	40	56
18.28	2.13	0.746	41	2
17.92	2.37	0.730	41	9
17.69	2.47	0.703	41	15
17.40	2.59	0.673	41	22
17.10	2.74	0.655	41	28
16.99	2.82	0.655	41	34
16.76	2.91	0.637	41	41
16.61	2.97	0.627	41	47
16.44	3.03	0.611	41	53
16.20	3.09	0.590	42	0
15.87	3.16	0.561	42	6
15.88	3.19	0.568	42	13

Fig. 1

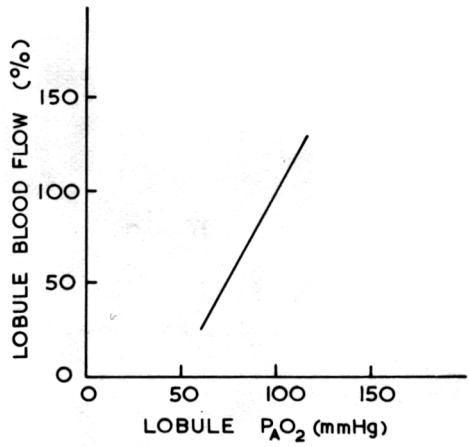

Fig. 3.

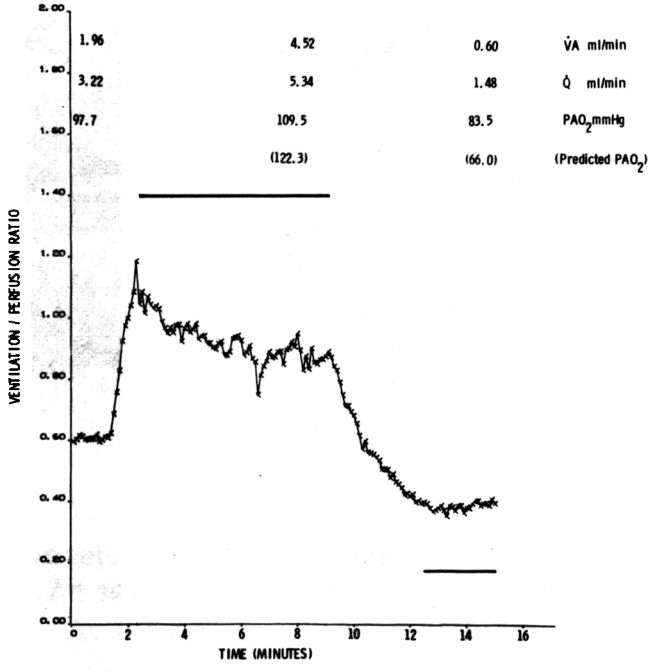

Fig. 2.