Middle Articles

FOR DEBATE...

Stratified Pulmonary Blood Flow: Some Consequences in Emphysema and Pulmonary Embolism

JOHN READ,* M.D., F.R.A.C.P.

British Medical Journal, 1969, 2, 44-46

Summary: Both ventilation and blood flow in the secondary lobule of the lung are stratified; each unit of lung tissue in the proximal portion of the lobule receives up to four times the blood flow of units in the peripheral portion. Questions of the limiting role of gas diffusion within the small airways become virtually irrelevant in the face of this stratification of function.

The central portion of the lobule, with its high ventilation, blood flow, and gas exchange, is very vulnerable; small lesions at this site will produce disproportionately large disturbances of gas exchange and of pulmonary vascular resistance. This may well account for some of the phenomena of conditions such as centrilobular emphysema and pulmonary microembolism.

Introduction

There is ample evidence that differences of ventilation and blood flow between different regions of the lungs are important in health and disease. In normal subjects, for example, gravitational factors determine an approximately twofold difference in ventilation and a fourfold difference in blood flow between upper and lower portions of the lung in the erect position, with consequent differences in gas exchange and alveolar gas tensions between these regions. In disease pronounced regional differences of ventilation—for example, in obstructive airways disease—and blood flow—for example, in pulmonary embolic disease—are common and account for much of the observed abnormality of blood gas tensions in such conditions.

Variation of ventilation and blood flow at the level of smaller lung units has not been extensively considered in the past. The present thesis is that there exists considerable variation of ventilation and blood flow *within* normal secondary lobules, and that disturbances at a lobular level may contribute to a number of phenomena in lung disease.

Anatomically the secondary lobule of the lung, which includes all those structures beyond a terminal bronchiole, consists of a repeatedly branching system of small airways (respiratory bronchioles and alveolar ducts) with their accompanying blood vessels. In all except the most proximal of these small airways the walls consist almost wholly of alveoli. Any single pathway traced peripherally might then be regarded as a number of alveolar spaces arranged in series (Fig. 1a).

Intuitively one might expect the distal alveoli in such a system (layer V in Fig. 1a) to be less well ventilated by fresh air on inspiration than the proximal alveoli (layer P). There is evidence that this is so in normal man (Read, 1966a, 1966b; Cumming, Crank, Horsfield, and Parker, 1966), though diffu-

sive mixing of gases along the terminal airways will greatly reduce any initial large gas tension differences between layer P and layer V.

FIG. 1.—Ventilation and blood flow in the secondary lung lobule. (a) Essentially serial arrangement of gas-exchange spaces along the path of incoming ventilation. (b) Stratification of blood flow; the density of the dots represents the distribution of blood flow (not vessels) found by Wagner *et al.* (1967) in the rat secondary lung lobule.

Indirect studies in man (Read, 1966b) have indicated that there also exists a gradient of diminishing capillary blood flow from layer P to layer V in this stratified system. The magnitude of this gradient has been studied in the secondary lobule of the rat lung (Wagner, McRae, and Read, 1967), where a 4:1 gradient of blood flow per unit of lung volume (Q_c/V_A) from the innermost to the outermost segment of the secondary lobule was demonstrated (Fig. 1b). The more indirect data (Read, 1966b) are consistent with a comparable gradient in man. It has proved possible to alter the intralobular gradient of blood flow with oxygen in the rat (Wagner *et al.*, 1967) and by exercise in man (Read, unpublished).

Functionally, then, there is "stratification" of both ventilation and of blood flow in the mammalian secondary lung lobule. The direction of the stratification is the same for both ventilation and blood flow, and this will reduce the disparity of ventilation/blood flow (V_A/Q_c) ratios which would otherwise exist *along* the gas-exchanging portions of the respiratory tract. The proximal portion of the lobule (layer P), with its somewhat higher V_A/Q_c ratio and its much higher blood flow per unit of lung volume, will account for a disproportionately large part of total oxygen and CO_2 exchange.

Much previous argument has centred around the point that, even if stratification of ventilation existed, gas diffusion along the small terminal airways would rapidly equalize all resulting gas tensions within a lobule. Stratification of ventilation, while thus allowed as a mathematical probability, has been held to be

* Professor of Medicine, Department of Medicine, University of Sydney, Sydney, Australia.

of no clinical or functional significance unless local lobular anatomy is disturbed by disease (Cumming, Horsfield, Jones, and Muir, 1968). The demonstration of a marked stratification of blood flow, in the same direction as the stratification of ventilation, changes the whole point of the argument. Even if gaseous diffusion along the terminal airways completely ablated all stratification of *gas tensions*, there would still be major stratification of *function* (ventilation, blood flow, and gas exchange). The magnitude and rate of gaseous diffusion then become distinctly minor considerations.

In the normal subject the differences of blood flow and gas exchange between various parts of the secondary lobule will be of the same order of magnitude as the well-known differences between upper and lower zones of the lung in the erect position. In disease the central portion of the secondary lobule represents a particularly vulnerable region; small areas of damage there will lead to disproportionately great changes in function.

Basis of Stratified Blood Flow Gradient

In order to explain the stratified distribution of lobular blood flow it is not necessary to invoke the presence of more capillary vessels per unit of lung volume in the proximal compared with the distal part of the lobule. Fig. 2a shows the general pattern of blood vessels in a secondary lobule. (If as shown diagrammatically in Fig. 2b) any significant part of the vascular resist-

FIG. 2.—Blood flow in the secondary lung lobule: (a) arrangement of artery (art.), vein, and a few capillary plexuses; (b) diagrammatic arrangement of vascular resistances (only a few loops shown); (c) hydrostatic model; (d) simplified arrangement of intralobular resistances. On the right are shown the percentage volume (V_0), blood flow per unit of lung volume (Q_c/V_0), and resistance (R) (last two in arbitrary units) of four segments of the lobule.

ance to blood flow lies in common conducting vessels on either side of the capillary plexuses, resistances to flow from P to Q through circuits PRSQ, PTUQ, and PVWQ would each be progressively greater than direct flow from P to Q. This may be visually demonstrated in a uniform-calibre glass hydrostatic model (such as in Fig. 2c) with water flowing through it. Dye injected just upstream from P runs in large part swiftly through the PQ connexion, while progressively smaller threads run more and more slowly round the more distal circuits.

If one assumes a regularly branching system (such as a detailed version of Fig. 2b), with a uniform concentration of vascular units throughout the lobule, the distribution of blood flow in the rat secondary lobule (Wagner *et al.*, 1967) is predicted by assigning to each "conducting" segment—for example, PR, RT, TV—a resistance equal to one-eighth of that of a "capillary" segment. Biologically this ratio seems not unreasonable.

For the purposes of the following discussion let us simplify the model of vascular resistances in the lobule to four single resistances in parallel (Fig. 2d). The "segments" of the lobule refer to four slices of equal depth. The vessels in each of the four segments in the lobule are then assigned resistances which will produce the blood flows found by Wagner *et al.* (1967) in the rat secondary lobule. The relative volumes, blood flows, and resistances of these segments are shown in Fig. 2. Simple calculations then allow prediction of the changes of total vascular resistance which would follow destruction or obstruction of any of the segmental resistances.

Emphysema

The inset of Fig. 3 shows semi-diagrammatically the position and nature of the destructive lesion in centrilobular emphysema. Horsfield (1968) pointed out that the position of the dilatation and alveolar wall destruction in the central portion of the lobule may crucially influence the efficiency of ventilation of the whole lobule. It does this by forming a large "pool" through which fresh inspired air must diffuse en route to the more peripheral air spaces.

FIG. 3.—Pulmonary vascular resistance (P.V.R.) plotted against percentage of lobule volume destroyed. "Central" line shows the predicted relationship if the pathological process involves the central portion of lobules, "peripheral" line if it involves the more peripheral parts of lobules. Inset shows general position of the destructive process in centrilobular emphysema.

But there must be equally important implications for blood flow as well. If all alveolar walls in the central segment of the lobule were destroyed (along with the capillaries in them), resistance to blood flow through the lobule would rise to 116% of control for the loss of less than 6% of lobular parenchyma (Fig. 3). Similarly (Fig. 3), if alveolar wall destruction were to increase progressively from the centre of the lobule, destruction of 21% and 49% of lobular parenchyma would produce vascular resistances of 160 and 320% of control levels respectively. Thus, destructive changes in the central portions of the lobules would produce increases of pulmonary vascular resistance out of all proportion to the relative volume of lung parenchyma involved.

Fig. 3 also shows, for contrast, the situation which would be expected if some destructive process began peripherally in the lobules and spread centrally. The increase of vascular resistance would be very much smaller than for a central lesion of comparable size. For example, destruction of 50% of the lobular parenchyma would produce more than a trebling of vascular resistance if the lesion were a central one, compared with only a 45% increase if the lesion were peripheral.

On anatomical grounds alone, then, one would expect pulmonary vascular resistance in centrilobular emphysema to increase to an extent out of all proportion with the relative area of emphysema seen on the cut surface of the lung. Panacinar emphysema involves the whole lobule rather than just the peripheral portion, so that one would expect pulmonary vascular resistance in this condition to increase to an extent intermediate between the "central" and "peripheral" lines of Fig. 3.

Such considerations as these may partly explain the relatively poor correlations that exist between volume of lung destroyed in emphysema and the extent of right ventricular hypertrophy.

They may also explain several other functional aspects of emphysema rather better than concepts based only on gross topographic variations of ventilation and blood flow. The best-ventilated part of the lobule in centrilobular emphysema will still be the apical portion. If alveolar walls with their contained capillaries have been extensively destroyed there, much of this ventilation will be "wasted" in terms of gas exchange. In other words, this will be dead-space ventilation. Indeed, since the alveolar walls destroyed in centrilobular emphysema are

those which we have shown normally carry a disproportionately large part of the blood flow, the loss of gas exchange per unit of ventilation in the apex of the lobule will be particularly marked. Compared with the normal the apical lobular space in centrilobular emphysema will be particularly "dead." A significant part of the very large physiological dead space often seen in emphysema may be accounted for in this way.

Pulmonary Embolism

Pulmonary embolism is another condition in which increases in pulmonary vascular resistance may appear to be far greater than would be expected from the degree of anatomical vascular obstruction. In experimental pulmonary microembolism, too, the injection of relatively small quantities of tiny particles produces a marked rise in pulmonary vascular resistance. Widespread pulmonary vasoconstriction has been invoked to explain both phenomena, but one would suggest that considerations similar to those of the last section may, at least in part, explain the features observed.

The technique used by Wagner *et al.* (1967) to explore the lobular distribution of blood flow in the rat involved intravenous injection of radioactive particles of a size designed to impact predominantly in pulmonary capillaries. Subsequent counting of these particles showed a gradient of concentration (and hence of blood flow), with the greatest concentration in the central segments of the lobule. If, then, particulate matter of the same general size reaches the lungs via the blood stream, one would expect it to become impacted preferentially in the more central portions of the lobules. The results will be similar to those shown by the "central" line in Fig. 3. Embolization

by sufficient particulate matter to produce widespread obstruction of vessels in the proximal 30% of each lobule would lead to a doubling of pulmonary vascular resistance, and obstruction of the vessels in the proximal 50% of lobules to more than a trebling of pulmonary vascular resistance. Relatively small amounts of particulate embolic material might thus produce large increases of pulmonary vascular resistance.

In addition, preferential reduction of blood flow in the proximal part of the lobule (where ventilation is greatest) would once more contribute to the very large physiological dead space which is a feature of clinically severe pulmonary embolism.

It is not certain whether microembolism plays a significant part in the overall picture of pulmonary embolism in man. If it does in fact occur, the present considerations suggest that it may make a major contribution to the clinical and haemodynamic features.

The original work referred to from this department was supported by grants from the National Heart Foundation of Australia, the Australian Research Grants Committee, and the Medical Research Fund of the University of Sydney.

REFERENCES

- Cumming, G., Crank, J., Horsfield, K., and Parker, I. (1966). *Respiration Physiology*, 1, 58.
 Cumming, G., Horsfield, K., Jones, J. G., and Muir, D. C. F. (1968). In *Form and Function in the Human Lung*, edited by G. Cumming and L. B. Hunt, p. 56. Livingstone, London.
 Horsfield, K. (1968). In *Form and Function in the Human Lung*, edited by G. Cumming and L. B. Hunt, p. 242. Livingstone, London.
 Read, J. (1966a). *Journal of Applied Physiology*, 21, 1511.
 Read, J. (1966b). *Journal of Applied Physiology*, 21, 1521.
 Wagner, P., McRae, J., and Read, J. (1967). *Journal of Applied Physiology*, 22, 1115.

COMPUTERS IN MEDICINE

Locating the Elderly in a General Practice*

J. A. FORBES,† M.A., M.D.

British Medical Journal, 1969, 2, 46-47

Summary: A preliminary survey undertaken before compiling a geriatric register showed that about 90% of the information on the practice files for patients over 65 was accurate. It is emphasized that such a register—which should be as accurate and up-to-date as possible—is important for the successful organization of a preventive geriatric clinic, or to any project designed to "screen" a defined population.

In the National Health Service we have opted for the universalist approach, where medical care is available to all who require it. Nevertheless, one of the disadvantages of this method is that the available facilities may not be fully utilized. Certain groups in the population know how to make effective and frequent use of a service, while others for a variety of reasons do not. The universalist method may therefore fail or not realize its full potential if certain groups do not use the services available, and a more categorical approach becomes necessary aimed at bringing the service to the patient, or at least taking steps to ensure that the services are widely known.

It would appear that the elderly form one of these groups. Some old people are too apathetic, or too humble, or are

incapable of communicating effectively, while a small minority, often the most vocal and militant, receive more care than they merit. The result is an unbalanced service, with the available resources concentrated on the few to the detriment of the remainder. It would seem, therefore, that the logical approach is to try to bring the service to the patient by making an assessment of the medical and social needs of all patients in a given category and deploying the existing resources according to these needs.

With this in mind it was decided in this practice to start a preventive geriatric clinic, where all patients over the age of 65 registered with the practice would have a social assessment by the health visitor, followed where necessary by a physical examination by one of the partners in the practice. As an essential first step it was necessary to compile a geriatric register consisting of the names, addresses, and ages of all patients over 65 in the practice and to ensure so far as possible that this information was accurate. This paper describes the method used, by sampling techniques, to determine whether our information about the existence and whereabouts of the elderly in the practice was sufficiently accurate for our needs.

Material and Method

The practice described is situated in North Oxfordshire. There are three partners, and the practice is associated with the

* From the Oxford Record Linkage Study, Headington, Oxford.
 † General Practitioner, Bicester, Oxford.