

# Broncho-pulmonary circuits: A synoptic appraisal<sup>1</sup>

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Because pulmonary arteries are end arteries, the circulation within the lung once appeared to be simple. However, an increasing amount of information concerning the systemic contribution to this circulation, mainly through broncho-pulmonary anastomoses, has made the picture complex. The intricate network that the bronchial vessels establish between the aorta and the pulmonary arteries on the one hand, and between the pulmonary veins and the caval system via the azygos veins on the other hand, is capable of expansion in various pathological states (Camarri and Marini, 1962). This work is an attempt to classify all the presently recognized situations into five circuits readily visualized and easily remembered. First, the anatomical connexions within the lung will be briefly reviewed; then I shall propose a model of the position these connexions hold in the framework of the whole circulation, and the four pathological aspects of this model.

The bronchial arteries normally irrigate the bronchi down to the bronchioles but do not reach the alveoli, which are irrigated solely by the pulmonary vessels proper. Precapillary anastomoses are present between the two types of arterioles, as can be demonstrated in the human lung (Fig. 1), but they are not of functional importance in normal conditions. A second anastomotic pathway results from the absence of a limit between the bronchiolar and the alveolar capillary beds. A third connexion exists at the venous slope of both systems in the form of so-called broncho-pulmonary veins joining the venous bronchial plexus to the pulmonary veins. Towards the hilum this venous plexus forms true bronchial veins that drain into the azygos and caval systems.

Thus there are three levels in the pulmonary vessels where systemic blood can enter: pre-, intra- and post-capillary (Fig. 2; a, b, and c). Depending on that level, the systemic blood will

or will not come into contact with the gas in the alveoli.

## NORMAL SYSTEMIC-PULMONARY CIRCUIT

At the precapillary and capillary levels, anastomotic flow is in bronchial to pulmonary direction because the systemic arterial pressure is six to eight times greater than the pulmonary arterial pressure. At the venous level the pressure gradient is small between the two systems, and flow is believed to be in both directions in the broncho-pulmonary veins but predominantly from the bronchial to the pulmonary veins (Auld, Rudolph, and Golinko,

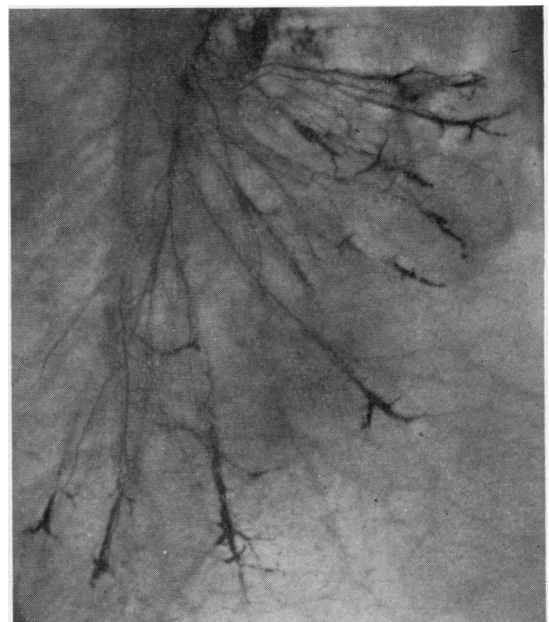


FIG. 1. Radiograph showing a suspension of lead oxide passing from the bronchial arterioles into the pulmonary arterioles (largest) at the periphery of a normal human lobe. Bronchial artery injection. The size of the particles would not allow passage through the capillaries. Such precapillary anastomoses are represented at 'a' in Fig. 2.

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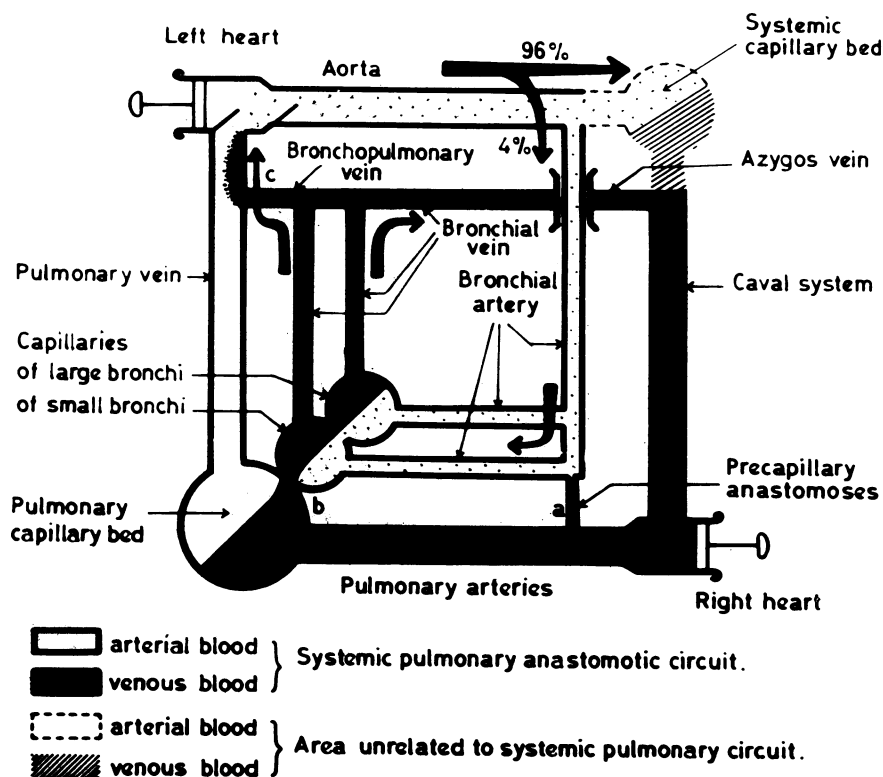


FIG. 2. Normal broncho-pulmonary circuit represented in the frame of the whole circulation. The bronchial vascular tree is enclosed in the main systemic and pulmonary vascular tree. Notice how this bronchial tree bridges the arterial and the venous slopes of the systemic and pulmonary systems. *a*, *b*, and *c* represent the three levels of broncho-pulmonary anastomoses—pre-, intra- and post-capillary. Pre-capillary anastomoses are shown thin because of their small importance in the normal lung. Approximately 4% of the left heart output enters the bronchial arteries. The stippled area shows partial desaturation of arterial blood by broncho-pulmonary venous admission.

1960). By this channel, two-thirds of the bronchial venous flow escapes the normal return to the right heart and passes directly into the aerated blood of the pulmonary veins and to the left heart. This mechanism represents part of what is known as the 'venous admission' resulting in the normal relative desaturation of arterial blood (Daly, Aviado, and Lee, 1953). It is generally estimated that the overall systemic to pulmonary exchange through all three anastomotic pathways in the normal human lung represents 1% to 4% of the total left heart output (Fritts, Harris, Chidsey, Clauss, and Cournand, 1961).

Figure 2 illustrates these facts. In this diagram (and in Figs. 3 to 6) the right and left hearts have been separated in order to place the bronchial system in its correct position with only one intersection.

The bronchial arteries join the aorta to the

pulmonary arteries through precapillary anastomoses, but most of their blood-flow goes to the bronchial capillaries: of the 4% of the left output that flows into the bronchial arteries very little reaches the pulmonary arteries.

There are three capillary beds in the lungs that communicate with each other: the large bronchi bed, the segmental and smaller bronchi bed, and the alveolar bed. The metabolic changes occurring at capillary level are in an opposite direction through the bronchial capillaries as compared to those in the alveolar capillaries. Despite the contacts between the three beds their main drainages are distinct: the large bronchi drain off into the azygos system hence to the right heart, whereas the two other areas drain off into the left heart via the pulmonary veins or via the broncho-pulmonary and the pulmonary veins (see arrows).

Figure 2 shows how the broncho-pulmonary,

bronchial, and azygos veins form a venous systemic-pulmonary bridge just as the bronchial arteries form an arterial systemic-pulmonary bridge.

#### ABNORMAL SYSTEMIC-PULMONARY CIRCUITS

**LEFT HEART TO LEFT HEART CIRCUIT (Fig. 3)** When precapillary broncho-pulmonary anastomoses become largely patent, 10% to 30% of the left heart output bypasses the right heart through the lungs. From Fig. 3 it is easy to understand why the left heart output will exceed the right by the same amount. Measurement of this right to left output discrepancy is the classical method of estimating the broncho-pulmonary flow (Cudkowicz, 1962; Liebow, Hales, Harrison, Bloomer, and Lindskog, 1950).

This situation exists when the pulmonary arteries are congenitally stenotic as in tetralogy of Fallot and also when the systemic blood supply to the lungs is abnormally large, either in chronic pulmonary disease (especially bronchiectasis) or in congenital anomalous systemic artery to the lung (Turner-Warwick, 1963).

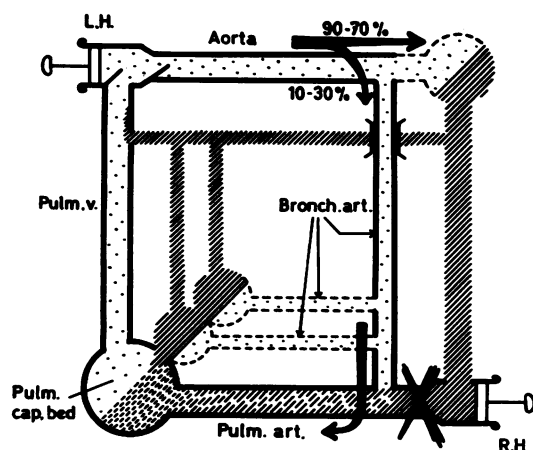


FIG. 3. *Modified broncho-pulmonary circuit in cases of increased systemic flow to the lungs, with opening of precapillary broncho-pulmonary anastomoses; see Fig. 2. R.H., right heart, L.H., left heart, L.H. to L.H., circuit. In this and in the three following graphs, only the considered circuit is mentioned. Notice how the arterial systemic-pulmonary bridge bypasses the right heart. X is the site of the obstacle that reduces the pulmonary blood pressure in tetralogy of Fallot. Mild cyanosis is figured here, as is present in this condition, although it does not necessarily exist in the two other conditions mentioned in the text.*

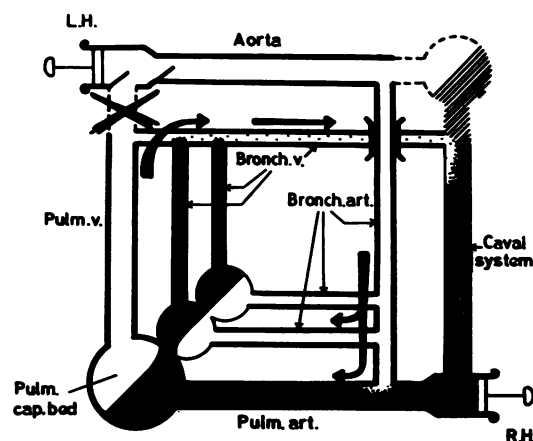


FIG. 4. *Modified broncho-pulmonary circuit in the presence of an obstruction to the pulmonary venous drainage, producing pulmonary hypertension: left heart to right heart circuit. Blood is forced through the venous pulmonary-systemic bridge. See Figs 2 and 3. X is the site of the obstruction. The bronchial arteries are generally hypertrophic in these conditions.*

**LEFT HEART TO RIGHT HEART CIRCUIT (Fig. 4)** When there is some impairment in the normal pulmonary drainage, with venous pulmonary hypertension, blood is forced through the venous broncho-pulmonary bridge from the pulmonary veins to the caval system. This creates a functional partial anomalous pulmonary venous drainage. It causes submucosal varices in the bronchi with haemoptysis and is accompanied by hypertrophy of the bronchial arteries.

This situation is present in mitral stenosis and in compression of the pulmonary veins by tumours (Ferguson, Kobilak, and Deitrick, 1944).

**RIGHT HEART TO RIGHT HEART CIRCUIT (Fig. 5)** When no vascular channel exists in the embryo to drain the lungs off into the left heart, because of a congenital anomaly, the bronchial veins remain the only possible route. This results in total anomalous pulmonary venous connexions.

To be compatible with survival, this anomaly must be accompanied by an atrial septal defect through which blood may reach the left heart; this defect may preferentially drain arterial blood (as shown in Fig. 5) or venous blood (Swan, Toscano-Barboza, and Wood, 1956). Figure 5 shows why, in this condition, the right heart output exceeds the left, a situation diametrically opposed to that shown in Figure 3.

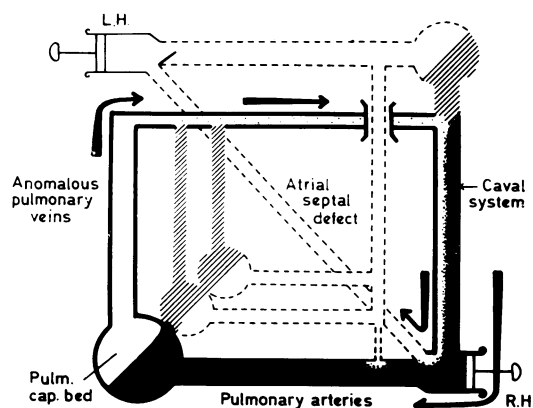


FIG. 5. Modified broncho-pulmonary circuit in cases of total anomalous pulmonary venous connexions: right heart to right heart circuit. See Figs. 2 and 3. On phylogenetic and embryological grounds the abnormal veins may be comparable to bronchial and broncho-pulmonary veins.

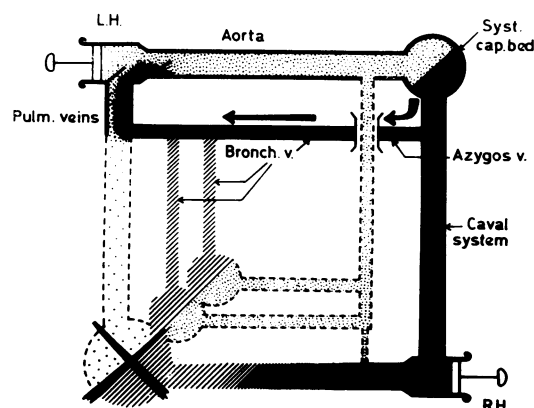


FIG. 6. Modified broncho-pulmonary circuit in cases of an obstruction in the pulmonary capillary bed: right heart to left heart circuit. See Figs. 2 and 3. X is the site of the obstacle producing pulmonary hypertension limited to the arteries. Here blood is forced through the systemic-pulmonary venous bridge in the opposite direction to that in Fig. 4, i.e., from the azygos to the pulmonary veins. Notice how the venous systemic pulmonary bridge bypasses the alveoli. Heavy stippling shows the increased broncho-pulmonary venous admission.

**RIGHT HEART TO LEFT HEART CIRCUIT (Fig. 6)**  
When pulmonary hypertension is limited to the arterial slope and is complicated by right heart failure, the consequent caval hypertension may cause a reflux through the bronchial venous system. In this way venous blood from the azygos veins flows into the pulmonary veins by the

venous systemic-pulmonary bridge and never reaches the alveoli. This is the only circuit where broncho-pulmonary anastomoses may cause cyanosis, and this has been called 'parapulmonary cyanosis'.

This situation exists in pulmonary emphysema and may be found in certain cases of Laënnec's cirrhosis (Liebow, 1953; Calabresi and Abelmann, 1957).

#### SUMMARY

A simple representation of the broncho-pulmonary anastomotic circulation is proposed. This emphasizes the two systemic-pulmonary shunts that broncho-pulmonary anastomoses establish between the arterial slopes of both circulations and between the venous slopes.

Four abnormal situations are presented. These result from one of the following conditions: (1) an obstacle somewhere in the pulmonary vessels; (2) congenital anomalous pulmonary vessels; and (3) the development of a collateral circulation in response to chronic lung disease.

The four pathological systemic-pulmonary circuits described may appear somewhat unreal, but they help one to understand and summarize the most important facts that had previously been published on the matter. They apply mainly to the seven following conditions: congenital stenosis of the pulmonary artery, anomalous systemic artery to the lung, bronchiectasis, bronchial tumour, mitral stenosis, total anomalous venous pulmonary connexions, and pulmonary emphysema.

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