

A STUDY OF THE RELATION OF PULMONARY AND BRONCHIAL CIRCULATION.*

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A detailed report of the history of the lesser circulation is rendered unnecessary by the article of Tigerstedt.¹ Somewhat less well known is the history of the circulation in the bronchial vessels, but the earlier work has been carefully reviewed by Zuckerkandl² and also by Miller.³ Much has been written, both descriptive and controversial, in reference to the physiology and anatomy of the two systems of vessels, and this literature is largely included in a recent paper by one of us.⁴ In spite of the work of Miller⁵ who claims that there is no real anatomical anastomosis other than by terminal capillaries between the two systems, the general opinion appears to be that functionally, at least, there is free exchange of bloods, a dictum of Virchow⁶ practically contradicted in the earlier writings of Cohnheim and Litten,⁷ who, however, retracted in later publications. In this period the work of Küttner⁸ stands

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¹ Tigerstedt, R., Der kleine Kreislauf, *Ergebn. d. Physiol.*, 1903, ii, pt. 2, 528.

² Zuckerkandl, E., Ueber die Anastomosen der Vena pulmonalis mit den Bronchialvenen, etc., *Sitzungsber. d. k. Akad. d. Wissensch., math.-natur. Kl.*, 1881, lxxxiv, pt. 3, 310; Ueber Verbindungen zwischen den arteriellen Gefässen der menschlichen Lungen, *idem.*, 1883, lxxxvii, pt. 3, 171.

³ Miller, W. S., Das Lungenlappchen, seine Blut- und Lymphgefässe, *Arch. f. Anat. u. Physiol., Anat. Abt.*, 1900, 197; The Arrangement of the Bronchial Blood Vessels (Preliminary Communication), *Anat. Anz.*, 1906, xxvii, 432; The Vascular Supply of the Pleura Pulmonalis, *Am. Jour. Anat.*, 1907, vii, 389.

⁴ Karsner, H. T., and Ash, J. E., Studies in Infarction. II. Experimental Bland Infarction of the Lung, *Jour. Med. Research*, 1912, xxvii, 205.

⁵ Miller, W. S., *loc. cit.*

⁶ Virchow, R., *Gesammelte Abhandlungen*, Frankfurt, 1856, 295, experiment XX.

⁷ Cohnheim, J., and Litten, M., Ueber die Folgen der Embolie der Lungenarterien, *Virchows Arch. f. path. Anat.*, 1875, lxxv, 99. Litten, M., Untersuchungen über den haemorrhagischen Infarkt, und über die Einwirkung arterieller Anaemie auf das lebende Gewebe, *Ztschr. f. klin. Med.*, 1880, i, 131. Cohnheim, J., *Vorlesungen über allgemeine Pathologie*, Berlin, 1882, 207.

⁸ Küttner, Beitrag zu den Kreislaufverhältnissen der Froschlunge, *Virchows Arch. f. path. Anat.*, 1874, lxi, 21; Beitrag zur Kenntniss der Kreis-

out sharply as supporting the belief that there is extremely free interchange of blood and rich anastomosis between the two systems. More recently Königstein⁹ has made a series of studies of the comparative anatomy and physiology of the two systems in the lungs of reptiles, birds, and amphibia, and has reached the same conclusions. Königstein lays much stress on the importance of the bronchial blood for the nutrition of the lungs. He states that it not only nourishes lung tissue in its own area of distribution, but also by mixing with the pulmonary blood can nourish more remote parts of the lung. This statement apparently is made on the basis of the fact that in certain of the animals which he examined the analogue of the bronchial artery can supply large amounts of blood for the nutrition of the lung, while the animal is not breathing. He further supports this statement by saying that under pathological conditions there appear no well marked alterations in the lung as a result of obstruction to branches of the pulmonary arteries because the bronchial arteries suffice for nourishment. This statement was made by Virchow in reference to obstruction of the main vessel to a lobe, but as has been shown by the work of Küttner and also by other work by one of us,¹⁰ does not apply to obstruction in a smaller branch. Further studies are in progress which sustain our contention in this respect. The lack of serious disturbance to circulation when obstruction is present in a small branch of the pulmonary artery is due to the rich capillary and other anastomosis of the pulmonary itself rather than by anastomosis with the bronchial arteries. On the basis of injections of lungs Miller claims that coarse anastomosis between the bronchial and pulmonary arteries does not exist, although he admits that free interchange of fluids occurs when the injecting mass is of such a character that it will pass through capillaries.

In considering the function of the two systems the latter admission is sufficient, for if a capillary anastomosis is provided for free interchange of bloods, as Küttner conclusively pointed out, there is little need for discussion as to the exact size of the vessels that are concerned.

In order properly to appreciate the possibilities of the circulation in the lungs in a variety of pathological conditions, the following study was instituted, particularly with the idea of learning how great is the interchange between the two systems when the pressure in each is normal, and to what degree the mixture is changed under variations in the pressure in both systems. For this purpose, simultaneous injection of the two systems, under determined constant pressure, was considered necessary.

Mercury manometers and mercury safety valves were connected

laufsverhältnisse der Säugethierlunge, *Virchows Arch. f. path. Anat.*, 1878, lxxiii, 476.

⁹ Königstein, H., Zur Morphologie und Physiologie des Gefäß-systems am Respirationstrakt, *Anat. Hefte*, 1903, xxii, 309.

¹⁰ Karsner, H. T., and Ash, J. E., *loc. cit.*

with two compressed air outlets, and gelatin injection masses of carmine and of easily soluble Berlin blue were injected simultaneously, under measured pressures, into the pulmonary and systemic aortas of the dog. After orientation experiments it was found that 40 millimeters' pressure was the minimum pressure of good injection of the pulmonary artery and its capillaries, and 140 millimeters' pressure the minimum pressure of good injection of the bronchial arteries when injected by way of the aorta. In one series of dogs 40 millimeters was used as a constant pulmonary pressure, and pressures of 0, 40, 60, 100, 140, 160, 180, and 200 millimeters in the aorta. In a second series a constant pressure of 140 millimeters was used in the systemic aorta and pressures of 0, 10, 20, 30, 40, 60, and 80 millimeters in the pulmonary. Then with zero pressure in the aorta, pressures of 40 and 80 millimeters were used in the pulmonary, and with zero pressure in the pulmonary, pressures of 60, 140, and 180 millimeters were used in the aorta.

The technique was as follows: Under artificial respiration and complete ether anesthesia the dog's sternum was split¹¹ and the thorax held open with a self-retaining retractor. Ligatures were carefully placed about the pulmonary and aortic trunks near the heart, but not tied. Then the internal mammary arteries were ligated as a precautionary measure against subsequent leakage of the injection mass. To prevent free diffusion of the staining mass during injection, the brachiocephalic and left subclavian arteries (the two main branches of the aortic arch in the dog), the aorta just above the diaphragm and the inferior vena cava just below the heart were ligated. As quickly as possible cannulæ were inserted into the aorta and through the right ventricle into the pulmonary artery and tied in position by means of the previously placed ligatures. The cannulæ were filled to the tip with the injection mass before insertion and the pressures in each injection system regulated by means

¹¹ The dogs were normal except that immediately before opening the thorax five turnip radish seeds measuring from 2.5 to 3.5 mm. in diameter were placed in the right heart through a cannula in the jugular, so that the seeds lodged in smaller branches of the pulmonary artery. This was done so as to permit of an accessory study of the circulation in pulmonary embolism (Karsner, H. T., and Ghoreyeb, A. A., *Studies in Infarction. III. The Circulation in Experimental Pulmonary Embolism, Jour. Exper. Med.*, 1913, xviii, 507).

of the safety valves. A cannula was tied in the left ventricle and connected with an outlet tube. At a signal, the flow was started simultaneously in both systems, artificial respiration being continued and the flow maintained until the lungs ceased to collapse with the cut off pressure in the respiration apparatus. Then the outlet tube from the left ventricle was clamped and injection continued for a few minutes so as to make it complete. The tubing was clamped near the cannulæ and cut, the trachea clamped, the posterior part of the animal cut away, the head and thorax were placed in formalin (10 per cent.) in a refrigerator for forty-eight hours, and frozen sections of the lung were made for histological study. As a rule, considerable fluid appeared in the trachea before the end of the experiment, at first colorless, later considerably stained with the blue of the pulmonary injection mass.

The injection masses were made as follows: Twenty grams of gelatin were soaked in 300 cubic centimeters of cold water for thirty minutes. Twenty grams of easily soluble Grüber Berlin blue were dissolved in 1,200 cubic centimeters of water. The two were mixed in a hot water bath, after heating, and stirred until completely dissolved, then filtered and used on the same day. The carmine mass was made in the same proportions, but in order to dissolve the carmine it was necessary to add a small amount of strong ammonia water to the water of solution. The same process was followed and immediately before injection the solution was neutralized with acetic acid. Both masses were brought to 40° C. before injection.

Series 1.—Constant pressure of 140 mm. in the systemic aorta, and pressures of 0, 10, 20, 30, 40, 60, and 80 mm. in the pulmonary aorta. Of this series the fifth experiment combined the two minimal pressures of best injection. In this experiment the injection through the pulmonary was complete and perfect and the bronchial vessels also contained some of the blue injection mass. For the most part the bronchial vessels were filled with the red injection mass (aorta), and in the neighborhood of the larger bronchi (1 to 3 mm. calibre) the infundibular and alveolar capillaries were injected from the bronchial artery. With diminution of the pressure in the pulmonary artery down to as low as 10 mm., the injection of the pulmonary capillaries became somewhat less perfect, but remained fairly good. The injection of the bronchials was almost completely by the red mass (from the aorta) but still showed some injection from the pulmonaries. The tendency of the red mass to extend into pulmonary capillaries did not become more marked with diminu-

tion of the pulmonic pressure to 10 mm. With no pressure in the pulmonary artery it was possible after about fifteen minutes to inject from the aorta so that the pulmonary capillaries were almost completely injected.

Increase in pulmonary pressure to 60 mm. showed practically the same picture as that of 40 mm. pressure, and the same is true of the pulmonary pressure of 80 mm. The extension of the red to the neighboring alveoli is no less marked and the mass of blue (pulmonary injection mass) in the bronchial vessels is slightly greater than in the type experiment.

It would seem fair to state that the admixture of pulmonary and bronchial blood is very slight in lungs in which the pressure in the pulmonary is greater than zero and the pressure in the bronchials approximately normal. The slight extension of the bronchial circulation to the alveolar and infundibular capillaries is not influenced by variations in pulmonary pressure between ten and eighty millimeters. The mixture of bloods in the bronchial vessels varies slightly with the degree of pulmonary arterial pressure.

Series 2.—Constant pressure of 40 mm. in the pulmonary artery and pressures of 0, 40, 60, 100, 140, 160, 180, and 200 mm. in the aorta. The type experiment in this series is the same as in series 1, *i. e.*, pressures of 40 mm. in the pulmonary and 140 mm. in the aorta. With decreases in aortic pressure down to 40 mm. it was found that with aortic pressure of 100 mm. the picture remained practically the same as at 140 mm., and lower pressures showed no greater tendency of the red bronchial mass to pass into the alveolar or infundibular capillaries than with normal pressures; but, on the other hand, the blue pulmonary injection mass was found in increased amounts in the bronchial vessels. With no pressure in the aorta, the injection of the bronchial vessels by way of the pulmonary circulation was only partial. With increase of aortic pressure to 160, 180, and 200 mm., only after the pressure had reached 200 mm. was the extension of the bronchial injection mass into the infundibular and alveolar capillaries more marked. The mixture of the two masses in the bronchial vessels remained about the same.

It is apparent that when the bronchial pressure is lowered the pulmonary pressure when normal is sufficient partly to replace the bronchial circulation, but when the bronchial pressure is raised it does not tend to increase the circulation of bronchial blood in the pulmonary capillaries (alveolar and infundibular) until an extremely high pressure (200 millimeters) in the aorta is employed.

Series 3.—Constant pressure of zero in the pulmonary artery and pressures of 60, 140, and 180 in the aorta. With the lowest aortic pressure the bronchials showed complete injection, but there was practically no injection of the alveolar and infundibular capillaries except immediately in continuity with pulmonary vessels of a calibre of about 20 μ and larger. Pulmonary arteries

of 1 mm. and larger were not injected, although those smaller than 1 mm. in calibre were almost completely injected. A pressure of 140 mm. in the aorta, as has been stated, sufficed to inject, practically completely, the lung, and the same is true of a pressure of 180 mm. in the aorta.

Series 4.—Constant pressure of zero in the aorta and pressures of 40 and 80 mm. in the pulmonary artery. These animals showed complete injection of the pulmonary system. The lower pulmonary pressure resulted in partial injection of the bronchial vessels, whereas the higher pressure sufficed to inject almost completely the bronchial system, the submucous capillary loops being very well injected.

SUMMARY.

The most striking point brought out in this study is that as long as a definite pressure is maintained in either the pulmonary or bronchial circulations, the admixture of bloods is extremely limited. It is easily conceivable that more mixture occurs normally than under the conditions of the experiment, but there is no reason for considering this to be a large difference. If, however, in either system the pressure sinks to zero the possibility of supply by the other system becomes evident. It takes much longer for the mass injected through the bronchial arteries to penetrate to all parts of the lung than when the mass is injected through the pulmonary artery; but when accomplished, the injection reaches to all capillaries including those of the pleura, the only vessels remaining uninjected being the larger trunks of the pulmonary artery. On the other hand, the injection of the bronchial vessels by way of the pulmonary arteries is not complete with normal pressure, but occurs rapidly when a high pulmonary pressure is employed. It is therefore probable that either circulation can suffice for the simple nutritive demands of the lung if the other system is interfered with. It has been shown¹² that embolism of the pulmonary artery, without other circulatory disturbance, does not lead to necrosis of the affected area of the lung, but it is probable that the preservation of circulation is not due to collateral bronchial circulation so much as to the free anastomosis and early division into capillaries of the pulmonary artery. In support of this statement is the fact that the appearance is not altered when the bronchials are ligated at their origin. The same ligation shows no subsequent interference with the nutrition of the bronchi up to a period of five weeks, demonstrating

¹² Karsner, H. T., and Ash, J. E., *loc. cit.*

that the pulmonary circulation is sufficient to provide for the nutrition of the bronchi. If, however, as Virchow¹³ has shown, the pulmonary artery supplying an entire lobe be occluded, the bronchial circulation can and does suffice for the nutrition of the lobe. In the case of the occlusion of a branch of the pulmonary artery the pressure in the area interfered with does not sink to zero because of the collateral circulation in this area; whereas, if the main trunk is occluded no collateral supply is available, the pressure sinks to zero, and the bronchial artery becomes available as a source of blood supply.

It must be remembered that the lung tissue, as a whole, has ready access to oxygen and this gas is the nutritive element acquired by the blood in the lungs. From these studies it would appear that the part of the lung tissue not in intimate contact with oxygen in the air is supplied by oxygenated blood of the bronchial arteries, and that the tissues through which the pulmonary blood circulates take up whatever organized nutriment they need from the pulmonary blood and possibly provide for their oxygen and carbon dioxide interchange (which must be very slight) either directly with the alveolar air, or by finding sufficient oxygen in the venous blood of the pulmonary artery.

The studies of the injected specimens confirm Küttner's findings of a very rapid breaking up of the pulmonary artery into capillaries.

In all the specimens studied it was found that although the pleural vessels can be injected by way of the bronchial arteries when there is zero pressure in the pulmonary arteries, yet when the two sets of vessels are injected simultaneously in the dog, the pleural vessels invariably derive their supply of injection mass from the pulmonary artery.

¹³ Virchow, R., *loc. cit.*