THE VASCULAR SUPPLY OF THE PLEURA PULMONALIS.

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WITH 12 TEXT-FIGURES.

In a paper presented before the Association of American Anatomists in 1905 (9 e), I described the vascular supply of the bronchi and the relation which the bronchial circulation bore to the pulmonary. I purposely refrained from making any statements in regard to the distribution of the bronchial artery to the pleura for I wished to make a more extended study of the problem.¹

That the histological structure of a given organ may differ in animals of different species, and even in different animals of the same species, is coming to be accepted more and more by investigators and it seems quite probable that eventually each animal will have to be studied independently. In no place is this fact so forcibly presented as in the excellent series edited by Oppel (10).

Because a given structure, or relation of structures, is found in, for example, rabbits, it is no criterion that the same structure, or relation of structures, will be found in rats, and the inverse is true. We may, however, find a type which, modified to a greater or less degree, runs through an extended series of animals of different species.

In previous communications (9) I have stated that the pleura did not receive its vascular supply from the bronchial artery. I fear I failed to impress on the minds of my readers that this statement was made in regard to the dog; for some of my co-workers, notably Königstein (7), have taken me to task for this statement. I myself made the mistake of thinking that the arrangement found in the dog's pleura would hold true elsewhere and so found myself at variance with Küttner (8) and Zuckerkandl (15) who described branches of the bronchial artery as being distributed to the pleura of the human lung. That they were correct in so stating, the present paper will show and, at the same time, I trust, will bring out some facts hitherto overlooked.

¹ I wish to express here my thanks to Professor F. P. Mall and Dr. A. W. Meyer, of the Johns Hopkins Medical School for their generous assistance in procuring the necessary material for this study.

METHOD OF STUDY.

In my study of the blood-vessels, I have used as a means of differentiating the various systems of vessels a 20 per cent solution of gelatine containing colored granules. If a Prussian blue or carmine gelatin be used, one can not be sure that a given network belongs to any individual system of vessels. If, on the other hand, the injection mass be charged with granules of such size that they will not readily pass the capillaries, then all the derivatives of the vascular trunk injected will stand out sharply and distinctly. I can not but think that this method of injection gives more exact results than the former. Take for example a lobe of a dog's lung. A cannula is tied in the branch of the pulmonary artery which supplies the lobe; a second cannula is tied in the branch of the pulmonary vein coming from the lobe. A 10 per cent solution of Prussian blue gelatin is first injected into the artery until the lobe is thoroughly blue and the mass runs freely from the open cannula tied in the vein. The injection is now discontinued and a flask of 20 per cent gelatin containing vermilion granules is connected with the pulmonary artery and a second flask of 20 per cent gelatin containing Ultra-marine blue granules is connected with the pulmonary vein. These two granular masses are injected simultaneously. The result is that the capillaries are filled with a transparent blue mass; while the pulmonary artery and its branches are opaquely red; the pulmonary vein and its branches are opaquely blue. There is no mistaking one set of vessels for the other. It is by means of various modifications of this method that the present study has been made.

Dog.—In the dog, repeated injections of a granular mass, prepared as above, directly into the bronchial artery have failed to demonstrate any branches passing to the pleura. Only at the hilus have I seen short twigs, two to five millimeters in length, given off from the main stems of the bronchial artery, these were distributed to the connective tissue about the hilus of the lung and did not extend to the pleura. I have also failed to find any branches of the bronchial artery extending from the depth of the lung to the pleura. It seems quite probable that the absence of pronounced connective-tissue septa in the dog's lung is an important factor in the arrangement of the bronchial artery.

Küttner (8) has described branches of the bronchial artery as being distributed directly to the pleura and anastomosing with the pulmonary artery. My injections have failed to confirm his results.

I have previously stated in regard to the pulmonary artery (9), that,

"as a rule no artery passes to the periphery of the lobule." The significance of the exceptions I failed for some time to appreciate.

If sections be made at right angles to the pleura of a dog's lung, in which the blood-vessels have been injected as above indicated, here and there, it will be seen that a branch of the pulmonary artery extends beyond the plane at which the others break up into capillaries. When this branch reaches the pleura it bends upon itself, gives off radicles to the pleura, then passes towards the center of the lobule for a short distance where it breaks up into capillaries (Fig. 1, *P. A.*).

FIG. 1. Section of the lung of a dog taken at right angles to the pleura. Camera lucida tracing showing the relation of the blood-vessels to the pleura. The parenchyma of the lungs is omitted from the drawing. *P* = pleura pulmonalis. *P. A.* = pulmonary artery, one branch of which can be seen arching under the pleura and sending a small radicle to the pleura. *P. V.* = pulmonary vein, one branch of which originates from the network into which the pleural radicle of the pulmonary artery breaks up. $\times 50$.

In sections, taken parallel to the pleura and which include the pleura, it will be seen that only a small portion of the pulmonary artery approaches the surface and that this is situated nearly equi-distant from the branches of the pulmonary vein (Fig. 2).

From the branches of the pulmonary artery, which extend to the pleura, a system of capillaries is formed which, in turn, empties into the radicles of the pulmonary vein (Fig. 1).

The pulmonary veins, on the other hand, as they approach the pleura branch repeatedly, and all of these branches run for some distance in, or just beneath, the pleura (Figs. 1, 2).

The present study of the pleural blood-vessels has brought out one point which I overlooked at the time I studied the lymphatics of the pleura (9 c), and which I do not find mentioned or illustrated in any previous contribution to the histology of the lung, namely, a distribution of blood-vessels to the lymphatics.

FIG. 2. Surface view of the pleura of the lung of a dog. P. A. = pulmonary artery. P. V. = pulmonary vein. The pulmonary artery is seen arching under the pleura and giving off branches to the pleura. The characteristic branching of the pulmonary veins is also shown. Camera lucida tracing. Details omitted. $\times 50$.

From the radicles of the pulmonary artery, which extend to the pleura, branches are given off which arrange themselves parallel to the course of the lymphatics. Generally, there is a blood-vessel on each side of a lymphatic; these are connected at intervals by transverse branches which run external to the lymphatic. There is thus formed a network of blood vessels the mesh of which is roughly rectangular, the long axis of the rectangle being placed at right angles to the course of the lymphatic (Fig. 3).

FIG. 3. From a section taken parallel to, and including, the pleura of the lung of a dog. Thickness of section 100 micra. The lymph vessels are fully distended. *L. V.* = lymph vessel. *P. A.* = pulmonary artery, situated beneath the pleura. A radicle can be seen arising from the artery and giving origin to the network of vessels about the lymphatics. $\times 50$.

The under surface of the lymphatics is apparently supplied by the capillary network of the air sacs (*sacculi alveolares*), over which they run, since encircling loops are rarely present in my preparations.

When the lymphatics are collapsed, the relation of the blood-vessels to the lymph vessels is not so apparent; it is only when the lymph vessels are distended that the relationship is best seen. On the other hand, having become familiar with this relationship, the situation of the lymphatics can be made out from the course of the blood-vessels, when they are well injected.

The capillary network of blood-vessels, which belongs to the remaining portion of the pleura, though continuous with that over the lymphatics, differs in the size and shape of its mesh and is readily distinguished from that over the lymphatics (Fig. 3). The entire network of pleural capillaries discharges its blood into the radicles of the pulmonary vein.

That which I have figured in a previous contribution (9 c) as the capillary network of the pleura belongs to the peripheral walls of the *sacculi alveolares* and not to the pleura proper. The mesh of the system of capillaries belonging to the *sacculi alveolares*, just beneath the pleura, is much coarser than that of the *sacculi alveolares* in the depth of the lung; that belonging to the pleura itself is still coarser.

Sheep.—In the sheep, the pleura receives its vascular supply in a manner quite different from that in the dog. Though thus far I have failed to demonstrate the bronchial artery as being distributed to the pleura of the dog, the first injection made showed a rich distribution of the bronchial artery to the pleura of the sheep.

From the hilus of each lung, and from a main trunk which runs along the pulmonary attachment of the *ligamentum pulmonale*, branches of the bronchial artery can be seen passing to all the lobes of the lung (Fig. 4). In general, the main branches on the *facies mediastinalis* and *facies diaphragmatica* may be said to run parallel to each other. These main branches are connected by numerous anastomoses and there is thus formed a coarse plexus of vessels the mesh of which is occupied by a network of still finer vessels.

Figure 4 shows several branches of the bronchial artery entering the *incisura interlobaris*. These branches are distributed to what may be called the *facies interlobaris* of the superior and inferior lobes of the lung.

The *facies costalis* (Fig. 5) receives its vascular supply in quite a different manner. Branches of the bronchial artery extend over the *margo inferior* and the *margo anterior* to the *facies costalis* and there break up

into finer ramifications. Branches also arch over dorsally from the facies diaphragmatica and facies mediastinalis. One or more of the branches which enters the incisura interlobaris extends through the incisura and reaches the facies costalis.

FIG. 4. Left lung of a sheep partially distended. Two-thirds natural size. The lung is seen from below and somewhat from the mesial surface. *F. d.* = facies diaphragmatica. *F. m.* = facies mediastinalis. *F. c.* = facies costalis. *I. i.* = incisura interlobaris. *L. p.* = ligamentum pulmonale. *L. s.* = lobus superior. *L. i.* = lobus inferior. The cut bronchus and vessels are readily recognized at the hilus. From the hilus and from the branch situated along the attached border of the ligamentum pulmonale the branches of the bronchial artery (solid black lines) can be traced to their distribution on both lobes of the lung.

This arrangement leaves the center of the facies costalis without any direct branches of the bronchial artery. The deficiency is supplied, however, by branches of the bronchial artery which come to the surface from the depths of the lung.

Along the margo inferior certain of the arteries instead of arching over the margin turn and enter one of the septa of the lung and, passing along this, appear on the facies costalis. Several of such examples are shown in Fig. 5.

FIG. 5. Facies costalis of the lung shown in Fig. 4. *B.* = bronchus sinister. *L. s.* = lobus superior. *L. i.* = lobus inferior. *I. i.* = incisura interlobaris. The branches of the bronchial artery (solid black lines) can be seen arching over the margins of the lung and coming up from the depth of the lung. Many of the vessels have been omitted; only those easily seen with the unaided eye are shown. Two-thirds natural size.

Not only is the pleura in the sheep supplied by branches of the bronchial artery, which pass directly to it, but it is also supplied indirectly by branches of the bronchial artery which pass into the substance of the lung at the hilus and, after giving off branches to the bronchi and to the connective-tissue septa, send radicles to the pleura. These radicles anas-

tomose with the network already described. Just mesial to the termination of the incisura interlobaris a very prominent branch can be seen in Fig. 5 which comes from the depth of the lung.

Fig. 6 shows a combination drawing of three consecutive sections taken perpendicular to the pleura. A branch of the bronchial artery can be seen

FIG. 6. Lung of the sheep. Combination of three successive sections taken perpendicular to the pleura. *B.* = bronchus in the wall of which sections of the bronchial artery are seen. *B.* = a branch of *B* which here runs a short distance beneath the surface. *B. A.* = bronchial artery. *P.* = pleura. *P. A.* = pulmonary artery. For further description, see text. $\times 25$.

following a bronchus and one of its branches, which here runs a short distance beneath the pleura, then, leaving the bronchus, it joins the network of vessels derived from the branches of the bronchial artery which pass directly to the pleura.

The vascular network about the lymphatics in the sheep's pleura is

FIG. 7. From a section taken parallel to, and including, the pleura of the lung of a sheep. Thickness of section 200 micra. The lymphatics are partially collapsed. *B. A.* = bronchial artery. *B. A.*' = points at which the pleural and pulmonary branches of the bronchial artery anastomose. *L. V.* = lymph vessel; in several places the valves are plainly visible. * = point at which a deep lymphatic joins the superficial network. $\times 33\frac{1}{2}$.

derived from the bronchial artery. There is usually a main arterial trunk on one side of a lymphatic and from this branches are given off which pass over and also beneath the lymphatic to the opposite side where they join to form a smaller vessel (Fig. 7). There is thus formed an arterial plexus which is placed external to the lymphatic. Along smaller lymphatics the two parallel arteries are usually of the same size. Here and there, branches can be recognized which connect the pleural vessels with those within the lung (Fig. 7).

In sections taken perpendicular to the course of the lymphatics it can be seen, in lungs in which the bronchial and pulmonary systems have

FIG. 8. Lung of sheep. Section taken at right angles to the pleura. Semi-diagrammatic. The outline, size, and position of vessels drawn by means of the camera lucida. P. = pleura. S. = septum. B. A. = bronchial artery. L. V. = lymph vessel cut obliquely. P. V. = pulmonary vein. ** = places where the capillaries from the bronchial artery join the radicles of the pulmonary vein. From one of these points the course of the venous radicle can be traced along a septum to a main branch of the pulmonary vein. $\times 50$.

been injected with differential masses, that from the plexus about the lymphatics capillaries are given off which unite to form radicles and that these radicles join branches of the pulmonary vein which are situated in the septa of the lung (Fig. 8). A few of the capillaries enter directly into the capillary network of the sacculi alveolares which are situated just beneath the pleura.

That the plexus about the lymphatics is to be considered as arterial is shown by granular injecting masses completely filling the plexus while

FIG. 9. From a section taken parallel to, and including, the pleura of the lung of a horse. Thickness of section 200 micra. The lymphatics were collapsed and difficult to follow. The lymphatic represented in the illustration was selected because it followed one of the main branches of the bronchial artery and gave an excellent opportunity of showing the large size of the bronchial vessels in the pleura of the lung of the horse. In the lower portion of the illustration the thickness of the arterial wall is shown in outline. B. A. = bronchial artery. L. V. = lymph vessel. $\times 50$.

the same mass does not enter the capillaries which go to join the radicles of the pulmonary vein.

At the hilus of the lung I have occasionally seen pleuro-bronchial veins, which join the true bronchial veins, coming from the first, and sometimes from the first two, divisions of the bronchi within the lung (9e).

Horse.—In the horse branches of the bronchial artery are distributed directly to the pleura and also reach the pleura indirectly; that is, after having first traversed the substance of the lung. The later branches, on reaching the pleura, anastomose with those that go directly to the pleura.

FIG. 10. Section taken at right angles to the pleura of the lung of the horse. Semi-diagrammatic. The outline of the section, the size and position of the vessels were drawn by means of the camera lucida. *P.* = pleura. *S.* = septum. *B. A.* = bronchial artery. *L. V.* = lymph vessels. *P. V.* = pulmonary vein. $\times 50$.

The main branches of the bronchial artery, which are directly distributed to the pleura, are of large size, much larger than in any other lung I have studied; their walls are very thick and contain a large amount of smooth muscle.

In the sheep and in man the pencil line with which the injected lumen of the arteries were outlined under the camera included at the same time the walls of the vessels; this is not the case in the horse. Fig. 9 shows one

FIG. 11. A lymphatic and its accompanying blood-vessels from the pleura of the lung of man. The lymphatic is partly collapsed. The encircling network of blood-vessels is well shown. B. A.=bronchial artery and its branches. L. V.=lymph vessel. $\times 50$.

of the main branches near the margo inferior of the right lung and, consequently, near its final breaking up into smaller vessels. This branch can be readily compared with the branches of the bronchial artery in the pleura of the sheep and man (Figs. 7 and 11), because they are drawn on the same scale. In the lower part of Fig. 9 the contour lines indicate the thickness of the arterial walls; in the remainder of the drawing only the injected lumen of the artery is indicated.

The lymphatics in the pleura of the horse, like those of the sheep, are supplied by the bronchial artery. In Fig. 9 the encircling network of blood-vessels is not as pronounced as in the sheep or in man. The illustration was selected more especially to show the large size of the

FIG. 12. Section taken at right angles to the pleura of the human lung. Semi-diagrammatic. The outline of the section, the size and position of the vessels were drawn by means of the camera lucida. *P.* = pleura. *S.* = septum. *L. V.* = lymph vessels. *P. V.* = pulmonary vein. The branches of the bronchial artery are represented by heavy black lines. $\times 50$.

blood-vessels. In Fig. 10 the relation between the lymph and blood-vessels is well demonstrated and one can see that there is in the horse the same relationship between the two systems as in the sheep and in man. In the pleura of the horse there is a thick, dense layer of elastic fibers overlaying the blood- and lymph-vessels which makes it difficult to obtain clear surface views of the finer blood-vessels and transparent lymph vessels.

Man.—In no instance have I been able to demonstrate in the human pleura the long, nearly parallel, branches of the bronchial artery which are such a prominent feature in the pleura of the sheep and the horse:

only here and there, have I found branches of the bronchial artery passing directly to the pleura. It does not seem to me that this is due to faulty injections, for I have always been able to obtain a well-filled system of vessels in the pleura.

I have always found that the branches of the bronchial artery which reach the pleura came from the depth of the lung and that they are larger in proportion and more branched than in the sheep or in the horse.

Küttner (8) has given an excellent illustration in his Fig. 7 of the artery spreading out in the pleura of the lung of an infant. The figures which I have obtained in the adult agree with his of the child.

It appears therefore, that in the sheep and in the horse the type of the distribution of the bronchial artery to the pleura is different from that in man. In the two former, the supply is mainly direct, in the latter, indirect.

The lymphatics of the pleura in man, like those of the sheep and the horse, are surrounded by a network of blood-vessels which is derived from the bronchial artery (Fig. 11). This network seems to be finer and there are more encircling branches than is the case with either the sheep or the horse, though some of my preparations of the sheep's pleura show a very complete network.

The capillary network into which the bronchial artery breaks up in the pleura gives rise to radicles which join the pulmonary vein. These venous radicles are larger in the human pleura than in either the sheep or the horse (Fig. 12).

ANASTOMOSES BETWEEN THE BRONCHIAL ARTERY AND THE PULMONARY ARTERY.

The question naturally arises: What constitutes an anastomosis? In general, we understand by the term, as applied to the vascular system, a communication between two different sets of vessels, as, for example, that between the carotis interna and the cerebri posterior; or between branches of the same set of vessels, as, for example, that between the branches of the mesenterica superior. In each of these instances we have to do with sizable vessels and it is the absence of sizable vessels that plays an important rôle in determining what constitutes an "end artery." An example of this differentiation is found in Spalteholz's study of the distribution of the blood-vessels in muscle (14).

Ruysch (12), Haller (4), Hyrtl (6) and others, say that the anastomosing branches between the two arterial systems are of sufficient size to be seen with the unaided eye. If this be true, an injecting mass con-

taining vermilion granules should pass freely from one set of vessels to the other set of vessels, as is illustrated in the anastomoses between the superficial and deep bronchial arteries in the lung of the sheep where the anastomosing branches are discernible to the eye (Fig. 6).

In the present study, and also in my study of the bronchial artery within the lung, I have failed to demonstrate by the use of granular injecting masses any anastomoses between the bronchial and pulmonary arteries. On the other hand, by using injection masses which flow freely through the capillaries I have injected both sets of vessels but only by a backward flow of the injecting mass through the capillary network (9 e).

In my study of the bronchial artery of the pleura of the lung of man, in one instance, I inserted a cannula directly into a branch of the bronchial artery and injected an aqueous solution of Berlin blue. On cutting into the lung it was seen that the fluid had entered both the pulmonary vein and pulmonary artery. Serial sections showed that the fluid had followed the capillaries, the pulmonary artery being injected indirectly. This can in no way be interpreted as showing an anastomosis between the two arterial systems, for it is absurd to call an indirect capillary communication an anastomosis.

VASA VASORUM OF THE PLEURAL LYMPHATICS.

The presence of a network of blood-vessels about the lymphatics has been overlooked by most of the later investigators but was recognized by those of the eighteenth and early part of the nineteenth centuries. Cruikshank, for example, says: "I have injected, in quadrupeds, the arteries on the coats of the lymphatic vessels, and seen them ramifying very elegantly through their substance (1)."

Panizza (11), searching for the origin of the lymphatics, says that whenever he has seen the injection appear in the lymphatics, after having completely filled the blood-vessels, he has found a network of capillary blood-vessels of a microscopical tenuity surrounding the lymph vessels. He concludes from this that the passage of the injection is a phenomenon of porosity. Evidently, Panizza overlooked the possibilities which might result from a rupture of this network of capillaries.

Sappey (13) and Dogiel (2) seem to be the only modern investigators who have recognized the vasa vasorum of lymph vessels. Sappey says: "The lymphatics are provided with vasa vasorum which one can very easily observe under the microscope and follow into the thickness of their walls." In another place he says the wall of the lymphatic trunks is rich in vessels and nerves. Each pulmonary lymphatic, for example, being encircled by a blood vascular network with coarse longitudinal meshes.

Dogiel demonstrated a plexus of blood-vessels about the lymphatics in the ear and hind leg of the rat and in the mesentery of the rat, the cat, and the dog. In his second contribution he described a plexus about the lymphatics of the capsule of the kidney in the dog.

Arnstein, in a foot-note to the earlier of Dogiel's contributions, remarked on the fact that the blood vascular network was external to the lymphatics and supported the opinion advanced by Dogiel that they, in some way, assisted in the circulation of the lymph. In a supplementary note to Dogiel's second paper, Arnstein considers Dogiel mistaken in calling the network in the capsule of the dog's kidney perilymphatic.

When the lymphatics are collapsed they lose their beaded appearance and it is quite difficult to distinguish their valves; many run for some distance in practically a straight course, conditions which were noted by Hewson (5).

In making injections of the lymphatics of the pleura of the horse and of man it has frequently happened to me that the injection mass would fail to enter any lateral branches and, for a distance of fifty or sixty millimeters, there would be a straight trunk (Fig. 12), which eventually broke out into a complete network of lymphatics. It would be erroneous to say that there were no other lymphatics in the area through which this single trunk passed, for under a dissecting lens they could readily be made out.

When the lymphatics are collapsed there is often an appreciable distance between the encircling network of blood-vessels and the lymphatics; but, when the lymphatics are distended, the network of blood-vessels is in close contact. The former conditions are indicated in Fig. 9, the latter, in Fig. 3. Dybkowsky (3) has noted a similar relation in his study of the lymphatics of the pleura costalis.

NOTE.—After the manuscript for the above article had left the author's hand, H. M. Evans (3*) published the results of his investigations on the vasa vasorum of lymphatics. The author regrets that it appeared too late to be noted in the review of the literature, since it is the most complete work on the subject that has thus far been published.

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