THE MORPHOLOGY OF THE LYMPHATICS OF THE MAMMALIAN HEART [1]

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ONE TEXT FIGURE AND SEVEN PLATES (NINETEEN FIGURES)

INTRODUCTION

The purpose of this study is to clarify our information concerning the morphology of cardiac lymphatics in mammals, particularly the dog. In spite of many investigations, the first begun about 1653, our knowledge of the lymphatics of the heart is incomplete and inaccurate, and their description in current anatomical text and reference books is brief and faulty. A rather extensive literature on this subject reveals a great variety of observations, many of them conflicting and inadequate, so that the need for accuracy and clarification definitely presents itself.

Cardiac lymphatics have usually been described as comprising three groups of vessels. These lymph vessel groups are named according to their locations and are the subepicardial, the myocardial, and the subendocardial. The existence of subepicardial lymphatics is well established and their distribution is fairly well known, but three entirely different conceptions of myocardial lymphatics seem to exist which obscure our knowledge of their actual morphology. Very little is known concerning subendocardial lymphatics. Their actual existence has been doubted by many investigators and they have repeatedly been confused with the ramifications of the Purkinje system.

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HISTORICAL

The investigation of cardiac lymphatics probably had its beginning with Rudbeck in 1653. According to Mascagni (1787), Rudbeck was the first to observe and describe any such structures. During his study of the lymphatics in the dog, he dissected a few subepicardial lymphatics which were seen to empty into some small mediastinal lymph nodes.

The discovery by Nuck in 1692, that lymphatics could be directly injected with mercury opened the way for further lymphatic study. He was able by this method to fill a number of the larger subepicardial lymphatics. His illustrations show a number of large vessels well supplied with valves. A number of years later Musschenbroek (1715), utilizing the direct injection of air into the lymphatics, demonstrated subepicardial lymphatics and described them as being double valved. Cassebohm (1746) also inflated subepicardial lymphatics and confirmed his findings by further dissection of the vessels. Cruikshank (1786) collaborated with William Hunter and published their findings after the latter's death. They improved the method used by Nuck and for the first time injected human subepicardial lymphatics. Blair ('25) states that some of Hunter's original specimens showing mercury filled lymphatics are preserved today in the 'Hunterian Museum' in the University of Glasgow. Mascagni (1787) again utilized the direct injection of mercury and obtained results quite similar to those of Cruikshank.

Fohmann (1833) greatly advanced the study of lymphatics by his discovery of the indirect or puncture method. His procedure consisted of inserting a canula into the myocardium and forcing mercury into the tissues. The canula insertion, he believed, mechanically ruptured the lymphatics and the mercury passed from the tissues into the lymph vessels through these artefacts. Utilizing this new method, he was the first to fill small subepicardial lymphatic vessels and capillaries. Lauth (1830), a student of Fohmann's, was the first actually to investigate the presence of subendocardial lymphatics. He injected mercury indirectly and, in the endocardium of the horse, found a superficial plexus of large

anastomosing vessels and a deep plexus of smaller vessels which were closely applied to the myocardium. No communications between the two plexuses were noted. The deep vessels he asserted lay parallel to the muscle fibers and were united by other vessels lying at right angles to the muscle fibers. The deep plexus, he continued, were the size of a hair and formed both large and small meshed networks. Gurlt (1844) reported the presence of large subepicardial lymphatics in the horse and Leyh (1859), who also studied lymphatics in the horse, pointed out the presence of lymphatics in the substance of the heart. The deep vessels, he explained, united with the subepicardial lymphatics and they in turn emptied into mediastinal lymph nodes.

Teichmann (1861) substituted colored starch injection masses for mercury and greatly advanced the indirect injection method of Fohmann. In his study of the lymphatic system, however, he only mentioned the presence of lymphatics in the epicardium. Two years later, His (1863), according to Aagaard ('24), described subepicardial lymphatics lying directly on the myocardium and connected with vessels embedded in the interstitial connective tissue of the myocardium. Aagaard believes this to be the first description of myocardial lymphatics based on microscopic observation. Luschka, also in 1863, reported the presence of a rich plexus of fine lymphatics in the myocardium. These vessels passed into subepicardial lymphatics which were located in the longitudinal sulci on the vortex of the heart. Eberth and Belajeff (1866) employed the indirect injection method and also a silver impregnation method, and in some specimens they also perfused the blood vessels with variously colored solutions. They studied both human and mammalian hearts and reported the finding of a myocardial network which is not so dense as that described by Luschka and which is continuous with both the subepicardial and subendocardial lymphatic plexuses. In the endocardium they encountered confusion between lymphatics and what they described as muscle sheaths which are

easily injected. Nevertheless, they described a plexus of subendocardial lymphatics which extended even into the atrioventricular and semilunar valves. They concluded that ". . . . that is no noteworthy difference between lymphatics of the epicardium and endocardium," and that ". . . . the heart is just as rich in lymphatics as other serosae or mucous membranes."

Henle (1868) discussing the structure of heart muscle, stated that intermuscular fissures and spaces convey lymph. The term 'Henle spaces' has been used subsequently by many authors to indicate similar structures. Confirming Henle, Schweigger-Seidel (1871) likened the myocardium to a 'lymphatic sponge.' In the same year Wedl (1871) studied subepicardial lymphatics in a number of mammals, particularly the sheep. He pointed out that in the horse these vessels may be seen and identified by the naked eye. He was however, unable to demonstrate any subendocardial lymphatics. Skvartzoff (1874) using the indirect method found the myocardium to contain endothelial lined lymph channels emptying into a dense subepicardial lymphatic plexus. He, too, was not successful in filling any subendocardial lymphatics. Skworzow (1874) using the same method as Skvartzoff, described, in the myocardium, intercellular and interfascicular unlined lymph spaces which empty directly into the subepicardial lymphatics. He also stated that the subepicardial lymphatics are united with the pericardial cavity by lymph spaces which pierce the epicardium. Bizzozero and Salvioli (1878), by their investigations, confirmed the results of Skvartzoff. Salvioli (1878) using the indirect method found a rich interfascicular network of lymph vessels in the myocardium which was continuous with the subepicardial network. He was unable to inject any lymph spaces and stated that the conception of the myocardium as being a 'lymph sponge' was incorrect. Navalichin (1882) reported M. P. Kolsoff's investigation done under his direction. The indirect injection method was again used and the results indicated that cardiac muscle fibers and blood vessels were surrounded by lymph spaces.

Sappey (1885) revived the method of direct mercury injection and described an extensive plexus of subendocardial lymphatics which was united to the subepicardial plexus by vessels which passed between the muscle bundles of the myocardium. His subendocardial plexus is a loose meshed extensive network completely covering the walls of the cavities. These vessels were large enough in the horse and calf, the principal animals investigated, to be seen easily with the naked eye and readily cannulated and directly injected. Bianchi (1886), returning to the indirect method, was unable to demonstrate lined lymph vessels in the myocardium and contended that lymph passed through the intermuscular clefts finally to be absorbed by the subepicardial vessels.

Albrecht (1887) introduced a physiological method of injecting cardiac lymphatics. His procedure was to inject a colored substance into the myocardium of the living heart, maintaining that the spontaneous movement of the contracting myocardium spread the injection mass. The myocardial network disclosed was composed of capillaries which lay at right angles to the long axis of the muscle fibers and surrounded each individual fiber. They were located with the blood vessels within the 'Henle spaces' and united with larger lymphatics also located there. In the same year Masini (1887) upheld the findings of Salvioli while two years later Ranvier (1889) stated, "The mammalian heart can be considered as a lymphatic sponge the same as the heart of the frog is a blood sponge." Lacroix (1891) found that silver impregnation methods yielded the same results in the epicardium as did injection methods. Renaut (1893), using the same methods as did Lacroix, confirmed the latter's findings and also described a myocardial plexus of lymphatics surrounding muscle bundles and emptying into the subepicardial plexus. In an attempt to settle the then existing controversy between those who described lymph spaces and those who described lymph vessels in the myocardium, Nyström (1897) employed the indirect injection method, a modified Golgi impregnation method, and uninjected stained microscopic sections. He arrived at

the conclusion that there existed in the myocardium an intercellular and intracellular system of lymph spaces, and also an endothelial lined vessel system. He inferred, although he demonstrated none, that open communications existed between the two systems. He also briefly described subepicardial and subendocardial lymphatics and likened them to those described by Sappey.

Bock ('05), whose findings are accepted and described in most present day anatomical texts, employed the indirect injection method and also perfused the blood vessels with a differently colored injection mass. His method was to knead the heart to remove blood from the coronary blood vessels and replace it with a carmine gelatine solution. He then injected Berlin blue under heavy pressure into the myocardium. His description of lymphatics was limited to the myocardium. He asserted that the lymphatic capillaries are similar to blood capillaries only more profuse and varied in shape. According to Bock, every muscle fiber had paralleling it a lymph vessel or two and any spaces between muscle cells were pathological. Rainer ('08) studied the subepicardial lymphatics of the atria and described principally their drainage into mediastinal lymph nodes. In a later work ('09) he described similar studies of the ventricular lymphatics and followed ('11) with a comparative study in a number of mammals. Tanasescu ('08) described interfascicular vessels which emptied into subepicardial lymphatics and cited Severeanu ('06) as having obtained similar results. Mouchet ('09) by means of the indirect injection method, studied the drainage of cardiac lymphatics into mediastinal lymph nodes, and noted the presence of small lymph nodes embedded in the epicardium overlying the interventricular sulci. He found these small lymph nodes quite readily in the dog and horse but was unable to locate any in human hearts. He also disclosed two subendocardial lymphatic plexuses, one lying superficial to the other. The superficial plexus was said to contain small vessels and form a compact network. The deep plexus, described in greater detail, was composed of large vessels which outlined sharp

angled geometrical figures and possessed extensive ramifications. He made no mention of the Purkinje system but compared his results favorably with those of Sappey. Aagaard and Hall ('14) directly injected and described the Purkinje system and described subendocardial lymphatics injected by the indirect method. They stated that confusion between the Purkinje injections and lymphatic injections does not exist but that confusion between the lymphatics and veins is possible. The subendocardial plexus, according to these authors, lies superficial to the Purkinje fibers, and, in part, parallels them but no communications between the two systems were found. By injecting the Purkinje system with mercury, they were able to duplicate the findings of Sappey.

Cash ('17) investigated the lymphatics of the embryo pig by the direct injection method. He found that cardiac lymphatics took origin by two single vessels, one from the right lymphatic duct, the other from the tracheal plexus. These two vessels passed to the heart and gave rise to the subepicardial plexus which reached its greatest density in the 60-mm. stage. Not until the complete formation of this plexus was reached, did any myocardial buds invade the musculature of the heart. Cash also slightly modified and repeated Bock's experiments, and in the adult cat injected India ink into the myocardium of the living anesthetized animal. His results in the adult heart led him to believe that Bock described and illustrated blood vessels and capillaries. He contended that the myocardial lymphatics formed a well-woven plexus of vessels, the smallest of which were larger than blood capillaries and that the lymphatics became fewer and fewer as the endocardium was approached. He was unable to inject any subendocardial lymphatics and said that all claims for such a plexus were based upon partial injections of the bundle of His.

Aagaard ('24) presented an extremely detailed study of cardiac lymphatics in man and some animals. The direct injection method was used. He described the subepicardial plexus in detail and in some cases traced its drainage into

the regional lymph nodes. The myocardial plexus was said to consist of an interfascicular plexus of vessels of varying diameters. The smaller vessels paralleled, for the most part, the direction of the muscle fibers and were drained by larger vessels which accompanied blood vessels and drained into the subepicardial lymphatics. His description of the subendocardial lymphatics was a repetition and elaboration of his findings as previously published in collaboration with Hall. The subendocardial plexuses injected were located principally on papillary muscles and on the ventricular septum. In the animal hearts he found vessels which accompanied the chordae tendineae for short distances and also some vessels which passed from the base of the atrioventricular valves into their leaflets, but in human hearts he could locate no corresponding structures. He found that the subendocardial plexus was drained by the myocardial plexus.

Shore ('28) investigated the drainage of cardiac lymphatics by means of indirect injections and also by observations following infection. He injected streptococci pyogenes intravenously in rabbits, and, following the establishment of cardiac valvular lesions, examined the regional lymph nodes for enlargement and inflammation. He believed that in this way he could determine which lymph nodes were concerned with cardiac drainage. Kampmeier ('28) injected human embryos and fetuses. He found two main cardiac lymphatic trunks. One arose from the pretracheal plexus and the other from the upper reaches of the thoracic duct. At 30 mm. they reached the heart, the one from the pretracheal plexus following the left coronary artery and the one from the thoracic duct following the right coronary artery. At 4 months, the greater part of the surface of the heart had been supplied by lymphatics. Valves made their initial appearance at the end of the third month in the larger lymphatics and continued to form in smaller vessels throughout the first part of the fourth month. He found valves most numerous in vessels on the anterior surface of the heart, not so numerous in vessels on the diaphragmatic surface and only a few in vessels of the atria. In

his discussion concerning the flow of lymph, Kampmeier believed the subepicardial lymphatic plexus to be a reservoir for lymph forced from the myocardium during each systole and that during each diastole the pressure of the expanding heart against the pericardium emptied this reservoir. He believed, however, that valves were necessary because of the action of the dilated pulmonary artery and aorta during systole on the closely applied lymphatic trunks leaving the heart, and because of the suction action caused by the relaxing of the cardiac muscle fibers on the myocardial lymphatics during diastole.

MATERIALS AND METHODS

The method deemed most suitable for the demonstration of cardiac lymph vessels was the physiological type of injection in which particulate matter, India ink (Higgins' American India Ink), is injected into the muscular wall of the intact heart of a living animal. By this method an attempt was made first to inject the cardiac lymphatics in a manner which would least alter the normal physiological activity of the heart and its vessels and second simultaneously to utilize this physiologic activity as an aid in filling the lymphatic vessels and as a means of distributing the injected material within them.

Twenty-eight animals were used in all, four rabbits, four cats and twenty dogs. Using a series of four animals, two cats and two rabbits, intramyocardial injections were attempted without first opening the thoracic cavity. The animals were anesthetized with ether. A thirty gauge platinum iridium hypodermic needle, similar to the one used by Hudack and McMasters ('32) in their study of cutaneous lymphatics, was inserted between the fourth and fifth ribs near the left border of the sternum into the heart. Slowly, and under minimal pressure, 0.05 to 0.10 cc. of India ink was injected into the myocardium by means of a syringe graduated to hundredths of a cubic centimeter. The puncture and injection were repeated a few times in order to cover as much of the subadjacent myocardium as possible. The animal was allowed

to recover from the anesthetic, and after 2 to 2½ hours was again anesthetized. The heart was removed and placed in physiological saline at 37°C. Then a canula was tied into the aorta and the coronary arteries were perfused with physiological salt solution at 37°C. (maximal pressure 80 cm. H_2O) in order to wash out blood and any India ink which might have entered the blood vascular system. The saline perfusion was subsequently replaced with Ranvier's Prussian blue solution so that confusion between blood vessels and lymphatics would not result and to make possible comparisons between the two types of vessels. The aorta was then tied and the heart allowed to remain in the salt solution a few hours, fixed in 10% formalin for 24 hours, methyl alcohol for 24 hours, and finally preserved in Kaiserling's solution. This method was not found to be satisfactory because only the anterior surface of the heart could be approached and the exact position of the tip of the needle could not be controlled.

The above procedure therefore was modified in a second series of animals composed of two rabbits and two cats in which the heart was exposed before injection. These animals were anesthetized by the intraperitoneal injection of pentobarbotal (1 cc. of a 1 grain per cubic centimeter solution per 5 pounds of animal). The trachea was exposed and a tracheal canula inserted and connected to an artificial respiration apparatus. This apparatus is a modification of the one described by Van Liere and Allen ('28). The sternum was cut in the midline from xyphoid process to jugular notch and the cut edges were retracted. The needle and syringe were the same as those used in the first series. The tip of the needle was inserted through the pericardium into the myocardium and approximately 0.07 cc. of India ink was slowly injected under minimal pressure. This was repeated in several other places until all surfaces were injected. The animal remained under anesthesia for about 2½ hours when the heart was removed and the coronary arteries were injected as before.

This method proved more successful than the first, but the results were still unsatisfactory. The only lymphatics which

contained India ink, as determined by gross inspection and microscopic study, were the large subepicardial vessels. The unsatisfactory results were due to the size of the heart; the thin contracting ventricular myocardium either forcing the tip of the needle into the ventricular chamber or ejecting it from the heart. If the tip of the needle was maintained in position by force, considerable trauma resulted. For the same reasons, atrial injections were wholly unsuccessful.

Due to difficulties noted above larger animals, dogs, were used in a third series of injections. Young animals of about 25 pounds were found best suited for study. In all, twenty animals were used. The heart was exposed and injected as before, except that the pericardium was opened to permit direct observation of the living heart during injection. Further, the heart was removed immediately following the last injection. The blood vessels were washed with salt solution and filled with Ranvier's Prussian blue solution and the heart was preserved as previously described. Even in the larger hearts atrial lymphatics could not be demonstrated for the same difficulties were met here as in the smaller hearts—the tip of the needle could not be held within the atrial wall. Necessarily, then, subsequent discussion will be limited to the lymphatics of the ventricles.

The description and study of the lymphatics were based on gross morphology as seen in the preserved specimen, on microdissection, and on thick and thin microscopical sections. Since the gross morphology of these vessels is characteristic and quite different from that of the blood channels, and because histologic similarity between lymphatics and veins is pronounced, thick microscopic sections (1 to 2 mm.) were primarily depended upon for the study of myocardial lymphatics, and gross and low power ($\times$ 10 to $\times$ 130) microscopic observation for the study of subepicardial and subendocardial plexuses. Occasionally microdissection was utilized to demonstrate more completely the continuity of certain vessels. The color of the material found in any vessels could not always serve to identify them as lymphatics or blood vessels. It was

impossible to puncture the myocardium and blindly inject India ink into it without rupturing and filling some blood vessels, and it was found impossible completely to wash out every blood vessel by coronary perfusion. In a few instances Prussian blue escaped from a ruptured blood vessel and entered a ruptured lymphatic.

In order to avoid confusion between the terms 'capillary' and 'vessel' the distinction will be one of gross morphology rather than of histology. The term 'lymphatic capillary' will signify the terminal lymphatic unit of that particular region, while the term 'lymphatic vessel' will signify the channel or channels which drain that terminal unit. To distinguish lymphatic capillaries from lymphatic vessels by histologic structure is impossible since even large lymphatic vessels which drain considerable areas may possess a wall composed of only a single layer of cells. To differentiate capillaries from vessels by the presence or absence of valves is unsatisfactory for valves may sometimes occur in lymphatic capillaries.

DESCRIPTIVE

A. Observations in the living heart

When the tip of the needle was inserted into the myocardium of the dog and a small quantity of India ink injected, the lymphatics lying in the subepicardial connective tissue filled to a greater or lesser extent with ink which first appeared in these lymphatics 3 to 45 seconds after the beginning of the injection. The extent and character of the vessels injected showed considerable variation. In certain hearts, a few lymphatic capillaries and one or two main trunks were seen to fill with a single injection, while at the same location in another heart, an extensive lymphatic capillary network and a few main trunks became visible. In still other hearts, similar injections failed to fill any subepicardial lymphatics.

The location of that portion of the myocardium in which the injection was made, modified the filling of the overlying subepicardial lymphatics. The vessels overlying the apex were the easiest to inject. From apex to base, filling of the subepicardial lymphatics proceeded with increasing difficulty.

Though the appearance of lymphatic plexuses at the base of the ventricles was unusual, in a certain few, rather extensive networks were seen to fill.

The depth to which the tip of the needle was inserted brought out some interesting facts. As might be expected, the closer the tip of the needle was placed to the endocardium, the fewer subepicardial lymphatics filled. If the needle was placed too superficially the ink would spread interstitially toward the surface, thus obliterating any vessels which may have been injected.

It has been noted that the filling of the subepicardial lymphatics was very rapid, 3 to 45 seconds after injection. Confirming the observations of Drinker and Field ('32) in the lymphatics of the web of the frog, material injected into the cardiac lymphatics soon disappears, presumably being carried away and dispersed by the flow of lymph. The time between the first appearance of India ink in the subepicardial lymphatics and any appreciable disappearance of the ink from these vessels was about 3 minutes. Within 10 minutes after the initial appearance of the ink, numbers of vessels and capillaries had completely vanished from view while others were only lightly outlined by the adhesion of ink particles to their walls and valves. A few capillaries not in the direct line of lymph flow often contained much ink. It was for this reason that the dogs' hearts were removed immediately upon completion of the last injection.

B. Subepicardial lymphatics

1. Subepicardial lymphatic plexuses. The ink-containing subepicardial lymphatics lie in a single plane between the myocardium and epicardium in the subepicardial connective tissue. They are filled with or outlined by India ink particles which have been carried to them from the underlying myocardium into which the ink is injected.

The subepicardial lymphatic plexuses are formed by vessels of quite irregular diameters and vary somewhat in morphology. Although the networks present definite variations in

different parts of the heart and in hearts of different dogs, they generally conform to a fundamental scheme. The fundamental type (figs. 2, 3, 4 and 5) is a plexus composed of straight parallel capillaries varying in diameter from 0.042 mm. to 0.228 mm. which are joined together by narrower capillaries, varying in diameter from 0.020 mm. to 0.176 mm. They may pass at right angles or obliquely in joining adjacent parallel capillaries, thereby forming rhomboidal or rectangular figures. The large parallel capillaries overlie the slight depressions between adjacent muscle bundles, accompany small blood vessels, and receive afferents from the underlying myocardium. The smaller connecting vessels pass transversely across the muscle bundles. When two or more, usually three capillaries converge, an irregularly shaped reservoir or lake is occasionally formed (fig. 6). All the afferents and efferents of a reservoir are of about the same caliber.

The lymphatics of the anterior surface of the right ventricle (fig. 7) and the apical regions (figs. 8 and 9) consistently present variations from the fundamental type as seen in the rest of the heart. In the former location the vessels are all narrower and of nearly uniform diameter, averaging 0.051 mm. They tend to form parallelograms which give the plexus a somewhat lattice-like appearance. Also in this location two hearts contained ink-filled capillaries which formed a chain-like plexus composed of oval loops of varying length. At the apex, the networks, although conforming to the general type, are composed of capillaries which are occasionally curved and often quite irregular.

Other modifications in the fundamental type appeared in several hearts. There was no regularity in regard to their location. One of the more common modifications (figs. 6 and 8) consisted of a plexus containing large meshes. The meshes, bordered by large capillaries averaging 0.191 mm. in diameter, contained fine capillaries whose diameters averaged 0.024 mm., and which originated within the meshes and passed radially to unite with the large bordering capillaries. They often anastomosed with others of their kind, thereby subdividing

the large meshes into smaller ones. Modifications occur also in the relation of the capillaries to the subadjacent myocardium. The large parallel capillaries may cross the muscle bundles transversely while the small uniting vessels overlie the interfascicular depressions (fig. 9), or the vessels may have no definite relation to the course of the underlying muscle bundles.

The various groups of ink-filled plexuses are, in most cases, connected to each other by anastomotic capillaries so that in a completely injected specimen there would be a continuous anastomosis covering the whole of each ventricle. No capillary plexus crossed the atrioventricular sulcus, the anterior interventricular sulcus, the posterior interventricular sulcus, or the left ventricular margin. The lymphatic capillaries contain a few irregularly placed valves, which are found principally in the larger capillaries.

2. Subepicardial drainage vessels. The subepicardial drainage vessels are, as the subepicardial capillaries, located in the subepicardial connective tissue between the epicardium and the myocardium, and in all instances are associated with blood vessels. These lymphatics may be divided into five orders of vessels. The classification of a vessel depends upon the area which that vessel drains rather than the size of the vessel itself. For example, a vessel draining a given area is often much smaller than another draining an area of equal size. Again, a single vessel formed by the conversion of two vessels usually has a greater diameter than either of the vessels from which it arose, but frequently its diameter is no larger than that of either one of its tributaries.

The drainage of the capillary plexus is similar in all cases (figs. 1, 10 and 11). The larger capillaries converge to form single drainage vessels of the first order, whose diameter is 0.32 mm. These vessels accompany blood vessels toward the anterior and posterior interventricular sulci, and toward the left ventricular margin where they converge to form vessels of the second order whose average diameter is 0.64 mm., and which accompany the corresponding blood vessels. The vessels which drain a given area lie along the same side of the

blood vessels as their origin. They may continue to do so for short distances, after which a lymphatic vessel lying on one side of the blood vessels may cross them, usually superficially, to anastomose with a similar vessel of the opposite side. In this manner vessels of the third order whose average diameter is 0.768 mm. are formed. The vessels of the third order are named according to their location, the anterior and posterior interventricular and left marginal trunks. These trunks may remain on the same side of the associated blood vessels as the plexuses from which they arise, or they may cross the blood

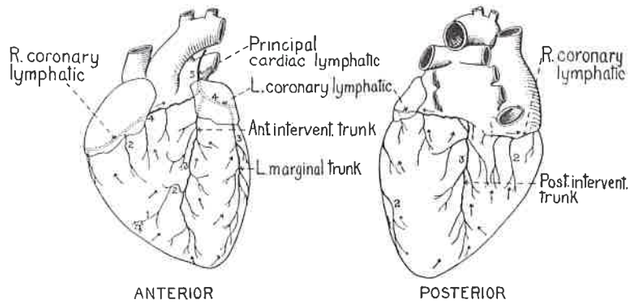

Fig. 1 Diagram of the anterior and posterior surfaces of the dogs' heart showing the course of the principal lymphatic trunks. Vessels of the first, second, third, fourth and fifth orders are indicated by the figures 1, 2, 3, 4 and 5. Arrows indicate the direction of lymph flow. × ½.

vessels, again superficially, to gain the opposite side. In a few cases the trunks form a loose meshed plexus surrounding the blood vessels. In their course these trunks receive many tributaries of the second order. On the left anterior surface of the apex of the heart, the anterior and posterior interventricular and left marginal lymphatic trunks often anastomose and form an irregularly shaped, large meshed plexus (figs. 3 and 12).

In the dog, the entire heart is drained by one principal coronary lymphatic, or vessel of the fifth order, which is formed by the union of what may be called the right and left coronary lymphatics or vessels of the fourth order (fig. 1).

The formation of these vessels is variable, the most common arrangement being as follows: The right coronary lymphatic arises in the atrioventricular sulcus a few millimeters from the posterior interventricular sulcus. It passes to the right margin of the heart, then curves anteriorly and passes to the left in the same sulcus as far as the base of the pulmonary artery. Here it leaves the heart and passes superiorly for 5 to 10 mm. on the anterior surface of that vessel. In its course it receives tributaries of the first and second order from the right ventricle. The left coronary lymphatic takes its origin as the posterior interventricular trunk. It passes from the posterior interventricular sulcus to the left atrioventricular sulcus. At the left margin of the heart it receives the left marginal trunk. It then passes to the anterior surface of the heart still lying in the atrioventricular sulcus. Here it receives the anterior interventricular trunk and leaves the heart to join the right coronary lymphatic which lies on the anterior surface of the pulmonary artery. These two vessels thus form the principal coronary lymphatic. In its course on the anterior surface of the heart the left coronary lymphatic is overlapped by the left auricle. It receives directly a number of small tributaries of the first and second order from the left ventricle. The diameters of the right and left lymphatic trunks are usually equal, the average diameter being 1.0 mm. In some instances the left lymphatic trunk is somewhat larger than the right, in which case its diameter may reach 1.4 mm. The diameter of the principal coronary lymphatics varies between 1.0 mm. and 1.5 mm. The most common variations which occur in the formation of the right and left coronary lymphatics, are found in cases in which the posterior interventricular trunk drains into either the right coronary lymphatic or into both the right and the left coronary lymphatics. The anterior interventricular trunk shows less frequent variation. It may empty into the right lymphatic trunk or pass directly to the common trunk formed by the right and left coronary lymphatics. Occasionally the right coronary lymphatic, instead of leaving the heart by passing

directly on to the pulmonary artery passes behind the aorta to reach the pulmonary artery. In a few instances the right and left coronary lymphatics do not unite to form a single vessel.

The valves of the subepicardial drainage lymphatics (fig. 13) are numerous and located at fairly regular intervals in the larger vessels and trunks. In those vessels which contain a small amount of ink, as particles which adhere to the vessel walls and valves, the valves are beautifully outlined. When the vessel is well filled with ink, the valves are only indicated by constrictions between nodular swellings along the course of the vessel.

C. Myocardial lymphatics

The India ink deposited in the myocardium of the dog's heart with each injection was found in the interstitial connective tissue spaces surrounding the various structural elements of the myocardium. Ink-filled blood vessels and capillaries, and often one or more lymphatics were seen extending from these areas (figs. 14, 15 and 16). The lymphatics, made visible by their ink content, were usually well filled and easily identified. In most cases only the short anastomosing vessels appeared, but in a number of instances extensive plexuses were injected.

The myocardial lymphatics form a loose meshed plexus of three dimensional proportions which is uniformly distributed throughout the entire myocardium. This plexus (fig. 15) is composed of vessels which lie in the interfascicular connective tissue and surround the muscle bundles. These vessels may be divided into two groups. The first group is composed of vessels which lie roughly parallel with the muscle fibers, while those forming the second group pass transversely or obliquely across the muscle fibers and unite the vessels of the first group. Each muscle bundle is paralleled by two to four vessels and these vessels are united by the oblique or transverse vessels at irregular intervals of from 0.100 mm. to 0.800 mm.

Although the diameter of each lymphatic is characteristically not uniform throughout its course, the myocardial plexus as a whole is composed of vessels more or less similar in size. Their average diameter is 0.045 mm. The lack of a uniform diameter in these lymphatics causes them to appear well valved, whereas actual valves are very scarce and their locations not predictable.

The larger myocardial blood vessels are accompanied by one or two anastomosing lymphatics (fig. 14) or are surrounded by a plexus of lymphatics. These lymphatics are no larger than any other myocardial lymphatics and cannot be considered as drainage vessels. Although they accompany blood vessels, they participate in the formation of the myocardial plexus and their relation to the blood vessels is similar to the relations of a group of lymphatics to a bundle of muscle fibers.

Communications of the myocardial plexus with the subendocardial and with the subepicardial plexuses (figs. 14 and 16) are similar. The myocardial plexus receives short communicating branches from the subendocardial plexus. They arise at fairly regular intervals from the subendocardial plexus and pass superficially between the Purkinje fibers, then between the innermost muscle bundles of the myocardium and enter the myocardial plexus. In their course they pass transversely across the Purkinje fibers and the innermost muscle bundles and give no communication to either. From that part of the myocardial plexus lying just below the most superficial layer of muscle bundles, short vessels pass between the bundles directly to the surface and empty into the subepicardial lymphatic capillaries which overlie the interfascicular depressions. Often two or three communicating vessels unite just before entering a subepicardial capillary. Those lymphatics which accompany blood vessels often continue with them to the surface and empty into the larger subepicardial lymphatics.

Since, in the dog's heart, the vessels forming the myocardial lymphatic plexus contain few valves, because they give

off no twigs which penetrate the muscle bundles and do not form trunks, and for the most part empty into the subepicardial lymphatic capillaries, the entire plexus may be said to be composed of lymphatic capillaries.

D. Subendocardial lymphatics

In the dog's heart, subendocardial lymphatics, located in those areas of the subendocardium lining the smooth myocardial surfaces were easily injected, whereas none were demonstrated in those parts of the subendocardium roughened by numerous trabeculae carneae although repeated attempts were made to inject them. The subendocardial areas successfully injected were directly associated with the longitudinal muscle columns of the left ventricle, the septal wall of the right ventricle and the papillary muscles of both ventricles.

The subendocardial lymphatics were found to form plexuses which occupy a single plane parallel to the endocardial surface, their depth in the subendocardium depending on their regional location. The plexus on the surface of the longitudinal muscle columns of the left ventricle and that on the papillary muscles is located in the layer of loose connective tissue between the middle layer of dense elastic fibers and the lining endothelial cells, while the plexus of the right ventricular septal wall is found in the layer of loose elastic fibers deep to the middle layer of dense elastic fibers. The lymphatics were in all instances situated between the lining endothelium and the Purkinje fibers. In no instance was any communication found between the subendocardial lymphatics and Purkinje fiber sheaths.

The subendocardial lymphatic plexuses on the longitudinal muscle columns of the left ventricle (fig. 17) are characterized by the uniformity in size of their constituent vessels and the uniformity in the density of the plexus itself. The average diameter of the vessels is 0.040 mm. and each vessel usually maintains the same diameter throughout its length. These lymphatic vessels tend to form elongated meshes whose long axes lie transversely to the long axis of the related longitudinal muscle columns. The length of each mesh is about

three times its diameter. All of the lymphatics of these areas participate in this plexus formation, no collecting trunks, formed by converging vessels, being found. In no instance did any lymphatic leave a plexus to accompany a trabecula carnea which was attached to the muscle column. Many short lymphatics were seen to originate blindly within the meshes. The blind beginnings were usually rounded and often dilated and bulb-like. Microscopic examination and microdissection proved them to be actual beginnings and not incomplete injections terminated by a valve. In fact no valves were found in any plexus overlying the longitudinal muscle columns.

Lymphatics in the endocardium covering papillary muscles (figs. 17 and 18) are, in general, similar to those overlying longitudinal muscle columns. The vessels forming these plexuses, in some instances, become slightly smaller in diameter as they approach the apex of the papillary muscle. Their average diameter is 0.032 mm., and they form a more irregular and smaller meshed plexus. The meshes of these plexuses are, as a general rule, of an elongated type and traverse the long axis of the papillary muscle. In a few instances single vessels which were found to be continuous with the plexus on the papillary muscles, accompanied the chordae tendineae for a few millimeters, but were never found to pass beyond the first third of the distance between papillary muscle and valve leaflet. As in the plexuses on longitudinal muscle columns, these also contained short blind vessels, and were without collecting vessels; however, an occasional valve was seen.

The morphology of the subendocardial lymphatic plexus of the septal wall of the right ventricle (fig. 19) differs greatly from that of the other subendocardial plexuses. The vessels of this plexus vary greatly in diameter, ranging from 0.224 mm. to 0.035 mm. No uniform pattern exists in the arrangements of these vessels, the meshes formed being of irregular shapes and sizes and the course of the vessels having no definite relation to the directions of the muscle fibers of the septum. Here again, no collecting trunks were found, but individual vessels in some instances, were quite long. Also,

as in all the other subendocardial plexuses, blind vessels were injected, and as in the papillary muscle plexuses, a few valves were seen.

The communications between the subendocardial plexuses and the myocardial plexus (fig. 16) is by way of short vessels which leave the subendocardial plexuses and pass directly into the myocardium where they anastomose with the myocardial lymphatics. The diameters of the communicating vessels are approximately the same as the diameters of the subendocardial vessels from which they arise. All attempts to inject lymphatics which may exist in the atrioventricular valves proved unsuccessful.

One may conclude that in the dog, subendocardial lymphatic plexuses are composed entirely of lymphatic capillaries. They do not converge to form collecting trunks, possess few valves, and drain into the myocardial plexus, which has been shown to be composed entirely of lymphatic capillaries.

DISCUSSION

That a subepicardial plexus of lymphatics exists has been well established by a number of investigators. They all agree that these vessels lie in the subepicardial connective tissue and that the larger trunks accompany the blood vessels. However, there is lack of agreement regarding the patterns outlined by small lymphatic vessels and capillaries and their relations to the underlying myocardium. To account for these minor differences, one must consider the variations between hearts of the same species and between hearts of different species. Another important factor is the variable degree of distortion of the subepicardial plexus by active contraction and by shrinkage of the closely related myocardium. If, for example, one heart is placed in a fixing solution before rigor mortis sets in, another during rigor mortis, and a third after rigor mortis has passed off, the first contracts violently due to the irritation of the living muscle by the fixative, the second is only slightly modified because it is already in a contracted state, and the third is least modified because it is not in a

contracted state and because it is no longer irritable, since it is dead. Experience has also shown that if a heart is cut open for endocardial examination or injection before fixation, greater contraction and shrinkage distortion will result than if it is immersed in the fixative in the unopened state. It is, therefore, readily seen why one author may describe a plexus outlining squares or rectangles, while another will describe rhomboids and why the relations of these vessels to the muscle fibers are not similarly described by all investigators.

As to the nature and extent of the myocardial lymphatics, there has been considerable controversy. Some describe unlined lymph spaces, some a capillary network surrounding individual muscle fibers, while others describe an interfascicular network of endothelial lined vessels. If a canula or hypodermic needle is plunged at random into the myocardium, and an injection mass is forced into the tissues, as is the procedure in the direct injection method, the result will be a spreading of the injection mass within the connective tissue in the interstitial tissue spaces surrounding blood vessels and muscle fibers. This injection mass will then mix with the normal tissue fluids and be further dispersed. Also, in this type of procedure, it is impossible to avoid rupturing numerous blood vessels and capillaries and some lymphatics. The injection mass, which is under the pressure of the injection and the pressure of muscular contractions in the case of the beating heart, will be forced into the ruptured vessels and partially fill them. If thin microscopic sections of the above described areas are studied, the orderly arrangement of muscle fibers, connective tissue, and shrinkage artefacts, may cause the injection filled areas surrounding these structures to appear somewhat like a well-organized channel system. This, in addition to the fact that cardiac lymphatics are difficult to distinguish histologically from veins, the only difference being that the lymphatics contain valves while the veins, as first pointed out by Schweigger-Seidel (1871), contain no valves, may cause the investigator to describe unlined lymph spaces.

To distinguish lymphatics from blood vessels, it is necessary to study thick sections under low magnification. These sections should be at least 1 to 2 mm. thick. On such sections it is possible to identify the vessel systems by their morphological pattern rather than by the cellular structure of their walls. To aid in the identification of these systems, the blood vessels may be perfused with a solution of different color than the injection mass. Although the different colors may help to some extent, it is impossible to rely on color alone, because the removal of all of the injection mass from blood vessels and the perfusion of the entire blood vascular system is impossible. Further, the perfusion fluid may pass into the lymphatics by diffusion or through rupture; and the injection mass may leave the lymphatics and enter the blood vessels. Bock ('05) attempted to identify lymphatics by color differentiation, but made the error of first perfusing the blood vessels. As has been shown, it would have been impossible for him, using the indirect method, to avoid rupturing and filling blood vessels with the injection mass, thus displacing the perfusion fluid. His description, consequently, is that of blood vessels and not lymphatics, and most of his illustrations are of typical blood vessels and capillaries. Cash ('17) found, in the living heart, that the closer to the endocardium the injections were made, the fewer subepicardial lymphatics were seen to fill. From this observation and microscopic study, he concluded that the myocardial lymphatic plexus becomes increasingly less dense as we approach the endocardium. Observations during injection in the living heart have confirmed many of Cash's findings, but myocardial lymphatics have been found to be as dense in the depths of the myocardium as near its surface. To explain why subepicardial vessels are not filled when deep injections are made, one must consider the pressure necessary to fill vessels of such small diameter from a needle of comparatively large diameter. Further the increased resistance offered by the longer more irregular deep myocardial vessels and the increased vessel bed involved, must be taken into consideration. Cash's observations were made on hearts which were allowed to beat for 2 to 3 hours after the injection.

Such a long time interval after the injection must definitely alter the picture as it has been shown that the lymph flow washes the injection mass from the lymphatics in a few minutes.

The satisfactory injection and identification of subendocardial lymphatics requires an adequate method of injection, a considerable knowledge of the finer ramifications of the Purkinje system, and a method of distinguishing veins from lymphatics. The usual method of injecting subendocardial vessels is to open the excised heart and repeatedly inject colored substances through the endocardium into the subendocardial connective tissue. In this investigation better success was obtained in the dog's heart if the injections were made in the living heart, the needle being inserted through the myocardium to the subendocardium.

Before the discovery of the true nature of the Purkinje system and its sheath, its ramifications were often taken for lymphatics. The earliest description of subendocardial lymphatics, as previously noted, was by Lauth (1830) who described a plexus consisting of two independent layers, one superficial, the other deep. Considering that no communications were found between these two plexuses, it may be assumed that he injected two distinct systems. The deep plexus, because of its location and relation to the myocardium, is readily recognized as consisting of ramifications of the Purkinje system, while the superficial plexus, so briefly described, is possibly composed of lymphatics or subendocardial veins. The first recognition of the possibility of error in the identification of lymphatics was by Eberth and Belajeff in 1866, before the discovery of the Purkinje system. In their report on cardiac lymphatics, they state that in the subendocardium, particularly of the calf, "Nets of fine grey threads which contain principally short muscle cells can under certain circumstances cause confusion. If one should puncture such a thread, he can succeed very easily in driving air or colored injection mass in long stretches through the entire net." With this knowledge to guide them they described and illustrated

vessels which they stated were similar to myocardial and subendocardial lymphatics, so that there is good evidence that they actually injected and described subendocardial lymphatics.

Sappey's (1884) descriptions of subendocardial lymphatics are undoubtedly descriptions of the Purkinje system. In their study of the Purkinje system, Aagaard and Hall ('14) injected mercury into the Purkinje sheaths and the result was a duplication of Sappey's findings. Nyström only briefly described subendocardial lymphatics, and since he thought that he confirmed Sappey's findings, they were probably not lymphatics but Purkinje fibers. Mouchet ('09) although familiar with Sappey's work, did not recognize the latter's errors even though the morphology of the Purkinje system and its sheath was known at that late date. His description of deep subendocardial lymphatics is similar to Sappey's and therefore is questionable. His description of a superficial subendocardial lymphatic plexus, however, is possibly a description of lymphatics. Aagaard and Hall ('14) who injected and studied the Purkinje system as well as endocardial lymphatics were well qualified to distinguish between the two systems. Their method of injection was similar to Eberth and Belajeff's and microscopic study supplemented gross observations. Their descriptions were unquestionably of lymphatics and their photographic illustrations conclusively prove that they injected subendocardial lymphatics. Cash ('17) was unable to inject any subendocardial lymphatics and concluded that all descriptions of such vessels were probably descriptions of the Purkinje system. When one considers the difficulty encountered in placing the tip of the injection needle near the endocardium of the relatively large living dog's heart, it is likely that he was unable to control the position of the tip of the needle in the comparatively thin myocardium of the living cat's heart.

The mechanical factors involved in the flow of lymph from the myocardial to the subepicardial lymphatics and from the subepicardial to the main external drainage lymphatics are

well explained by Kampmeier ('28). He contends that the subepicardial lymphatic plexus acts as a reservoir which receives lymph from the myocardial vessels with each contraction of the myocardium and that during diastole the expanding heart against the pericardium forces the lymph from the subepicardial lymphatics into the main vessels draining this plexus. The finding, in this investigation, of comparatively large lakes at the junctions of many of the subepicardial lymphatics would lend support to his belief that this plexus of vessels acts as a reservoir. It may also be stated that the pressure of the blood filling the heart cavities during diastole would force lymph from the subendocardial lymphatics into the myocardial lymphatics.

It may be concluded from the above that differences in the descriptions of the morphology of the subepicardial lymphatics are due to normal variations in this plexus and to distortion and shrinkage artefacts. Regarding the myocardium, it is readily seen that the so-called unlined lymph spaces are only ink-filled tissue spaces or shrinkage artefacts; and further, plexuses of small vessels surrounding individual muscle fibers are in reality blood capillaries; while true myocardial lymphatics form an interfascicular plexus of vessels which is uniform in density throughout the myocardium, and whose vessels have greater diameters than blood capillaries. It has also been shown that a subendocardial lymphatic plexus actually exists in the subendocardium. This plexus may be injected in the living heart or in the opened excised heart and is readily differentiated from the Purkinje system which has often been injected and erroneously identified as a lymphatic plexus. It may also be concluded that mechanical factors, active during both systole and diastole, are responsible for the flow of lymph within and from the heart.

SUMMARY

1. In the dog the subepicardial lymphatics consist of capillaries and drainage vessels. a) The subepicardial lymphatic capillaries form continuous plexuses which cover the whole of

each ventricle. These plexuses are made up of both large and small capillaries. The large capillaries overlie the interfascicular depressions formed by the most superficial layer of muscle bundles, receive afferents from the myocardial plexus and converge to form drainage vessels. The small capillaries cross the muscle bundles and unite adjacent large capillaries. b) The drainage vessels in all cases accompany blood vessels. They may be divided into five orders depending not so much upon their size, but on the size of the area drained. The vessels of the first order drain the capillary plexus and receive a few lymphatic capillaries from the myocardial plexus. Three or four of these vessels unite and form drainage vessels of the second order. A number of drainage vessels of the second order unite and form drainage vessels of the third order, and so on, until a single trunk which drains the entire heart leaves it by passing on to the anterior surface of the pulmonary artery.

2. The myocardium possesses a lymphatic plexus uniform in density from subepicardium to subendocardium. It is composed entirely of lymphatic capillaries, the smallest of which is about three times the diameter of myocardial blood capillaries. These lymphatic capillaries lie in the interfascicular connective tissue and surround muscle bundles and accompany blood vessels. No collecting trunks are present in the myocardium. The drainage of this plexus is principally by short capillaries which pass directly into the subepicardial capillaries. Those lymphatic capillaries which accompany blood vessels also participate in the plexus formation. Capillaries, however, may continue with the blood vessels to the surface and empty into the small subepicardial drainage vessels of the first order.

3. The subendocardial lymphatic plexuses, similar to the myocardial lymphatic plexus, are composed entirely of lymphatic capillaries. They lie in a single plane parallel to the surface of the endocardium and are always between the endocardium and the Purkinje fibers. Plexuses were injected only beneath those surfaces which are smooth. In no subendocardial area roughened by numerous trabeculae carneae were any lymphatics found. The areas injected were related to the longitudinal muscle columns of the left ventricle, the papillary muscles of both ventricles and the septal wall of the right ventricle. The plexuses lying on the longitudinal muscle columns of the left ventricle and the papillary muscles are uniformly dense and are characterized by elongated meshes whose long diameters cross the muscle fibers transversely. The subendocardial plexus of the septal wall of the right ventricle is composed of large and small capillaries and the meshes are very irregular in both size and shape. All plexuses possess numerous short blind capillaries. The communications between these plexuses and the myocardial plexus are by means of short capillaries which pass directly into the myocardium. Lymphatic capillaries, continuous with the papillary muscle plexuses, were seen to accompany the chordae tendineae for a few millimeters. Injections into the atrioventricular valves failed to demonstrate the existence of lymphatics within them.

4. Cardiac lymphatics in no instance communicated with the sheaths surrounding Purkinje fibers. The relation between lymphatics and Purkinje fibers is similar to that between lymphatics and bundles of muscle fibers.

5. Valves are quite numerous in the subepicardial drainage lymphatics. However, only a few scattered valves were found in the capillary plexuses of the subepicardium, myocardium and subendocardium, with the exception of that part of the subendocardial plexus which is related to the longitudinal muscle columns of the left ventricle. In this particular plexus no valves were found.

6. The flow of lymph in the cardiac lymphatics was found to be quite rapid. India ink injected into the myocardium of the living heart appeared in the subepicardial lymphatics within a few seconds. Within 3 minutes after the injection, the ink in the subepicardial lymphatics had appreciably diminished, presumably being washed away by the lymph flow.

7. From the above reported observations concerning the lymphatics of the dog's heart, the normal flow of lymph in

and from that organ could be explained as resulting from the pressure exerted on the lymph vessels during both systole and diastole. It seems probable that the pressure of the blood in the ventricle during diastole drives lymph from the subendocardial lymphatics into the myocardial lymphatics. During systole the contraction of the myocardium, as pointed out by Kampmeier, probably forces the lymph from the myocardial lymphatics into the subepicardial lymphatics and the pressure of the dilated heart against the pericardium toward the end of diastole may reasonably be expected to drive the lymph from the subepicardial lymphatics into the main lymphatic trunk leaving the heart.

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PLATES

PLATE 1

EXPLANATION OF FIGURES

Figures 2 to 13 inclusive and 17 to 19 inclusive are actual unretouched photographs. Figures 14 to 16 inclusive are camera lucida drawings of thick microscopic sections. Figure 20 is a schematic drawing based on a large number of thick microscopic sections.

2 Left posterior view of left ventricle showing injected subepicardial lymphatic capillary plexus. Dog. × ¾.

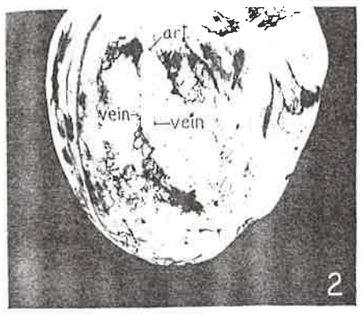
3 Right posterior view of left ventricle showing injected subepicardial lymphatic capillary plexus, and a plexus of large drainage vessels. Dog. × ¾.

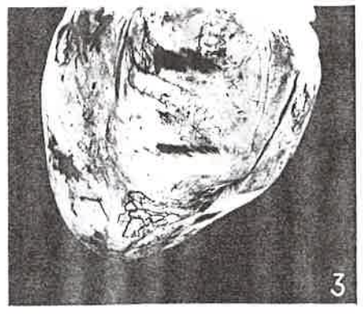
4 Enlargement of subepicardial lymphatic plexus illustrated in figure 2. Dark area, lower left is extravasation of ink around point of injection. The India ink in places has permeated the walls of the lymphatics obliterating their exact outline. Dog. × 2½.

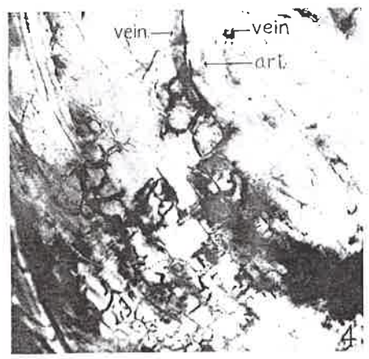
5 Enlargement of subepicardial lymphatic capillary plexus illustrated in figure 3. The dark area above is due to the extravasation of ink around the point of injection. The dark area below is due to the infiltration of ink through the myocardium to the surface. Dog. × 2½.

6 Enlargement of subepicardial lymphatic capillary plexus on the posterior surface of the right ventricle illustrated in figure 11. Two subepicardial lymphatic reservoirs have been injected. Dog. × 7½.

7 Enlargement of subepicardial lymphatic capillary plexus on the anterior surface of the right ventricle illustrated in figure 10. The lattice-like arrangement of this plexus is characteristic of the region. Dog. × 4½.







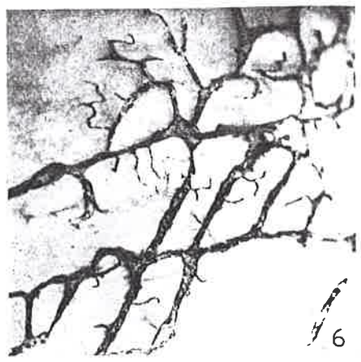


PLATE 2

EXPLANATION OF FIGURES

8 Enlargement of the subepicardial lymphatic capillary plexus on the anterior surface of the apex of the left ventricle illustrated in figure 10. This plexus is an example of the type in which small capillaries subdivide large meshes formed by large capillaries. Dog. × 3¾.

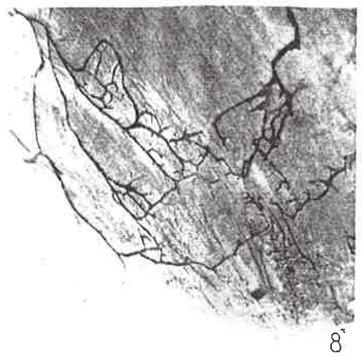
9 Enlargement of the subepicardial lymphatic capillary plexus on the posterior surface of the apex of the left ventricle illustrated in figure 11. The large capillaries in this plexus cross transversely the fibers of the underlying myocardium. Dog. × 3¾.

10 Anterior view of the heart showing subepicardial lymphatic capillary plexuses and drainage vessels. Dog. × ¾.

11 Posterior view of the same heart illustrated in figure 10. Dog. × ¾.

12 A plexus of large subepicardial drainage vessels located on the anterior surface of the apex of the left ventricle. Dog. × 7.

13 Valves outlined by ink in large drainage vessels. Dog. × 7.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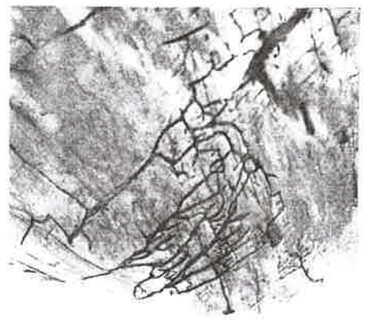
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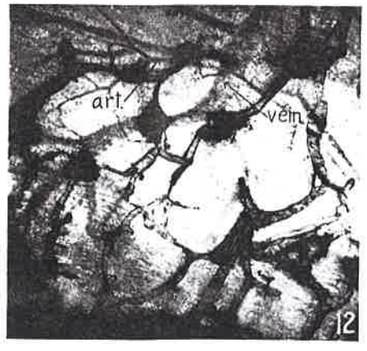

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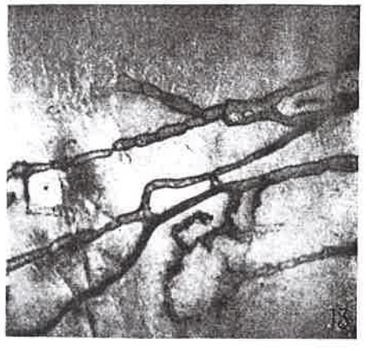

13

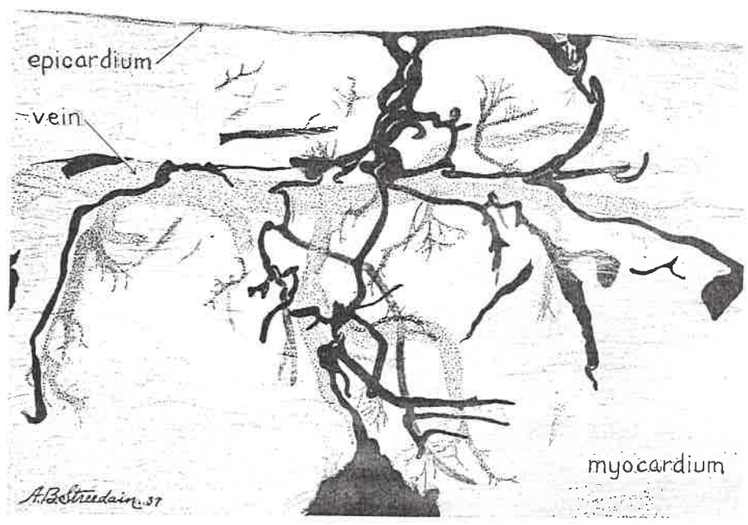
PLATE 3

EXPLANATION OF FIGURE

14 Myocardial lymphatics intimately related to a vein and its tributaries and communicating with the subepicardial lymphatic plexus. Dark area below is point of injection. The direction of the muscle fibers is indicated. Dog. × 30.

LYMPHATICS OF THE HEART
PAUL R. PATEK

PLATE 3



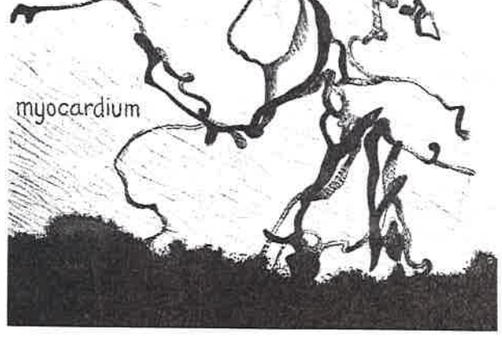
EXPLANATION OF FIGURES

15 Myocardial lymphatic plexus. Dark area below is point of injection. The direction of the muscle fibers is indicated. Dog. × 30.

16 Communicating lymphatics uniting the subendocardial lymphatic plexus and the myocardial lymphatic plexus. Dark area in upper right corner is the point of injection. The direction of the muscle fibers is indicated. Dog. × 30.

LYMPHATICS OF THE HEART
PAUL R. PATER

PLATE 4



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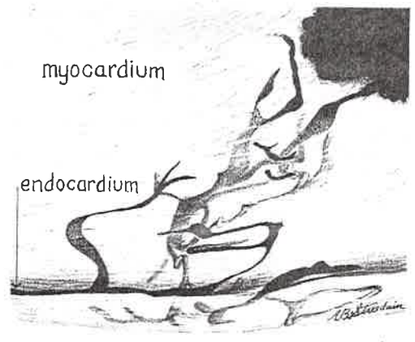

16

PLATE 5

EXPLANATION OF FIGURE

17 Subendocardial lymphatic plexuses on the longitudinal muscle bundles and papillary muscle of the anterior wall of the left ventricle. Enlarged views (A and B) show the details of the plexuses. Dog. × 7 and × 14.

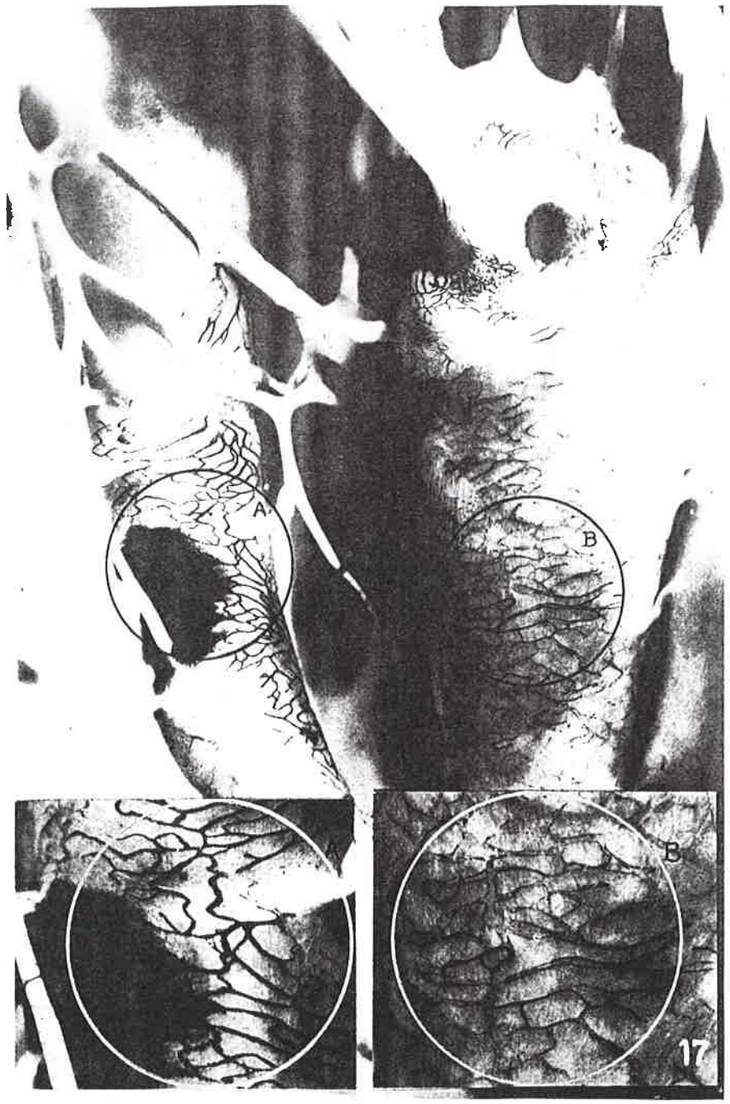

PLATE 6

EXPLANATION OF FIGURES

18 Subendocardial lymphatic plexus on papillary muscle of the right ventricle. Dog. × 14.

19 Subendocardial lymphatic plexus on septal wall of the right ventricle. Dog. × 14.

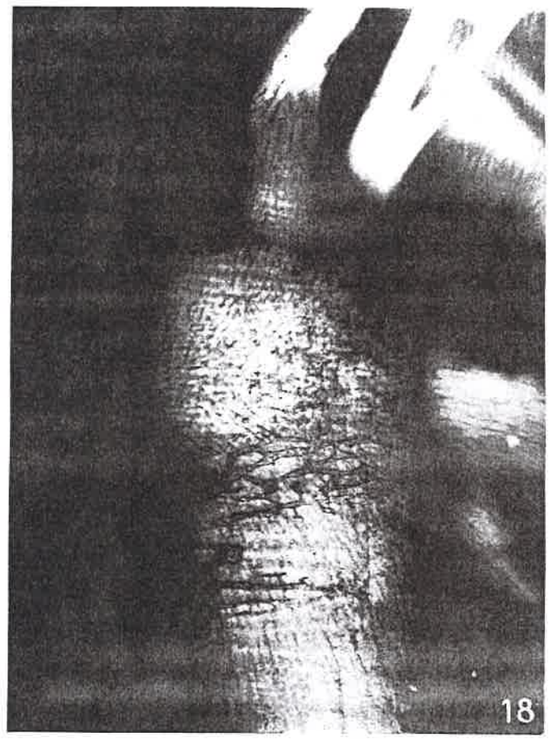

PLATE 7

EXPLANATION OF FIGURE

20 A schematic drawing of a section of the ventricular wall of a dog's heart, illustrating the relationship between the subendocardial, myocardial and subepicardial lymphatic plexuses and the relation of the myocardial lymphatics to the muscle bundles and arteries (white) and veins (stippled). Approximately × 12.