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THE LYMPHATIC DRAINAGE OF THE PARIETAL PERICARDIUM IN MAN

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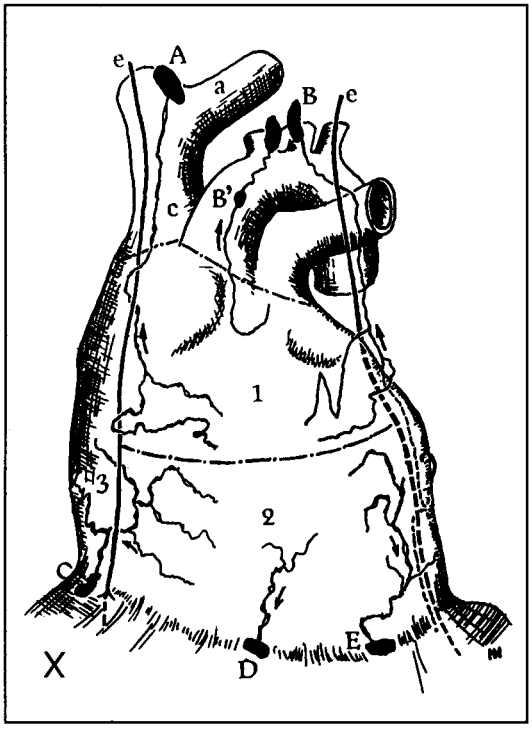
ABSTRACT

Parietal pericardial lymphatics were visualized by indirect and direct India ink injections in 35 human cadavers. Studies included examination of cleared specimens under the dissecting microscope and standard light microscopy.

The lymphatic vessels of the ventral pericardial surface most often pass along the phrenic nerves cranially to terminate in the anterior right and left and transverse mediastinal nodes, or caudally to the diaphragm or prepericardial lymph nodes. The lymphatics draining the lateral parts of pericardium pass to the anterior mediastinal, tracheobronchial, lateropericardial, prepericardial and posterior mediastinal (juxtaesophageal) lymph nodes. The posterior part of the pericardium drains to the juxtaesophageal and tracheobronchial nodes. Lymphatics from the diaphragmatic part of the pericardium pass to the right lateropericardial and prepericardial, juxtaesophageal and tracheobronchial nodes. The pericardial cupula is anteriorly drained to the anterior mediastinal nodes, and posteriorly to the tracheobronchial nodes. In cleared specimens two networks of lymphatic vessels are seen to surround the pericardial space. On the ventral surface, the lymphatics of the parietal pericardium connect to lymphatics in the pericardial fat and areolar tissue. On the lateral and posterior surfaces, the lymphatics of the parietal pericardium anastomose with lymphatics of the reflected mediastinal pleura. These anatomical observations offer new insights into the mechanisms of turnover of pericardial fluid and into the mechanisms of occurrence of chylopericardium.

In the past five decades a number of clinical and experimental studies have examined the removal of protein and other substances from the pericardial space (1-11). Though it is generally considered that the lymphatics are a major route of absorption from the pericardial space, as noted by Miller in 1982 (7), no studies have addressed the details of the morphology of the lymphatics in the parietal pericardium. In 1789, Mascagni (12) described lymphatics passing from the pericardium to mediastinal lymph nodes. In 1932, Rouviere (13) described the lymphatics of the human parietal pericardium as scant and fine, and reported that they drained to the anterior mediastinal and diaphragmatic nodes. More recently, in 1972, Weinberg (14) noted that the main lymphatics of the parietal pericardium pass along the phrenic nerve and receive lymphatics from the diaphragm. These descriptions, none of them offering anatomical details of the lymphatic drainage of the parietal pericardium, are quoted to varying extents in some textbooks of anatomy.

In a previous study we explored the lymphatic drainage of the parietal pericardium in the dog (15), and since that time we



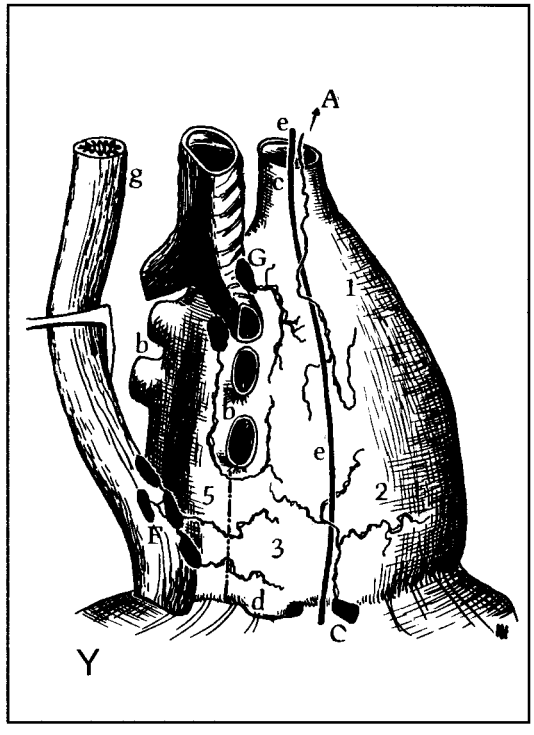
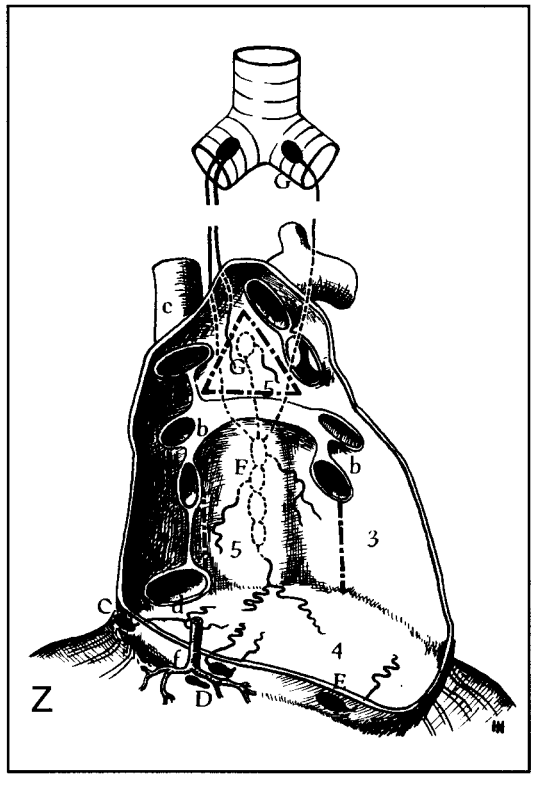


Fig. 1. X) Lymphatics of the anterior surface of the parietal pericardium; Y) Lymphatics of the lateral and posterior parts of the parietal pericardium; Z) Lymphatics of the posterior and diaphragmatic parts of the parietal pericardium. 1: Upper anterior part of the parietal pericardium and pericardial cupula. 2: Lower anterior part of the parietal pericardium. 3: Lateral part of the parietal pericardium. 4: Diaphragmatic part of the parietal pericardium. 5: Posterior part of the parietal pericardium and the pericardial cupula. A – Right anterior mediastinal nodes; B and B' – Left anterior mediastinal nodes; C. Lateral pericardial node; D – Medial prepericardial node; E – Lateral prepericardial node. F – Posterior mediastinal nodes; G – Lower and upper tracheobronchial nodes. a – brachiocephalic vein; b – pulmonary veins; c – superior vena cava; d – inferior vena cava; e – phrenic nerve; f – internal thoracic artery and vein; g – esophagus. Arrows indicate the direction of lymph flow. Boundaries between the different parts of the parietal pericardium are marked by interrupted lines.



have been stimulated to pursue the present study in man. In this study we have used various techniques to visualize the lymphatics in an attempt to be as concise as possible and present a definitive work.

MATERIAL AND METHODS

Postmortem studies were accomplished in 35 individuals (30 males; 5 females) ranging in age from 6 months to 85 years in the Forensic Medicine and Anatomy Departments of the Charles University. Our studies were allowed to precede other routine postmortem examinations.

It is undoubtedly true that the paucity of studies of the kind here described is related to the technical difficulties in visualizing small lymphatics. We found that warming the specimens with warm water prior to injections of India ink suspensions directly into lymphatics made successful efforts more likely. Injections of India ink suspensions into adipose tissue or into loose subpleural connective tissue invariably failed to visualize lymphatics, with the India ink remaining as a localized pool.

Our lymphatic visualization method utilized India ink suspended in a 2 percent gelatin solution (16,17). Initially, a suspension of India ink in 2 percent gelatin was injected into the pericardial wall between the fibrous (outer) and mesothelial (inner) layers. After lymphatics were visualized near the site of this initial injection, a fine needle (27 gauge) was used to then inject the lymphatics directly under the dissecting microscope. Thus, for the most part, lymphatic plexuses were visualized after direct injections of the India ink suspension in 2 percent gelatin into lymphatic vessels. In the ventral (anterior) and lateral parts of the parietal pericardium, these intralymphatic injections were made from the external (outer) surface. However, the lymphatics of the diaphragmatic surface and of the posterior part of the pericardial cupula were injected from the inner parietal pericardial surface after the pericardium had been opened and the heart had been removed. Lymphatic channels were followed by these intralymphatic India ink injections until they terminated at a lymph node. Thirty-five samples of parietal pericardium that effectively showed the lymphatic drainage channels after the intralymphatic India ink injections were removed from the various surfaces. These samples were prepared for study both by light microscopy and under the dissecting microscope. The sections for light microscopy were stained with the blue trichrome method, and semi-thin sections were stained with Azur. The specimens for examination under the dissecting microscope were fixed in 10 percent formalin solution and were then dehydrated and cleared in methyl salicylate.

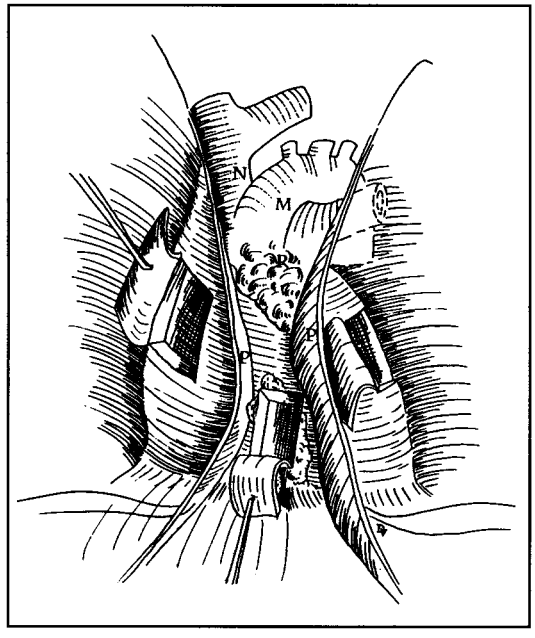


Fig. 2. Anterior (ventral) view of the parietal pericardium, showing the reflection of the mediastinal pleura laterally and the sites from which pericardial specimens were taken. The sites of pericardial sampling are designated by small boxes. M – aorta; N – superior vena cava; P – pleura; R – prepericardial fat.

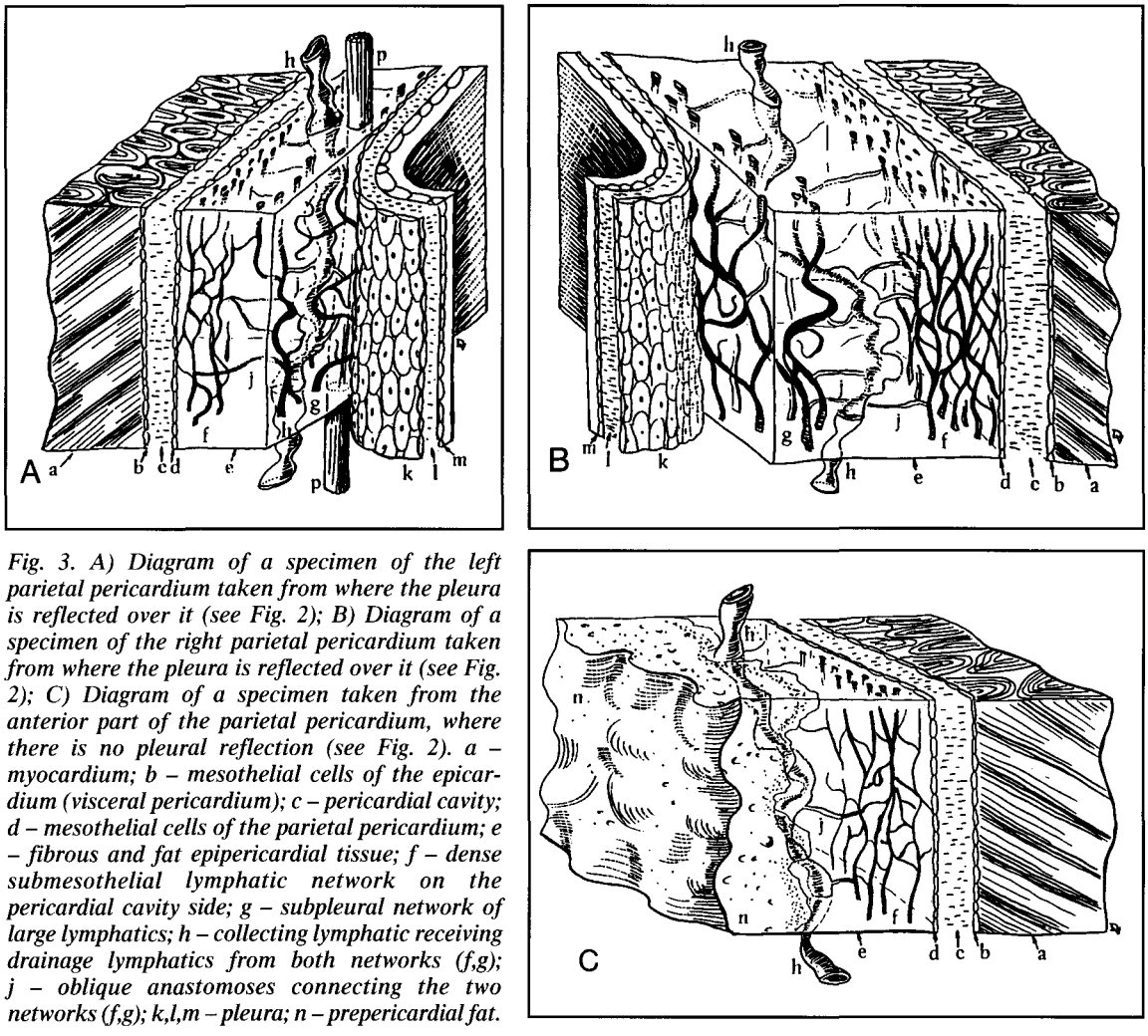


Fig. 3. A) Diagram of a specimen of the left parietal pericardium taken from where the pleura is reflected over it (see Fig. 2); B) Diagram of a specimen of the right parietal pericardium taken from where the pleura is reflected over it (see Fig. 2); C) Diagram of a specimen taken from the anterior part of the parietal pericardium, where there is no pleural reflection (see Fig. 2). a – myocardium; b – mesothelial cells of the epicardium (visceral pericardium); c – pericardial cavity; d – mesothelial cells of the parietal pericardium; e – fibrous and fat epipericardial tissue; f – dense submesothelial lymphatic network on the pericardial cavity side; g – subpleural network of large lymphatics; h – collecting lymphatic receiving drainage lymphatics from both networks (f,g); j – oblique anastomoses connecting the two networks (f,g); k,l,m – pleura; n – prepericardial fat.

RESULTS

The Geography of our Anatomical Studies

The human pericardium is essentially cone-shaped, with a part of its base attached to the diaphragm. For the purposes of our study, we divided the pericardium into four sections, using essentially the same approach as we had previously done in the dog (15). The geography of this approach is illustrated in *Fig. 1.*

a. Anterior part. This section of the pericardium is delimited laterally by the right and left phrenic nerves and includes the anterior portion of the pericardial cupula.

b. Lateral parts. The sections dorsal (posterior) to the phrenic nerves, overlapped by the mediastinal pleura, and extending as far as a perpendicular line drawn from the openings of the pulmonary veins to the diaphragm.

c. Posterior part. The section of the parietal pericardium facing the posterior

mediastinum, including the posterior aspect of the cupula, extending anteriorly as far as the pulmonary veins.

d. Diaphragmatic part. That portion of the parietal pericardium that is adherent to the diaphragm.

General Observations on the Lymphatic Pathways

a. Anterior part of the parietal pericardium

Most of the lymphatics in this area run along with blood vessels *(Figs. 1X,Y)*. From the upper (cephalad) one-half to two-thirds of the pericardium, the lymphatics travel towards the phrenic nerves and pericardiophrenic arteries and veins, and then along with them pass cephalad towards the brachiocephalic veins. In the area of the brachiocephalic veins, the lymphatics enter the right and left anterior mediastinal nodes, efferents from these nodes then passing to the venous angles bilaterally. From the ventral surface of the pericardial cupula, lymphatics ascend cephalad to lymph nodes ventral to the aortic arch. Efferent lymphatics then pass from these nodes to a group of left anterior mediastinal nodes (one to five, generally, each measuring 0.5 to 2.0 cm) situated near the origins of the left carotid and subclavian arteries.

Lymphatics drain the lower one-third to one-half of the anterior part of the pericardium in two directions: some of them pass laterally to the phrenic nerve and then continue caudally to enter the diaphragm, and other lymphatics travel along the ventral border of the pericardium and enter prepericardial nodes situated at the junction of the pericardium with the diaphragm.

b. Lateral parts of the parietal pericardium

The lateral portions of the parietal pericardium have reflected upon them the mediastinal pleura. These surfaces show the most pronounced variability in the patterns of lymph drainage *(Fig. 1Y)*. In the lower (caudad) halves of the lateral parts the lymphatics run towards the phrenic nerve and the pericardiophrenic vessels, bilaterally. Along the nerve and the blood vessels, the lymphatics pass downward (caudad) to reach the diaphragm. Occasionally small lateral pericardial nodes are present near the site where they come to the diaphragm. At times, lymphatics draining the lateral wall passed towards the diaphragm and then, crossing beneath the phrenic nerve, extended medially a variable distance to enter lateral prepericardial nodes.

The lymphatics of the upper (cephalad) portions of the lateral parietal pericardium run cephalad to the peribronchial and tracheobronchial nodes. A strip of pericardium about 1.0 cm wide just dorsal to the phrenic nerve is drained by lymphatics that pass upward along the phrenic neurovascular complex to enter anterior mediastinal nodes.

The lymphatic vessels draining the posterior (dorsal) aspects of the lateral parietal pericardium run dorsally behind the inferior vena cava to enter the chain of nodes in front of the esophagus.

c. Posterior part of the parietal pericardium

The lymphatic vessels draining this area run towards the posterior mediastinal nodes, particularly those at the right esophageal margin. From the three or four nodes usually found in this area (measuring up to 1.0 cm across), the lymphatics pass upwards (cephalad) to enter the lower and upper tracheobronchial nodes *(Figs. 1Y,Z)*.

From the posterior part of the pericardial cupula, above the level of the pulmonary veins, lymph drainage is to the lower and right tracheobronchial nodes.

d. The diaphragmatic part of the parietal pericardium

The right side of the diaphragmatic surface of the parietal pericardium *(Fig. 1)* is drained by comparatively short lymphatics to the lymph node at the right border of the foramen venae cavae, the right lateral pericardial node. From the central part of the diaphragmatic parietal pericardium short lymphatics run antero-posteriorly to enter the nodes between the posterior pericardial wall and the right esophageal margin, the posterior mediastinal nodes or the tracheo-bronchial nodes. Some lymphatics were parallel to blood vessels passing to the lateral parts of the diaphragm.

From the ventral part of the diaphragmatic parietal pericardium, tiny lymphatics passed forward to enter prepericardial nodes. These lymphatics generally were near a branch of the internal thoracic artery that entered the diaphragm, and consisted of one to two nodes that measured 5 to 7 mm across. In 14 of the individuals studied a lateral prepericardial node was present about 5 cm from the central nodes, and from here lymphatics passed ventrally to parasternal lymphatics along the sternum and to diaphragmatic lymphatic vessels that drained to the thoracic duct.

Observations on Cleared Specimens of the Parietal Pericardium

In cleared specimens of the diaphragmatic surface of the parietal pericardium, there were dense networks of regular polygonal to quadrangular meshes. Near the central tendon, the meshes became somewhat elongated. The diameter of the vessels forming the networks ranged from 25 to 50 µm, and the size of the meshes varied between 0.15 and 0.5 mm across. Oblique anastomoses projected from the meshes to deeper layers to drain to larger vessels, 50 to 70 µm, that had valves. Draining lymphatic collectors 0.3 to 0.4 mm in diameter demonstrated the characteristic tortuous course of such vessels.

The lymphatic networks of the various free pericardial surfaces did not demonstrate any particular specific local differences. In the cupula of the pericardium the meshes did not exceed 0.5 mm across, and none of the individual lymphatics was larger than 60 µm. In other parietal pericardial surfaces the sizes of polygonal and quadrangular meshes ranged from 0.15 to 0.8 mm across. In some specimens the diameters of the vessels forming the meshes ranged from 20 to 50 µm. In some specimens the lymphatic diameters were as small as 15 µm, and in others the lymphatics appeared dilated to 80 to 100 µm in diameter. These diameter differences may have been due to varying functional states of the lymphatic vessels.

Some of the specimens studied by the "clearing" technique permitted the identification of two distinct lymphatic networks at different levels of the parietal pericardial wall *(Figs. 2-4)*. Between the inner mesothelial layer of the pericardium and its fibrous layer were narrow lymphatics constituting rather delicate and regular meshes. From these finer meshes oblique lymphatic anastomoses of 20 µm size, or less, traversed outward (towards the outer mediastinal surface) to join another layer of small and larger lymphatic meshes. On the ventral parietal pericardial surface this second complex of lymphatic meshes was in pericardial fat, along with small arteries and veins. On the lateral parietal pericardial surfaces these secondary lymphatic drainage complexes were in the reflection of the mediastinal pleura, along with small arteries and veins. The distance between these primary and secondary parietal pericardium lymphatic drainage complexes varied depending on the amount of fat and connective tissue present. At times drainage collectors were found between the two networks, tending to be closest to the mediastinal pleura, the largest of them being 0.5 to 1.0 mm in diameter near the phrenic nerve *(see Figs. 3,4)*.

In one of the flat cleared specimens which had been injected with India ink in 2 percent gelatin we found a lymphatic-venous

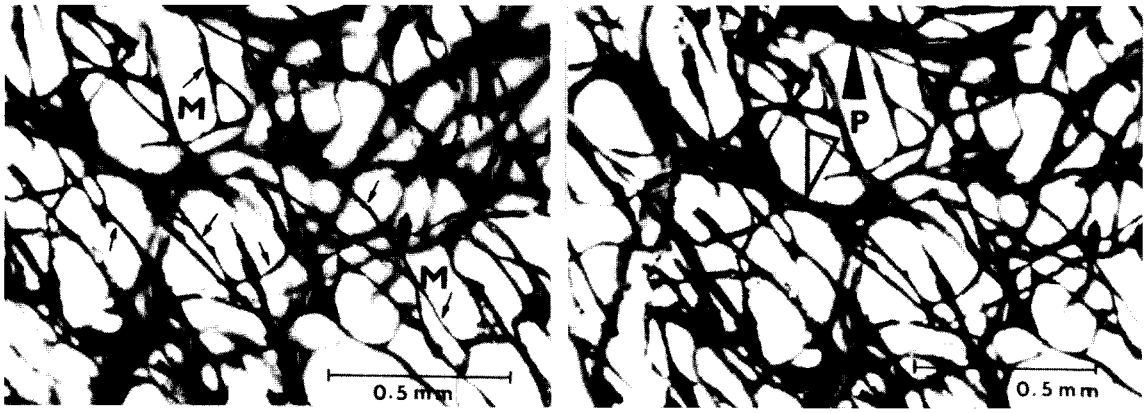


Fig. 4. Cleared specimen from area where the pleura reflects over the parietal pericardium, showing the two lymphatic networks at different levels. The photograph on the left shows a parietal pericardium (submesothelial) lymphatic network (M), with narrow, delicate lymphatic meshes designated by arrows. The photograph on the right shows a subpleural lymphatic network (P), with larger vessels and lymphatic meshes (arrowheads).

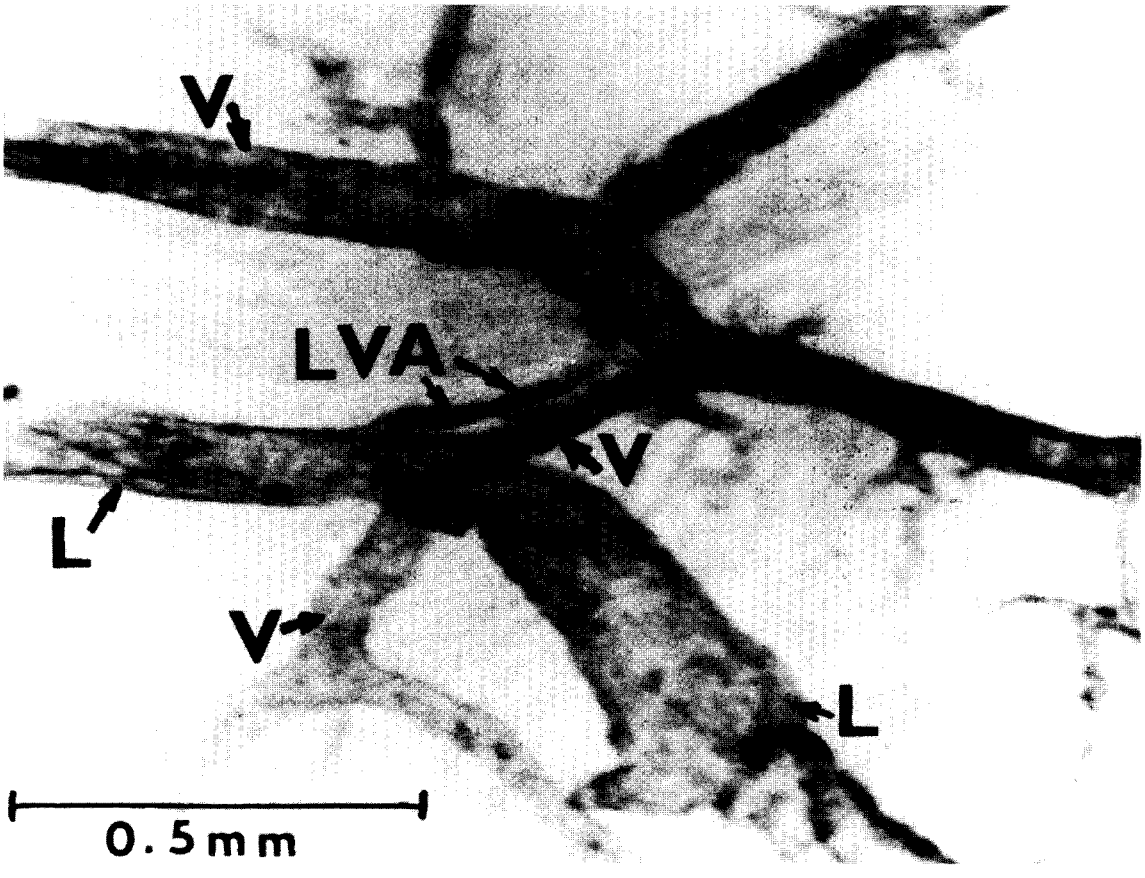


Fig. 5. Photograph of a cleared specimen demonstrating a lymphovenous anastomosis. L – lymphatic; v – vein; LVA – anastomosis (20–30 μm).

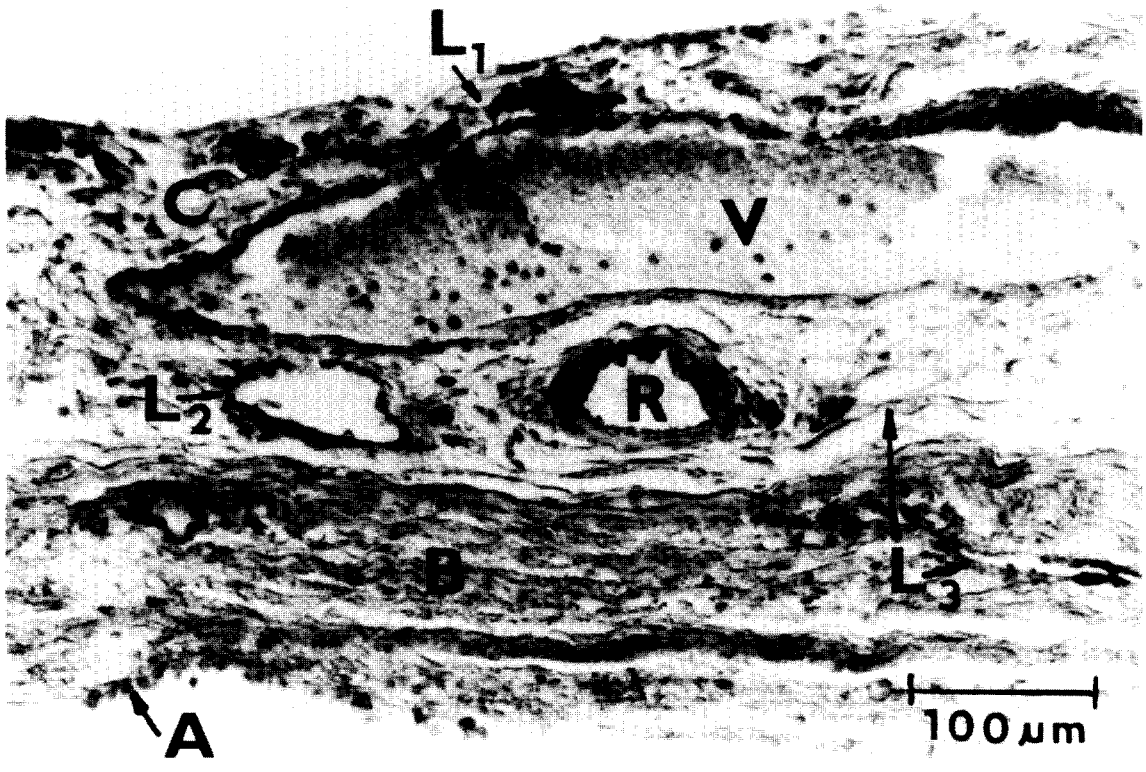


Fig. 6. Cross–section of specimen taken from the ventrolateral parietal pericardium. Lymphatics are partly filled with India ink. Blue trichrome stain. A – mesothelial cells; B – fibrous part of the parietal pericardium; C – epipericardial (mediastinal) connective tissue; L1 – Mediastinal (subpleural) lymphatic network; L2 – Collecting lymph vessel; L3 – Lymphatics receiving lymph from fibrous and submesothelial layers; R – artery; V – vein.

anastomosis measuring 25 µm in diameter *(Fig. 5)* (18).

Microscopic Observations of Lymphatics of the Parietal Pericardium

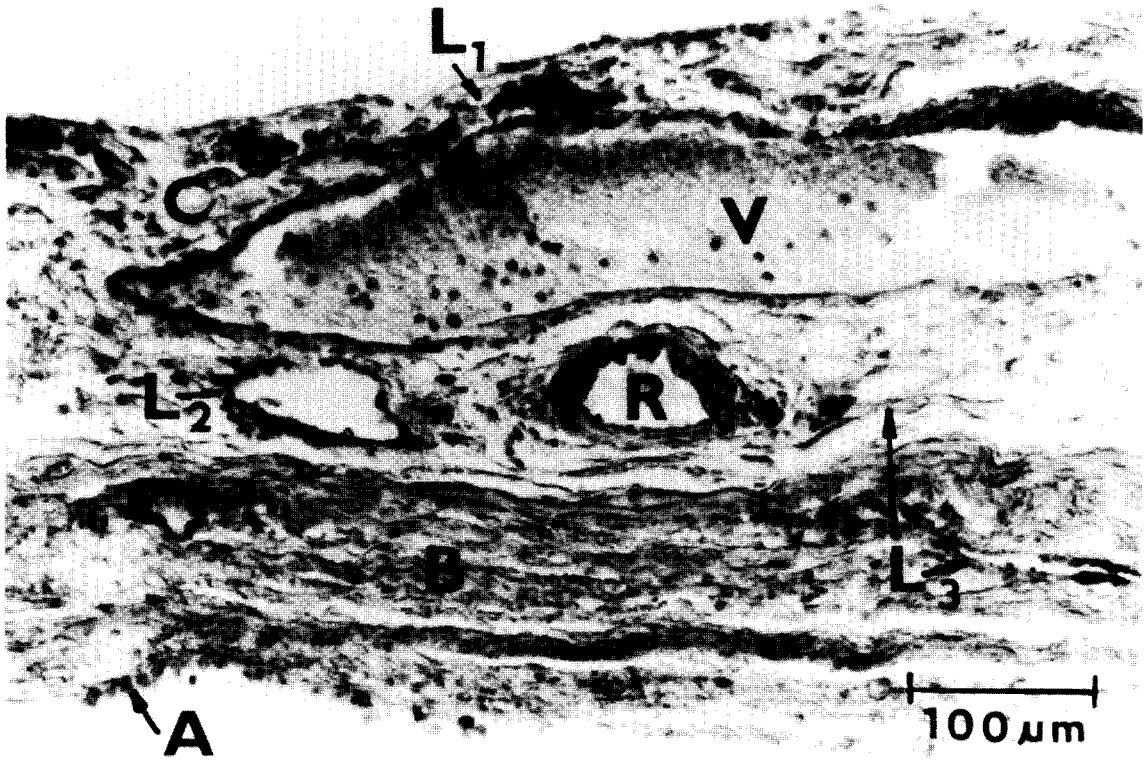
a. Specimens obtained from the ventral and lateral parts of the pericardium

In the submesothelial layer of the parietal pericardium, between it and the fibrous layer, lymphatic vessels measured 8 to 20 µm in diameter. Some lymphatics also were seen between compact bundles of collagen fibers. Oblique anastomotic lymphatic channels penetrated outward to larger lymphatic capillaries and vessels in the epicardial fat on the ventral surface, or to the mediastinal pleura abutting the parietal pericardium on the lateral surfaces *(Fig. 6)*. These latter lymphatics ranged between 20 and 70 µm in diameter, some of them paralleling adjoining blood vessels.

b. Specimens obtained from the diaphragmatic surface of the parietal pericardium

In this area anastomotic lymphatic vessels often passed between rather coarse bundles of collagen fibers to connect lymphatics in the loose connective tissue that occurred between the fibrous layer of the parietal pericardium and the muscular bundles of the diaphragm.

In all the specimens obtained from



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In all the specimens obtained from

the parietal pericardium, valves were noted to be present in lymphatics measuring 30 to 40 μm, or greater.

DISCUSSION

The striking aspect of our findings is the "double layer" of lymphatics that surround the pericardial space. On the ventral surface of the parietal pericardium, lymphatics in anterior fat and loose areolar tissue provide a "second level" of lymphatics to which the pericardial lymphatics connect.

Laterally and posteriorly the reflection of the mediastinal pleura onto the surface of the pericardium contains a layer of lymphatics which connect with the pericardial ones. Finally, on the diaphragmatic surface of the parietal pericardium, connections to the diaphragmatic lymphatics are seen. These "layers" of lymphatic vessels surrounding the parietal pericardium, with interconnections to its submesothelial lymphatics, are likely additional routes by which pericardial fluid flows from the pericardial space. We know from various studies (7,8) that there is an active turnover of protein and various other substances from within the pericardial sac. Though some of this turnover is undoubtedly via venous and lymphatic capillaries from the epicardial surface of the heart, our anatomical findings strongly suggest that a substantial turnover is also likely via the parietal pericardium.

Many regional lymph nodes are involved in receiving lymph from the pericardial sac, undoubtedly an important factor in explaining the occurrence of chylopericardium. The lymphatics draining to the posterior mediastinal nodes close to the esophagus might be involved in the development of chylopericardium by reflux from the thoracic duct through direct anastomoses (19). Also, retrograde filling of the pericardial lymphatics from the tracheobronchial and anterior mediastinal nodes may play a role in the development of chylopericardium (20,21).

Our observations indicate that medial and lateral prepericardial nodes are drained to lymphatic vessels accompanying the internal thoracic arteries. These findings are in agreement with those obtained by computer tomographic scanning in humans (22).

Finally, it is important to appreciate that the lymphatics from the parietal pericardium enter regional lymph nodes that also drain lymphatics from other sites, including the heart, lungs, diaphragm and esophagus. From these regional lymph nodes, the lymphatics ascend to reach nodes in the superior mediastinum, bilaterally. Thereafter, and after numerous anastomoses between vessels, lymphatics course cephalad to enter the right lymphatic duct and the thoracic duct, or directly into the right and left venous angles. Our findings do not enable us to speculate on the relative lymph flow via each of these terminal pathways.

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