

ABSORPTION FROM THE PERICARDIAL CAVITY

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PLATES 5 AND 6

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While engaged in a general analysis of the functions of the lymphatic system and the mechanism of lymph movement, we were surprised to find little information upon absorption from the pericardial sac. Hamburger (1) made five experiments on the pericardium of the dog, using salt solutions and horse serum. He found slow removal of serum. His observations were not concerned with possible routes of absorption and do not apply to our interest. Coupled with lack of data on absorption is lack of an adequate description of pericardial lymphatics.

Schumkow (2) described somewhat sketchily two sets of lymphatics in the pericardium of the dog and calf. If he excised the pericardial sac and filled it first with salt solution and later with Berlin blue, he had no trouble in making the dye flow into these vessels. His colleague, Skworzow (3) very briefly confirmed his findings and declared that the dye got into the lymphatics through stomata such as von Recklinghausen had declared existed on the peritoneal surface of the central tendon of the diaphragm.

Our experiments have been made entirely upon the rabbit. In this animal the pericardium is exceedingly thin, very like the omentum except toward the base of the heart where it becomes heavily loaded with fat. We have never found lymphatics in the thin, transparent pericardium, though they are abundant in the fatty tissue at the base of the heart and where lines of fat extend down upon the pericardium. They drain into several small nodes embedded in the basal cardiac tissue. It is quite possible that the transparent parts of the pericardium do contain a few lymphatics just as is probably the case for the thinnest parts of the omentum (4, 5); but they are certainly not numerous, and this is equally true of the blood vessels.

The pericardial sac is a fibrous bag, very impermeable and very inactive in providing for removal of foreign material. When fluids or particles are placed in the pericardial cavity, the absorbing surface also includes the heart and the short intrapericardial lengths of the great blood vessels. In the areolar tissue immediately below the epicardial serosa, both upon the heart and upon the great vessels, there is a rich plexus of lymphatic capillaries which communicates with the lymphatics in the heart muscle and eventually with the subendocardial lymphatic plexus. All of these vessels drain into the large trunks which pass to the same nodes at the base of the heart as are entered by the pericardial lymphatics. In addition to the absorptive routes offered by the scanty supply of lymphatic capillaries in the pericardium and the larger number in the epicardium, there are the blood capillaries in both areas. Blood vessels are not numerous in the pericardium but are thoroughly so in the epicardium.

As a result of many different groups of experiments one may expect that lymphatics will be the paths for removal of particulate material and of solutions such as the blood proteins. The blood capillaries, on the other hand, will provide for rapid absorption of water and salts of small molecular size. Entrance to lymphatics is both indirect and direct. If particles of carbon or other foreign material are deposited in the neighborhood of lymphatic capillaries, phagocytosis begins fairly promptly and phagocytic cells carrying particles migrate into the lymphatics. This indirect method of entrance is exceedingly slow. On the other hand, many observations have shown that motion is extremely important, not only for getting lymph to move along lymphatics but also for bringing about the direct entrance of material into the lymphatic capillaries. Thus, Macallum (6) observed the effectiveness of diaphragmatic movements in causing particles in the peritoneal cavity to enter the lymphatics of the central tendon. Recently Florey (7) has found that if India ink was injected into the thigh muscles of a rat, and these muscles then tetanized at second intervals for 20 minutes, the glands at the bifurcation of the aorta became filled with carbon and the lymph trunk running along the back of the femoral vessels was jet black. When the same experiment was done without activity the ink remained localized, and removal depended upon the indirect phagocytic method.

In the face of such observations as these, one would expect that particles or serum in the pericardial cavity subjected to the pounding and churning of the heart would enter lymphatics rapidly and be carried promptly to adjacent lymph nodes. Much to our surprise this did not prove to be the case. Lymphatic absorption from the pericardial sac is an extremely sluggish process.

EXPERIMENTAL

Technique.—In spite of the extreme delicacy of the pericardium of the rabbit, these animals were employed since it is possible to expose the pericardium without entering either pleural cavity because of the widely separated and complete mediastinal partitions. Artificial respiration is unnecessary and animals can live for 2 hours with pericardium exposed. Sodium barbital was the anesthetic in terminal experiments and ether in recovery experiments. The pericardium was exposed through a small opening made on the left side and as near to the sternum as possible. After resection of 1 cm. of the third rib, the intercostal muscles and membranes between the lower border of the second and the upper border of the fourth ribs were cleaned away. The mammary vessels, being at some distance from the sternum, could usually be sufficiently retracted to make ligaturing unnecessary. Fat above the heart and on the pericardium was dissected off and a good view of the heart in the pericardium was obtained.

Material was injected into the pericardium by means of a syringe with a No. 26 hypodermic needle. In those experiments in which injections were to be made from time to time, a blunt syringe needle was inserted into the pericardial cavity, care being taken not to touch the heart. This was held in place with a hemostat and the syringe was in turn held by an adjustable clamp. Measured injections were made by pushing in the plunger of the syringe.

The jugular vein was cannulated and the venous pressure was recorded by means of a water manometer. Measurements were made simultaneously with the injections.

In those experiments in which the material introduced into the pericardium was to remain for some time, all of the usual precautions for asepsis were taken. A piece of the pericardium was picked up with a hemostat, the syringe needle inserted, and the injection made. After withdrawing the syringe, the small hole in the pericardium was ligatured securely beneath the tip of the hemostat. The wound was then sewed up, and the animals recovered rapidly from the operation. All of them remained in excellent condition.

At the conclusion of the experiment, the animal was bled to death through the carotid artery and a very thorough autopsy was performed on the thorax. The pericardium was opened and whatever liquid remained in the cavity was withdrawn by means of a pipette.

Absorption of Salt Solution

One series of experiments was done to determine the rate and manner of absorption of a 1.6 per cent solution of methylene blue in Ringer's solution. The solution was injected at such a rate that there was no appreciable change in the venous pressure which was simultaneously recorded. 0.5 cc. of solution was injected every 5 or 10 minutes for a period of about an hour. Table 1 shows the amount and rate of absorption of Ringer's solution from the rabbit pericardium. The average rate was about 1.3 cc. per hour.

The appearance of the heart in all these experiments was striking. The auricles and great vessels were very deeply stained and the thin right ventricle presented a marked contrast to the left ventricle. Quite frequently the staining of the ventricles would be concentrated in the groove between the two ventricles or would be in patches on the anterior side. The pericardium itself stained lightly but uniformly. The right and left ventricles, when slit open, showed no blue staining on the inside, whereas the interior of the auricles down to the coronary sulcus was quite deeply and distinctly stained. This would seem to indicate that the thinner parts of the heart, the parts nearer the base of the heart and under low pressures, are most easily penetrated by pericardial fluids. Fig. 1, A and B, shows typical hearts. The protocol of a typical experiment from which Fig. 1-A was drawn follows:

March 31, 1930. Absorption of a 1.6 per cent solution of methylene blue in Ringer's solution. Normal rabbit. Weight 2.6 kg. 8:45 a.m., 24 cc. 10 per cent sodium barbital intraperitoneally for anesthesia. 10:30 a.m., operation begun. Chest opened without injury to either pleural cavity. 11:00 a.m., pericardium cannulated. 11:03-12:25 a.m., 4.5 cc. of solution injected at 10-minute intervals. Venous pressure at the beginning, 2.5 cm. of water; at the end, 2.0 cm. of water with no appreciable change at any time during the period of injection. 1:15 p.m., autopsy. 1.0 cc. of blue solution recovered from the pericardial cavity. Heart stained in characteristic manner (Fig. 1-A). Lymph nodes in fat around the base of the heart stained blue.

Samples of urine, taken from the rabbits at the conclusion of the experiment, were usually tinged with blue. Lymph nodes in the fat at the base of the heart were occasionally found to be stained blue. The staining of the heart, however, indicates that much of the absorption of a simple salt solution from the pericardial cavity of the

rabbit is cardiac and vascular. The rate is slower than one would expect considering the large number of subepicardial capillaries.

One experiment, done on the cat, indicates that most of the absorption of simple solutions from the pericardial cavity must be cardiac.

The chest of the anesthetized cat was opened under artificial respiration, the pericardium slit open and the edges sewed to the sides of the chest, thus making it absolutely tight (8). A glass oncometer was slipped over the heart, the thin rubber membrane resting at the auriculoventricular sulcus, only the ventricles being contained within the oncometer. The hole through the membrane was sufficiently loose so as not to constrict the vessels. 6 cc. of Ringer's solution and methylene blue were introduced into the oncometer. At the end of 2 hours, 2 cc. of solution

TABLE 1

Absorption of Physiological Salt Solution from the Pericardium of the Rabbit

Experiment	Amount injected	Amount recovered	Amount absorbed	Time	Rate of absorption per hour
	cc.	cc.	cc.	hours	cc.
4	3.0	0.0	3.0	2.0	1.5
5	7.0	5.0	2.0	2.0	1.0
6	5.0	1.25	3.75	2.0	1.88
7	5.0	1.75	3.25	1.33	2.5
8	5.0	3.0	2.0	1.5	1.33
9	3.5	3.25	0.25	1.0	0.25
11	4.5	2.25	2.25	2.0	1.1
12	4.5	1.0	3.5	2.0	1.75
13	5.0	1.0	4.0	2.0	0.5

were recovered, indicating the absorption of 2 cc. an hour by the heart itself. The staining of the heart was very distinct, there being a very definite line of demarcation where the solution touched the heart. The two ventricles were well stained, but the thin right ventricle was much more deeply stained than the left. Urine, removed at the end of the experiment, was slightly bluish green in color.

Absorption of Serum

Table 2 shows the second series of experiments done to determine the absorption, if any, of normal serum introduced into the pericardial cavity. Both rabbit and horse serum, colored with methylene blue or trypan blue, were used. The absorption of the serum was negligible; in four out of six experiments there was none whatever. The staining of the heart in these cases was quite different from that observed with

the simple salt solution. The epicardium over the left ventricle was only very lightly stained, if at all; and the thinner parts of the heart, the auricles, the tissue around the great vessels, and the right ventricle were stained, but far below the values obtained with the same dyes in physiological salt solution. In no case was there any staining of the pericardium.

Graphite.—A third series of experiments was done to determine the manner and path of absorption of particulate matter from the pericardial cavity. For this purpose a sterile solution of graphite suspended in salt solution (9) was employed. From 1 to 2 cc. of this suspension diluted with salt solution was introduced into the pericardial cavity and allowed to remain there for lengths of time varying

TABLE 2
Absorption of Serum from the Pericardium of the Rabbit

Experiment	Amount injected	Amount recovered	Amount absorbed	Time
	cc.	cc.	cc.	hours
16	1.1	0.0	1.1	5.0
17	1.1	0.0	1.1	5.0
18	3.0	3.0	0.0	3.75
19	1.5	1.5	0.0	2.75
21	2.0	2.0	0.0	4.0
22	1.0	1.0	0.0	2.0

from 24 hours to 3 weeks. At the end of the chosen period, the animals were killed.

Almost invariably there was found a large amount of thick graphite-containing exudate of a fibrinous nature. This was tightly adherent to the heart in the longer-period animals—2 to 3 weeks. In short-period animals it appeared as a slimy, membranous exudate just inside the pericardium.

The pericardial exudate, as a result of the sterile irritant, graphite, is very characteristic. Large mononuclear phagocytes, such as are shown in Fig. 2-B, are very plentiful. These cells were invariably strongly phagocytic for graphite and, apparently with slight help from polymorphonuclear leucocytes, represent the normal means of getting the foreign material out of the pericardium. Sections of the heart invariably showed these large cells filled with graphite in the

subserous areolar tissues—in certain instances definitely within lymphatics. Very little graphite was free, and that seen was most probably due to breakdown of phagocytes with release of their load. Spreads of the pericardium showed, in transparent areas, many of the same large mononuclear phagocytes, often completely covered by graphite so that they appeared as small black balls. They were tightly adherent to the surface but never appeared to be in vessels. Toward the base of the heart in the fatty tissue, graphite could be seen occasionally within lymphatics and was almost invariably intracellular.

Fig. 2 illustrates typical phagocytes.

The large cardiac lymphatic trunks never contained enough graphite to be visible with a binocular dissecting microscope. That this should be true after 3 weeks time is strong evidence for the difficulty with which the cardiac lymphatics are entered from the pericardial cavity.

DISCUSSION

The pericardium in the rabbit proves to be a singularly inert protective membrane. Simple solutions placed within the sac are held without leakage and are absorbed practically entirely by the subepicardial blood capillaries. Such solutions do not leak through the extraordinarily thin pericardial membrane into the pleural cavities even if subjected to slight pressure. When substances such as serum or graphite are injected removal is extraordinarily slow. No evidence was obtained showing the abrupt, direct type of lymphatic entrance which is seen in the central tendon of the diaphragm after intraperitoneal injections. Such lymph drainage as occurs is through lymphatics in the pericardium around the base of the heart and to a slight extent along lines of fat deposition in the pericardium. The subepicardial lymphatics are entered with great difficulty from the pericardial sac, a condition favorable to exclusion of the heart from participation in pericardial infections.

SUMMARY

1. Physiological salt solution is absorbed from the pericardial cavity of medium-sized rabbits at a rate of approximately 1.3 cc. per hour. This absorption is via the subepicardial blood capillaries.

2. Rabbit serum and horse serum are absorbed extremely slowly—an indication of the low-grade lymphatic drainage of the pericardial sac.

3. Graphite particles of bacterial dimensions are also removed very slowly. Such particles enter lymphatics only after phagocytosis. The lymphatics in the basal part of the pericardium are the principal source of drainage. Subepicardial lymphatics are entered with difficulty from the pericardial cavity.

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EXPLANATION OF PLATES

PLATE 5

FIG. 1, A and B. Distribution of dye on the outside and inside of rabbit hearts after injections of dye into the pericardial sac. Identical results were obtained with methylene blue and trypan blue.

PLATE 6

FIG. 2. A, mononuclear phagocytes from the normal pericardial fluid of a rabbit which had received graphite 24 hours before; supravital preparation; large round inclusions, stain; small black particles, graphite. B, typical field of exudate 5 days after graphite injection; Wright's stain; the large mononuclear phagocytes can be shown to take vital stain. Magnification, $\times 650$.

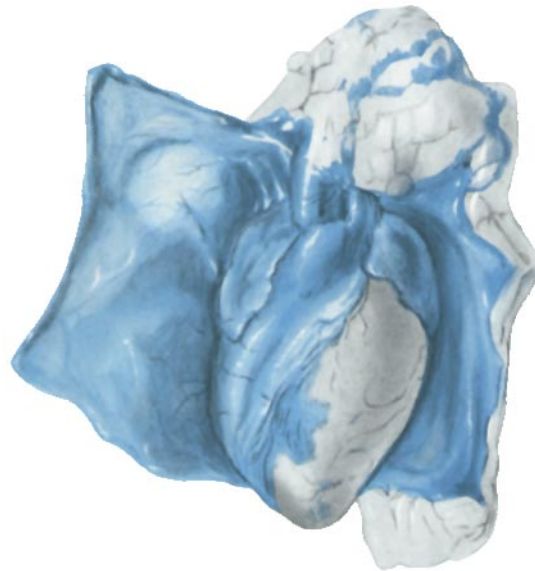


FIG. 1-A

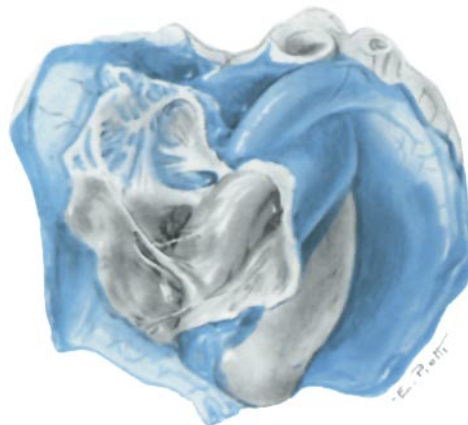


FIG. 1-B

(Drinker and Field: Absorption from pericardial cavity)



FIG. 2-A

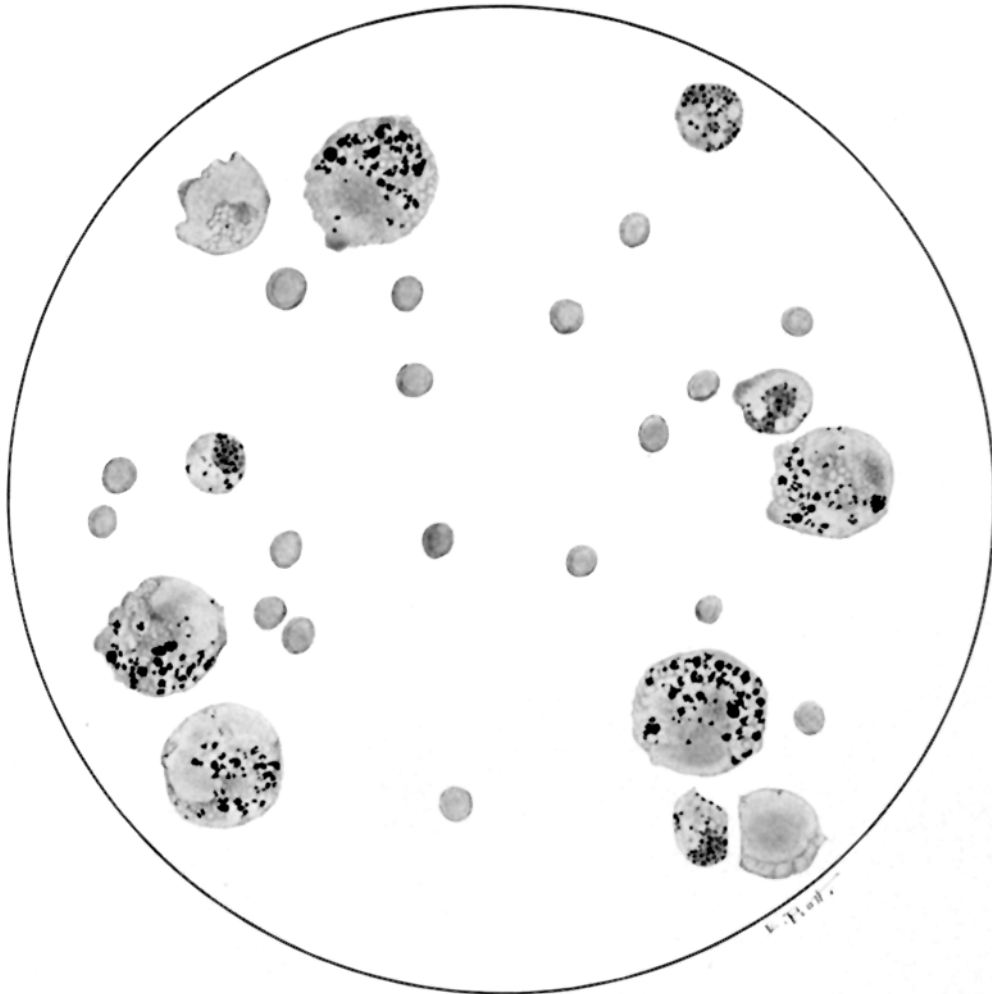


FIG. 2-B

(Drinker and Field: Absorption from pericardial cavity)