THE MICROSCOPICAL ANATOMY OF THE HUMAN HEART.

SHOWING THE EXISTENCE OF CAPILLARIES WITHIN THE MUSCULAR FIBRES.

BY

ARTHUR V. MEIGS, M.D.,

PHYSICIAN TO THE PENNSYLVANIA AND CHILDREN'S HOSPITALS.

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In the pursuit of pathological studies directed especially to the investigation of Bright's disease, vascular changes, and heart disease, and to the relations of these morbid processes one to another, I have examined a large number of human hearts. At the present time there are in my collection sections of forty-nine hearts, which are in most instances accompanied by full clinical histories of the patients. The causes of death included violence and many different diseases, and the ages ranged from an early embryological condition to three weeks after birth, and upward to old age. My studies have been carried on now during a number of years, and it has impressed me, as of course it must everyone who attempts to investigate pathological changes, that the most important and difficult problem is to decide what particular appearances in a given tissue are histological and what pathological. One result of my labors has been to lead me to the observation of certain appearances of the normal microscopical structure of the heart which are, so far as I know, new, and which certainly are not commonly known either to histologists or pathologists. These appearances are connected with the condition both of the vascular supply and of the structure of the muscular fibres, and it will be impossible to describe the one without alluding to the other also, but so far as possible the arrangement of the bloodvessels will be dealt with first.

Upon the surface of the heart there are numerous arteries and veins of the ordinary structure, having three coats, the middle or muscular one having circular fibres. Though veins having three coats are always present on the surface of the heart, my studies have led me to the conclusion that they are rare in the muscular walls, where the three coats are found only in veins of large size, and the smaller ones have but a single coat. This single layer is composed of endothelium, and is in appearance and thickness precisely like the wall of the smallest capillary. On the other hand, the arteries can be seen to have three coats, the circular muscular fibres being distinctly visible, until the size of the vessel is little greater than that of the capillaries of least diameter. This process of transition from arteriole to capillary is one of great interest, and is accurately depicted in Fig. 1.

The mode of transition from arteriole to afferent capillary is in strong contrast with that of the efferent vessels. The condition of things will be better understood by examining Fig. 2, which admirably represents the ordinary appearances of the return vessels, than by any verbal description. The vessel into which the capillaries of the smallest size empty their contents is, as may be seen, one having walls no thicker than the smallest capillaries, and of a structure precisely similar. The smaller capillaries, too, at their junction with the larger vessel often form much less acute angles than is usually the case at the points where the arterioles break up into afferent capillaries. The small efferent capillary even forms a right angle with the larger one, thus emptying its blood into a stream flowing directly at a right angle to its course up to its termination. Another striking point, and one worthy of note, is that these efferent capillaries seem much more numerous than the afferent ones, perfect showers of them emptying into the larger vessels within small areas, while at the points where the arterioles break up the number of capillaries is relatively much less. The large efferent vessels are of much greater diameter than the arterioles by which they are accompanied and with which they correspond, but whether this was the case during life or whether the vessels carrying blood out from the tissue are larger because they remained distended after death with blood, it is, of course, impossible to decide.

The usual condition of things, then, in the substance of the heart is that when parallel vessels, the one a carrier of venous and the other of arterial blood, are examined, the arteriole is found to have the structure commonly described as proper to vessels of that nature, being composed of three coats, while the venous vessel exhibits but one, and this coat presents an appearance identical with that of capillaries of the smallest size, being endothelium alone. The appearances described are fairly well represented in Fig. 3, and the nature of the material forming the vein is further made evident by the fact that at one end it was slightly folded.

The important anatomical point to be made is that the *venæ comites* of arterioles in the walls of the heart are vessels having but a single coat.

The distribution of the capillaries in the muscular substance of the heart is well known up to a certain point; histologists thoroughly understand that the minuter arterioles have their termination in capillaries which, after ramifying among the muscular fibres, finally end in venous radicles to discharge the blood at last into the right auricle. To say, however, that the whole circuit of the vessels has been thoroughly traced out as has that of even the minutest capillaries in the liver and kidneys, would not be true, for in the ordinary works upon the subject the matter is not pursued beyond the statement that the muscular fibres are richly supplied with capillaries. The capillaries run, of course, in all directions amongst the muscular fibres, parallel with and between them, at acute angles across them, and again often at right angles. The appearances presented in the last instance are well shown in Fig. 4, which represents a small capillary crossing muscular fibres at nearly a right angle. This describes the more ordinary conditions of the minute vessels of the heart as they have presented themselves to me, and it becomes necessary now to approach the second and still more important part of the subject, the appearance and structure of the muscular fibres in their more intimate relations with the smallest capillaries.

Sections in which the muscular fibres have been cut as nearly as possible directly across their length show the position and number of the smallest capillaries and their relation to the fibres in a more graphic and unmistakable manner than any others. Under these circumstances the vessels present themselves in the form of circles, or, if the section has been at all oblique, as ellipses. Those who have studied sections of bloodvessels will realize how vastly easier it is to draw conclusions in regard to their condition when transverse sections are under consideration than if they be longitudinal. The vessels being hollow cylinders, the variety of the appearances is infinitely less in the case of transverse sections, for then the pictures presented are always in the form either of a circle or an ellipse, and if it be an ellipse the difference between the longer and shorter diameters gives a knowledge of the degree of obliquity of the section. On the other hand, in the case of longitudinal sections, the variety of appearances that may be produced is almost infinite. It would be quite impossible to give any adequate description of these varying appearances, but the mere mention of their existence is sufficient to remind anyone who has given personal attention to investigation of the subject, of the truth of the statement, and of the further truth too, that under the best circumstances studies with the microscope of vessels in longitudinal section yield less satisfactory and less conclusive results than cross sections. Fig. 5 is a carefully made scale-drawing of a single field under the microscope of such a cross section, and it exhibits all the different appearances which it is desired to describe as existing in the heart when seen in that way. It is easy to recognize the vessels as they lie in the connective tissue, where they generally appear as minute circles, with walls of exceeding delicacy and of equal thickness around the entire circuit. There are a few, however, of the capillaries which exhibit upon one side much greater thickness of wall than elsewhere, reminding one of the appearance of a seal ring when looked at from the side. Such thicker spots are caused by the knife having cut through a nucleus in the endothelium of which the walls of the capillary are formed. A closer examination of the drawing, however, brings to light the fact that these empty circles are not to be seen in the connective tissue alone, but exist also half-imbedded in the sides of the muscular fibres and even entirely within them. When I first observed these circles lying within the muscular fibres, and at their edges partially imbedded in them, I did not know what explanation to offer for their appearance. It seemed as if they must be capillaries, and yet the fact that they were closely surrounded by the darkly-stained muscular material made it at first impossible to determine that there was any endothelial wall separating the lumen from the encircling muscular fibre. Closer examination, however, brought to light the fact that in places endothelial nuclei could be distinctly seen (see Fig. 5), and study of a great number ot sections from many different hearts showed that occasionally the endothelial wall could be seen in capillaries entirely imbedded in muscular fibres, thus forcing me to the belief not only that the capillaries enter the muscular fibres, but that they actually penetrate to their very centres.

In order to prove this conclusion to be correct it was necessary to find corresponding appearances in longitudinal sections. As has been stated, longitudinal sections do not yield such satisfactory results as transverse ones, and the appearances are much more difficult to interpret owing to the infinite variety of forms produced. Fig. 6 represents muscular fibres cut longitudinally, and there can be no doubt of the presence of cavities in the centres. The nuclei look as though they lie loosely in the spaces. It is curious, too, how frequently the appearance here represented may be seen, that of two nuclei lying quite close to each other in the same fibre. It cannot, of course, be expected that a section should be cut which would run precisely parallel to the centre of a fibre for a great distonce, though this would be necessary to demonstrate ocularly any great length of a canal in such a fibre. At the same time some of my sections do show fibres which seem to be channelled out for a considerable portion of their length. Of course, it might be said that all these spaces which have been depicted and described are simply the result of splitting of the tissue in course of preservation and preparation, and such an assertion would be difficult to disprove so far as the appearances in the longitudinal sections are concerned. The appearances, however, in the transverse sections do not seem to admit of such a view being reasonably entertained. The presence of the endothelial nuclei, and the fact that occasionally the whole circle of endothelium can be made out, most emphatically contradict such an assertion.

It would be interesting to know at how early a period of life the capillaries exist within the muscular fibres, for the manner in which the muscle tissue grows from nuclei, which at an early period are not to be distinguished morphologically from the nuclei from which the other tissues arise, proves that capillaries do not exist within the muscular fibres in young embryos. The explanation of the presence of the brown pigment which is always found in the muscular fibres of adult hearts is one requiring investigation. The fact that the cavities or channels which have been described are most common and most marked in the parts of the fibres near to the nuclei, and that the pigment too is found in the same position, would seem to point to this pigment being in intimate relation with or derived from the blood.

Before leaving the subject, it would seem well to call attention to the fact that if further investigation by others should confirm the correctness of the views that have been unfolded, it may be found that we will be able to improve our understanding of the pathological processes that take place in the heart; processes which constitute an immensely important element in a great portion of chronic diseases, especially those of people past middle life. The fact that return vessels of considerable size, whether we choose to call them veins or large capillaries, have walls of exactly the same thickness and structure as the smallest capillaries is another evidence of the thorough provision there is for a bountiful supply of nutrient material to the heart. Vessels of this character, it would seem, must have a double, if not treble, function—the walls are so thin that they must partake directly in the nourishment of the tissue; they probably act as reservoirs, owing to their great distensibility; and, lastly, they certainly are carriers.

It would be easy for me to enter at length, and the temptation to do so is great, into a discussion of the bearing of the observations that have been detailed upon questions of the pathology of the heart, but I must content myself by saying that in conditions of disease the cavities in the fibres are sometimes enlarged to such an extent that such fibres, when seen in cross-section, present themselves as hollow cylinders with thin walls.

A brief recapitulation of the points it has been especially desired to emphasize may form the best conclusion of my remarks upon this anatomical question—a question which, viewed by itself, is of great interest, but when considered in its relation to pathology seems to me to open a field for labor and increased knowledge which may be of almost boundless extent. The points, then, are as follows:

1. That the return vessels in the substance of the heart, except a few of the largest size, have thin walls and a structure identical with that of the most minute capillaries. In this respect they present a strong contrast with the arterioles, as the latter, even when of very small size, are similar in structure with large arteries, both having three coats.

2. At points where these return vessels are formed by the coming together of minute capillaries, the number going to form the return vessel is very much greater than at corresponding positions where arterioles (supply vessels) break up, and the angles formed are much less acute, right angles even being formed at such junctions of the venous vessels.

3. The observation of the presence of spaces in the fibres of normal human heart muscle is likely to prove of great importance, if the explanation that they are capillaries is correct. The fact that endothelial nuclei can be seen at the edges of such spaces in almost all properly-prepared sections, and that occasionally even the whole circle of the endothelial wall is visible, would seem almost conclusive evidence of the correctness of this explanation.

EXPLANATION OF PLATES.[1]

Fig. 1. Represents the transition of a minute arteriole into capillaries. It is seen that circular muscular fibres are scattered along the vessels even after they are of the smallest size, at last disappearing, and the capillary then being composed of endothelium alone. The angles formed at the points of division are acute.

Fig. 2. Is a picture of the coming together of many capillaries of the smallest size to form one of the comparatively large efferent vessels which perform functions directly the opposite of those of such arterioles as that represented in Fig. 1. It is noticeable that the number of capillaries is very great, and that the angles formed are much less acute than at the subdivision of the arteriole, in some instances being almost right angles. The vessel, too, is of fully twice the diameter of the arteriole.

Fig. 3. Shows a portion of an arteriole and its accompanying return vessel lying beside each other. The vein has a bit of muscular fibre lying over a portion of it, and at one end is folded. The fold shows how thin is the substance forming the wall. The accompanying arteriole is of only about half the diameter of the vein, and the circular muscular fibres cut across are very distinctly visible upon one side. The contrast in structure of the two vessels could not be made more plain than it is by this picture. The difference in size, too, of the two vessels is a most striking feature.

Fig. 4. Is a drawing of a capillary running nearly at right angles to the muscular fibres it is crossing.

Fig. 5. In this picture are seen primitive muscular fibres, with the intervening connective tissue and many capillaries cut across. It should be noted that the muscular fibres in cross sections do not generally appear as circles, as is commonly represented, but are very irregular in outline, though some are nearly circular. This must be due to the branching, or, as it is commonly called, anastomosing, of the fibres. The important feature, however, is the situation and appearance of the capillaries. It is easy to see that they lie in the connective tissue, are partially imbedded in the sides of the muscular fibres, or are even in their centres. The fact that they are capillaries is shown by the presence of the endothelial nuclei cut across in some of them, giving them the appearance of a seal-ring seen from one side. This resemblance to a seal-ring is very plain in a number of capillaries in the picture, and in a number of instances capillaries can be seen in the very centres of muscular fibres. The most marked instance is that of the large capillary near the centre of the picture to which there is a pointer. The pointers draw attention to capillaries which exhibit the described characteristics in marked degree.

Fig. 6. Represents two muscular fibres in longitudinal section which have large, elongated cavities in their centres. It is noticeable that in both instances there are two nuclei quite close together, and that they seem to lie in the spaces without attachment to anything.

[1] The plates are from drawings made by Dr. Allen J. Smith.

FIG. 1.

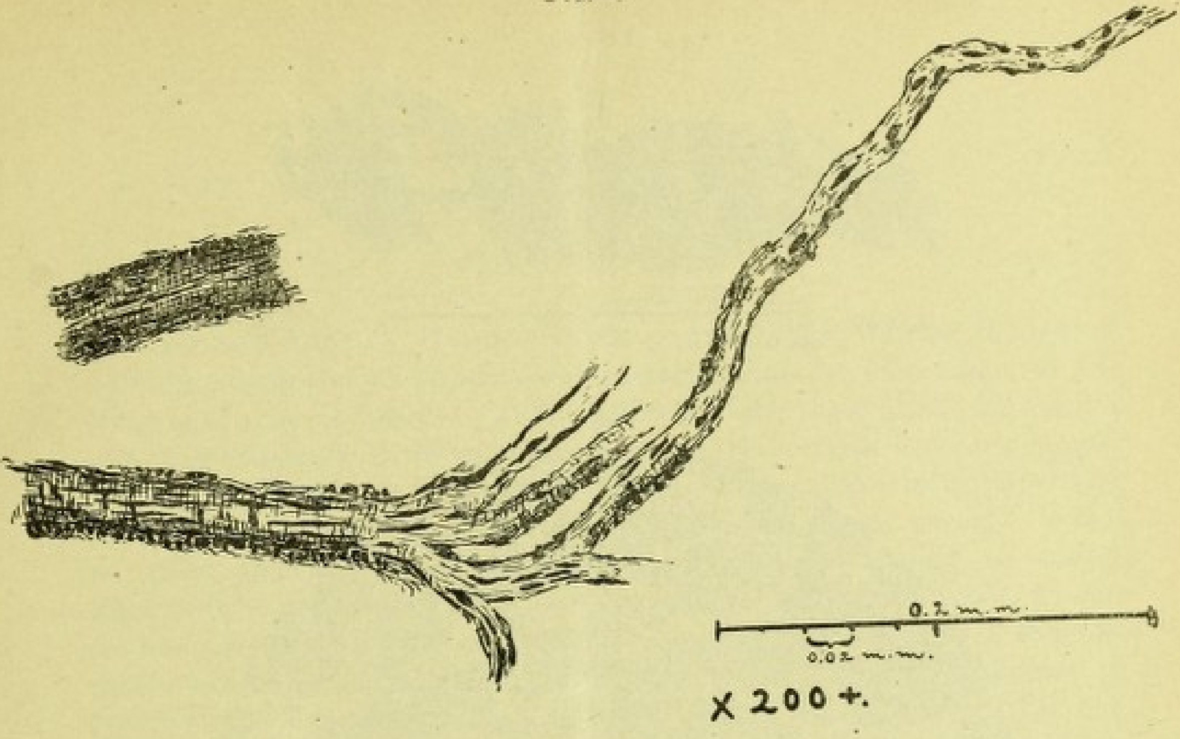


FIG. 2.

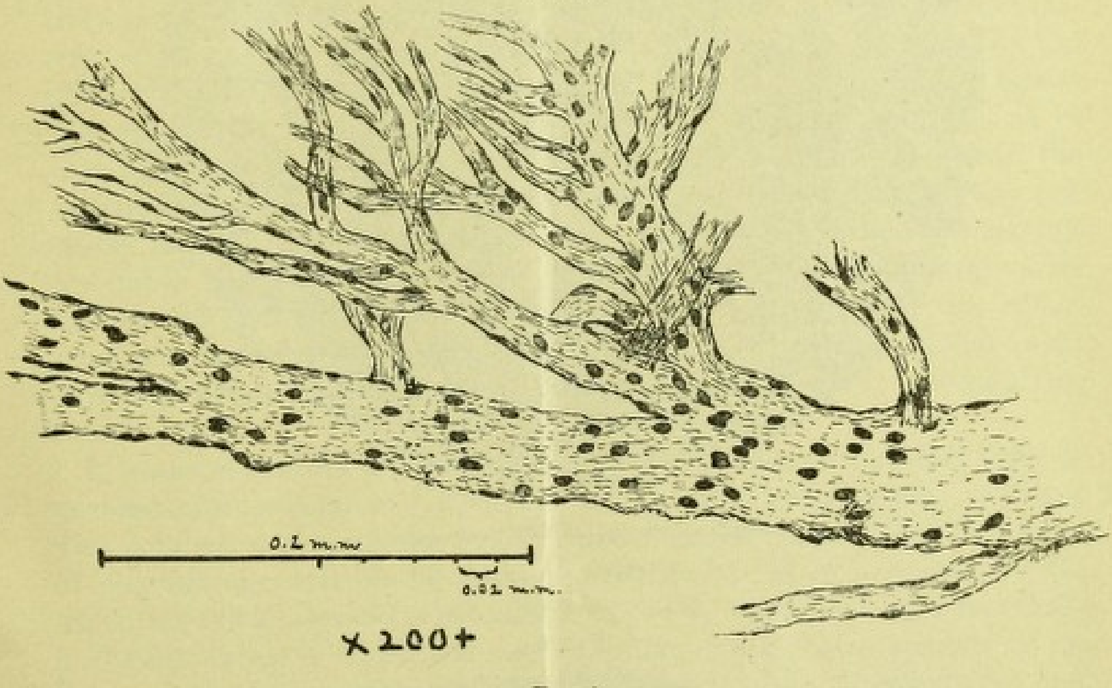


FIG. 3.

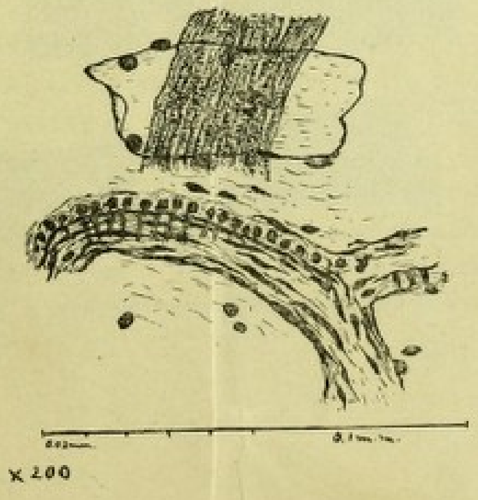


Fig. 4.

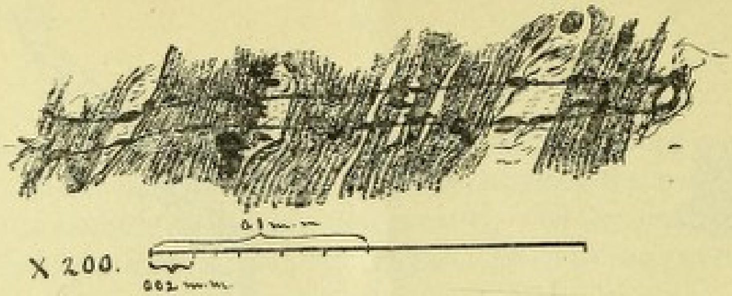


Fig. 5.

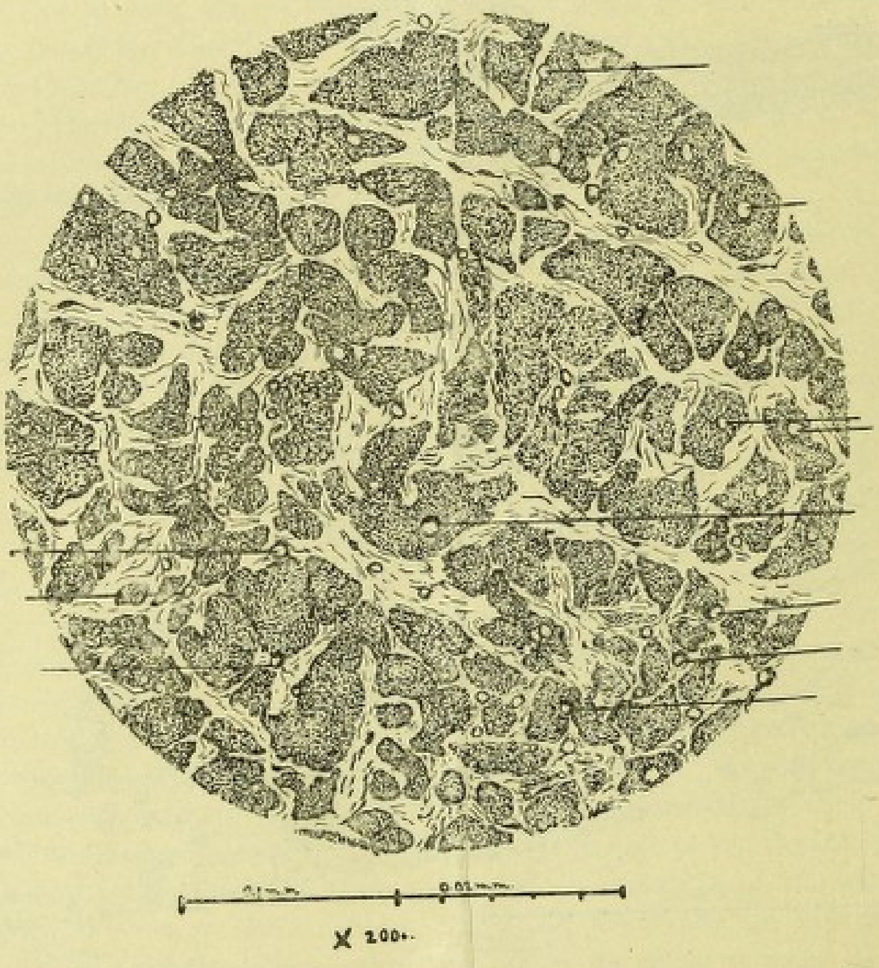
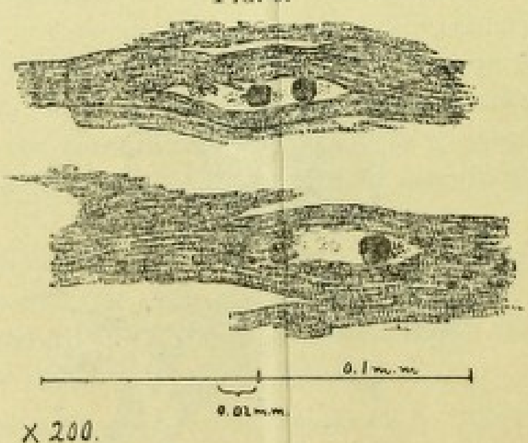


Fig. 6.



DISCUSSION.

PROFESSOR JOHN A. RYDER: It has seemed to me, viewing the matter from the standpoint of physiological anatomy, that the observation of Dr. Meigs is of extreme interest. I can understand why these capillaries are not seen in cross section of the muscular fibres of the heart in the early stages. Many of the structures that we see in the adult organ are really developed during what embryologists speak of as the post-embryonic period. When we reflect upon the way in which muscle universally develops, no matter whether it be in the salamander, the fish, reptile, bird, or mammal, we can see how, in the later stages of the development of the heart, such a thing as enveloping or inclusion of capillaries might occur. It is well known to everyone who has made a cross section of a developing muscle, that the fibrillæ appear as delicate threads imbedded in the protoplasm forming the body of the muscle-cell. That is the type found in the highest form of muscular development. There are forms of muscular development in which the fibrillæ are developed in a continuous roll, and, as a result, the muscular fibre resembles a flat plate made up of parallel filaments. However, as we pass up in the animal scale, and particularly in mammals and birds, the muscular fibres become irregular in shape and excessively numerous and closely packed together, with very little protoplasm between. When we remember that the multiplication of these fibrillæ seems to result from splitting up or multiplication of the fibres already present, we can understand that, as the muscular fibres grow in thickness, any capillaries that might lie beside them might readily be engulfed and covered in by the multiplying fibres.

It seems to me that the points raised are exceedingly interesting from an anatomical standpoint, and from the standpoint of physiological anatomy. This occurrence of capillaries in the muscle fibres is remarkable. We know of very few instances of the canalization of cells. There are some cases in which the cell is actually penetrated by a canal. Such instances are found in the flat worms in which the water-vascular system which answers to the kidney in the higher animal is made up of a set of cells placed end to end, which are chanelled out, forming a system of vessels. Penetration of the muscular fibres in this way by capillaries is analogous, although, of course, not identical. The subject is one which admits of a good deal of expansion, and, I think, is well worthy of some extensive investigation, particularly as to the mode of development.

So rare is it for anatomists to discover anything new in the human body, a subject which has been threshed over by so many capable hands, that it is really creditable to Dr. Meigs to have worked out so carefully these results. I believe that in the course of time these capillaries will be referred to as

"Meigs's capillaries," named after him as many such discoveries have been named after the one who first called attention to them.

Dr. Henry Hartshorne: I rise simply to express the wish that Dr. Meigs had said something in regard to the application of these facts to pathology. If he has a hint or two on that subject it would be of interest.

Dr. Francis X. Dercum: If any doubt could exist in regard to the structure of these capillaries, it might be possible to make injection preparations. This would settle any cavil in regard to their existence. Certainly the discovery is a marvellous one from the fact that it is a distinct addition to our knowledge of the old subject of anatomy. It certainly makes clear how abundantly the heart is nourished, and how magnificent are the provisions for the maintenance of a structure which has so little rest. It also explains how, in conditions of weak heart, return of strength and recovery may occur under proper treatment.

Dr. Thomas J. Mays: I have listened with a great deal of pleasure to this paper by Dr. Meigs. It has occurred to me that there may be an analogy between what Dr. Meigs has discovered and the lacunæ in the frog's heart, described by Pintz in 1883. It is well known that the frog's heart continues pulsating for a long time after removal from the body, and the query has been, Where does the heart obtain the nutritive element or force with which it performs this work? Pintz, on investigation, found spaces in which nutriment was deposited. König and he named these lacunæ—that is, spaces in the muscle which contain nutriment. Whether these are located in the fibres or between the fibres I do not know.

It is remarkable that these spaces should also exist in the human heart, and in close communication with the circulation. It is also remarkable that both Dr. Meigs and Pintz should come to the same conclusion as regards the physiology of these spaces, that they serve as reservoirs for the storage of nutriment.

Dr. Meigs: It is, of course, desirable that injections of the heart should be made to further prove the conclusions I have announced. Such preparations I have not made, partly from lack of time and partly because it has seemed to me that the reasons already given are almost final. My conclusion that the spaces are capillaries is fortified by certain appearances sometimes seen in diseased hearts. In persons dying of disease the histological appearances found are very variable. It is not at all uncommon for the muscular fibres, when seen in cross section, to appear as mere hollow tubes with thin walls. This condition, which I have often found in pathological hearts, led me to the belief in the first place, and fortified me in the conclusion finally, that the spaces in the muscular fibres in healthy hearts are actually capillaries, and not the result of bad technique or alteration of the tissue in course of preparation.