TOPOGRAPHIC ANATOMY AND HISTOLOGY OF THE VALVES IN THE HUMAN HEART *

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An accurate knowledge of the structure of the valves in the human heart is of prime importance for at least three very practical reasons. The first is that the various anatomical peculiarities in the valve leaflets suggest an explanation for at least some of the mechanical components entering into the localization of inflammatory, as well as of degenerative (atherosclerotic) processes in these sites. Secondly, the insight into pathological processes thus obtained helps one differentiate these lesions from one another. Thirdly, one is better able to cope with the long disputed question as to whether or not blood vessels or myocardium normally exist in valves. This is not a merely academic question, myocardium having been implicated by various authors as the source of the alleged existence of blood vessels in normal valves.

The descriptions of the valves found in the literature are difficult to follow because the best ones are given by workers who limit themselves to only one or two valves and, since the terminology used is often different, confusion results. As an illustration of this, one may mention that the same layer of tissue in the valve is called "Klappenplatte" by Seipp, "Mittelschicht" by Beitzke, "Grundstock" by Königer, "Lamina Fibrosa" by Tandler, "Klappenskelet" by Benninghoff, and by other investigators is referred to by number. Perhaps the greatest source of dispute lies in the fact that, with rare exceptions, no attempt is made to set definite limits to the valve. It may be said at once that this factor alone is largely responsible for the controversy on the extent to which myocardium has been found in valves and, because of this, on the frequency with which blood vessels have been found in the valves.

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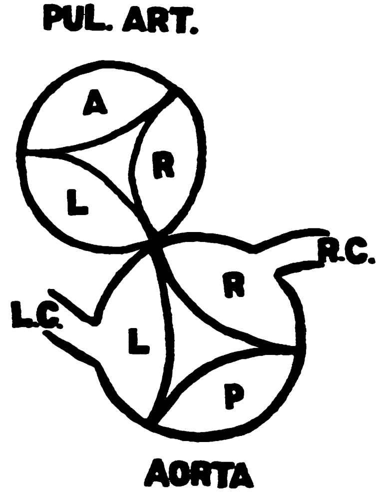
In this paper we propose to describe and picture the valves of the human heart, both in their more minute histology as well as in their typographical relations to other structures, setting as far as possible the limit as to what is valve and where the adjoining cardiac structures begin. We shall also attempt to establish a descriptive nomenclature and indicate at the same time what changes occur in the various structures at different age periods. In our experience with pathological anatomy we feel that the latter point, to which practically no attention has been paid, may carry with it some leads on the mechanical factors concerned with valvular disease.



TEXT-FIG. 1. Diagram to illustrate terminology of pulmonary and aortic valve cusps. LC, left coronary artery; RC, right coronary artery; L, left cusp; R, right cusp; A, anterior cusp; P, posterior cusp.

The plan is to discuss the general structure of valves in brief and to follow this by a detailed description of each cusp, instead of grouping together the semilunar valves and the auriculoventricular valves, as has been the general practice heretofore.

In this article the B. N. A. nomenclature is used (Text-Fig. 1). Thus, the aortic cusp corresponding to the ostium of the right coronary artery is called the right cusp, that corresponding to the left coronary ostium is called the left cusp and the non-coronary cusp is called the posterior. The right pulmonary cusp is that one which is apposed to the right aortic cusp. The left pulmonary cusp is that one which is apposed to the left aortic cusp. The remaining pulmonary cusp is the anterior. The terminology of the auriculoventricular valve cusps needs no special explanation.

Methods and Material

The descriptions which follow are based on an examination of 1000 normal human hearts. These were opened in the customary manner, the chambers washed out and packed, and the hearts fixed in a 10 per cent neutral formaldehyde sodium chloride solution.* Occasionally a formaldehyde solution of Mueller's fluid † was used as a fixative and, if the specimens were very fresh (less than six hours postmortem), Bouin's fluid was employed. After fixation, suitable blocks were cut from the heart and at least two slides were stained from each block, one with hematoxylin and eosin, the other with Weigert's elastic and Van Gieson's connective tissue stains. Latterly, Masson's trichrome stains were used with excellent results.

For the hearts available during the latter part of these studies the standardized method for sections described by Gross, Antopol and Sacks was used in order to obtain comparable statistical material.

General Description of Human Heart Valves

Human heart valves have certain general features in common and yet sufficient individual differences to distinguish them sharply from one another. All the valves carry as their main backbone a dense collagenous layer which we propose to call the *Fibrosa* (Figs. 1 and 6). On its auricular aspect in the auriculoventricular valves (Fig. 8), as well as on its ventricular aspect in the semilunar valves (Fig. 6), the *Fibrosa* shows a looser structure which we propose to call the *Spongiosa*. In the semilunar cusps this looser structure may be so conspicuous as to constitute a sharply defined layer.

Each valve cusp is attached at its base to a more or less dense connective tissue structure called *Annulus Fibrosis*. This *Annulus*

* Solution of formaldehyde, U. S. P., 10 parts; 1 per cent sodium chloride solution, 90 parts. This solution is rendered neutral with a weak alkali.

† The formaldehyde solution of Mueller (Formol-Mueller) is prepared as follows: potassium bichromate, 2 parts by weight; water, 100 parts; solution of formaldehyde, U. S. P., 10 parts. The "solution of formaldehyde" is added just before use.

differs considerably with the various cusps in its extent, distribution and connections. Its topography for the aortic valve has been admirably described by Lewis and Grant. There exists, however, an important strategic site which includes part of the base of the valve as well as the adjacent portion of the *Annulus*. We designate this area the *Ring* (Text-Fig. 2). The exact descriptions of the several valve *Rings* will be given under their appropriate headings. *It is of utmost importance to mention here that the valve "Ring" should be considered to constitute the proximal end of a valve leaflet.* This will be taken up further in greater detail.

The *Rings* of the semilunar valves (Fig. 5 and Text-Fig. 2) generally contain a conspicuous *Spongiosa* referred to by Curtis as "un espace triangulaire . . . occupé par un tissue conjonctif spécial." On the other hand, the auriculoventricular valve *Rings* in this area show only a slightly looser structure of the collagenous *Fibrosa* (Fig. 8). We designate these areas *Ring Spongiosa*.

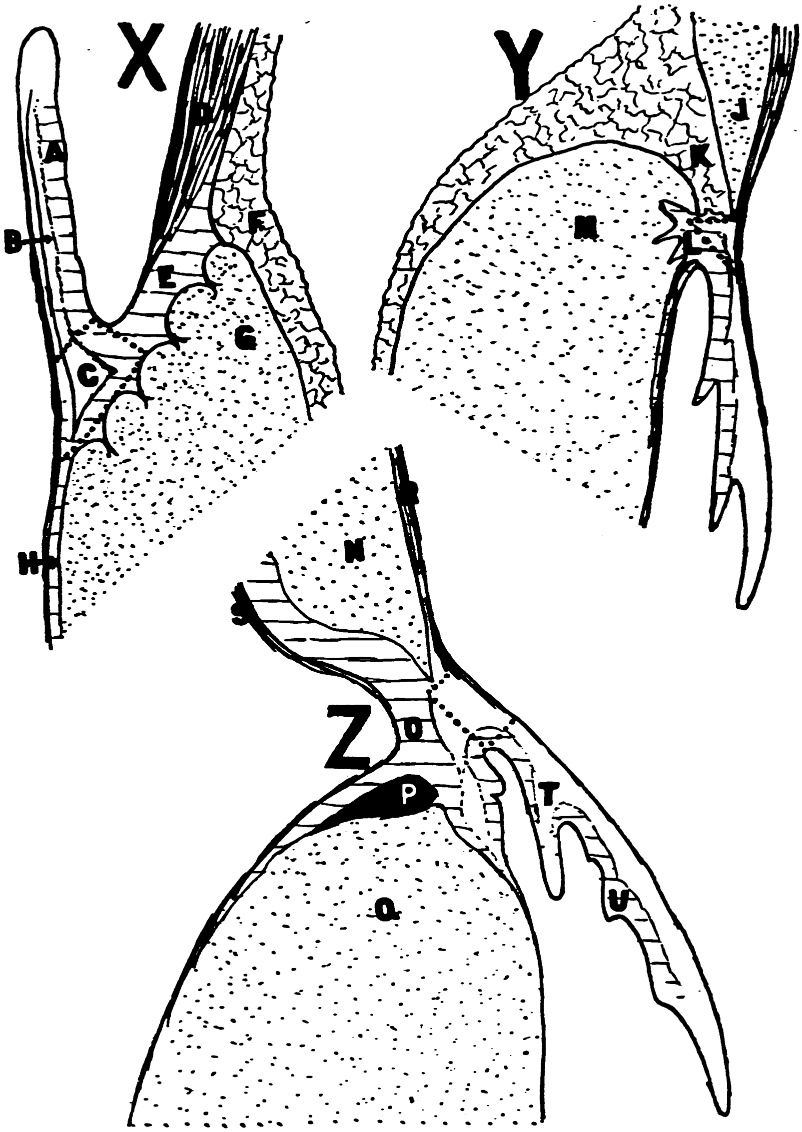
The *Fibrosa*, with its looser layer, is clothed on both sides by a continuation of the arterial intima or ventricular or auricular endocardium, as the case may be. These arterial or endocardial connective tissue mantles contain more or less conspicuous elastic sheets. The elastic sheets which are situated on the outflow surface of the valve (auricular surface of the auriculoventricular valves; ventricular surface of semilunar valves) are generally the heavier and longer (Seipp). Both elastic layers thin out progressively as they approach the tip of the valve.

As a generalization it may be stated that while the separation of these valve layers is already seen in early fetal life, they become more and more clearly defined with advancing postnatal age periods (Veraguth). Furthermore, the differences in their extent, thickness, structure and distribution give to each cusp its individual characteristics.

Aortic Valve

Topography

The topographic relations to their attachments of each aortic cusp, indeed of various parts of each aortic cusp, show wide individual differences. This is due largely to the peculiar linking up of the left and posterior aortic cusps with the anterior leaflet of the mitral valve and the consequent deformation of the auricular myo-



TEXT–FIG. 2. Diagrams of typical semilunar and auriculoventricular valve rings.

X. *Typical Semilunar Cusp.* A, fibrosa; B, valve spongiosa; C, ring spongiosa; D, aorta; E, annulus; F, pericardium; G, ventricular myocardium; H, subvalvular annulus.

Area enclosed by dotted lines is the valve ring.

Y. *Typical Auriculoventricular Cusp.* I, auricular endocardium; J, auricular myocardial wedge; K, pericardial wedge; L, annulus; M, ventricular myocardium.

Area enclosed by dotted lines is the valve ring.

Z. *Typical Septal Flap of Tricuspid Valve Section.* N, right auricular myocardial wedge; O, septum fibrosum; P, bundle of His; Q, interventricular septum; R, right auricular endocardium; S, left auricular endocardium; T, valve spongiosa dipping into chorda tendinea insertion; U, valve fibrosa.

Area enclosed by dotted lines is the valve ring.

cardial and pericardial wedges which are, as it were, pressed in between them (Fig. 6). Other contributing irregularities in structure are the juxtaposition of the pulmonary myocardial conus and the presence of the *Septum Fibrosum* situated below the commissure between the right and posterior aortic cusps on the left side and the septal and anterior tricuspid leaflets on the right side.

As is well known, the aortic media is rich in elastic fibers. These exist as more or less parallel concentric sheets with, here and there, communicating transverse bars which include between them smooth muscle cells and connective tissue. As the media approaches the base of the aortic cusps it loses all but the most delicate of its elastic fibers and thus becomes the aortic *Annulus* (Fig. 1). Lewis and Grant have shown that for the greater part of the cusp, and in general, the aortic media ends in a wedge-shaped process whose apex is superficial to the *Annulus*. In the commissural region, however, the reverse of this takes place. They also found that in congenital bicuspid aortic valves the region of the fusion or absence of a commissure presents alterations in these relations. We have been able to confirm this and have noted in addition that as one approaches the commissures the wedge-shaped aortic termination changes into a more or less square pattern (Fig. 2) which again transforms itself into a wedge, now situated on the adventitial side of the aorta (Fig. 3). Furthermore, the commissural region is often marked by a slight thickening of the aorta at the level of the free edge of the cusps. Other parallel changes to be found in this region will be discussed in connection with the description of the *Sinus Pocket* * to be given. Below the commissural junction the *Annulus* acquires elastic fibers and smooth muscle on its superficial (intimal) surface and thus again assumes the structure of aorta.

In the case of the *Right Aortic Cusp* (except that portion situated above the *Septum Fibrosum*) the aortic media generally changes into *Annulus* a short distance above the latter's insertion into the interventricular septum (Fig. 1). This insertion takes place by means of finger-like connective tissue processes which interdigitate with myocardial bundles. The main portion of the *Annulus*, however, makes a more or less obtuse-angled bend transversely and downward,† and

* The more or less transverse portion of *Annulus* and intimal covering which lines the bottom of the sinus we designate *Sinus Pocket* (Fig. 5).

† In these descriptions, "transversely" will be considered in reference to the main anatomical axis of the heart; "downward" is synonymous with "toward the apex."

riding atop the interventricular septum makes another bend abruptly cephalad as it reaches the ventricular cavity. The region of the cephalad bend is the *Ring*. Here fibers of the *Annulus* split off into two bundles to surround the *Ring Spongiosa*. The bundle which rounds the *Sinus Pocket* and enters the valve flap to make up its main support, the *Fibrosa*, is generally the larger one. The smaller bundle courses under the *Ring Spongiosa* and continues for a short distance down the inner surface of the ventricle under the endocardium, as a thin fibrous tissue sheet which we call the *Subvalvular Annulus*. The endocardial layer clothing the *Subvalvular Annulus* generally shows smooth muscle cells on section. It is to be observed that for the greater part of its insertion the *Ring* of the right aortic cusp sits on myocardium and has no direct connection with the pericardial wedge. However, here as in all other semilunar cusps, the *Ring* insertion lies almost directly over the pericardial wedge in the region of the commissure.

The line at which the *Annulus* meets the interventricular septum is generally clothed by pericardial tissue, usually fat, which serves to separate this arterio-annulus junction from the adjacent myocardium of the pulmonary conus, the latter being a direct muscular continuation of the interventricular septum. Particular attention should be paid to the presence of the pulmonary conus in this section, since it forms an absolute means of identifying this cusp. Furthermore, if the section is cut high enough, it is possible to distinguish the arterior half of the right aortic cusp from the posterior half. The former section contains the root of the pulmonary artery, the latter will show a cross-section of the right coronary artery.

It has already been mentioned that as one passes from the middle of the valve toward a commissure, alterations occur in the aortic media-annulus relations. In addition, it is to be noted that the *Sinus Pocket* formed by the *Annulus* becomes progressively smaller and the myocardium-annulus insertion line on cross-section assumes a horizontal direction instead of sloping from above downward (considered from the pericardial to the inner surface) as is the case in the middle of the cusp (Figs. 1, 2 and 3). These rules apply to all the aortic and pulmonary cusps.

With the following modifications, the description given for the topographic relations of the *Right Aortic Cusp* holds for the *Left Aortic Cusp* except the portion situated above the anterior mitral leaflet.

(*a*) In the case of the left aortic cusp (Fig. 4) the *Annulus* is inserted into left ventricular wall instead of interventricular septum.

(*b*) No pulmonary conus exists adjacent to the pericardial mantle.

(*c*) Smooth muscle is less frequently seen in the *Subvalvular Annulus* on section.

(*d*) If a block is cut through the middle of the valve, the left coronary artery or one of its branches will be seen embedded in pericardium not far from the arterio-annulus junction. If a section is cut more anteriorly, *i. e.*, close to the left-right commissure, the base of the pulmonary artery will be included; if cut more posteriorly, *i. e.*, close to the left-posterior commissure, the topographic relations will be similar to those to be described for the posterior cusp.

The topographic relations of the remaining portion of the left cusp, of the *Posterior Cusp* (Figs. 5 and 6), and of that part of the right cusp situated above the *Septum Fibrosum* are different in one important respect. Here, the aortic *Annulus* makes no bend as described above, but instead continues down to form the *Septum Fibrosum* or the *Fibrosa* layer of the anterior mitral leaflet, as the case may be. Because of this difference the corresponding aortic cusp *Rings* are brought much closer to the pericardial wedge, often being seated directly thereon instead of on myocardium. The pericardial wedge extends for a variable distance between *Annulus* and auricular myocardium in the case of the last-mentioned aortic cusps, at times passing below the level of the corresponding aortic *Ring*.* From this description it will at once be grasped that there is a strategic proximity between these aortic *Rings* and the pericardium, so that an infection originating in the former could easily pass by contiguity into the pericardium, and *vice versa*.

In addition to the differences noted above we may mention that in the case of the posterior aortic cusp, the arterio-annulus junction is usually low, at times forming part of the *Sinus Pocket*.

Summarizing briefly these topographic relations of the aortic cusps, it is seen that they divide themselves into four types by which it is possible to recognize histologically the cusps from which the sections are cut as follows.

(*a*) The main portion of the right cusp has the "U" type of insertion in which the aorta forms one arm of the "U," the cusp the other arm, and the base of the "U" sits on the interventricular septum and forms the bottom of the *Sinus Pocket*. In this "U" type of insertion the valve *Ring* sits on myocardium

* Occasionally the Arteria Anastomotica Magna (Kugel) may be seen in the pericardial wedge.

through the intermediary of a band of *Annulus*. The arterio-annulus junction is clothed by pericardium and the pulmonary myocardial conus lies adjacent to it.

(*b*) The main portion of the left cusp also has the "U" type of insertion. Here, the distinctive features are the absence of adjacent pulmonary conus and the frequent presence of coronary artery embedded in free visceral pericardium.*

(*c*) Continuing the scheme of using letters to represent physical configuration it may be said that the main portion of the posterior aortic cusp has the "Y" type of insertion. Here, the aortic *Annulus* continues as anterior mitral valve *Fibrosa* and forms the stem of the "Y." The posterior aortic *Ring* usually sits on pericardial wedge.

(*d*) The portions of right and posterior cusps participating in the right-posterior commissure also have the "Y" type of insertion but here the *Annulus*, in the form of the *Septum Fibrosum* (stem of the "Y"), eventually inserts into interventricular septum. The insertion is by means of connective tissue bundles interdigitating with myocardium.

Histology

For practical purposes the description which follows corresponds to an average aortic cusp of between the third and fourth decades. The age period changes will be briefly commented on below.

Ventricularis: The aortic cusp is clothed on its ventricular aspect by a fibro-elastic layer of varying degrees of density (Figs. 1 and 9). This layer, which we propose to call *Ventricularis*, is virtually a continuation of the ventricular endocardium, except for the posterior and left aortic cusps, where it is a continuation of the *Ventricularis* of the anterior flap of the mitral valve. This will be taken up subsequently. Histologically, the *Ventricularis* is seen to be covered by a single row of flat endothelial cells with round or oval nuclei and to consist of vertically (*i.e.*, parallel with the long axis of the body) directed connective tissue fibers interspersed with delicate elastic lamellae. The latter tend to become thicker and bunched together toward the ventricular surface, thus forming the *Ventricularis Elastica.*

It has been claimed by various authors that the elastic fibers in the valves do not appear until after birth. Nevertheless, we have found them in the *Ventricularis* at the proximal portion of the valve flap in 19 cm. (crown-rump) fetuses.

* The term "free visceral pericardium" denotes the absence of adjacent cardiac structure. Note that the left aortic cusp is the only one which shows free visceral pericardium on section at the *Ring* level.

The ridge constituting the line of closure of the aortic cusps consists of an abrupt thickening of the *Ventricularis* layer. This thickening is made up of closely packed vertically directed fibers of connective tissue interspersed with elastic fibrillae. The whole structure rests on a somewhat condensed band of *Elastica* which separates it from the remainder of the valve substance. In the center of the valve this closure line assumes nodular proportions and is called Nodulus Arantii (Fig. 7). In advancing age periods these Noduli become increasingly prominent, hardened and elastified threads often breaking off them at one end to float as streamers in the blood current. These form the so-called Lamblian excrescences. They are of interest in that they have been confused with healed verrucae.

The *Ventricularis* as a whole is rather poor in cells, though fibroblasts and occasional large mononuclear cells with scanty protoplasm can be seen scattered throughout it. These cells are more plentiful in the earlier age periods. This decreasing cellularity with increasing age is found in all the valve layers of the semilunar, as well as auriculoventricular, cusps.

Spongiosa: It has already been mentioned that the backbone of each valve leaflet consists of a dense collagenous layer and that in the aortic cusps the ventricular aspect of this layer gives way to a much looser structure which we designated *Spongiosa*. In a fetus of crown-rump length 12 cm. the *Spongiosa* already begins to be discernible. In the average adult of the second and third decade it consists of a very loose connective tissue layer which extends from the *Ring* (*Ring Spongiosa*) for a variable distance almost to the tip of the valve (Fig. 6). At the *Ring* the *Spongiosa* has a triangular shape limited below by *Annulus*, above by *Fibrosa* and toward the ventricular surface by *Ventricularis*. Interspersed in the loose connective tissue of the *Spongiosa* with its scarce fibroblasts and other mononuclear cells there can be found irregular clumps of dense collagen fibers, as well as a delicate feltwork of elastic fibrillae which are continuous on the one hand with those springing from the *Ventricularis* and on the other hand with rare elastic fibrillae running between the collagenous bundles of the *Fibrosa* (Fig. 9).

Fibrosa: Under the heading of "Topography" it has already been mentioned that the root of the aorta loses its musculature and most of its elastic fibers, thus transforming itself into *Annulus*, and that much of this collagenous *Annulus* curves around the *Sinus Pocket*

(Valsalva) to ascend the valve leaflet as its *Fibrosa*. In rounding the *Sinus Pocket* the collagenous bundles change their general direction and structure. In the *Annulus* they are in the form of interlacing whorls. Under the *Sinus Pocket* the superficial bundles take on a course more or less parallel to the bottom of the "U" and, as the *Fibrosa* proper, they run mainly in a transverse direction.

In the crypts between the collagenous bundles there are to be found very delicate elastic fibrillae, as well as mononuclear cells with round dense nuclei and rather scant protoplasm. The *Fibrosa* ascends toward the tip of the cusp. In most instances, however, the arterial aspect of the tip of the *Fibrosa* consists of a much looser, at times myxomatous, structure, not unlike the *Spongiosa* in character (Fig. 1).

The *Fibrosa* is more or less sharply limited on its ventricular aspect by the looser *Spongiosa* and on its arterial aspect by the delicate *Arterialis* about to be described.

Arterialis: As one follows the more superficial elastic fibers down the intima of the aorta toward the cusps, they are seen to fuse into one or more bands which round the *Sinus Pocket* superficially and ascend the arterial surface of the aortic cusps as a delicate elastic layer. This rapidly thins itself out, often disappearing about one third of the way up the valve. Before progressive (hyperplastic) changes have taken place, this elastic lamella is clothed by a layer of flat endothelial cells and is separated from the adjacent *Fibrosa* by a very sparse, loose connective tissue containing extremely delicate elastic fibrillae, as well as mononuclear cells poor in cytoplasm with darkly staining nuclei. Normally, and in younger individuals, the endothelial cells sit practically directly on this elastic layer.

As has been mentioned before, the *Arterialis Elastica* is shorter and far more delicate than the corresponding *Ventricularis Elastica* (Figs. 5 and 9).

Pulmonary Valve

Topography

The topography of the pulmonary cusps is very simple. The general plan is the "U" type of insertion, as described for the aortic cusps. Because of this there is no direct insertion of pulmonary *Ring* on pericardium, except at the commissural junctions. As in the aorta, the metamorphosis of pulmonary artery into *Annulus* takes place at, or slightly above, the level of the subjacent ventricular myocardium. The relations of pulmonary artery to *Annulus* are similar to those described for the aorta and the rules laid down concerning the slope of the *Annulus* and the changes which take place on approaching the commissure hold for the pulmonary cusps.

TABLE I

Comparison of Histological and Topographical Features of Pulmonary and Aortic Cusps

Pulmonary Cusps	*Aortic Cusps*
* Pulmonary artery delicate.	* Aorta thick.
* Various layers delicate.	* Layers on the whole thick.
Fibrosa frequently shows transverse ridge-like projections into *Sinus Pocket*.	Ridge-like projections less frequent.
Ring Spongiosa often small and fibrillar. Not infrequently absent from section.	*Ring Spongiosa* generally larger. Seldom fibrillar, more often spongy. Seldom absent from section.
Valve Spongiosa less frequently definite. Character similar to *Ring Spongiosa*.	*Valve Spongiosa* sharply defined when present. Character similar to *Ring Spongiosa*.
Smooth muscle in *Ventricularis* rare in any cusp section.	Smooth muscle in *Ventricularis* not infrequent, especially in *Ventricularis* of right aortic cusp.
* *Subvalvular Annulus* is absent or very delicate.	* *Subvalvular Annulus* conspicuous.
* Interdigitations of *Annulus* with myocardium generally delicate.	* Interdigitations coarser, increasing with age periods.

(The items marked by asterisks demonstrate the more characteristic differences.)

The main differences between the pulmonary and aortic valve sections are brought out in Table I. The items marked by asterisks demonstrate the more characteristic differences. In addition to the points brought out in the table, it is to be noted that in contrast to the aortic valve where the left cusp section is the only one to show "free visceral pericardium," the latter is present on the anterior and right pulmonary cusps.

The individual characteristics of the several pulmonary cusps are as follows.

The *Left Cusp* (Fig. 11) is inserted on to the anterior portion of the interventricular septum; as a consequence of this a section through the middle of this cusp shows the double myocardial crest characteristic of the latter. If cut more toward the left, it will show a large transverse section of ventricular wall, possible with visceral pericardium. If cut toward the right, adjacent aortic root will be seen. These sections show no subvalvular *Annulus* but are apt to have left coronary artery present.

The *Anterior Cusp* (Fig. 12) is seated on the delicate anterior wall of the pulmonary conus. In this region the pericardial mantle is generally very thin. If subvalvular *Annulus* is present in the pulmonary valve it will generally be found in the anterior cusp section as a delicate layer extending several millimeters below the valve *Ring*. This, together with the very slender visceral pericardial layer mentioned above, is characteristic of the cusp.

The *Right Cusp* (Fig. 13) is seated on the more supple right wall of the pulmonary conus. Here the pericardial fat is generally quite thick. These features and the absence usually of *Subvalvular Annulus* are characteristic of this cusp. If a section is cut more posteriorly, adjacent aorta may be seen.

Histology

The histological differences between pulmonary and aortic cusps are much less obvious than are the topographic. In general, as mentioned before, the layers are more delicate in the former. The *Ventricularis* and *Arterialis* layers are generally so thin as to make the *Fibrosa* more conspicuous by contrast.

Whereas in the aortic cusps the *Ring* and *Valve Spongiosa* are, as it were, sharply scooped out of the *Fibrosa* and filled with a loose jelly-like tissue made up of transversely coursing collagen and elastic fibrillae with stellate cells, in the pulmonary cusps the separation of this layer from the *Fibrosa* is usually not so sharp, fragments of collagen being scattered throughout (*cf.* Figs. 6 and 12). Elastic fibrillae are not seen so often until later age periods and the connective tissue feltwork is often denser.

In later age periods the prominent Noduli Arantii of the aortic valve form a characteristic difference from the corresponding, more delicate, so-called Noduli Morgagni of the pulmonary cusps.

General Considerations Concerning the Auriculo-ventricular Valves

It is a relatively simple matter to set definite limits to the extent of the semilunar valve cusps. In a previous paragraph it was suggested that the valve *Rings* should be considered to constitute their proximal end. This gives one a fairly concrete point of departure, inasmuch as the valve *Ring* itself is almost invariably limited proximally by subjacent *Annulus* (Fig. 1). In any event, shifting the imaginary line of semilunar cusp insertion slightly one way or another is, in so far as one can see, of no great moment.

This, however, is distinctly different in the case of the auriculoventricular cusps for, as indicated earlier in this paper, one's conception of the limits of the cusps inevitably carries with it the question of the existence of myocardium, and because of this, of blood vessels in the valve. A glance at a typical cusp (Fig. 6) will make this point clear. If arrow "A" were to be considered the proximal end of the cusp, the auricular myocardial wedge would be included and it could therefore be said on this basis that many of the auriculoventricular cusps have myocardium. Further, since myocardium is always supplied by blood vessels, it follows according to this definition that these auriculoventricular cusps possess blood vessels. If, on the other hand, arrow "B" is to be considered the proximal end of the cusps (and this is the definition which we favor), the myocardium and its blood supply ceases to be a factor in the argument and the question of the existence of blood vessels in human heart valves involves consideration of only the fibro-elastic portion — an entirely different matter as will be seen. It seems to us that this is the crux of the discussion on whether myocardium exists in the auriculoventricular valves and it is on this very point that a large and confusing literature has sprung up. Various authors have chosen arbitrary limits for the origin of the auriculoventricular valves, particularly of the anterior mitral cusp, and have reported abundant or sparse auricular musculature extending for a greater or lesser distance down the valve according to their conception as to whether the base of the valve was higher or lower in the auricle (Kürschner, Reid, Joseph, Gussenbauer, Beitzke, Hoessli, Tandler, De Castro). The significance of the relatively infrequent occurrence of ventricular musculature in the base of the tricuspid valve will be discussed later.

It is obvious from what has been said that the presence or absence of myocardium in the auriculoventricular valves must be settled before one can intelligently discuss the existence of blood vessels in valves. Furthermore, inasmuch as the latter question is intimately bound up with the embolic theory of endocarditis, a clear definition of terms becomes not only desirable but absolutely essential. When one considers the question of the pathogenesis of valvulitis one is primarily concerned with the membranous structure. This very practical reason alone should justify a definite limitation of the valve to the fibro-elastic portion. But there are other reasons as well. We have seen that the valve *Ring* is a natural and simple limit to be set for the extent of the semilunar cusps. It is desirable that, if possible, a uniform conception be held for all valve cusps and that therefore the extent of the auriculoventricular valves should be limited in the same manner. Furthermore, it does not seem to be more unreasonable to exclude auricular or ventricular myocardium from our definition of valve leaflet than it does, for example, to exclude sclera from our conception of what constitutes cornea. Apparently, Weber and DeGuy appreciated this source of confusion in the case of the anterior mitral cusp and attempted to circumvent the difficulties by naming the entire structure "la région mitro-aortique" and dividing it into three zones, *viz.*: (1) la zone supérieure ou sigmoidienne . . . limitée . . . en bas par trois lignes . . . d'insertion des valvules aortiques; (2) la zone moyenne ou mitro-auriculaire, limitée . . . en bas *par une ligne traversale correspondant à la partie terminale des fibres musculaires venant de l'oreillette* . . . ; and (3) la zone inférieure ou grande valve mitrale. . . .

In view of all the considerations mentioned above and for many equally important reasons which need not be entered into here, we propose to use the valve *Ring* to set the proximal limit of the auriculoventricular cusps. Since all the auriculoventricular cusps have inserted into them a wedge of auricular myocardium, a line drawn through the apex of this wedge at right angles to the auricular endocardium may be considered an excellent and simple means of defining in turn the proximal limit of the auriculoventricular valve

Rings (Text-Fig. 2). In the case of all the auriculoventricular cusps, excepting the septal flap of the tricuspid, the *Ring* may be arbitrarily considered as an inverted pyramid-shaped portion of *Annulus* in the immediate vicinity of the auricular myocardial wedge apex, limited above by the line referred to, which constitutes the base of this inverted pyramid, and internally by the endocardium. We have found it convenient to consider the pyramid more or less equal-sided and have taken the width of the valve as a rough measure of each side. In contrast to all the other auriculoventricular valve cusps, the septal flap of the tricuspid, as will be noted in Fig. 16, is generally inserted onto *Annulus Fibrosis* or interventricular septum through the intermediary of a wide base. Here the *Ring* may be conveniently considered as roughly rectangular in shape. The upper limit is the transverse line drawn through the apex of the auricular wedge; the lower limit is a similar line drawn at right angles to the endocardium at the level of the *Sinus Pocket*; the outer limit is in an imaginary line drawn parallel to the endocardium at a distance from it approximately equal to the width of the valve; the inner limit is the endocardium.

Contrary to what is found in the semilunar valves, the auriculoventricular cusps seldom have a clearly delimited valve or *Ring Spongiosa*. In the region of the apex of the auricular myocardial wedge the *Fibrosa* generally shows a looser structure of its collagenous bundles. For the sake of uniform terminology this layer should also be referred to as *Spongiosa*. It may at times be seen extending along the auricular aspect of the *Fibrosa* toward the valve tip (Figs. 8 and 16). The layer is generally more conspicuous opposite the insertions of the chordae tendineae where it can be seen at times dipping into the latter in the form of a wedge. Both here and at the *Ring* the *Spongiosa* may acquire considerable fat during the course of the degenerative involutionary changes attendant on later age periods.

The most conspicuous feature of the auriculoventricular valve structure is the extremely dense, broad *Fibrosa* which constitutes the bulk of the cusp. As in the semilunar cusps, the *Fibrosa* not infrequently transforms itself into a looser, sometimes myxomatous, structure as it approaches the tip. The chordae tendineae may be considered as dense collagenous prolongations of the *Fibrosa* layer which link the latter to the papillary muscles or ventricular myocardium.

In leaving the *Fibrosa*, the chordae tendineae carry with them a light mantle of the *Ventricularis* covering the valve leaflet.

With the above mentioned points in mind, the typical auriculoventricular cusp section shows the following topographic features (Fig. 9).

An auricular portion consisting of endocardium and subjacent myocardium ends in a wedge.

Linking this wedge to ventricular myocardium and interdigitating with the latter there is a dense collagenous *Annulus*.

On the external surface, pericardium clothes this auriculoventricular junction and sends a wedge of adipose tissue to insert into the *Annulus*. The proximity of this pericardial wedge to the valve *Ring* and the frequency with which the latter is the seat of inflammation are matters of considerable interest from the point of view of pathogenesis.

The *Annulus* merges imperceptibly with the valve *Ring* at the level of the myocardial wedge.* The *Ring* in turn gives way to valve *Fibrosa* and this continues for a variable distance toward the valve tip.

The auricular endocardium continues beyond the myocardial wedge tip down the valve as its *Auricularis* layer. Similarly, too, the ventricular endocardium passes under the *Valve Pocket* clothing the ventricular surface of the *Annulus*, rounds the latter and spreads itself over the outer surface of the cusp as the *Ventricularis*.

Mitral Valve

Topography

The topography of the typical auriculoventricular valve has already been described and the description given is directly applicable to the *Posterior Mitral Cusp* (Fig. 8). A section through this region shows the characteristic dome-shaped crest of the left ventricular wall, the thick left auricular endocardial layer, the not infrequent passage of the left auricular myocardial wedge below the level of the ventricular crest and the presence, generally, of left coronary circumflex artery in the *Free Pericardium* of the auriculoventricular groove. At times a short subvalvular extension of the *Annulus* may be seen on the ventricular wall below the valve pocket.

The *Anterior* (*Aortic*) *Mitral Cusp* is unique in structure (Fig. 6). In describing the posterior aortic cusp it was mentioned that it falls into the category of the "Y" type of *Annulus* insertion, *i. e.*, the

* At times the auricular myocardial wedge may send several finger-like strands of tissue for as much as 1 cm. down the valve cusp. This places the *Ring* unusually low, but it is better so considered than to change the definition and thus confuse more important issues.

aortic *Annulus* continues down the ventricular face of the auricular myocardial wedge and after reaching the tip of the latter becomes successively anterior mitral cusp *Ring* and valve *Fibrosa*. The portion of *Annulus* which extends between the aortic and mitral *Rings* we call *Mitral-Aortic Intervalvular Fibrosa*. It is well to note that this structure belongs neither to aortic nor to mitral cusps. For embryogenetic and anatomical reasons this, like the myocardial wedge, should be considered part of the auricle.

Further points of importance are the characteristic auricular myocardial wedge clothed by thick left auricular endocardium and the typical structure of aortic cusp (left or posterior) superimposed.

Histology

Auricularis: As is well known, the left auricular endocardium is made up of dense fibrous and elastic sheets interspersed with smooth muscle bundles which are generally situated close to the subendocardium. As the elastic fibers are traced toward the mitral valve it is seen that the outermost lamellae (*i. e.*, those toward the subendocardium) tend to fuse into a more or less condensed stratum. In the region of the apex of the auricular myocardial wedge many of the remaining elastic lamellae fuse into this lower condensed stratum. In the later age periods, the innermost elastic sheets also show condensations which fuse with the subendocardial strata near the auricular myocardial wedge apex. The net result is that the number of elastic lamellae is considerably reduced and concentrated. This concentration zone continues down the auricular surface of the mitral valve for a variable distance toward the tip. Interspersed among the elastic fibers there can be seen stretches of collagen.

In the case of the anterior mitral cusp, a continuation of the endocardial smooth muscle can usually be traced down the *Auricularis* layer, clothed by *Auricularis* elastic lamellae. The smooth muscle can become so prominent as to form, in some cases, approximately one-fifth of the entire thickness of the valve leaflet. For about two-thirds of the way down the cusp the elastic lamellae can be seen to lie almost immediately beneath the endothelial-covered surface. However, as the closure line of the valve is approached at times the bulk of the elastic lamellae begins to occupy a slightly less superficial position, being covered by a thicker and wider band of dense connective tissue which may in turn carry more delicate strands of elastic tissue.

The most superficial covering of the auricular surface of the valve is the endothelial layer referred to above. This consists of flat cells with scanty protoplasm and moderately dense nuclei. Between this endothelial layer and the most superficial elastic band there is an almost imperceptible jelly-like zone containing an occasional mononuclear cell.

The tips of the mitral leaflets are generally of a more gelatinous, embryonal consistency (Figs. 6 and 8). The *Auricularis* layer described, together with the others about to be described, merge imperceptibly with this loose embryonal tissue of the valve tip. The latter consists of a network of stellate cells with scanty protoplasm lying in a matrix poor in collagenous fibrillae and staining at times faintly bluish with hematoxylin. As in the semilunar cusps the *Auricularis* layer is relatively poor in cells.

Spongiosa: The left auricular subendocardium consists of dense bundles of collagen interspersed with thick elastic fibers. A continuation of this structure mingles with the outer looser layer of the *Fibrosa* to form the essential substance of the mitral valve *Spongiosa*. In the case of the posterior cusp the structure is generally much looser than that of the anterior and, as mentioned before, opposite the insertions of chordae tendineae it may assume an appearance which is almost indistinguishable from that seen in the semilunar cusp *Spongiosa*. That is, small collagenous bundles may be seen irregularly interspersed with a feltwork of delicate elastic fibrillae, a very loose ground substance and scatterings of mononuclear cells. In the region of the *Ring* the elastic fibrillae are generally coarse. At or near the cusp tip the *Spongiosa* layer merges imperceptibly with the other layers.

Fibrosa: In the case of the *Posterior Mitral Cusp*, it has already been mentioned that the *Annulus* interdigitates with myocardium and generally continues as an extension under the ventricular subendocardium. These collagenous fibers, on the whole, run parallel to the ventricular surface, round the valve pocket and continue into the valve substance to form the *Fibrosa* layer (Fig. 8). Here the fibers run parallel to the chordae tendineae. Indeed, they form an unbroken continuation with the main body of the latter. The collagenous *Fibrosa* which is dense and shows mononuclear cells with scant protoplasm lying between its bundles is generally almost entirely free of elastic fibrillae (Fig. 10). It extends toward the cusp tip where it becomes continuous with the spongy structure referred to above.

The *Fibrosa* of the *anterior mitral cusp* is a direct continuation of the *Mitral-Aortic Intervalvular Fibrosa* and the general direction of its fibers is transverse.

Ventricularis: In the case of the *Posterior Mitral Cusp*, the endocardial fibro-elastic covering of the ventricle curves round the valve pocket and descends for a variable distance toward the cusp tip forming its *Ventricularis*. The elastic fibers are generally considerably more delicate and shorter than the corresponding ones on the *Auricularis* layer. They are covered by the same type of endothelium as described for the *Auricularis* layer and between the elastic lamellae and the *Fibrosa* there is to be found a small amount of relatively acellular loose gelatinous tissue. Under certain conditions the *Ventricularis* layer may become somewhat thickened.

In the case of the *Anterior Mitral Cusp* (Fig. 6), this layer is a direct continuation of the subaortic endocardial tissue, the latter in turn being a prolongation of the semilunar cusp *Ventricularis*. Furthermore, in this cusp the *Ventricularis* shows many dense bundles of elastic tissue, at times much more conspicuous than the *Auricularis* bundles. This is particularly well seen in the younger age periods where the *Ventricularis Elastica* carries with it a very definite structure of longitudinal running collagenous bundles. As in the case of the mitral posterior, this *Ventricularis Elastica* is generally shorter than the *Auricularis Elastica*.

TRICUSPID VALVE

Topography

The topography of the tricuspid leaflets follows closely the general description given for the auriculoventricular valves. However, they can be very easily distinguished from the mitral flaps because of their greater delicacy in structure and other peculiarities of their own about to be described. As in the case of the mitral cusps the general plan is that of an auricular endocardial and myocardial wedge which is joined to a ventricular crest through the intermediary of *Annulus*, the tricuspid cusps springing from this *Annulus*.

The *Anterior Flap*, the longest of the three, shows an extremely delicate auricular endocardium with scattered smooth muscle cells. The peculiarity of the ventricular crest easily distinguished this section because the myocardium tends to assume a trough shape, the concavity of which points toward the auricles (Fig. 14). A rather abundant free pericardial wedge fills in the space between this trough and the right auricular myocardial wedge. This wedge carries the right circumflex coronary artery. A few strands of subvalvular *Annulus* can occasionally be seen in the section.

The *Posterior Tricuspid* section differs from the anterior in several respects. Here, the auricular endocardium retains the slender structure characteristic of right auricle but is generally thicker than that seen in the anterior tricuspid section. The smooth muscle cells are generally more abundant. While the septal crest is seldom as rounded, dome-shaped and regular as in the mitral posterior section, the characteristic trough structure of the anterior tricuspid is rarely present — a more bulky, often irregular dome-shaped myocardial crest taking its place (Fig. 15). The separation between the auricular and ventricular myocardium is generally more marked in this section, the *Annulus* showing a neck-like extension. At times this neck-like extension may consist partly of myocardial bundles. There is seldom *Subvalvular Annulus* to be seen. The pericardial wedge is moderate in amount and generally carries a branch of coronary artery. The flap itself is shorter than the anterior.

The *Septal Flap* is the shortest of the three and its situation on the septum is so characteristic that one can easily distinguish this cusp from the others, as well as determine the particular point at which the section was cut (Fig. 16). The most anterior portion of this cusp is inserted on *Septum Fibrosum* so that the *Annulus* of this cusp becomes continuous with it. Since, further, the *Septum Fibrosum* is also continuous with the *Annulus* of the aortic cusps, there exists thus a collagenous linkage between mitral, aortic and tricuspid *Rings*. As one traces the septal cusp backward, however, its insertion line passes onto the top of the interventricular crest and occupies a progressively lower (caudad) site as it extends posteriorly. Thus, by estimating the approximate distance between the tricuspid *Ring* and the top of the septal crest, one can fairly well establish the position of the section.

The auricular endocardium is generally of about the same structure as that seen in the posterior tricuspid section. The auricular myocardium ends in a wedge whose apex is superficial to the *Septum Fibrosum*. The general slope of the latter is usually from above downward, considered from left to right.

In the region of the *Septum Fibrosum* the ventricular myocardium ends in a fairly regular dome-shaped crest. As one proceeds backward, however, the dome shape can at times be seen to be replaced by a sloping surface whose highest point is toward the left ventricle. It will be seen from this that the general slope of the *Septum Fibrosum* is also continued in the myocardial portion of the interauricular septum.

The pericardial wedge as such is present in an abortive form only in the posterior sections of this cusp where fragments of fatty tissue can be seen to surround the auriculoventricular node. The continuation of the latter in the form of the bundle of His can be readily seen in this section. As in the other two tricuspid sections, *Subvalvular Annulus* is inconspicuous. In the case of all three sections the ventricular myocardial interdigitations are slender.

Histology

The histology of the tricuspid leaflets is similar to that of the mitral valve posterior. The following features, however, should be noted.

The endocardium of the right auricle shows a considerable abbreviation of structure over that of the left auricle. It is generally thinnest over the anterior cusp. The latter tends to be rather dense in structure and shows the looser myxomatous tip less frequently than the other cusps. The general direction of the collagenous bundles is similar to that described for the mitral posterior cusp. There is often a greater difficulty in discerning the *Spongiosa* layer in the tricuspid cusps. The general distribution of the elastic lamellae and the cytology shows no fundamental differences from what has already been described. One peculiarity of the tricuspid leaflets to which attention has already been drawn in the literature is the fact that ventricular myocardial bundles are not infrequently found inserted fairly low into the base of the valve. This is particularly true for the posterior cusp and is found much less frequently in the septal cusp. In spite of the numerous reports published on this point it does not seem that the findings of these muscular bundles is of appreciable significance. The bundles generally do not descend deep into the cusps and are nothing more than a slight exaggeration of the natural infolding of the ventricular myocardial tube with that portion of the auricular canal which is concerned with the formation of auriculoventricular cusps. The same explanation accounts for the not infrequently low position of the auricular myocardial wedge in these sections.

The Question of the Existence of Blood Vessels in the Valves

It will be noted that in the description of the various valves given in this report blood vessels were not mentioned. We have deliberately avoided taking up the very controversial question as to the existence of blood vessels in normal valves largely because it can not be done justice, without going into very lengthy detail. Briefly considered, it may be said that there are three schools of thought on this subject: One group holds that human heart valves have no blood vessels; another believes that human heart valves are supplied with blood vessels in at least a considerable proportion of cases and that failure to demonstrate them by many observers is due to faulty technique; the third group believes that blood vessels occur at times in postnatal human heart valves and that when they occur they probably represent fetal remnants.

Without desiring to enter into controversy here, we may say that we are rather doubtful at present as to whether blood vessels occur, at any rate with any degree of frequency, in *normal* human heart valves, providing we have a very clear understanding as to what we consider *normal*.

In previous reports evidence was adduced by us which pointed to the fact that in at least 2 per cent of a group of 700 individuals who came to autopsy in the general hospitals from which our material was obtained, blood vessels were found in some valves of what appeared to be otherwise normal hearts. Our present scepticism is due to the fact that the results of our more recent investigations have caused us to doubt the normality of many of the hearts which we previously considered normal. Furthermore, as indicated in the description given above, our definition of the *Ring*, which is the proximal termination of the valve cusp, automatically excluded myocardium. Considered in this way, and we suggest that this is a logical and simple definition, the question of the existence of blood vessels in valves ceases to be one of major importance. Certainly if they occur at all they are most infrequent.

It may be said in passing that the practice of comparing human heart valves to those of lower animals is one which is very prone to lead one into erroneous conclusions.

The Question of the Existence of Blood Vessels in the Rings

In describing the various valve *Rings* we attempted to picture the cellular and tissue components which make up their structure. No mention was made of the presence or absence of blood vessels in these sites. This omission was deliberate and was done in order to simplify the description. Actually, in a statistical analysis made for this purpose on 100 hearts from various age periods, capillaries only were found in the *Rings* with the following frequency:

Anterior mitral valve *Ring*	1 per cent
Posterior " " "	2 " "
Aortic " "	0 " "
Tricuspid " "	14 " "
Pulmonary " "	7 " "

Excluding the tricuspid *Ring* from consideration for a moment, it may be stated that in not a single heart were vessels found in more than one of the other *Rings*. This fact, together with others to be discussed, seems to us to be of considerable importance.

It will be observed that capillaries are not infrequently found in the tricuspid *Ring* (14 per cent), particularly in the septal flap *Ring*. These capillaries are generally in the form of rather large thin-walled channels. They do not resemble granulation tissue capillaries in any respect.

The capillaries found in the other *Rings* are generally few, usually near to the subjacent myocardium, small and circular on cross-section, not surrounded by inflammatory cells, and in structure easily differentiated from granulation tissue capillaries.

It will be obvious from the above description that the great infrequency of capillaries, particularly in the mitral and aortic *Rings*, their relative infrequency in the other *Rings*, their normal appearance, the absence of inflammatory cells, the fact that the occurrence of capillaries in more than one *Ring* at the same time (excluding the tricuspid) must be very rare, together with the absence of arterioles or large vessels in these sites, make any definite deviation in these findings strongly suggestive of the occurrence of a pathological lesion past or present.

Holsti examined twenty-two hearts from cases of sudden death and found capillaries in the valve "roots" (Wurzel) of eight cases distributed as follows: eight in the mitral, six in the tricuspid and two in the aortic. The author, however, speaks of finding myocardium in the "roots" of many of his cases which obviously makes his definition of "root" different from our conception of what constitutes *Ring*. Furthermore, in eleven of the hearts, the author found definite evidence of valvulitis and in three cases marked vascularization of the "root" and valves as far as the tip. For these reasons it is impossible to compare statistically Holsti's findings with ours in respect to *Ring* vascularization.

While on this point it should be mentioned that a number of the hearts examined in our series showed inconspicuous scatterings of inflammatory cells. Often this was found in cases in which some form of sepsis had occurred during life. We did not mention these exudates in connection with our description of normal valves because they seemed obviously to be part of some pathological process, however slight.

Noduli Albini and Congenital Valve Hematomata

For completeness, mention may be made of the so-called Noduli Albini and of valve hematomata. According to Tandler, Cruveilhier was the first to describe the former. These consist of tiny jelly-like thickenings of the auriculoventricular valve substance and are to be found in the region of the insertions of the chordae tendinae of the first order. They are seen most frequently in the newborn and represent slight exaggerations of the myxomatous tip referred to in our previous sections.

The congenital valve hematomata consist of endothelial-lined spaces containing blood and are frequently found on the auricular aspect of the auriculoventricular cusps. These structures are seen only during the first year of postnatal life (Tandler). A number of investigators believe them to be vestigial remnants of valve vasculature. Others consider them endocardial sack-like infoldings. Another possibility which we would like to suggest is that during the course of development endothelial cells may be invaginated into the substance of the cusp, become nipped off and, because of their angioblastic properties, develop aborted vessels or vascular cyst-like spaces. The contained blood cells themselves may be of similar origin.

Age-Period Changes in Valves

The human heart valves, like other structures in the body, continue to show evolutionary and involutionary changes after birth. What the significance of these changes may be in respect to the production of disease processes one can only surmise. It is well to bear in mind, however, that with advancing age periods the various layers of the valves previously described become progressively poorer in cells and take on the following changes: The strata become increasingly well defined; the semilunar cusp *Spongiosa* becomes more and more fibrous and elastified; the auriculoventricular valve *Ring Spongiosa* and the *Spongiosa* situated opposite the chordae tendineae insertions become loose and often the seat of fat deposits; the elastic membranes become heavier and longer; the *Auricularis* and often the *Ventricularis* layers become appreciably denser, more collagenous and thickened; and the collagenous *Fibrosa* undergoes degenerative lipoid changes. The point last mentioned is inevitably associated with the arteriosclerotic calcium salt deposition of the later age periods. Particularly is this true of the lime changes which occur in the *Annulus* of the valve *Rings* (Mönckeberg).

Summary

There has been described in this paper in some detail the normal histology and topography of the individual cusps of the valves in the human heart. It has been shown that these have a number of characteristics in common and yet sufficient individual differences to distinguish them from one another. The desirability of sharply delimiting the different cusps has been discussed and a method of accomplishing this has been suggested. This method is calculated to clear up the confusion which exists on the question of the presence of

myocardium in the auriculoventricular valves. A simple but comprehensive classification of the various valve layers has been given. In designing this classification there has been borne in mind the advisability of using a uniform nomenclature and of reducing the variations in valve structure to as few common denominators as possible. Attention has been drawn to the possible bearing which the various differences in valve structures may have on the development of pathological processes which occur at these sites. An indication has also been given of the evolutionary and involutionary postnatal changes which take place in the cusps.

The main purpose of the work here reported is to serve as a base line for further studies on disease of heart valves, because it is realized that an intimate knowledge of the structure of the valve cusps, together with their normal variations and age-period changes, is essential for the recognition and understanding of pathological processes.

BIBLIOGRAPHY

Albini. Ueber die Noduli an den Atrioventrikularklappen des Menschen. *Wochenbl. d. Zeit. d. k. k. Ges. d. Aerzte in Wien*, 1856, **2**, No. 26, 401, 405.

Albrecht, E. Der Herzmuskel und seine Bedeutung für Physiologie, Pathologie und Klinik des Herzens. Julius Springer, Berlin, 1903.

Aschoff, L., and Tawara, S. Die heutige Lehre von den pathologisch-anatomischen Grundlagen der Herzschwäche. Gustav Fischer, Jena, 1906.

Beitzke, H. Ueber die sogenannten "weissen Flecken" am grossen Mitralsegel. *Virchows Arch. f. path. Anat.*, 1901, **163**, 343.

Benninghoff, A. Handbuch der mikroskopischen Anatomie des Menschen, Möllendorff, W. Julius Springer, 1930, **6**, 171.

Bernays, A. C. Entwicklungsgeschichte der Atrioventricularklappen. Morphologisches Jahrbuch, Gegenbaur, C., 1876, **2**, 478.

Coen, Edmondo. Ueber die Blutgefässe der Herzklappen. *Arch. f. mikr. Anat.*, 1886, **27**, 397.

Curtis, F. De la structure des valvules sigmoides de l'aorte et de l'artère pulmonaire. *Compt. rend. Soc. de biol.*, 1888, Ser. 8, 591.

Darier, J. Les vaisseaux des valvules du coeur chez l'homme à l'état normal et à l'état pathologique. *Arch. de physiol. norm. et path.*, 1888, Ser. 2, 35 and 164.

De Castro, Ugo. Disposizione anatomica e significato dei muscoli atrio-valvolari con speciale reguardo alla funzione delle valvole atrio-ventricolari del cuore (quotes early literature). *Cuore e circolaz.*, 1926, **10**, 441–467.

Dewitzky, W. Ueber den Bau und die Entstehung verschiedener Formen der chronischen Veränderungen in den Herzklappen. *Virchows Arch. f. path. Anat.*, 1910, **199**, 273.

Dreyfuss, M. Zur Histopathologie der Endokarditis. *Frankfurt Ztschr. f. Path.*, 1922, **27**, 527.

Fahr. Das elastische Gewebe im gesunden und kranken Herzen und seine Bedeutung für die Diastole. *Virchows Arch. f. path. Anat.*, 1906, **185**, 29–43.
Gross, L. The Blood Supply to the Heart in its Anatomical and Clinical Aspects. Paul B. Hoeber, New York, 1921.
Gross, L., Antopol, W., and Sacks, B. A standardized procedure suggested for microscopic studies on the heart. With observations on rheumatic hearts. *Arch. Path.*, 1930, **10**, 840–852.
Gussenbauer, C. Ueber die Muskulatur der Atrioventrikularklappen. *Sitzungsb. d. k. Akad. d. Wissensch.*, **57**, 186.
Henle, J. Handbuch der systematischen Anatomie des Menschen. Gefässlehre. Braunschweig, 1868, **3**.
Hoessli. Muskelreste im langen Mitralsegel. *Centralbl. f. allg. Pathol. u. path. Anat.*, 1910, **21**, 865–871.
Holsti, Olsen. Beiträge zur Kenntnis der entzündlichen Klappenaffektionen mit besonderer Berücksichtigung der Pathogenese. *Arb. a. d. path. Inst. zu Helsingfors*, Gustav Fischer, 1928, **5**, 401.
Joseph, L. Ueber die Ringe und Klappen des menschlichen Herzens. *Virchows Arch. f. path. Anat.*, 1858, **14**, 244.
Königer, H. Histologische Untersuchungen über Endokarditis. *Arb. a. d. path. Inst. zu Leipzig*, 1903, No. 2, 1.
Krause, W. Handbuch der menschlichen Anatomie. Hannover, 1876, **1**, 302.
Kugel, M. A. Anatomical studies on the coronary arteries and their branches. I. Arteria anastomotica auricularis magna. *Am. Heart J.*, 1928, **3**, 260.
Kugel, M. A., and Gross, L. Gross and microscopical anatomy of the blood vessels in the valves of the human heart. *Am. Heart J.*, 1926, **1**, 304.
Kürschner. (1) Ueber die venösen Klappen des Herzens und ihre Aktion. *Frorieps Neue Notizen*, 1840, No. 316.
(2) Herz und Herztätigkeit. Handwörterbuch der Physiologie mit Rücksicht auf physiologische Pathologie, R. Wagner, 1844, **5**.
Lambl. Papilläre Excrescenzen an der Semilunar-Klappe der Aorta. *Wien. med. Wchnschr.*, 1856, **1**, 244.
von Langer, L. (1) Ueber die Blutgefässe in den Herzklappen des Menschen. *Sitzungsb. der k. Akad. d. Wissensch.*, 1880, **208**, 81–82.
(2) Ueber die Blutgefässe in den Herzklappen bei Endocarditis valvularis. *Virchows Arch. f. path. Anat.*, 1887, **109**, 465.
Lewis, T., and Grant, R. T. Observations relating to subacute infective endocarditis. *Heart*, 1923, **10**, 21–29.
Luchsinger, B. Zur Architectur der Semilunarklappen. *Arch. f. d. ges. physiol. des Menschen u. d. Tiere*, 1884, **34**, 291.
Luschka, H. Die Structur der halbmondförmigen Klappen des Herzens. *Arch. f. Physiol. Heilk.*, 1856, 537.
Masson, P. Some histological methods. Trichrome stainings and their preliminary technique. *Internat. A. M. Museums Bull.*, 1929, **12**, 75–90.
Mönckeberg, J. G. Der normale histologische Bau und die Sklerose der Aortenklappen. *Virchows Arch. f. path. Anat.*, 1904, **176**, 472.
Nagayo, M. Zur normalen und pathologischen Histologie des Endocardium parietale. *Beitr. z. path. Anat. u. z. allg. Pathol.*, 1909, **45**, 283.
Odinzow, V. P. Die Vascularization der Herzklappen im Kindesalter. Inaug. Diss., München, 1904.

Poirier. Traité d'anatomie. Le coeur et les artéres. Paris, 1902, **2**, Ser. 2, 629.

Rappe, K. B. C. Ueber Gefässe in den Herzklappen. Inaug. Diss., Göttingen, 1904.

Reid. Todd's Cyclopaedia of Anatomy and Physiology. 1836–1839, **2**, 589.

Ribbert, Hugo. Handbuch der speziellen pathologischen Anatomie und Histologie, Henke, L., and Lubarsch, O. J. Springer, 1924, **2**, 184.

Ritter, S. A., Gross, L., and Kugel, M. A. Blood vessels in the valves of normal human hearts. From a study of 700 human hearts. *Am. Heart J.*, 1928, **3**, 433.

Seipp, L. Das elastische Gewebe des Herzens. *Anat. Hefte*, 1896, **6**, 63.

Stricker, S. Schweigger-Seidel's Manual of Human and Comparative Histology. Trans. Henry Power. London, 1870, **7**, 251.

Tandler, J. Anatomie des Herzens. Gustav Fischer, Jena, 1913.

Testut, J. L. Traité d'anatomie humaine. Paris, 1905, **2**, 80.

Torrigiani, C. A. Studio sullo sviluppo e sulla struttura dei seni del Valsalva e delle valvole semilunari nel cuore umano. *Arch. di anat. e di embriol.*, 1911, **9**, 570.

Veraguth, O. Untersuchungen über normale und entzündete Herzklappen. *Virchows Arch. f. path. Anat.*, 1895, **139**, 59.

Weber, A., and DeGuy, M. La région mitro-aortique. Étude anatomique et pathologique. *Arch. de méd. exper., et d'anat. path.*, 1897, **9**, 235–249, 339–378.

Zuckerkandl, E. Ueber Muskelgewebe in der Kammerfläche der Valvula tricuspidalis. *Allg. Wien. med. Ztg.*, 1877, **22**, No. 18, 155.

DESCRIPTION OF PLATES

PLATE 102

FIG. 1. *Right Aortic Cusp Section.* A, fibrosa; B, ring spongiosa; C, Annulus; D, subvalvular annulus; E, ventricularis; F, aorta; G, pulmonary conus; H, interventricular septum; I, arterialis; J, sinus pocket; K, pericardial wedge.

FIG. 2. *Aortic Cusp Approaching the Commissure* showing changes in the arterio-annulus relations. A, aorta; B, annulus; C, pericardium; D, sinus pocket; E, aortic cusp; F, arterio-annulus junction.

FIG. 3. *Aortic Cusp in the Immediate Vicinity of the Commissures* showing further changes in arterio-annulus relations. A, aorta; B, annulus; C, pericardium; D, aortic cusp; E, subcommissural elastica.

FIG. 4. *Left Aortic Cusp Section.* A, left coronary artery; B, left ventricle; C, aorta; D, annulus; E, sinus pocket; F, aortic cusp; G, free visceral pericardium.

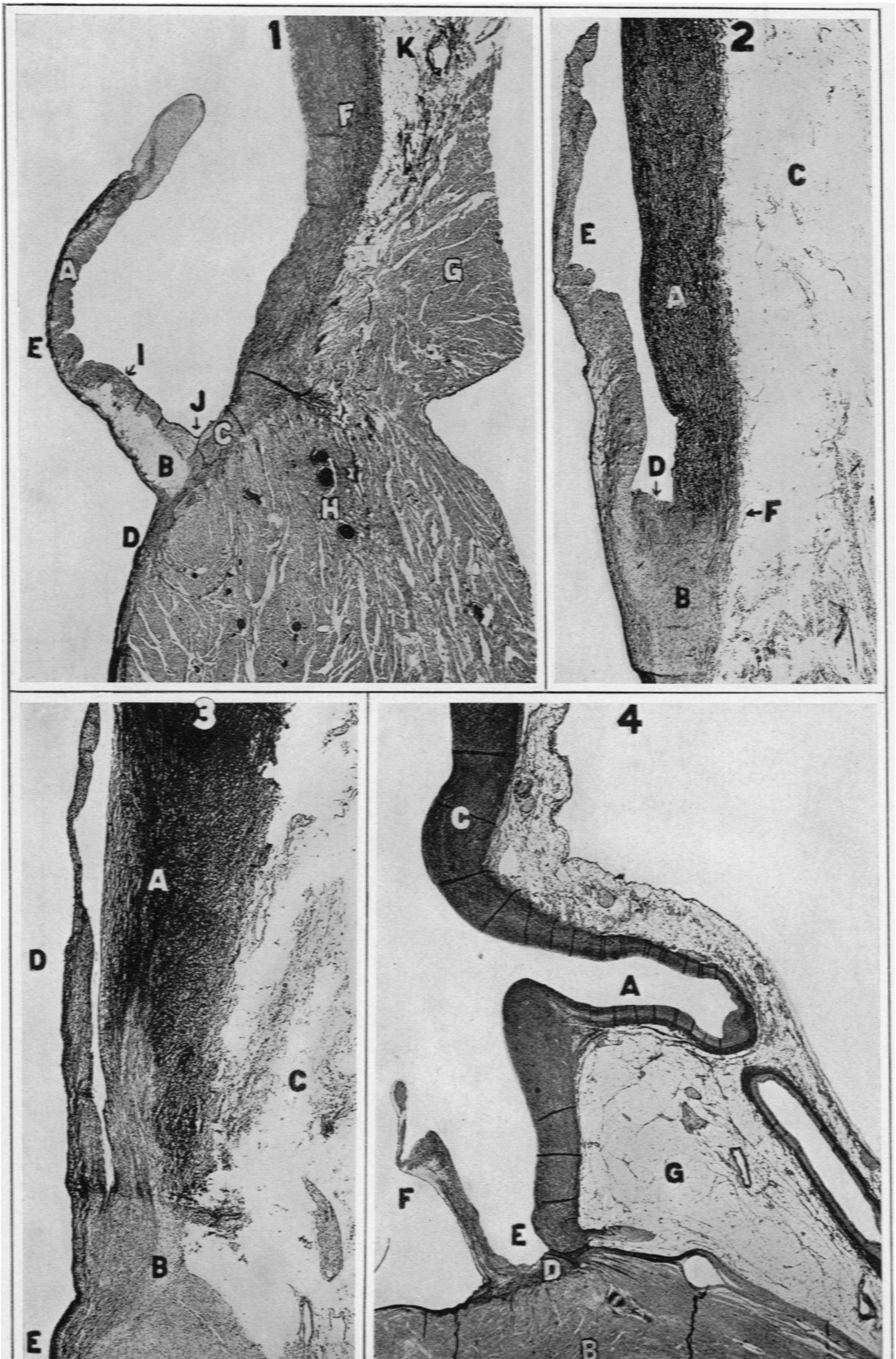

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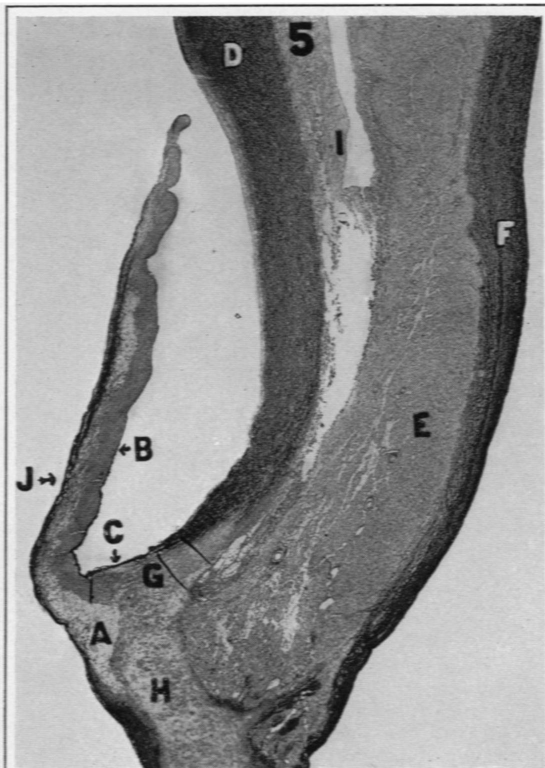
PLATE 103

FIG. 5. *Posterior Aortic Cusp Section.* A, ring spongiosa; B, arterialis; C, sinus pocket; D, aorta; E, left auricular myocardium; F, left auricular endocardium; G, annulus; H, mitral-aortic intervalvular fibrosa; I, pericardial wedge; J, ventricularis.

FIG. 6. *Anterior Mitral and Posterior Aortic Valve Section.* For explanation of arrow "A" and arrow "B," see text. C, mitral-aortic intervalvular fibrosa; D, ring spongiosa; E, valve spongiosa; F, aortic valve fibrosa; G, mitral valve fibrosa; H, aorta; I, pericardial wedge; J, myocardial wedge (left auricle); K, left auricular endocardium; L, chorda tendinea.

FIG. 7. *Nodulus Arantii* on aortic cusp. A, nodulus arantii; B, aorta; C, ventricularis elastica; D, ring spongiosa; E, sinus pocket; F, pericardial wedge.

FIG. 8. *Posterior Mitral Valve Section.* A, spongiosa; B, fibrosa; C, posterior mitral valve pocket; D, pericardial wedge; E, auricular myocardial wedge; F, left auricular endocardium; G, left ventricle.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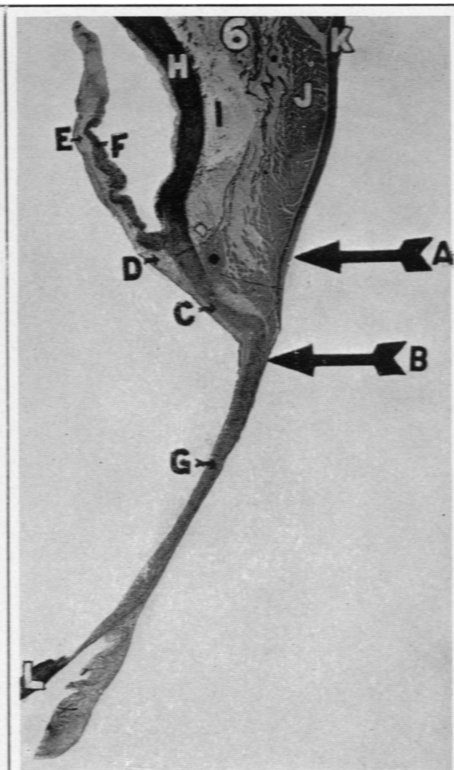
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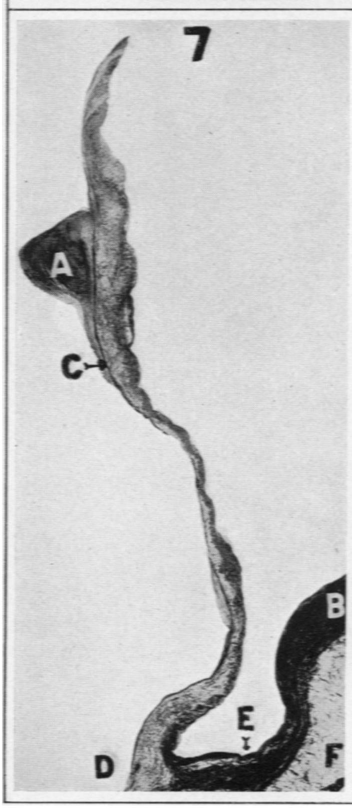
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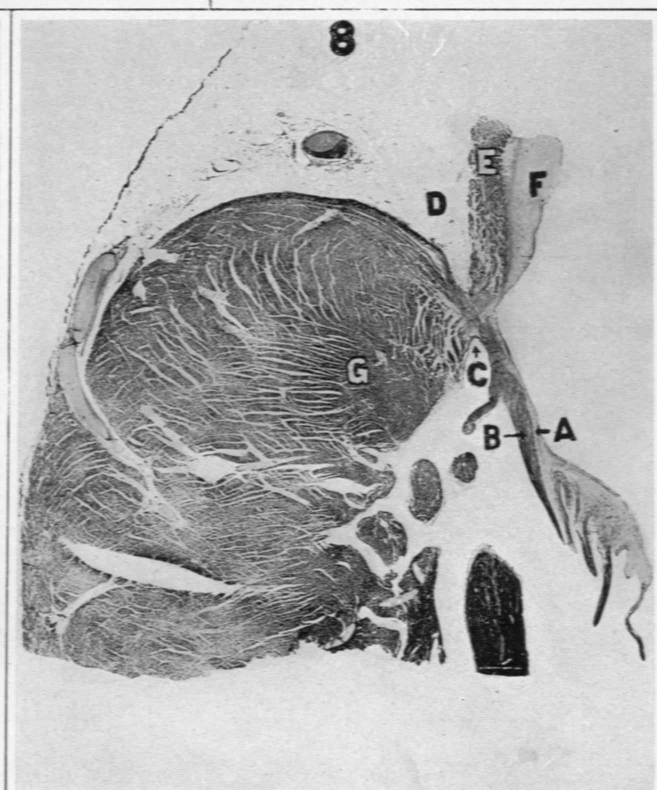
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Plate 104

Fig. 9. *Cross-section of a Semilunar Cusp* (High Power). A, ventricularis with its prominent elastica; B, spongiosa; C, fibrosa; D, arterialis.

Fig. 10. *Cross-section of an Auriculoventricular Cusp* (High Power). A, auricularis; B, spongiosa (inconspicuous); C, fibrosa; D, ventricularis.

Fig. 11. *Left Pulmonary Cusp Section.* Note double myocardial crest made up of A, right ventricle, and B, left ventricle. C, pulmonary artery; D, pericardium; E, pulmonary cusp.

Fig. 12. *Anterior Pulmonary Cusp Section.* A, pericardium; B, pulmonary artery; C, sinus pocket; D, ring spongiosa; E, pulmonary cusp; F, myocardium of pulmonary conus.

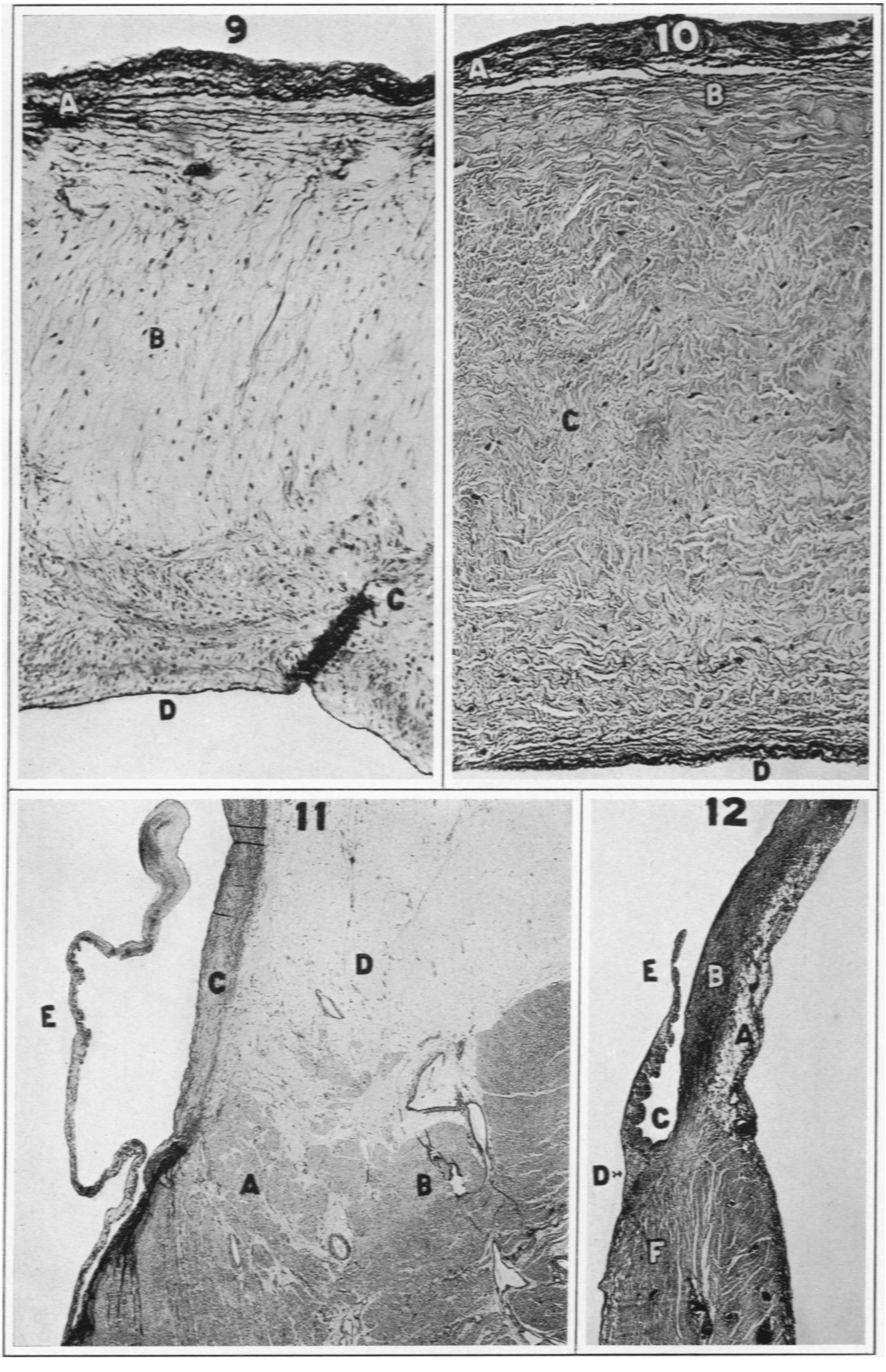
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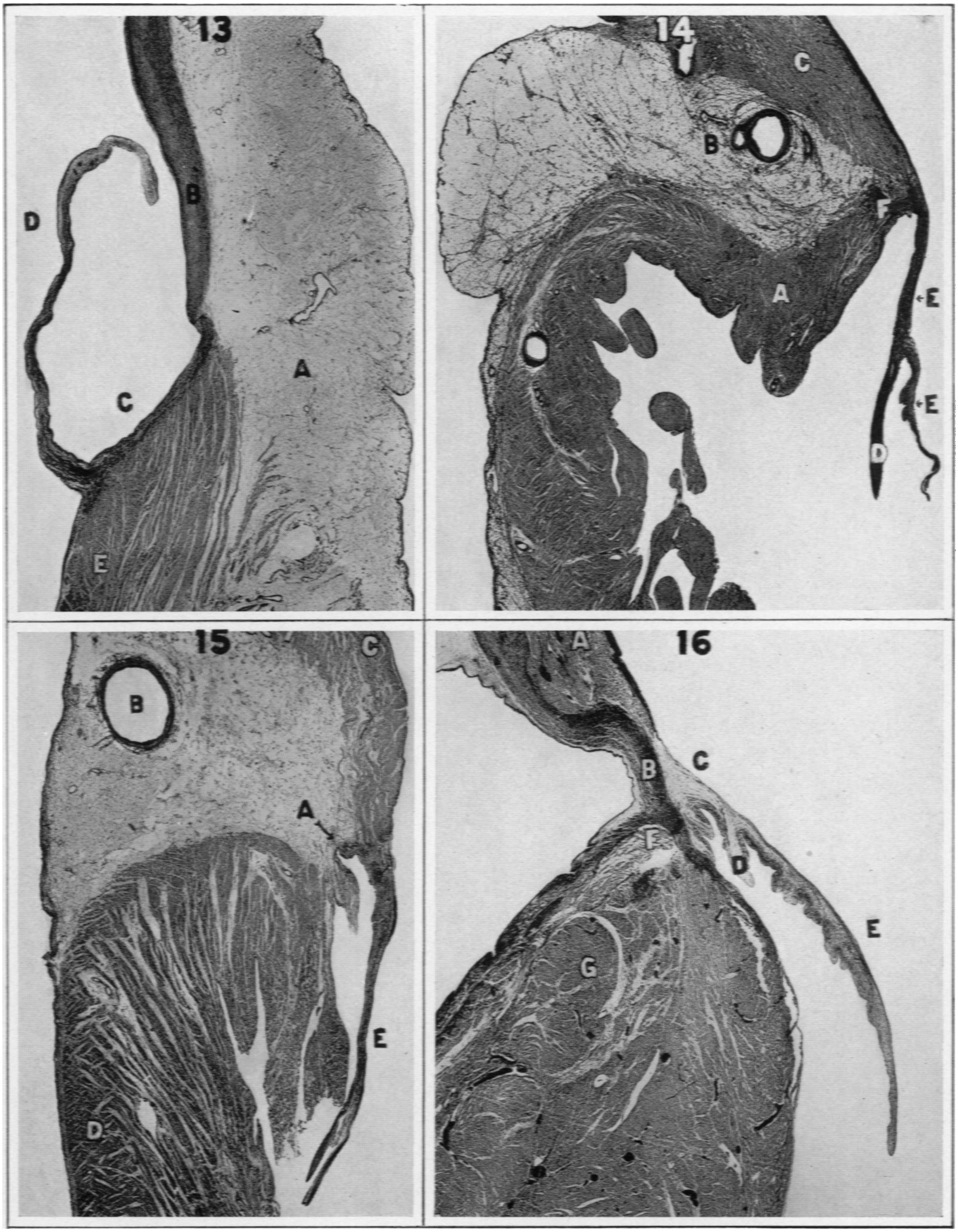
PLATE 105

FIG. 13. *Right Pulmonary Cusp Section.* A, pericardium; B, pulmonary artery; C, sinus pocket; D, valve cusp; E, ventricular myocardium.

FIG. 14. *Anterior Tricuspid Valve Section.* A, trough-shaped myocardium of right ventricle; B, pericardial wedge with right circumflex coronary artery; C, right auricle; D, chorda tendinea; E, anterior tricuspid valve section; F, annulus.

FIG. 15. *Posterior Tricuspid Valve Section.* A, neck-like annulus; B, right coronary artery embedded in pericardium; C, right auricle; D, right ventricle; E, tricuspid leaflet.

FIG. 16. *Tricuspid Valve Section* (septal flap). A, right auricular myocardial wedge; B, septum fibrosum; C, tricuspid valve ring; D, chorda tendinea insertion; E, septal flap; F, bundle of His; G, interventricular septum.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