THE HEART OF THE 20MM. PIG EMBRYO.

by

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Introduction.

The present article is one of a series planned by Professor Franklin P. Johnson describing the anatomy of the 20 mm. pig. This series, it is intended, shall supplement the descriptions of the 12 mm. pig by F. T. Lewis (11), and that of the 7.8 mm. pig by F. W. Thyng (18). In this paper is described the anatomy of the heart and its vessels, particular attention being paid to morphology. It includes descriptions of the form, size, and position and relations of the heart; its chambers, valves, atrio-ventricular bundle, and coronary vessels. It was first intended to include the whole vascular system, but a description of the peripheral vessels has been deferred to another paper.

For the basis of this work, embryo No. 1702 of the Harvard Embryological Collection, which was kindly loaned by Professor C. W. Minot, has been used. Other embryos of approximately the same age have constantly been referred to.

The form of the heart and its various parts have been portrayed by means of wax reconstructions made by Born's reconstruction method. These reconstructions include the following models:

1. The whole heart and its vessels. (Harvard Embryological Collection. No. 1702).
2. The cavity of the heart. (H.E.C. 1702)
3. A dissection of the heart showing the coronary ves-

sels and the atrio-ventricular bundle. (Univ. of Mo. Embryological Collection. No. 1.15)

4. The tricuspid valve. (H.E.C. No. 1702)
5. The bicuspid (mitral) valve. "
6. The sinus valves. "
7. The aortic valve. "
8. The pulmenary valve "

Many embryos were dissected under the binocular microscope, and median sagittal sections made of others, to clear up points not obtainable from serial transverse sections. In the case of locating the position of the heart, cleared embryos were used. They were first halved in the median sagittal plane with a sharp razor, and the cartilages stained with methylene green. This made possible an easy and ready means for the determination of the point desired.

In addition, dissections and injections of the heart of the adult pig have been frequently examined. The coronary arteries were injected from the aorta, the aortic valve being closed by the pressure exerted on it. The coronary sinus being tied off close to its entrance into the right atrium. Colored celloidin, red lead, and colored gelatin were used as injection masses. Best results, however, were obtained with the first.

External Form.

The heart, as can be seen in Fig. 5, is shaped somewhat like an egg, but is rather irregular and flattened from above downward. It may be described as having an apex, a base, and two surfaces - inferior (caudal) or diaphragmatic, and anterior (ventral) or sterno-costal.

Encircling the heart at almost right angles to its long axis, is a deep groove (sulcus coronarius) which separates the heart into two definite portions, a dorsal (atrial) and a ventral (ventricular), (Fig. 12). Each of these is again divided into two halves, a right and a left, by more or less definite longitudinal grooves. The separation of the atrial portion is marked externally, at the base of the heart only, by a definite inter-atrial groove. The division of the ventricular portion is accomplished by two longitudinal sulci, one on its anterior and the other on its inferior surface. These, however, are continuous to the right of the apex of the heart.

Apex cordis:- The apex of the heart is directed ventrally. It is a bluntly rounded prominence which serves as the meeting place of the sterno-costal and diaphragmatic surfaces, and is formed entirely by the left ventricle, the longitudinal sulcus running to its right, (Fig.5).

Basis cordis:- The base of the heart, as is shown in Fig. 6, is relatively smaller than in the adult and may be

described roughly as square. The opening of the right anterior cardinal vein (later the right superior vena cava) is situated at the upper angle of the square on the right; that of the inferior vena cava occupies the lower angle of the same side. The right side of the square is formed by the right margin of the sinus venosus. The left side is formed by the left superior vena cava, which, in order to reach the sinus venosus, bends at right angles to the right, thus forming the lower left angle and the inferior side of the square. The upper side of the square is formed by the continuous superior borders of the two atria. Between the right superior vena cava and the inferior vena cava, and the left superior vena cava, is a broad groove. In this groove run the small pulmonary arteries, and in it, just to the left of the point where the inferior vena cava empties into the right atrium, the short trunk of the pulmonary veins enters the heart. In this groove will later appear the inter-atrial groove of the adult.

Superiorly to the above described square, the aorta and the pulmonary arch arise from the heart, as can readily be seen in Fig. 6. These extend upward and then arch backward and downward, and pass dorsal to the base of the heart. The single trunk of the pulmonary arteries leaves the inferior surface of the pulmonary arch about its middle (Fig.6). The relation of the pulmonary arch to the aorta will be described later.

Facies diaphragmatica cordis:- The diaphragmatic surface, as seen in Fig. 12, is formed by the ventricular part of the heart. It is divided into two unequal areas, the left being much the larger, by an oblique groove (the inferior interventricular sulcus) which runs from the right posteriorly (dorsally) to the left anteriorly (ventrally). This surface is separated from the base by the inferior coronary sulcus.

Facies sterno-costalis cordis:- The sterno-costal surface is directed upwards and anteriorly. It, too, is formed by the ventricular part of the heart, and is separated into two areas, the right being the larger, by a groove (the anterior interventricular sulcus) which runs from the left posteriorly to the right anteriorly, and unites with the inferior interventricular sulcus around the apex. It is, like the diaphragmatic surface, separated from the atria by a portion, the anterior, of the coronary sulcus. (Fig. 5).

Size.

In determining the size of the heart, a number of points have been considered. These are:- measurements in various directions, weight of the heart, the volume of the heart, and the relative weight and volume of the heart as compared with those of the entire embryo.

Dimensions - The measurements given below were reduced from those obtained from a wax model of the whole heart:-

Length, from apex to base (ventro-dorsal)....4.493 mm.

Breadth, from side to side, measured thru the widest part ....4.155 mm.

Thickness, (cephalo-caudal) measured from the highest point on the superior surface of the heart to the lowest point of the diaphragmatic surface..3.266 mm.

Weight - In order to obtain the weight of the heart and the relation of it to the body weight, a number of embryos were first weighed, and then their hearts were dissected out under the binocular microscope, and weighed in turn. The following figures were obtained:-

Embryo No.	Weight.	Weight of heart	Percentage of body weight.
1	1.390 g.	.053 g.	3.80 g.
2	1.401 g.	.047 g.	3.35 g.
3	1.426 g.	.048 g.	3.36 g.
4	1.429 g.	.052 g.	3.51 g.
5	1.512 g.	.056 g.	3.71 g.
Average	1.431 g.	.051 g.	3.54 g.

Volume - The volumes of the body and heart were obtained as follows:-

$$\text{Vol. equals } \frac{\text{Weight}}{\text{Specific gravity.}}$$

The specific gravity of the embryo was determined by weighing it in and out of water.

$$\text{Specific gravity equals } \frac{\text{Weight in air}}{\text{Loss of weight in water}}$$

The specific gravity of the heart was obtained in the same manner. The volumes of the embryo and heart were calculated from the above formula.

	Weight	Sp. gr.	Volume.
of embryo	1.431	1.112	1.2870 c.c.
of heart	0.510	1.114	0.0458 c.c.

Percentage of body volume 3.56

The above figures were checked by determining the volume of the embryo and the heart (model) by displacement in water. The results obtained by this method follow:-

Vol. of embryo ....1.2650 c.c.

Vol. of model - 4046 c.c. Magnification - 45. Vol. of heart ....0.0444 c.c.

Percentage of body volume...........................3.51

As seen from the above tabulations, the volume as obtained by the two methods vary only 0.05 percent.

Jackson (9) gives the following percentages of the volume of the heart as compared with that of the body for human embryos:-

Age or length of embryo	Percentage of body volume.
11 mm.	3.64
8 weeks	2.50
17 mm.	1.71
31 mm.	1.32

It is to be seen from these figures that the 11 mm. human more nearly corresponds to the 20 mm. pig. It must be added, nowever, that I have included the cavity of the heart as a part of its volume; Jackson does not state whether he did or not.

Position and Relations.

With respect to the vertebrae, the position of the heart may be defined as lying between the levels of the intervertebral discs between the fifth and sixth cervical vertebrae above, and the fifth and sixth thoracic vertebrae below. This can be demonstrated from both transverse and sagittal sections. The heart, therefore, extends through seven vertebral segments.

With respect to surface markings of the embryo, the heart lies slightly to the left of the median plane. A plane passing through the caudal lines of the fore-limbs would almost cut through its middle.

The apex points almost directly ventrally, while the whole organ is tilted slightly to the left. The structures on the right side are, therefore, a little higher than those on the left.

Dorsally, the base of the heart is separated from the vertebral column in the median line by the oesophagus, trachea, aorta, and trunks of the pulmonary arteries and veins; while laterally lie the superior vena cavae, vagi nerves, lungs, and pulmonary arteries and veins. The bifurcation of the trachea is found at the level of the body of the fourth thoracic vertebrae. A short distance above the diaphragm, and a little to the right of the mid line, the inferior vena cava also lies between the heart and the

vertebral column.

The diaphragmatic surface rests upon the diaphragm which in turn separates the heart from the liver.

Ventrally, the sterno-costal surface is in relation throughout its extent to the body wall, the pericardium and pericardial cavity intervening. Laterally, in its upper part, this surface is also covered by the body wall, but in its lower part it rests against the diaphragm.

The Chambers of the Heart.

Atria:- The atrial of the heart taken together may be likened to the shape of a bowl, the concavity of which is directed forward and caps the posterior ends of the ventricles, (Fig's. 5 & 6). They are of about the same size and shape. Their walls are this, and thrown into folds. That portion which will later become the auricles is well developed, but little indication of differentiation into these structures is apparent.

The division into right and left atria, as can be seen from Fig's. 3,4,6,& 7, is marked only on the inside of the cavity. It is formed by two membranes, the septum atriorum and the septum secundum. The former lies inferiorly and is formed by the septum primum and the left sinus valve (Fig's. 3,4, & 7). It extends from the ventral wall of the atria a little to the left of the interventricular septum, almost directly backward. It closes the inferior three fourths of the original aperture between the two atria. The septum secundum is present as a slight ridge on the dorsal and superior walls of the cavity (Fig. 7). A large foramen, which has been termed by former authors the foramen ovale II, thus remains between the two atria. There is much the same condition present, there ore, as described by Tandler (16), Mall (12), and Born (1), in the human, in that which Tandler calls the third period

of development (including embryos 10-20 mm. vertex-breech measurement).

<u>Atrium dextrum:</u>- The right atrium, as shown in Fig. 6, receives posteriorly the right superior vena cava from above and the inferior vena cava and left superior vena cava from below. It is continuous ventrally with the right ventricle. On its left, superiorly it is related to the ascending aorta. A "sulcus terminalis" is fairly distinct. It is a shallow groove which runs from the left side of the right superior vena cava to the left side of the inferior vena cava, and marks the junction of the primitive sinus venosus with the atrium proper.

The interior of the right atrium is quite free from muscular bundles (musculi pectinati) except in that portion which is to become the auricle (Fig's. 1,2, & 3). Here the interior of the atrium is traversed by a number of the small vertical muscle columns.

At the superior and dorsal part of the cavity, is the aperture of the right superior vena cava, opening into the atrium between the two sinus valves. At the inferior and dorsal part of the cavity, the inferior vena cava opens into what is still a persistent part of the sinus. Its aperture is guarded also by the two sinus valves, the left one of which is partially fused inferiorly with the septum primum, forming the septum atriorum. Coming from the left, as shown in Fig. 12, the left superior vena cava opens into the same portion of the at-

rium as the inferior vena cava, but directly ventral to it. The coronary valve (valvula Thebesii) is not set apart as such at this stage. Ventrally, the atrium empties into the right ventricle through the atrio-ventricular orifice. This opening is guarded by the tricuspid valve. Its description will be taken up in connection with the right ventricle. To the left, as described before, the cavities of the right and left atria communicate through the widely open foramen ovale II.

Valvulae venosae:- As seen in Fig's. 4.&.7, both the right and left sinus valves are thin but prominent. Superiorly, they meet and fuse, and form a ridge (septum spurium) which runs very obliquely to the right on the dorsal wall of the atrium. The left valve is narrow in the dorso-ventral direction, but long supero-inferiorly. Whereas in earlier stages it lies within the sinus venosus, it now projects well into the right atrium. This condition has been brought about by an increase in the size of the atrium at the expense of the sinus venosus. Thus the former walls of the sinus now enter into the dorsal wall of the atrium.

Inferiorly the left sinus valve is fused to the septum primum, but above this there is a deep slit-like space between the two. To this Tandler (16) has applied the term "spatium intersepto valvulare". With the formation of the foramen ovale II, according to Tandler, this space gradually disappears by a further fusing of the left sinus valve with the septum

primum. The upper and middle portions of the valve are obliterated at the same time, but the inferior part is joined by the antero-inferior prolongation of the septum secundum, and takes part in the formation of the free border of the foramen ovale II.

The right valve is somewhat thicker and broader than the left. Beginning with the septum spurium superiorly, its fixed border is attached all along the dorsal and ventral walls of the atrium. It forms the right wall of the sinus venosus. No indication of its separation into Eustachian and Thebesian valves, which according to Tandler (16) it gives rise to, can be seen at this stage.

Atrium sinistrum:- The exterior of the left atrium closely resembles that of the right (Fig.5). It receives, however, as shown in Fig. 6, only a single blood vessel, the trunk of the pulmonary veins, which enters its dorsal surface.

The interior of the left atrium is smooth, except in that portion which is to become the auricle (Fig's. 1,2,3,&6). As in the right atrium, numerous musculi pectinoti cross the cavity of this part.

Dorsally, in the line where the dorsal wall of the left atrium meets the inferior wall, and very close to the septum atriorum, the small thin walled trunk of the pulmonary veins enters the cavity (Fig.6). Although this is short, almost immediately splitting into two branches (right and left), it enters the atrium as a single vessel. According to Tandler

(16), this short trunk will later disappear by becoming incorporated in the posterior wall of the atrium, so that there will be two veins opening into the atrium. Still later, he states, these two branches will be absorbed as far up as their bifurcation, and then there will be four veins entering the atrium. Thyng (17) reports, in a human embryo of 17.8 mm., two pulmonary veins opening by separate orifices into the left atrium.

<u>Ventriculi</u>:- The ventricular portion, which forms the greater part of the heart, lies ventral to the atria. As seen in Fig's. 5 & 11, it is roughly the shape of an egg, the pointed end of which is the apex of the heart. As stated before, it is separated into right a left halves by a definite groove, interventricular sulcus, which lies on its superior and diaphragmatic surfaces, and passes to the right of the apex (Fig's. 5 & 12). This groove marks externally the right and left ventricles.

Internally, the ventricular portion of the heart is divided into right and left chambers by the interventricular septum (Fig's 2 & 3). This lies in a plane which is almost parallel to the vertebral column, but is directed obliquely from the left side dorsally to the right ventrally. In this embryo it is a thick partition composed of numerous developing muscle fibers. Its development has been described by Mall (12) and others, who agree that it arises in connection with the so-

called endocardial cushions and septum aorto-pulmonale. As can be seen from Fig's. 2 & 3, this partition is not solid, but is perforated by numerous small sinusoidal channels which extend from one ventricular cavity to the other. These channels are very small, and take a tortuous course. In a 17.2 mm. human embryo, Mall describes a single interventricular foramen which is scarcely 0.02 mm. in diameter. The channels which I find are not so large, but their abundance is very striking.

Continued dorsally and inferiorly, this partition separates the left ventricle from the right atrium. That portion which lies immediately inferior to the developing tricuspid valve has been named by Hochstetter (8), the "septum atrio-ventriculare". This septum, according to Hochstetter and others, together with the aortic and interventricular septa, forms the septum membranaceum ventriculorum of the adult.

<u>Ventriculus dexter</u>:- The right ventricle has the shape of a half-cone whose base is rounded (Fig's. 5 & 12). The part which marks the apex of the cone is the orifice of the pulmonary aorta. It is directed dorsally, superiorly, and a little to the left. The part which corresponds to the base is the diaphragmatic surface of this ventricle, while the part which corresponds to the cut surface of the cone is the interventricular septum.

The cavity of the right ventricle is in the form of a bent tube consisting of an inferior portion into which the atrio-ventricular orifice opens, and of a superior por-

tion, conus arteruosus, which terminates in the pulmonary aorta (Fig. 6). The angle between the two limbs is formed by a thick ledge of muscle, which, in the adult, has been termed the "supra ventricular crest". The inferior portion is narrower in transverse diameter than from above downward, being similar in this respect to the slit-like atrio-ventricular orifice. Ventrally, at the bend of the tube, it becomes larger, and connects with the superior portion. The latter narrows rapidly into the funnel-shaped infundibulum, which terminates in the pulmonary aorta at the pulmonary valve.

The right atrio-ventricular orifice appears from the atrial side as a narrow Y-shaped cleft. It is guarded by the tricuspid valve which is better seen from the ventricular side. This consists of two distinct irregular flaps of heart tissue, the medial of which is the thinner, lying one on either side of the cleft. Both of these come together inferiorly where they are attached to the posterior papillary muscle - Mall (12), Tandler (16). The free border of the lateral is joined toward its upper part by a large band of muscle fibers, the anterior papillary muscle - Mall (12), Tandler (16) - which connects it to the ventral wall of the ventricle. The medial has its free border joined by a smaller bundle of muscle fibers which splits sending some fibers to the interventricular septum and others to the anterior papillary muscle. Extending inferiorly from the upper part of the lateral valve, is a narrow flap of tissue. This

probably is the beginning of a third valve. It is this flap which divides the upper part of the atrio-ventricular cleft into two limbs giving it its above described shape.

Mall (12), in describing the development of the tricuspid valve in the human embryo, says that correctly speaking there is no tricuspid valve. He states, "Both are bicuspid with medial and lateral cusps. Both are tied down by two muscles, the two papillary muscles on the left side, and the large papillary muscle and the median tendon on the right." He states further, "At any rate, the right and left ostia of numerous hearts (human) less than 20 mm. long are slit-like and similar, so that it is impossible to state that one is encircled by a tricuspid valve. Each is bordered by medial and lateral valves, and each medial and lateral valve is bound to the ventricle by anterior and posterior papillary muscles".

The position of the pulmonary orifice has already been noted. It is guarded by the pulmonary valve which, as is shown in Fig. 8, is composed of three cusps, two of which are placed superiorly and one inferiorly. The outer border of each valve is attached to the wall of the pulmonary aorta, while its inner border is free. At this stage the cusps are thick walled, but each shows a definite bulging toward the ventricular cavity, and a pocket away from it, indicating their capability of preventing a back-flow of blood from the aorta.

From the pulmonary orifice, the pulmonary aorta arches backward and inferiorly to empty into the descending aorta through the left pulmonary arch at a point a little below the level of the left subclavian artery (Fig.6). Its lumen is large, having about the same diameter as the ascending aorta. About two thirds of the distance from the pulmonary orifice to the point where the left pulmonary arch empties into the descending aorta, it gives off the single small trunk of the pulmonary arteries. According to Fedorow (6) and Bremer (2), the superior part of this trunk is formed from the original left pulmonary artery, which the inferior part is the fused left and right pulmonary arteries. Bremer describes in the 20 mm. pig a small persistent portion of the right pulmonary arch branching from the left pulmonary arch. In neither of the embryos of which I have made a careful study, do I find this structure. That portion of the left pulmonary arch between the point where the trunk of the pulmonary arteries is given off and the aorta is known as the truncus arteriosus (Fig. 6).

The cavity of the right ventricle is smooth in the region of the conus arteriosus, but it is in all other places filled up with a spongy mass of muscular bundles, the trabeculae carnae (Fig's. 2 & 3). Two kinds of these are recognizable: musculi pectinati, which are of varying lengths and attached to the walls of the ventricle; and the papillary muscles, which have one end joined to the valves and the other to

the ventricular wall. One particularly large bundle, the moderator band, passes from a point just ventral to the medial cusp of the tricuspid valve, ventrally, to the right ventricular wall (Fig.2). In its substance the right limb of the atrio-ventricular vundle, and a small branch of the left coronary artery are found. These will be described later. There are two papillary muscles present, the anterior and the posterior.

Ventriculus sinister:- The left ventricle is continuous dorsally with the left atrium with which it communicates thru the mitral orifice. Seuperiorly, and to the right, it is continued into the ascending aorta which, after passing under the pulmonary aorta, turns superiorly, and to the left, to produce the aortic arch (Fig's. 5 & 6).

As viewed from the ventricular side the left atrio-ventricular orifice is somewhat similar to the tricuspid, but is inverted (Fig's. 9 & 10). It consists of two definite flaps, a medial and a lateral. Both of these are fused together above and below where they are joined by the papillary muscles, the anterior and posterior respectively. The free borders are concave anteriorly. The medial cusp, between its two attachments, is free, and forms the medial side of the orifice along its whole extent. Projecting medially and superiorly from the lateral valve, is the beginning of what appears to be a third flap (Fig.9). The significance of this flap I am unable to determine.

Mall (12), Tandler (16), and others describe the mitral orifice in the human embryo of about this stage of development as a slip-like cleft guarded by a valve consisting of two cusps. No indication of the extra flap which I have described is shown by them. The atrial surfaces of the valves are smooth (Fig.9). This is true also for the ventricular surface of the medial valve along which the blood passes to reach the aorta (Fig.10). However, the ventricular surface of the lateral valve shows some indication of roughness produced by the attachment of chordae tendinae.

The cavity of the left ventricle is separable into two portions, the body and the aortic vestibule. The former is by far the larger part of the cavity, and includes all of the space to the left of the lateral valve and ventral to the margins of both cusps. It extends down into the apex, and is filled to a large extend by trabeculae carnae. The two large papillary muscles above described are attached ventrally to the ventricular wall in the region of the apex.

The aortic vestibule lies entirely to the right of the medial cusp of the mitral valve, and is, in its inferior part, separated from the left atrium by the attached portion of this cusp (Fig's. 6 & 9). Superiorly, the vestibule passes dorsally to the right, and comes to lie directly superior to both atria in the region of the septum atriorum. The walls of its cavity are smooth.

The aortic orifice is guarded by a semilunar valve consisting of three cusps exactly like those of the pulmonary

valve. Its cusps are placed, however, so that there is one superiorly and two inferiorly. On the aortic side of the cusps are small pockets which are known as the aortic sinuses and from which arise the coronary arteries.

Aortic arch and its branches:- There is but a single definite vessel coming off of the aortic arch (Fig's. 5, 6, & 11). This immediately splits into two branches, an innominate, which passes to the right and very shortly divides into common carotid and right subclavian, and a left common carotid. The left subclavian comes off a little below the junction of the ductus arteriosus and the descending aorta (Fig.6). In connection with the aortic arch should be mentioned a small pocket which extends upward, and ends blindly in its wall. Several similar small pouches were found on the pulmonary aorta, in front of the pulmonary valve (Fig.6). The significance of these I am unable to determine.

From the foregoing description, it is readily seen that the separation of the systemic and pulmonary aortae, the process of which has been fully described by many writers, is completed.

The atrio-ventricular bundle:- The atrio-ventricular bundle, as is shown in Fig's. 2,3,& 11), in the 20 mm. pig is a definite structure which stands out distinctly, in cross section, because of the spaces which surround it. As Tandler (16) described, "it is distinguishable even under low powers by its staining properties". As shown in Fig's. 3 & 4, its nuclei are dark, and the protoplasm of its cells stains faintly with eosin. The spaces which surround it, according to Mall (12), evidently persist in the adult, and form possibly the bursa of the bundle - Curran (4) - and the spaces

which encircle the Purkinje fibers. In addition I find in certain sections a small round canal near the center of the bundle, the significance of which I am unable to determine.

The atrio-ventricular bundle has its origin inferiorly in the mass of tissue lying ventral to the sinus venosus, and to which are attached the right sinus valve and the septum atriorum (Fig.4). Running superiorly, ventrally, and a little to the left, it becomes flattened laterally. It now occupies a position in that part of the interventricular septum known as the septum membranaceum. Continuing in the same direction, it reaches the level of the middle of the medial cusp of the tricuspid valve. At this point it befurcates into two unequal portions. The larger, broader limb passes to the left and ventrally to end in the interventricular septum at a point just medial to the medial cusp of the mitral valve (Fig.11). The smaller, rounder limb passes superiorly and ventrally to the right ventricle (Fig.11). In its course through the moderator band it is accompanied by an artery which will be described below.

The origin of the atrio-ventricular bundle is somewhat doubtful. His, Sr., His, Jr. ( ), and Mall (12) contend that it is the remnant of the wall of the atrial canal, after the anterior and lateral sides of the atrial canal have been broken up in the formation of the tricuspid and mitral valves; while Tandler (16) and Retzer (15) think that it arises independently as a new formation.

The Coronary Vessels.

Arteriae coronariae:- As in the adult, the coronary arteries are two in number, a right and a left. As seen in Fig. 12, they appear as small rounded vessels with relatively thick walls. They are distributed almost entirely to the heart but a few small branches are given off to the roots of the great vessels.

The right coronary artery:- This artery springs from the superior aortic sinus, a small pocket which lies above the superior cusp of the aortic valve. It runs downward and to the right, between the root of the aorta and that portion of the right atrium which will later become the auricle, to reach the coronary sulcus (Fig.1). In this it courses inferiorly along with the small cardiac vein (Fig's. 2,3,& 4). It continues to the left and passing the inferior interventricular sulcus, where it gives off its interventricular branch, ends by anastamosing with the circumflex branch of the left coronary artery (Fig.12). This anastamosis is accomplished in a fine network of vessels and can only be made out under high magnification.

The interventricular branch runs ventrally in the inferior interventricular sulcus, supplies both ventricles by short branches, and ends in a plexus on the diaphragmatic surface of the heart which is formed by its own terminal branches and those of the circumflex and interventricular branches of the left coronary artery (Fig.12). In its course, in the interventricular

sulcus, it lies in relation to the middle cardiac vein.

In addition to the interventricular branch, the right coronary artery gives off seven or eight small anterior ventricular branches which run ventrally on the lateral surface of the right ventricle. No "marginal" branch can be seen at this stage, but it is probably represented by one of the anterior ventricular branches.

The left coronary artery:- This artery, as is seen in Fig.1, springs from the left inferior aortic sinus. Its trunk which is short passes ventrally between the root of the left pulmonary arch and the left atrium to the coronary sulcus. Almost immediately it divides into a circumflex and an interventricular branch.

The circumflex branch turns to the left, and running inferiorly, turns around the left side of the heart to end in two branches, one of which anastamoses ventral to the coronary sinus with the right coronary artery, which the other ends in the above-described plexus on the diaphragmatic surface of the heart (Fig's. 2,3,& 12). In its course, in the coronary sulcus, the circumflex branch lies in relation to the great cardiac vein. It supplies branches to the left atrium, the left margin of the heart, and the inferior surface of the left ventricle (Fig. 3 & 12).

The interventricular branch runs in the anterior interventricular sulcus, turns around the ventral margin of the heart, and also terminates in the plexus of the diaphragmatic

surface (Fig.12). It supplies the sterno-costal surface of both ventricles.

Near its origin the interventricular branch of the left coronary artery gives off in addition a small branch which enters the ventricular wall, passes thru the interventricular septum, and enters the moderator band (Fig's. 2 & 11). In this it can be traced as far as the right wall of the ventricle where it terminates. In its course in the moderator band it accompanies the atrio-ventricular bundle. Because of its close relation to the atrio-ventricular bundle, this branch is of particular interest. I have been unable to find any mention of it in the literature and do not know whether it is present in the human heart. In the heart of the adult pig, I have found it present constantly as a vessel of considerable size. It arises as described in the embryo but courses through the moderator band into the right wall of the ventricle where it breaks up into capillaries.

From the trunk of the left coronary artery, small branches are given off to the root of the left pulmonary arch and the left atrium.

Sinus coronarius et venae cordis:- Owing to the fact that the left superior vena cava of the pig remains as a definite vessel, the relations of the entering cardiac veins are somewhat different from those found in the human. As seen in Fig. 12, there is, strictly speaking, no definite coronary sinus, for the cardiac veins all enter the terminal portion of the left superior vena cava. This portion of the

left superior vena cava which lies in the inferior portion of the coronary sulcus is somewhat enlarged, and represents the coronary sinus of the human heart. In the following description I have used the term "coronary sinus" to designate the terminal portion of the left superior vena cava. The coronary sinus receives five large veins. They are from left to right: the left superior vena cava, the great cardiac vein, the inferior cardiac vein of the left ventricle, the middle cardiac vein, and the small cardiac vein. It empties, as shown in Fig's. 5,7, & 12, into the sinus venosus just ventral to the inferior vena cava. There is as yet no indication of the Thebesian valve which in the adult pig guards its entrance.

The left superior vena cava receives the blood from the left side of the head and left upper extremity. It persists as a large definite vessel in the adult pig. In the adult human only a small portion of it remains, which is known as the oblique vein of Marshall (Fig.12).

The great cardiac vein arises about the point where the left coronary artery splits into its circumflex and interventricular branches. Receiving branches from the walls of the left ventricle and left atrium, it runs inferiorly in the coronary sinus (Fig.12). Near its termination it receives a rather large tributary from the wall of the left atrium.

The inferior cardiac vein of the left ventricle is represented by a short wide trunk. Into it drains a number of small tributaries which carry blood from a limited amount

of the diaphragmatic wall of the left ventricle. It opens into the ventral side of the coronary sinus about its middle (Fig.12).

The middle cardiac vein arises about the middle of the diaphragmatic surface of the heart in relation to the previously described plexus of arteries. It runs dorsally in the inferior interventricular sulcus, and being joined by a branch from the right side of the right ventricle, empties into the coronary sinus on its right side (Fig.12).

The small cardiac vein is by far the largest of the coronary veins of the 20 mm. pig. It arises as two definite vessels, one of which receives branches from the right atrium, while the other collects the blood from the right wall of the right ventricle. These run inferiorly on either side of the coronary sulcus, and unite at the point where the right lateral and diaphragmatic surfaces of the heart meet. The common trunk then runs to the left a short distance in the coronary sulcus to empty into the right extremity of the coronary sinus, just dorsal to the entrance of the middle cardiac vein (Fig.12).

In addition to the definite veins described above, there are a number of small veins which collect the blood from the lateral and inferior walls of the right atrium, and empty into the small cardiac vein, some into its ventricular tributary, and some into its trunk. These, in the adult, have been called the anterior cardiac veins (Fig.12).

Little seems to have been published on the development

or observation of the coronary vessels in embryos younger than 20 mm. In fact, Evans (5) says of the coronary arteries of the human, "Nothing is known of the development of the coronary arteries. Tandler has noted their beginnings in a 17 mm. human embryo (N.T.65). The only observations known to me (1904) on this subject are the fragmentary ones of Martin (1894) (13), and those of F. T. Lewis (1904) (10)"; and the only record which I can find of work done on the coronary veins is his statement, "---; of the left ductus Cuvieri only the proximal portion is preserved as the sinus coronarius (Marshall 1850) (14)". In the 20 mm. pig, while I find them instead of round and regular, as flattened and irregularly shaped channels which show enormous variation in their size in different parts, they are, at least, definite vessels, and with only moderate difficulty I have succeeded in making a model of them.

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Figure 1. A cross section of the heart at the level of the origin of the left coronary artery. (Section 571 H.E.C. 1702) X 23.

a.v............... aortic vestibule.
c.a.v............. cusp of the aortic valve.
c.r.v............. cavity of the right ventricle.
d.a............... dorsal aorta.
int.s............. interventricular sulcus.
l.a............... left atrium.
l.c.a............. left coronary artery.
l.v............... left ventricle.
oes............... oesophagus.
p.a............... pulmonary artery.
r.a............... right atrium.
r.c.a............. right coronary artery.
tr................ trachea.

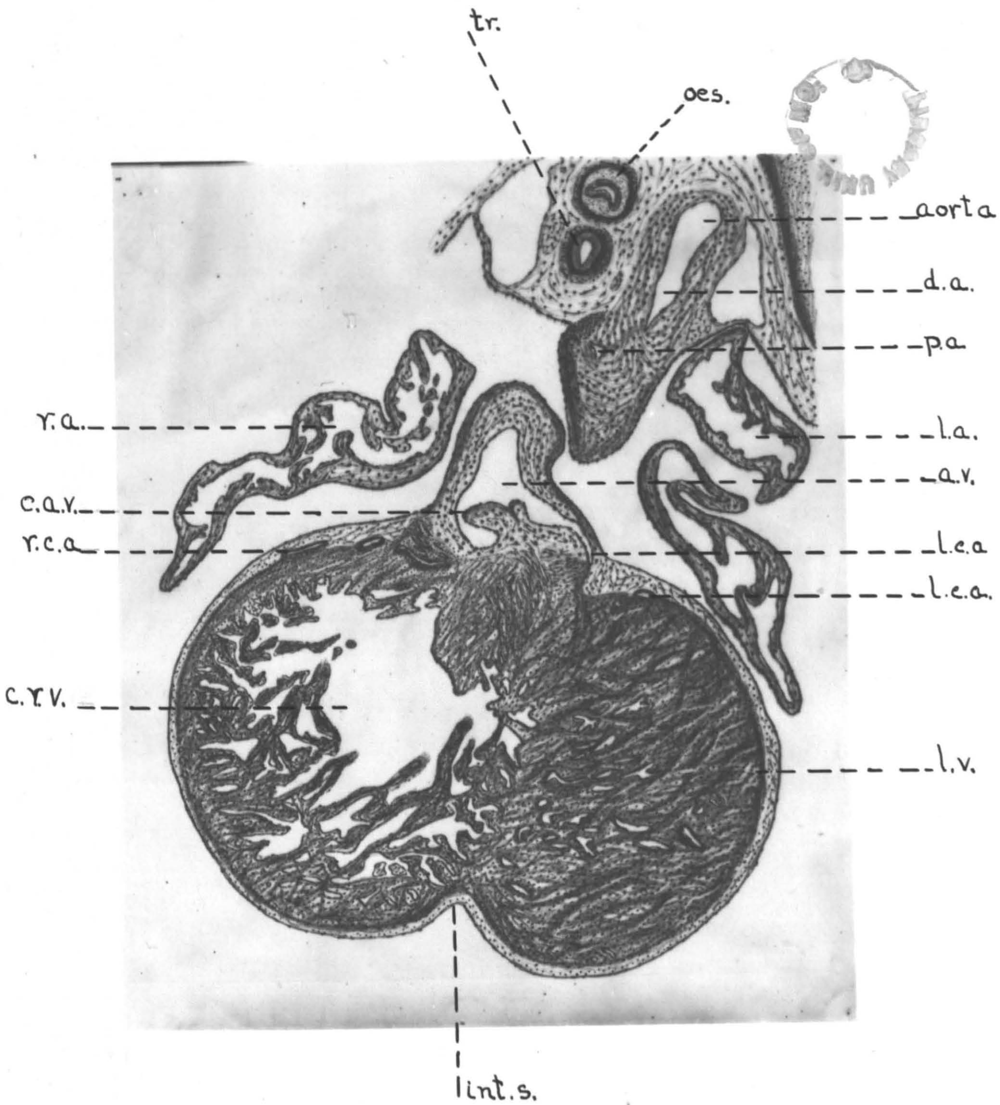
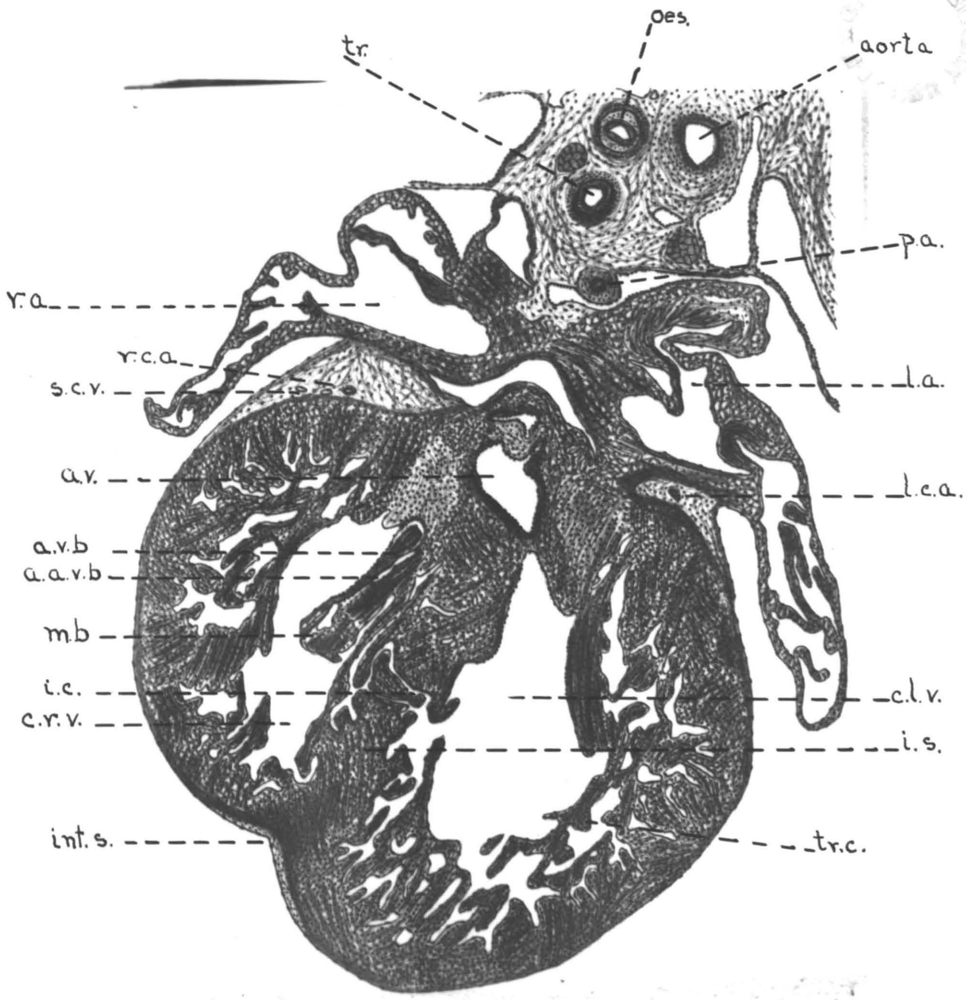


Fig. 1.

Figure 2. A cross section of the heart at the level of the moderator bundle. (Section 784 E.C.Univ. of Mo. #1.15) X 23.

a.a.v.b.	....	artery accompanying the atrio-ventricular bundle.
a.v.	....	aortic vestibule.
a.v.b.	....	atrio-ventricular bundle.
c.l.v.	....	cavity of the left ventricle.
c.r.v.	....	cavity of the right ventricle.
i.c.	....	interventricular canals.
int.s.	....	interventricular sulcus.
i.s.	....	interventricular septum.
l.a.	....	left atrium.
l.c.a.	....	left coronary artery.
m.b.	....	moderator band.
oes.	....	oesophagus.
p.a.	....	pulmonary artery.
r.a.	....	right atrium.
r.c.a.	....	right coronary vein.
s.c.v.	....	small cardiac vein.
tr	....	trachea.
tr.c.	....	traceculae carnae.

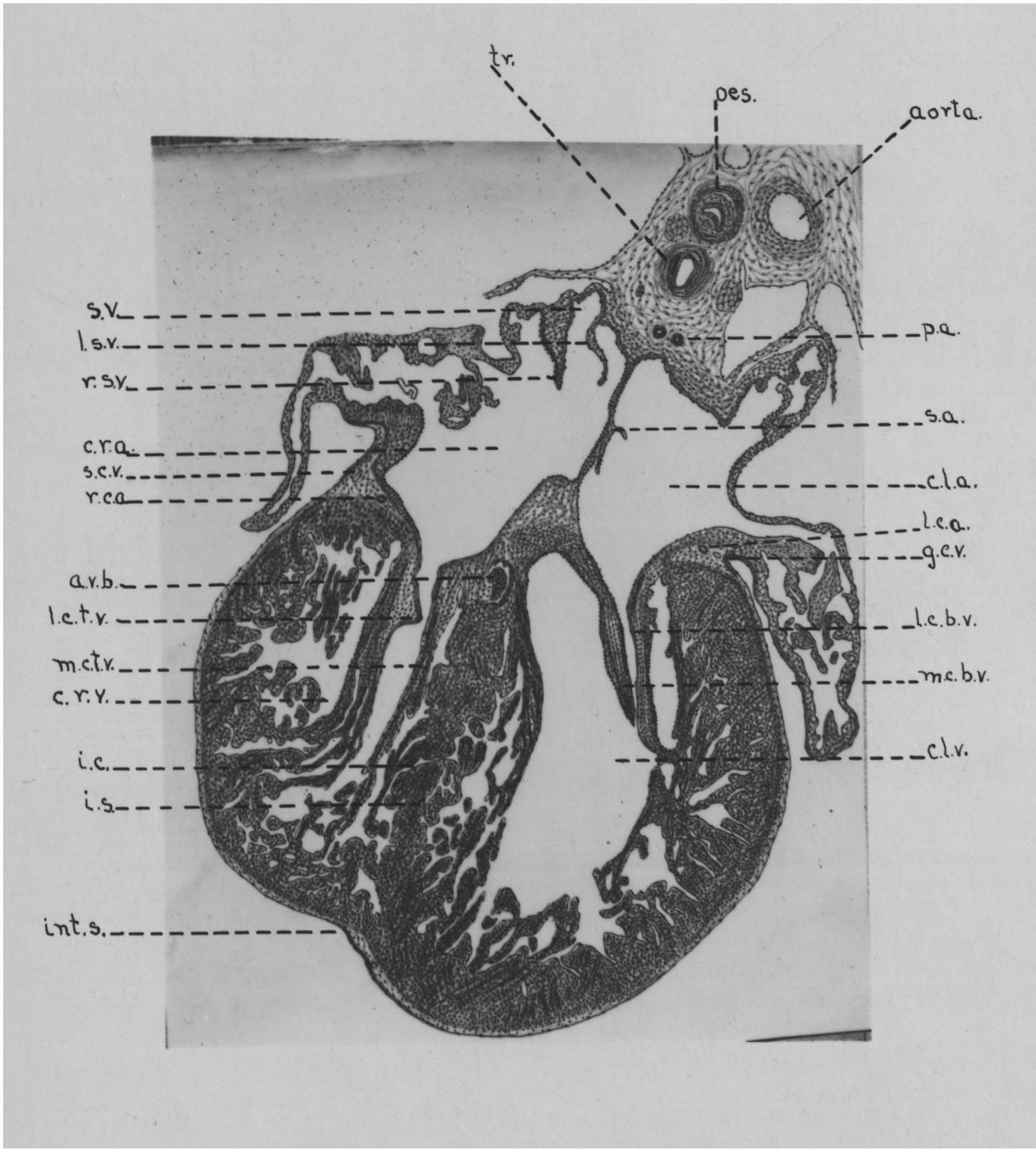


oes.
tr.
aorta
p.a.
r.a.
r.c.a.
s.c.v.
l.a.
a.v.
l.c.a.
a.v.b
a.a.v.b
m.b
i.c.
c.l.v.
c.r.v.
i.s.
int.s.
tr.c.

Fig. 2.

Figure 3. A cross section of the heart at the level of the atrio-ventricular orifices. (Section 620 r.e.c. 1702) X 23.

a.v.b.	atrio-ventricular bundle
c.l.a.	cavity of the left atrium.
c.l.v.	cavity of the left ventricle.
c.r.a.	cavity of the right atrium.
c.r.v.	cavity of the right ventricle.
g.c.v.	great cardiac vein.
i.c.	interventricular canal.
i.s.	interventricular septum.
int.s.	interventricular sulcus
l.c.a.	left coronary artery
l.c.b.v............	lateral cusp of the bicuspid valve.
l.c.t.v............	lateral cusp of the tricuspid valve.
l.s.v.	left sinus valve.
m.c.b.v.	medial cusp of the bicuspid valve.
m.c.t.v.	medial cusp of the tricuspid valve.
oes.	oesophagus.
p.a.	pulmonary arteries.
r.c.a.	right coronary artery.
r.s.v.	right sinus valve.
s.a.	septum atriorum.
s.c.v.	small cardiac vein.
s.v.	sinus venosus.
tr	trachea.



tr.
oes.
aorta.
s.v.
l.s.v.
r.s.v.
c.r.a.
s.c.v.
r.c.a.
a.v.b.
l.c.t.v.
m.c.t.v.
c.r.v.
i.c.
i.s.
int.s.
p.a.
s.a.
c.l.a.
l.c.a.
g.c.v.
l.c.b.v.
m.c.b.v.
c.l.v.

Fig.3.

Figure 4. A cross section of a portion of the heart at the level of the origin of the atrio-ventricular bundle. (Section 639 H.E.C. 1702) X 43.

a.b. .... atrio-ventricular bundle.

c.l.a. .... cavity of the left atrium.

c.r.a. .... cavity of the right atrium.

c.s.v. .... cavity of the sinus venosus.

l.s.v. .... left sinus valve.

r.c.a. .... right coronary artery.

r.s.v. .... right sinus valve.

s.a. .... septum atriorum.

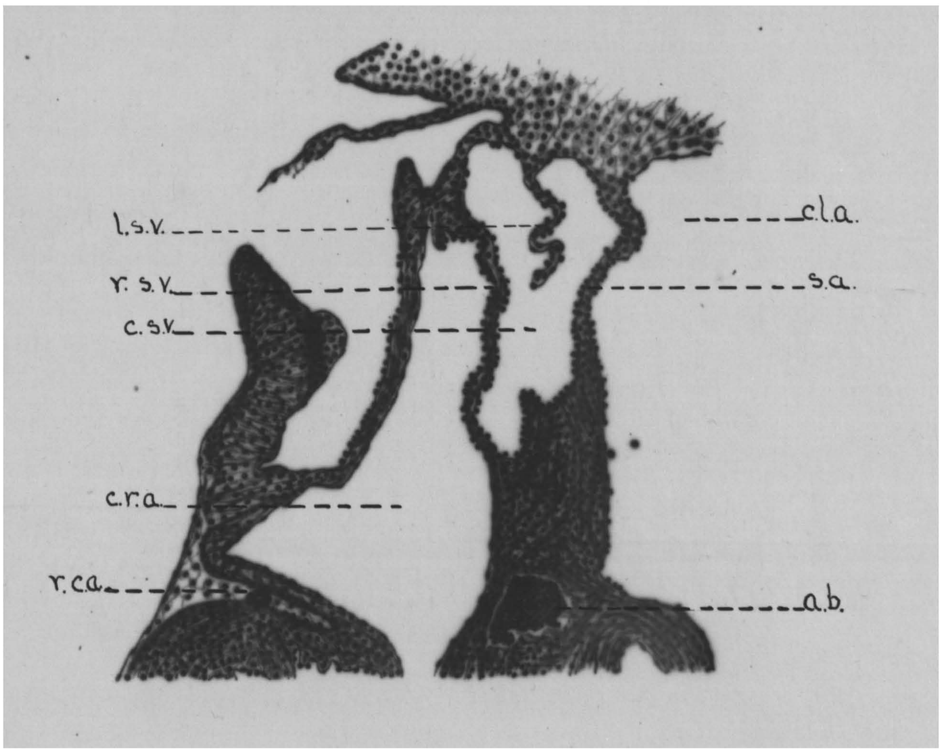


Fig. 4.

Figure 5. The model of the whole heart as viewed from above. X 23.

a	apex
a.a................	aortic arch.
a.i.s..............	anterior interventricular sulcus.
l.a.	left atrium.
l.aur..............	left auricle.
l.c.c..............	left common carotid.
l.s.v.c............	left superior vena cava.
l.v................	left ventricle.
r.a................	right atrium.
r.aur..............	right auricle.
r.c.c.	right common carotid.
r.s.	right subclavian artery.
r.s.v.c............	right superior vana cava.
r.v................	right ventricle.
t.a.	truncus arteriosus.

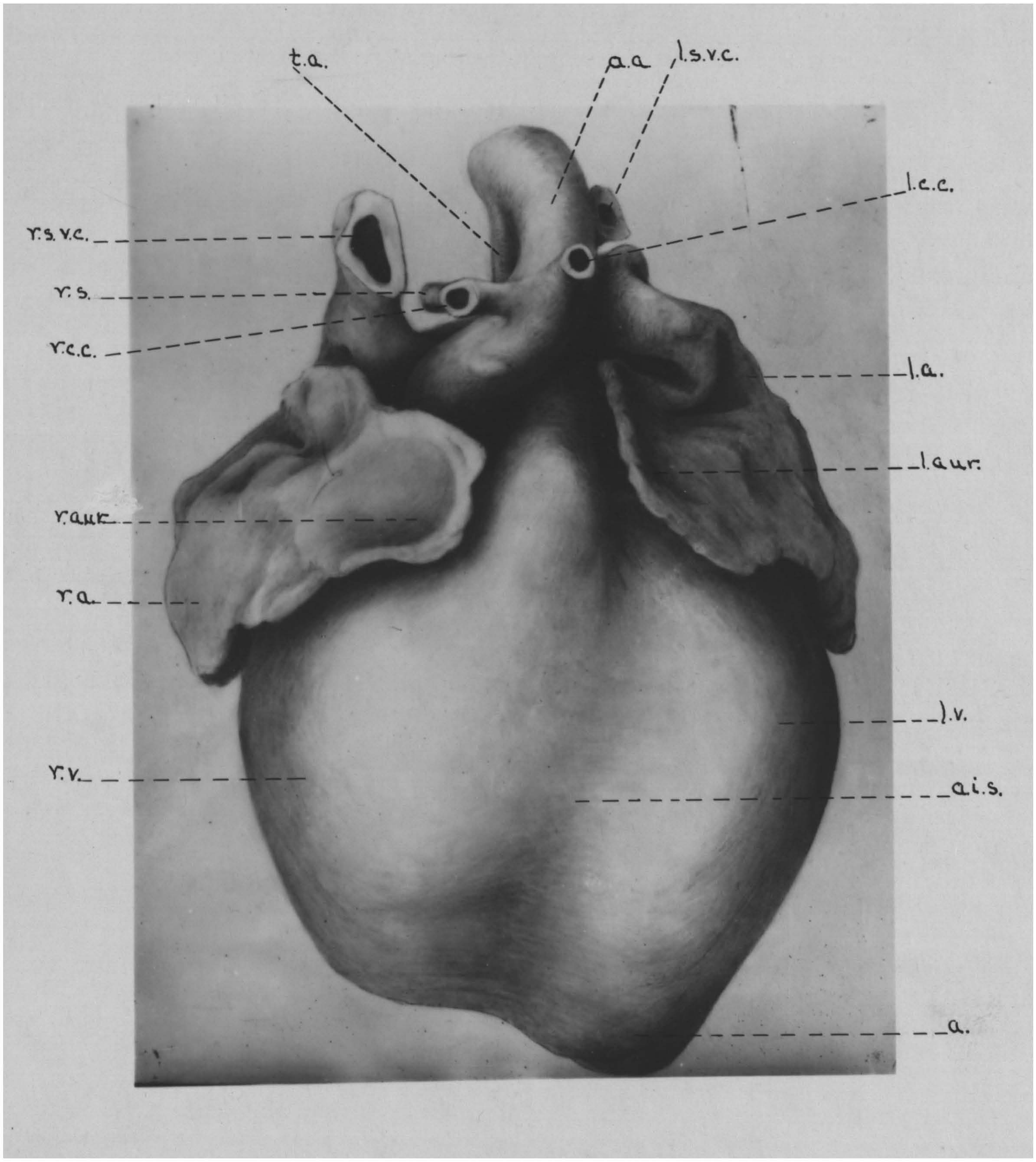


Fig. 5.

Figure 6. A model of the cavity of the heart as viewed from the right and behind. X 23.

a.a. .... aortic arch.

d.a. .... dorsal aorta.

i.v.c.............. inferior vena cava.

i.s.a.............. left subclavian artery.

l.s.v.............. left sinus valve.

l.s.v.c............ left superior vena cava.

oes................ oesophagus.

p.a................ pulmonary artery.

p.r.p.a............ pockets running from the pulmonary arch.

p.v................ pulmonary vein.

r.a................ right atrium.

r.aur.............. right auricle.

r.c.c.............. right common carotid.

r.s.a.............. right subclavian artery.

r.s.v.............. right sinus valve.

r.s.v.c............ right superior vena cava.

s.a................ septum atriorum.

s.v................ sinus venosus.

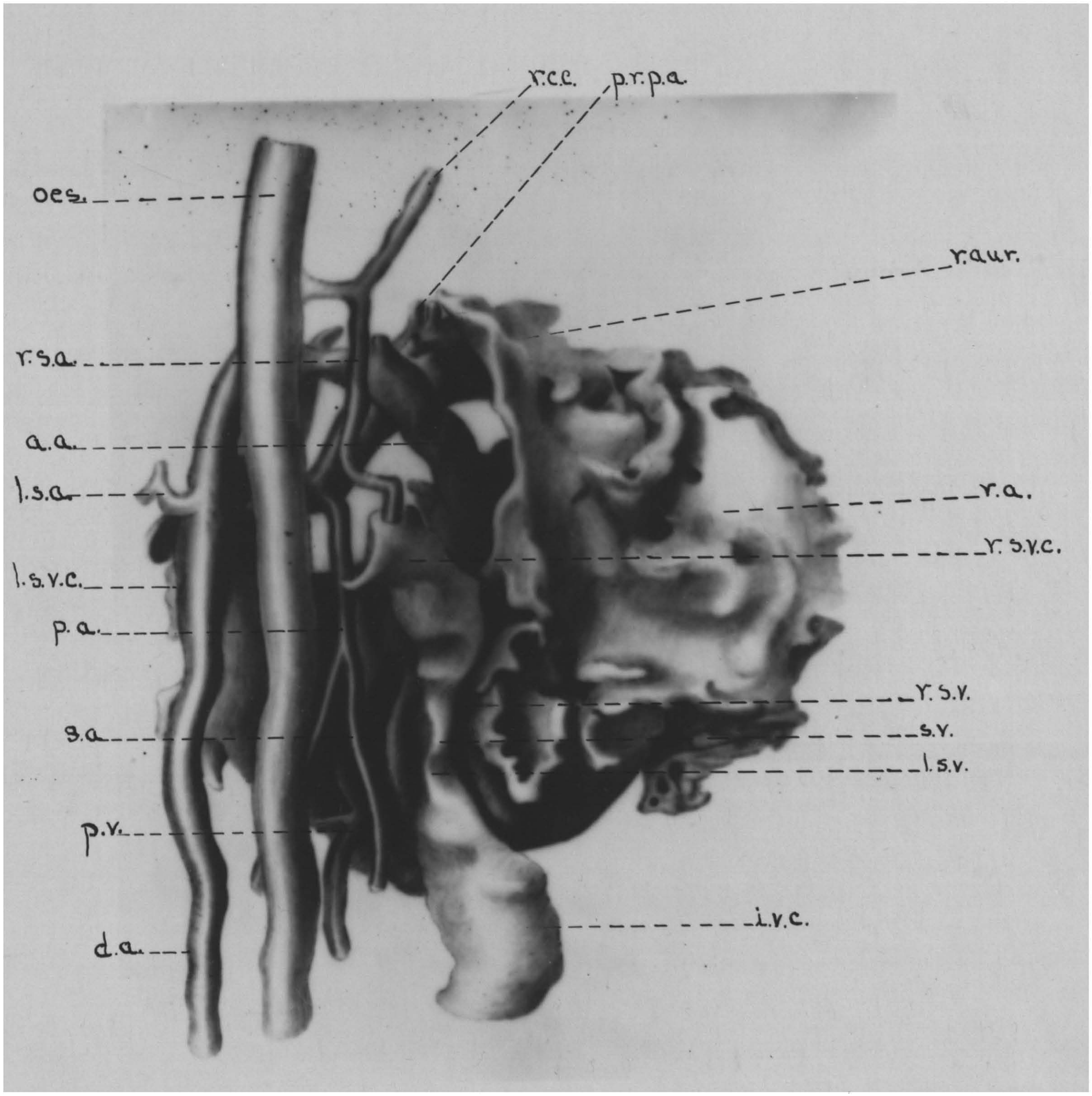

r.c.c.
p.r.p.a.
oes.
r.aur.
r.s.a.
a.a.
l.s.a.
r.a.
r.s.v.c.
l.s.v.c.
p.a.
r.s.v.
s.a.
s.v.
l.s.v.
p.v.
i.v.c.
d.a.

Fig. 6.

Figure 7. A model of the Eustachian valve as viewed from the atrial side. X 90.

c.l.a.............. cavity of the left atrium.
c.r.a.............. cavity of the right atrium.
c.s.v.............. cavity of the sinus venosus.
i.v.c.............. inferior vena cava.
l.s.v.............. left sinus valve.
l.s.v.c............ left superior vena cava.
p.v. .... pulmonary vein.
r.s.v.............. right sinus valve.
r.s.v.c............ right superior vena cava.
s.a................ septum atriorum.
s.s. .... septum secundum.
s.s.p.............. septum spurium.

Figure 8. A model of the pulmonary valve as viewed from the aortic side. X 90.

i.c. .... inferior cusp.
s.c. .... superior cusp.

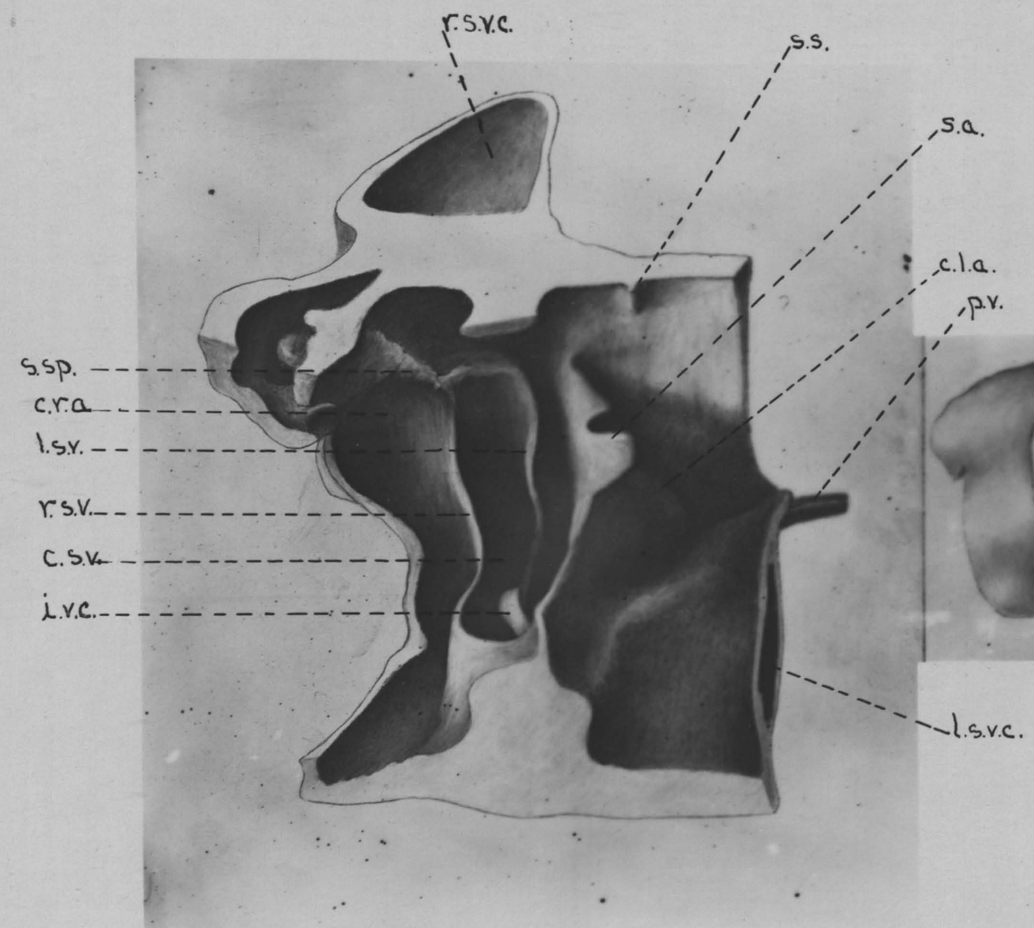


Fig. 7.

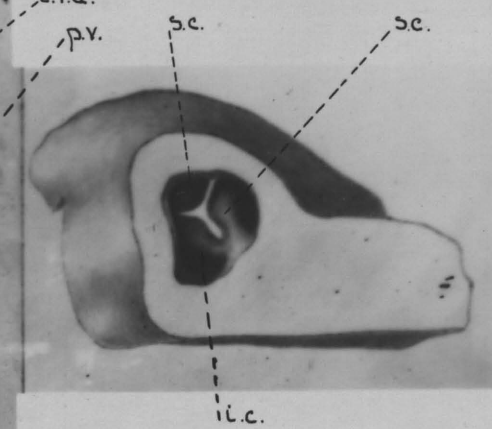


Fig. 8.

Figure 9. A model of the bicuspid valve as viewed from the atrial side. X 90.

a.s.l.c.b.v........ lateral cusp of the bicuspid valve.

a.s.m.c.b.v........ medial cusp of the bicuspid valve.

a.v................ aortic vestibule.

s.l.c.b.v.......... portion aplit from the lateral cusp.

Figure 10. A model of the bicuspid valve as viewed from the ventricular side. X 90.

a.p.m............. anterior papillary muscle.

a.v............... aortic vestibule.

c.l.v............. cavity of the left ventricle.

i.s............... interventricular septum.

p.p.m............. posterior papillary muscle.

v.s.l.b.v......... lateral cusp of the bicuspid valve.

v.s.b.v.m......... medial cusp of the bicuspid valve.

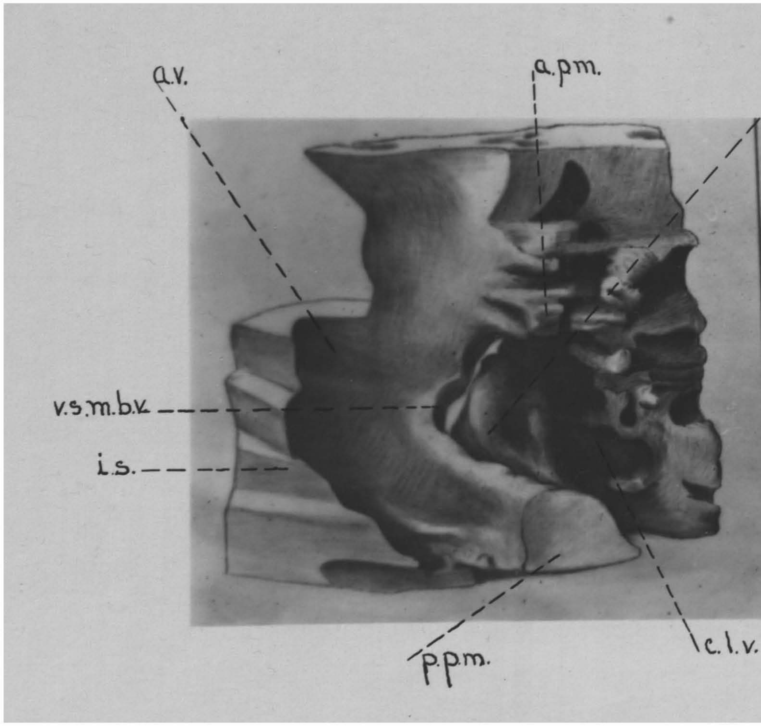


Fig.10.

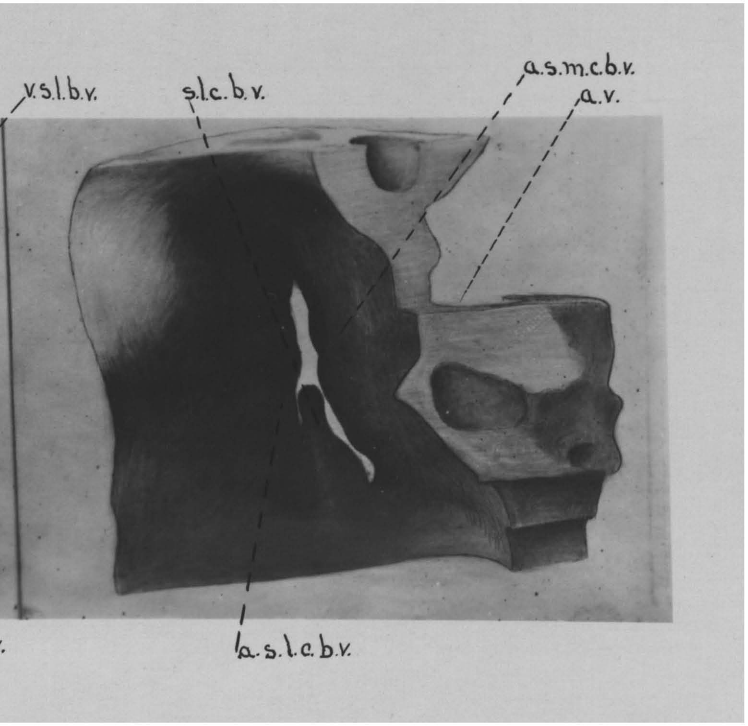


Fig.9.

Figure 11. A model of a dissection of the atrio-ventricular bundle as seen from the right ventricle. X 23.

a................. apex.

a.a............... aortic arch.

a.m.b............. artery of the moderator band.

d.a............... dorsal aorta.

i.s............... interventricular sulcus

i.v.c............. inferior vena cava.

l.c.a............. left coronary artery.

l.l.a.b........... left limb of the atrio-ventricular bundle.

m.b............... moderator band.

oes............... oesophagus

o.a.b............. origin of the atrio-ventricular bundle.

r.a............... right atrium.

r.c.c............. right common carotid.

r.l.a.b........... right limb of the atrio-ventricular bundle.

r.s.v.c........... right superior vena cava.

t.a............... truncus arteriosus.

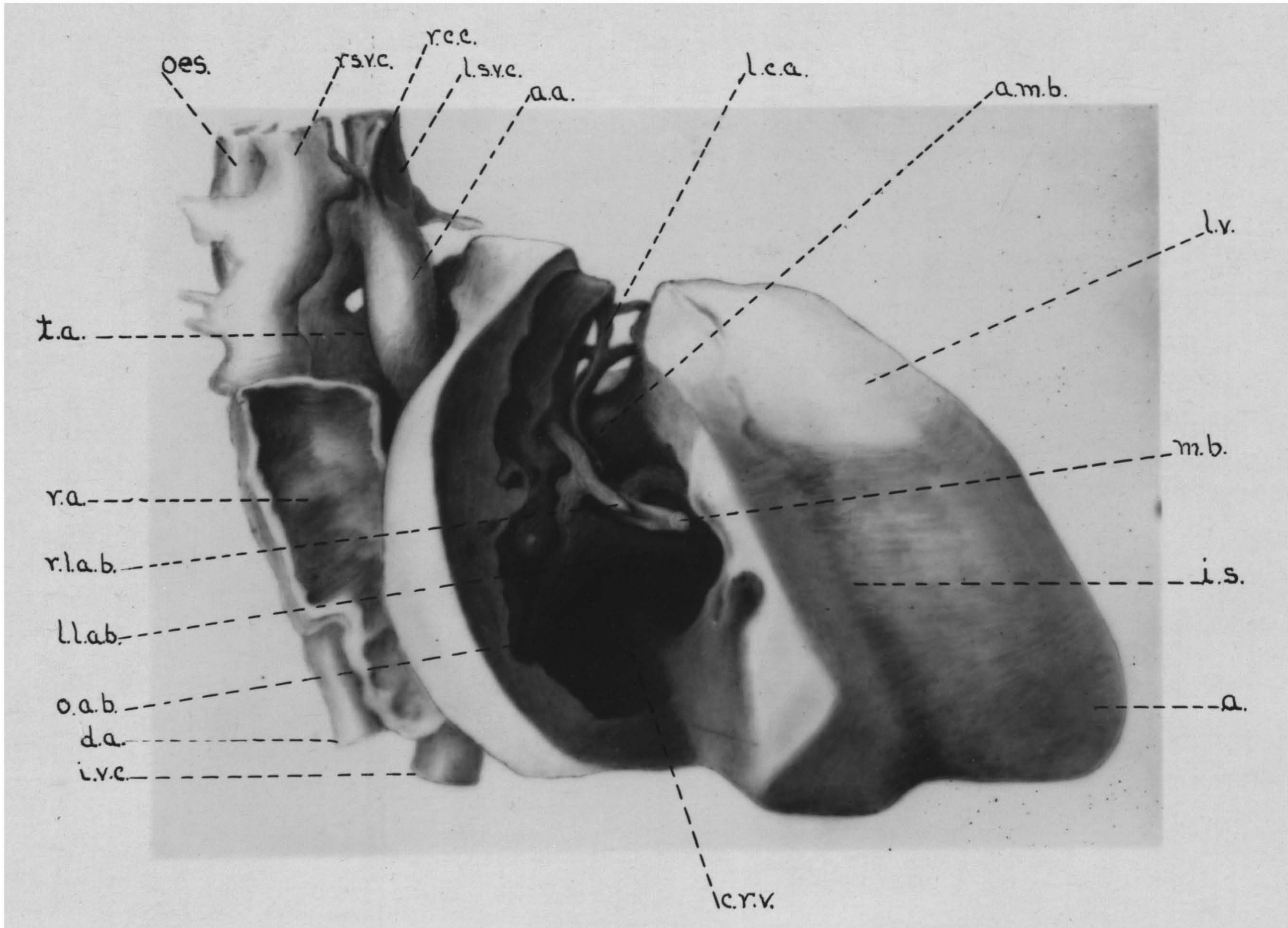
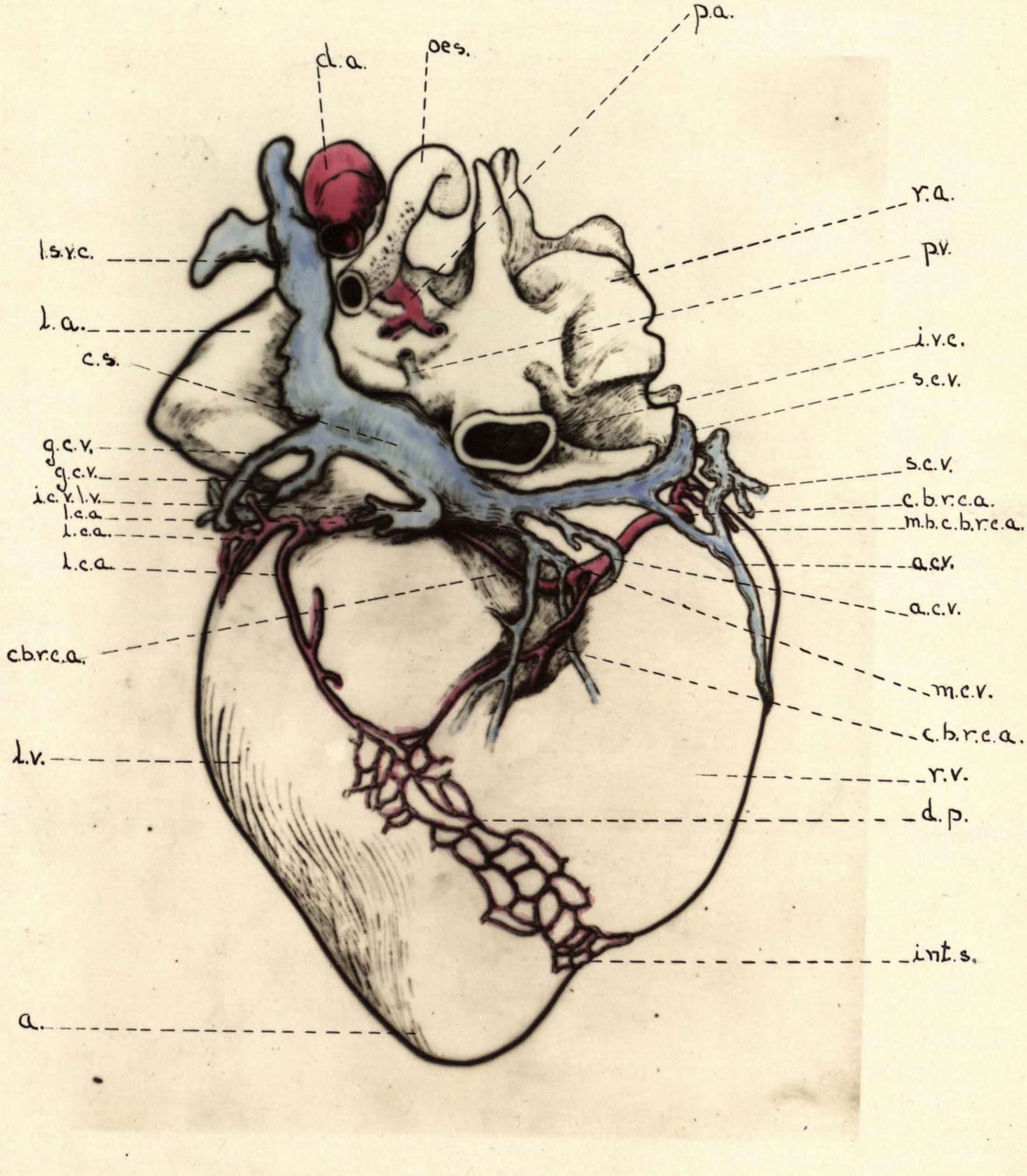

oes.
r.s.v.c.
r.c.c.
l.s.v.c.
a.a.
l.c.a.
a.m.b.
l.v.
t.a.
m.b.
r.a.
r.l.a.b.
i.s.
l.l.a.b.
o.a.b.
a.
d.a.
i.v.c.
l.c.r.v.

Fig.11.

Figure 12. A model of the dissection of the coronary vessels as seen from below. X 23.

a.................	apex
a.c.v.............	anterior cardiac vein.
c.b.r.c.a.........	circumflex branch of the right coronary artery.
c.s...............	coronary sinus.
d.a...............	dorsal aorta.
d.p...............	diaphragmatic plexus.
g.c.v.............	great cardiac vein.
i.c.v.l.v.........	inferior cardiac vein of the left ventricle.
int.s.............	interventricular sulcus.
i.v.c.............	inferior vena cava.
l.a...............	left atrium.
l.c.a.............	left coronary artery.
l.v...............	left ventricle.
m.b.c.b.r.c.a.....	Marginal branch of the circumflex branch of the right coronary artery.
m.c.v.............	middle cardiac vein.
p.a...............	pulmonary artery.
p.v...............	pulmonary vein.
r.a...............	right atrium.
s.c.v.............	small cardiac vein.


p.a.
d.a.
oes.
r.a.
l.s.v.c.
p.v.
l.a.
i.v.c.
c.s.
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g.c.v.
g.c.v.
i.c.v.l.v.
l.c.a.
l.c.a.
s.c.v.
c.b.r.c.a.
m.b.c.b.r.c.a.
l.c.a.
a.c.v.
a.c.v.
c.b.r.c.a.
m.c.v.
c.b.r.c.a.
l.v.
r.v.
d.p.
int.s.
a.

Fig. 12.

Approved
Franklin P. Johnson

A very creditable thesis. The work has apparently been done with much care & accuracy, and the results are presented in a clear, concise & logical manner.

George Lefevre