The Human Embryonic Heart in the Seventh Week[1]

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Although cardiac development has interested investigators for more than 2,500 years (see Kramer, '42 and Licata, '54 for historical reviews) the discovery of many of the details of cardiogenesis awaited the development of technics for the construction of enlarged models of the embryonic heart so that its anatomy could be seen more easily. Such a technic was described by Born in 1883, but the method is so pains-taking and time-consuming that many gaps still exist in the available series of models illustrating the human heart at various stages in its development. As these gaps become narrower, we are confronted with the problem of the individual variability that occurs at each stage.

The present paper, an attempt to fill one of the gaps in our knowledge of the embryology of the human heart, is based on an enlarged model of the heart in the seventh week of its development. This is the period during which the coronary vessels and the secondary interatrial septum appear. It is also a period in which many of the structures and relationships of the adult heart are recognizable.

MATERIALS AND METHODS

The model upon which the present study is based was made from the heart of an embryo[2] with a crown-rump length of 14.5 mm. The embryo was in Streeter's Horizon early XVIII. Several factors led to the selection of this particular heart for reconstruction: (1) it fits well into the existing series of reported reconstructions, (2) the crucial changes that are occuring during this period have often been described on the basis of interpolations between more carefully observed earlier and later stages, and (3) the heart was particularly well preserved to demonstrate internal features to best advantage.

Born's method of wax-plate reconstruction as modified by Kramer ('42) was employed. The model, reconstructed at a magnification of 100×, is dissectable at various levels in a plane coinciding with the transverse plane in which the embryo was sectioned. Figure 3 illustrates the internal structure that is evident as several succeeding segments of the model are removed. The proximal portions of the major vessels entering or leaving the heart have been included in the reconstruction (figs. 1 and 2).

Additional embryos of a comparable age examined and compared with the model are listed below:

U. of Mich. Number	Crown-rump length mm	Streeter's horizon number	Plane of section
EH286	14.5	XVIII	Transverse
EH314	14.8	XVIII	Transverse
EH407	14.5	XVII	Sagittal
EH568	14.0	XVIII	Transverse
EH583	14.6	XVII	Transverse

OBSERVATIONS

External configuration

The definitive positions and interrelationships of the four chambers of the heart and the associated major vessels are externally apparent at this stage.

The pulmonary trunk crosses anterior to the ascending trunk (fig. 1), arches dorsad and to the left of it, and is connected by the temporarily robust ductus arteriosus (fig. 2) with the ventral surface of the left dorsal aortic root.

The left fourth aortic arch and dorsal aortic root are larger than their counterparts on the right side.

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[2] The University of Michigan Collection No. EH-841.

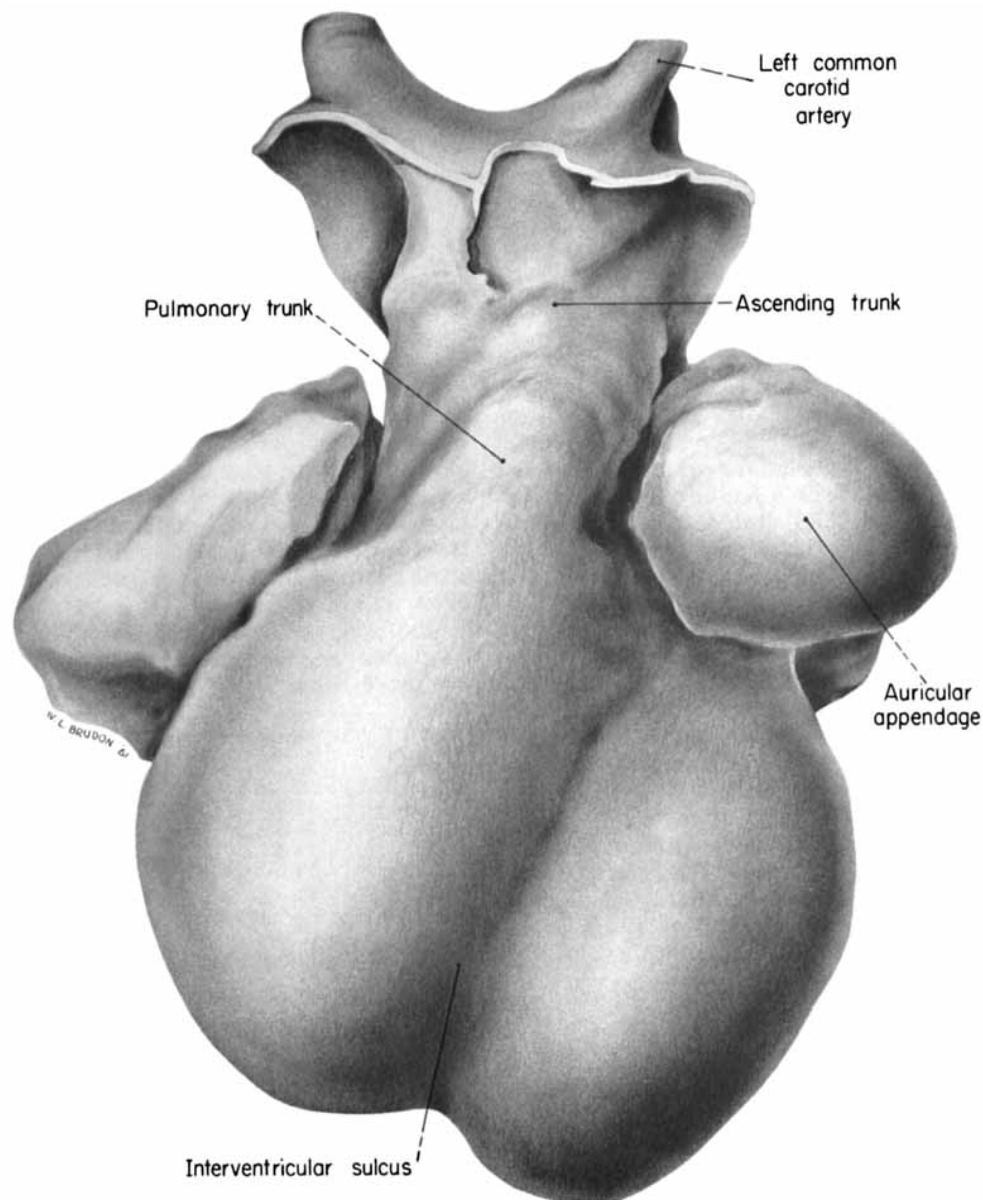

Fig. 1 Ventral view of a wax-plate reconstruction of the human embryonic heart in the seventh week of development. (Reconstruction × 100, illustration × 50.)

The continuity between the primordial pulmonary arteries (fig. 2) and the right sixth aortic arch is obscured by the mass of tissue deep to the cut surface of the dorsal mesocardium, although the more distal portions of these arteries can be seen projecting from this cut surface enroute to the developing lungs.

The four pulmonary veins converge into a common trunk, the pulmonary inlet, before entering the left atrium (fig. 3). Los ('58) refers to this dilated pulmonary inlet as the spatium pulmonale.

The wide lumen of the left common cardinal vein, and to a lesser extent that of the right, narrow (fig. 3) as they become continuous with the horns of the sinus venosus (venous sinus).

The left horn of the venous sinus has become more elongated than the right and

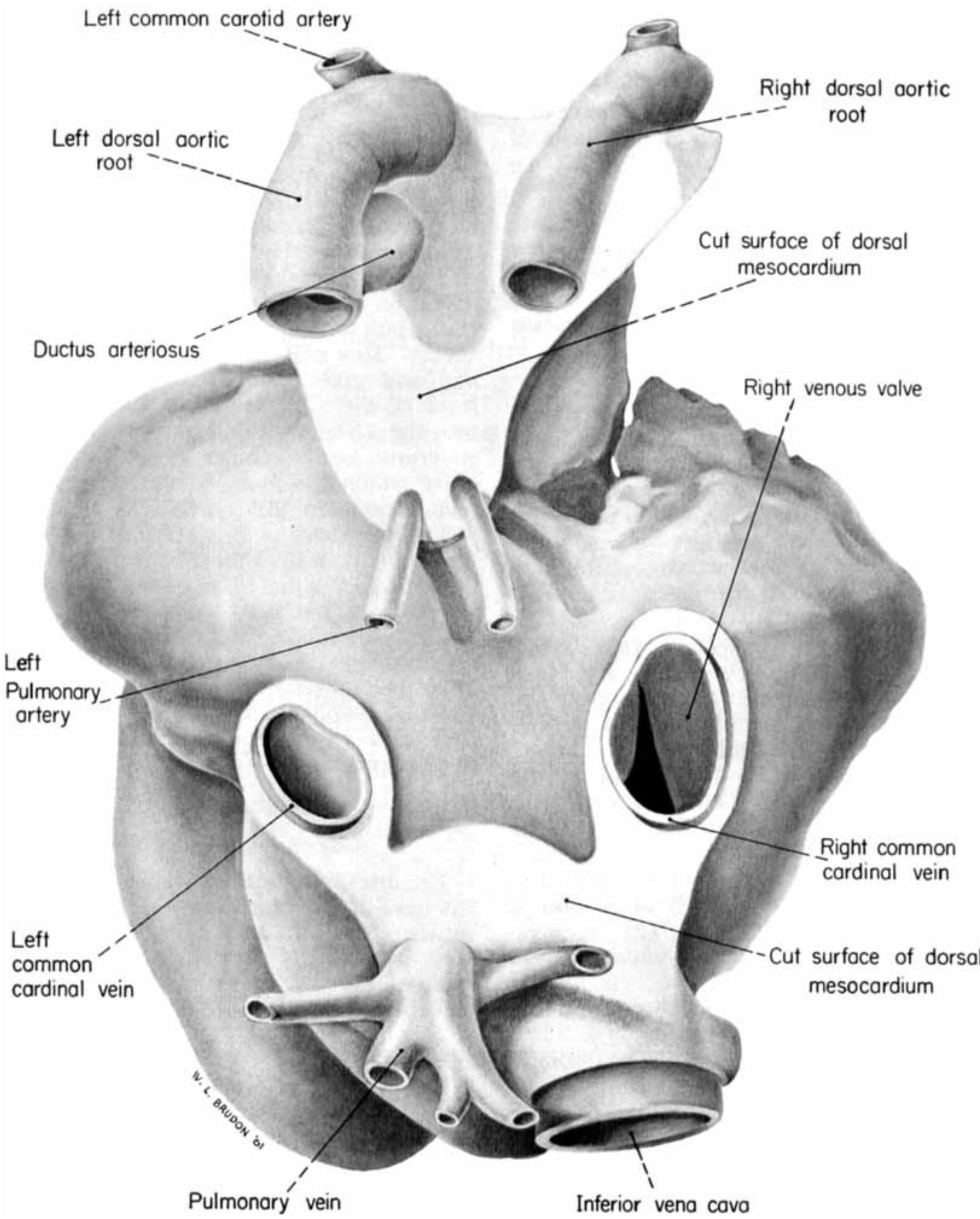

Fig. 2 Dorsal view of a wax-plate reconstruction of the human embryonic heart in the seventh week of development. (Reconstruction × 100, illustration × 50.)

passes diagonally across the dorsal wall of the heart in what approximates its ultimate position as the coronary sinus.

The anterior surface of the heart is devoid of attachment to the ventral body wall. Ventral attachments are found on the anterior surfaces of the ascending aorta and inferior caval vein.

The originally continuous dorsal mesocardium has separated into a venous and an arterial segment. The cut surfaces of these dorsal attachments are indicated by the light areas in figure 2.

The vessels of the coronary circulation are not apparent externally as yet although the proximal portions of the more major channels can be found in sections of the epicardium in the atrioventricular sulcus.

Internal structure

The most conspicuous structures within the atrial chambers are the primary interatrial septum and the right and left venous valves. There is no evidence of the secondary interatrial septum which if present would lie between the left venous valve and the primary interatrial septum in a recess referred to by Tandler ('12) as the interseptovalvular space.

The primary interatrial septum is distinguished by the large secondary interatrial ostium which occupies almost the entire cephalic half of this partition. The primary interatrial ostium has been completely obliterated by the fusion of the primary septum with the endocardial cushion masses which have partitioned the atrioventricular canal.

The left and right venous valves are both well developed, the left being almost as prominent as the right. The right venous valve forms a baffle which directs the blood leaving the sinus venosus toward the interatrial orifice and away from the chamber of the right atrium.

Both venous valves unite in the cephalodorsal portion of the right atrium, above the level shown in figure 3, to form the prominent, but transitory, septum spurium. From this ridge, the valves flare out (fig. 3) to enclose the deep sinal bay (Licata, '54) of the right atrium. Into this chamber is discharged the blood from the inferior caval vein and from the left and right horns of the venous sinus.

In the floor of the sinal bay, a ridge is visible between the orifices of the inferior caval vein and the coronary sinus (fig. 3). This ridge extends from the basal tip of the left venous valve in a dorsolateral direction toward the medial surface of the right venous valve.

The unguarded orifice of the pulmonary inlet (spatium pulmonale) is located in the floor of the left atrium in a bay which is similar to the sinal bay of the right atrium (fig. 3). The medial wall of this bay is partly formed by the primary interatrial septum. The atrial wall lateral to this pulmonary bay exhibits a local proliferation which Los ('58) refers to as the crista pulmonalis sinistra (left pulmonary crest). This crest deepens the pulmonary bay and marks the area where the left horn of the sinus venosus was absorbed into the atrial wall externally. The corresponding, but less clear, right pulmonary crest, which Los found at this stage is not recognizable in this model.

The ventricles at this stage are of similar size with walls that are richly trabeculated and of equal thickness. The conus ridges have not fused and the ventricles are in open continuity in this area. In the region of the atrioventricular canals, however, the interventricular septum has met the fused endocardial cushions, and the ventricles are separated from each other at this point.

DISCUSSION

External configuration

The discrepant size relation between the left and right fourth aortic arches and between the left and right dorsal aortic roots heralds the development of the left channel into the main systemic channel and the development of the right into the proximal portion of the right subclavian artery.

The convergence of the four pulmonary veins into a common channel before entering the left atrium gives little indication that they will subsequently enter this chamber separately after the common trunk has been absorbed into the back of the heart at later stages of development.

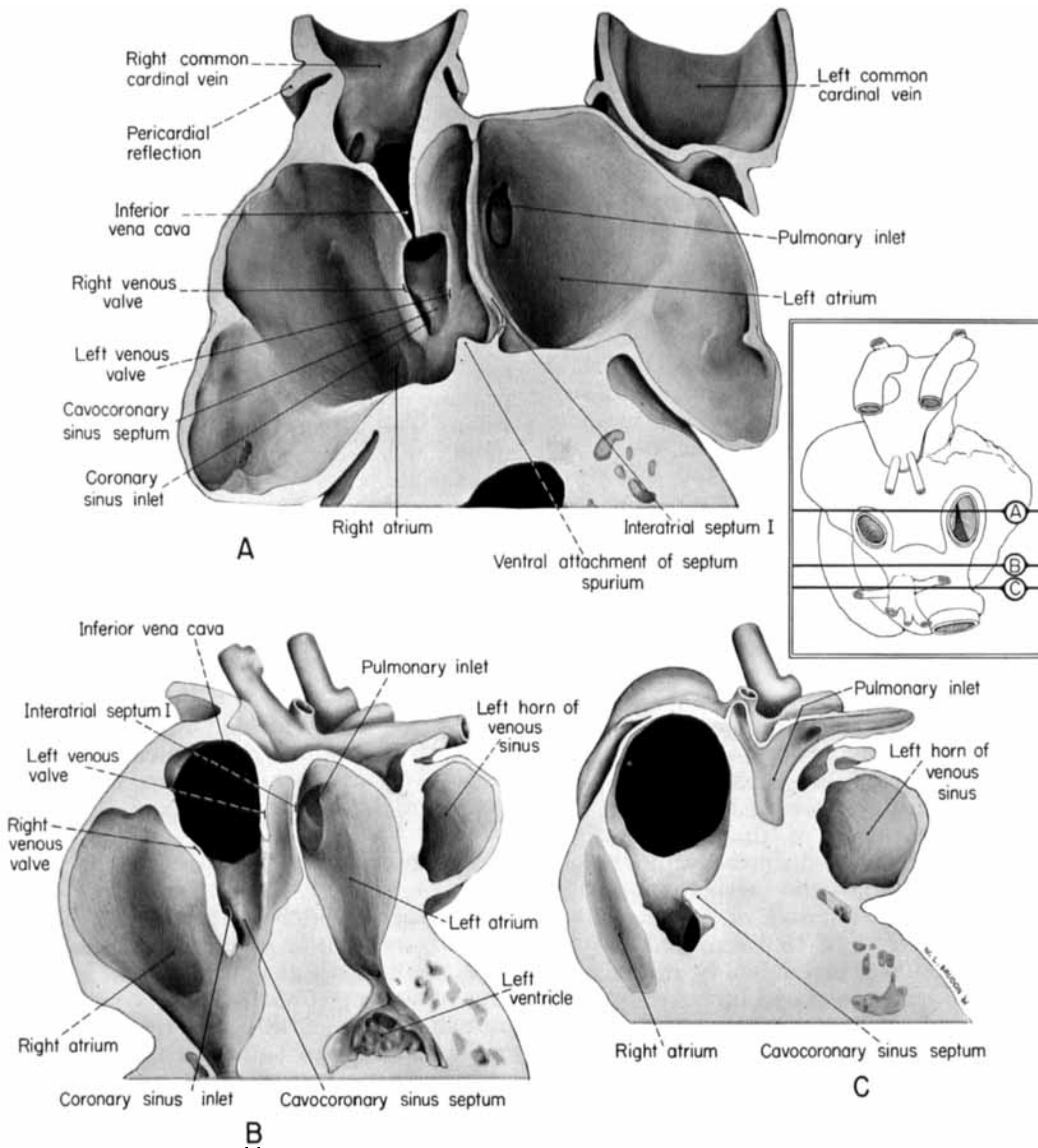

Fig. 3 Internal structure revealed as succeeding segments of the model are removed. (Reconstruction × 100, illustration × 32.)

The lumina of the common cardial veins are surprisingly wide relative to the caliber of the anterior and posterior cardinal veins. The boundary between common cardinal vein and sinus horn is indicated by the conspicuous narrowing of the channel that has been described by Los ('58) in even younger embryos (4.4 mm cr length).

The position and the elongation of the left sinus horn, as well as its point of entry into the right atrium, graphically illustrate the path followed by the venous sinus in its shift to the right of an original midline position.

The cut attachments to the ventral body wall that are visible on the anterior surfaces of the ascending aorta and inferior caval vein are not, according to James Baker (personal communication), remnants of a vanishing ventral mesocardium that arose from the fusion of separate lateral primordia. Examination of earlier stages of development indicates that they are actually formed by the extension of the pericardial cavity on each side of them.

The relatively broad arterial and venous segments of the dorsal mesocardium give little indication of the further narrowing of these dorsal attachments of the heart that will later occur. Only in the portions proximal to the cut surfaces of the right and left sinus horns is there some suggestion of this reduction. This is more apparent in the mesocardium associated with the distal portion of the left sinus horn presaging the formation of the ligamentous fold of Marshall in this area.

Internal structure

The absence in the interseptovalvular space of any evidence of the secondary interatrial septum casts some doubt upon the validity of the predictions of some investigators, such as Patten ('53), that this structure is always present at this stage. Odgers ('35) and Los ('58) reported that they were unable to find any definite indication of this septum until embryos had attained a crown-rump length of 17.5 and 19.0 mm, respectively. The fact, however, that two of the five other hearts from 14.0 to 15.0 mm embryos examined in the current study did exhibit recognizable secondary interatrial septa confirms, I feel, the prediction that this structure appears during the seventh week; but suggests that it is not so well-developed as had previously been supposed. The discrepancies between the various times at which the first appearance of the secondary interatrial septum has been reported emphasizes the necessity for examining more specimens at each stage of development in order to take individual variability into fuller account.

The extent of the foramen in the cephalic half of the primary interatrial septum would seem to permit the septum to offer only minimal resistance to interatrial flow. The area of this orifice is many times greater than that of the inferior caval vein (fig. 3). Licata ('54) reports that in the ninth week of development the area of the interatrial functional orifice is roughly equal to the area of the inferior caval inlet, and Patten, Sommerfield, and Paff ('29) describe this area at term as being only 40% of that of the inferior caval vein. Patten points out that this relative diminution in the size of the interatrial communication is correlated with the increasing pulmonary return to the left atrium as the lungs develop.

The flow of blood from the right to the left atrium is further encouraged by the position of the well-developed right venous valve. The effectiveness of this arrangement is demonstrated by the essentially similar size of the two atria in spite of the striking differences in size of the venous channels discharging into them. Some investigators were so intrigued with the efficiency of this set-up that they felt little or none of the inferior caval stream could escape being shunted into the left atrium. The various ingenious technics employed by Pohlman ('07, '09); Kellogg ('28, '30); Patten, Sommerfield, and Paff ('29); and Barclay, Franklin, and Prichard ('44) demonstrated conclusively, however, that not all of the inferior caval stream passes into the left atrium.

The integrity of the right venous valve has not, as yet, been violated by the thinned areas which will presage the subsequent resorption of much of this structure with the occasional persistence of strands that make up Chiari's net. Of the six human hearts of this age that were examined, only one exhibited such thinned areas. There is apparent in the model, however, a finger-like process which projects from the dorsal wall of the right sinus horn into the lumen of the sinus venosus. Such a structure would perhaps account for those portions of Chiari's net that are occasionally encountered in a position too medial to be considered a persistence of a portion of the right venous valve.

The left venous valve which Odgers ('35) described as being more prominent than the right in the 5 mm embryo is still well-developed but is by this time smaller than the right. Its position is such as to supplement the interatrial septum in forming a partial barrier to the flow of blood from the inferior caval vein into the left atrium.

The ridge that is present in the floor of the sinal bay of the right atrium marks the point where, in younger stages, the left and right sinal horns originally met. This primordium of the venous sinus septum will continue to develop until it completely separates the inlets of the inferior vena cava and left sinus horn. In the course of this development it will meet and fuse with the medial surface of the right venous valve which is thereby subdivided into the (Eustachian) valve of the inferior vena cava and the smaller, lower (Thebesian) valve of the coronary sinus. This partition is the structure that has been named the venous sinus septum by Los ('58), the cavocoronary sinus septum by Licata ('54), the sinus septum by Tandler ('12), and the *Querfalte* by Born (1888).

The medial wall of the pulmonary bay of the left atrium is formed by that portion of the primary interatrial septum that has not been perforated by the interatrial orifice. This arrangement serves to limit the flow of pulmonary blood across the interatrial septum into the right atrium. A further functional significance to the relationship between the orifice of the pulmonary inlet and the primary interatrial septum is pointed out by Licata ('54) who suggests that, at later stages, the mounting return of blood entering the heart at this point from the rapidly developing lungs would tend to crowd the primary interatrial septum against the secondary interatrial septum and encourage fusion.

The lateral wall of the pulmonary bay is formed by the left pulmonary crest. The gully-like channel between this pulmonary crest and the primary interatrial septum extends in the floor of the left atrium from the pulmonary inlet to the left atrioventricular canal.

SUMMARY

1. A wax-plate reconstruction of a heart from a human embryo in its seventh week of development with a crown-rump length of 14.5 mm and in Streeter's Developmental Horizon early XVIII is described. Sections of five other embryos, of a similar age, were examined and compared with the model.

External configuration

2. The four chambers of the heart and the associated major vessels are externally apparent in a close approximation to their adult positions. The pulmonary trunk arises anterior to the ascending aorta, arches around to the left of it, and connects with the anterior surface of the left dorsal aortic root via the large ductus arteriosus. The larger size of the left aortic channel presages its persistence as the dominant systemic channel accompanied by a relative reduction of the right into the proximal part of the right subclavian artery. The pulmonary arteries are small but conspicuous channels which project into the dorsal body wall. The four pulmonary veins enter the left atrium via a common trunk, the pulmonary inlet. The left horn of the sinus venosus is elongated. Its diagonal position across the back of the heart approximates the position it will occupy as the coronary sinus and reflects the path of the shift of the sinus venosus to the right from an original midline position. The proximal portions of the vessels of the coronary circulation are visible in sections of the epicardium in the atrioventricular sulcus.

3. The dorsal mesocardium has separated into a venous and an arterial segment, while the ventral mesocardium is absent. Ventral attachments are present on the anterior surfaces of the aortic trunk and inferior caval vein.

Internal features

4. The atrial chambers conspicuously exhibit a primary interatrial septum, left and right venous valves, and septum spurium. The secondary interatrial septum is absent from the model although two of the five other hearts examined did demonstrate a recognizable secondary interatrial septum. A large secondary interatrial foramen occupies, almost completely, the cephalic half of the primary septum. The well-developed right venous valve is located so as to direct the blood entering from the inferior caval vein toward the

interatrial orifice. The left venous valve is also well developed but is somewhat smaller than the right.

5. The sinal bay of the right atrium is deep and sheltered by the venous valves. The primordium of the cavocoronary sinus septum is present as a ridge in the floor of the sinal bay between the orifices of the inferior caval vein and the left sinal horn.

6. The inlet (spatium pulmonale) of the pulmonary veins opens into a conspicuous channel (pulmonary bay) in the floor of the left atrium.

7. The ventricles are in open continuity in the region of the unfused conus ridges but are separated in the area where the interventricular septum has become attached to the fused endocardial cushion masses of the atrioventricular canal. There is, as yet, no distinction between what will be the membranous and muscular portions of the interventricular septum. Both ventricles are similar in size, thickness of walls, and amount of trabeculation.

LITERATURE CITED

Barclay, F. P., K. J. Franklin and M. L. Prichard 1944 The Foetal Circulation. Charles C Thomas, Springfield, Ill., XVI + 275 pp.

Born, G. 1883 Die Plattenmodellirmethode. Arch f. mikr. Anat., *22:* 584–599.

——— 1888 Uber die Bildung der Klappen, Ostien, und Scheidewande im Saugetierherzen. Anat. Anz., III Jahrg., *3:* 606–612.

Chiari, H. 1897 Ueber Netzbildungen im rechten Vorhofe des Herzens. Beitr. z. path. Anat. u.z. Allg. Path., *22:* 1–10.

Kellogg, H. B. 1928 The course of the blood through the fetal mammalian heart. Anat. Rec., *42:* 443–465.

——— 1930 Studies on the fetal circulation of mammals. Am. J. Physiol., *91:* 637–648.

Kramer, T. C. 1942 The partitioning of the truncus and conus and the formation of the membranous portion of the interventricular septum in the human heart. Am. J. Anat., *71:* 343–370.

Licata, R. H. 1954 The human embryonic heart in the ninth week. Ibid., *94:* 73–125.

Los, J. A. 1958 De Embryonale Ontwikkeling van der Venae Pulmonales en de Sinus Coronarius Bij de Mens. Doctoral Dissertation, Rijksuniversiteit te Leiden, Drukkerij "Luctor et Emergo" — Leiden. 131 pp. + 56 figs.

Odgers, P. N. B. 1935 The formation of the venous valves, the foramen secundum and the septum secundum in the human heart. J. Anat., *69:* 412–422.

Patten, B. M., A. Sommerfield and G. H. Paff 1929 Functional limitations of the foramen ovale in the human foetal heart. Anat. Rec., *44:* 165–178.

Patten, B. M. 1953 Human Embryology. The Blakiston Division, McGraw-Hill Book Co., Inc., New York, 2nd ed., XVII + 798 pp.

——— 1960 The Development of the Heart. Gould, The Pathology of the Heart. Charles C Thomas, Springfield, Ill., 2nd ed., Chap. *II:* 24–92.

Pohlman, A. G. 1907 The fetal circulation through the heart. A review of the more important theories, together with a preliminary report on personal findings. Johns Hopkins Hosp. Bull., *18:* 409–412.

——— 1909 The course of the blood through the heart of the fetal mammal, with a note on the reptilian and amphibian circulations. Anat. Rec., *3:* 75–109.

Streeter, G. L. 1948 Developmental horizons in human embryos. Description of age groups XV, XVI, XVII, and XVIII, being the third issue of a survey of the Carnegie Collection. Contrib. to Embryol., Carnegie Inst. of Washington, *32:* 133–203.

Tandler, J. 1912 The development of the heart. In Keibel and Mall, Manual of Human Embryology. J. B. Lippincott Co., Philadelphia, *2:* 534–570.