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THE INTERVENTRICULAR SEPTUM

BY

E. W. T. MORRIS

From the Anatomy Department, St. Thomas's Hospital Medical School, London

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It is difficult to find in the literature a clear and concise account of the development and form of the interventricular septum. Moreover, some of the accounts in the clinical literature are at variance with that generally accepted by embryologists. For this reason and in view of the recent technical advances in the surgery of the heart, it seems opportune to describe the development and anatomy of the interventricular septum and to correlate this knowledge as far as possible with the sites of interventricular septal defects.

At an early stage the heart consists of the sinus venosus, the common atrium, the common ventricle, and the bulbus cordis, serially arranged in that order from the venous to the arterial end (Figs. 1 and 2).

The formation of the interventricular septum is a complicated process involving the partitioning of the common ventricle into a right and left, and the separation of the distal part of the bulbus cordis into pulmonary and aortic outflow channels in continuity with the ventricles, the proximal portion of the bulbus cordis forming the infundibulum of the right ventricle.

The process begins at about 5 mm. crown–rump length (35th day) and normally ends about 17 mm. crown–rump length (49th day).

The septum is formed from the following structures, which begin their contribution in this order: (1) the muscular wall of the common ventricle, (2) the bulbar ridges, and (3) the dorsal atrioventricular cushion.

(1) The muscular contribution starts as a ridge on the dorsal wall (Fig. 3) and extends on to the ventral wall of the common ventricle. It is then crescentic in form and its dorsal horn reaches the right end of the dorsal atrioventricular cushion. The ventral horn approaches the ventral atrioventricular cushion near its centre (Fig. 4). While this septum is forming the central parts of the atrioventricular cushions fuse (11 mm. C.R.L.). The ventricles now communicate by a foramen, the boundary of which is formed mainly by the free border of the muscular septum, except between the tips of its two horns where the boundary is formed by the fused atrioventricular cushion (A, in Fig. 4). This septum does not lie in one plane and the main part of its free border forms a spiral (Figs. 4 and 5).

(2) While the muscular part is forming. changes are taking place in the relative positions of the bulbus cordis and the ventricles. Earlier the heart tube is flexed at the bulboventricular junction so that the bulbus cordis comes to lie ventrally and to the right of the ventricle (Fig. 2). Their contiguous walls form a septum—the bulboventricular septum—around the lower free border of which the two cavities communicate (see Figs. 1, 2, and 3). This septum intervenes between the distal part of the bulbus cordis and the atrioventricular opening (Fig. 3). It must disappear before the interventricular septum can be completed.

The absorption of the bulboventricular septum takes places while the muscular septum is forming, and, as a result and of unequal growth rates in the different parts, the cavity of the upper part of the bulbus cordis comes to lie astride the middle and dorsal parts of the upper free border of the muscular septum (Fig. 4). The next step has meanwhile begun; it is the division of the distal part of the bulbus cordis by two ridges, the right and left bulbar ridges, which grow from its walls and ultimately fuse. These ridges start distally and grow proximally (caudally). One grows down the right side of the dorsal wall of the bulb to the right end of the ventral component of the fused atrioventricular cushions opposite the attachment of the dorsal horn of the muscular septum to the dorsal component. In its progress this ridge grows over and obliterates the ventral part of the right atrioventricular canal (Fig. 4). The other ridge grows down the left side of the ventral wall of the bulbus cordis and approaches and fuses with the muscular septum on its right side a little distance along its margin from its ventral end (Figs. 4 and 5). The ventral end of the muscular septum lies to the left of the left

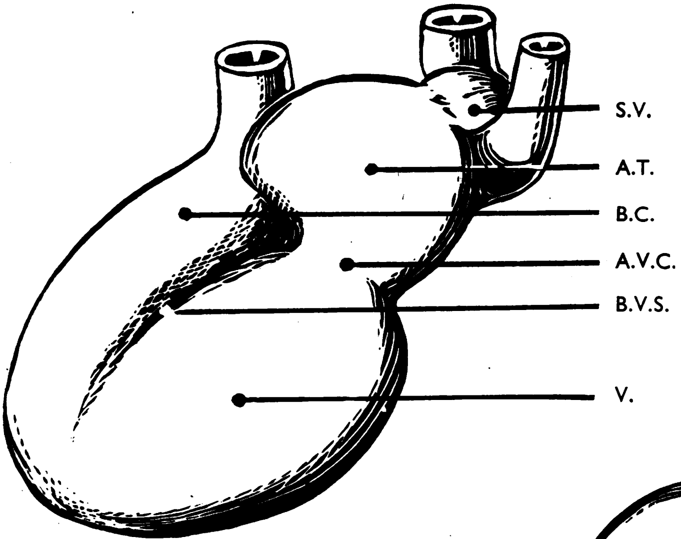
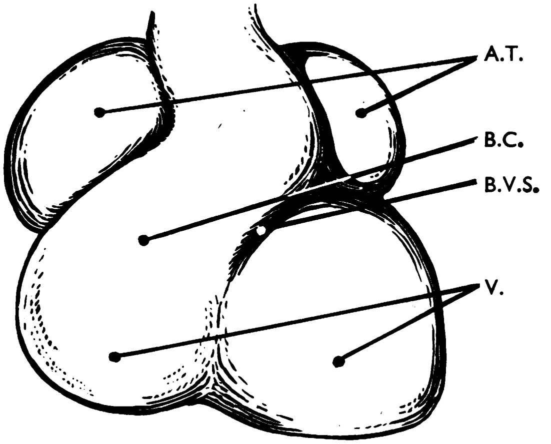


FIG. 1.—Left lateral view of foetal heart. S.V., sinus venosus. A.T., common atrium. A.V.C., atrioventricular canal. V., common ventricle. B.C., bulbus cordis. B.V.S., bulboventricular septum.

FIG. 2.—Ventral view of heart in Fig. 1. Key as in Fig. 1.

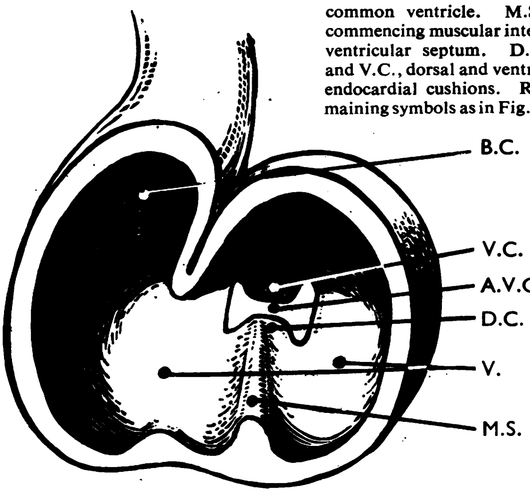


bulbar ridge. When the interventricular septum is completed the part of the original interventricular foramen, which is bounded by the ventral horn of the muscular septum and the fused atrioventricular cushions between the horn tips, also lies to the left of the completed interventricular septum and so in the outflow channel of the left ventricle, and the ridge formed by the ventral horn is subsequently absorbed leaving a smooth wall. The interatrial septum joins the atrial aspect of the fused atrioventricular cushions about their centre. As a result the fused atrioventricular cushions between the attachment of the interatrial septum and the dorsal horn of the muscular septum intervene between the outflow part of the left ventricle and the right atrium (Fig. 9). This becomes reorientated and finally lies in the plane of the interventricular septum. In the final form of the heart it becomes the atrioventricular part of the pars membranacea septi (Fig. 7C).

At this stage in the formation of the interventricular septum the distal bulbus cordis is divided by a septum with a lower free border which forms the upper boundary of a deficiency in the interventricular septum, the lower boundary of which is formed by the upper free border of the muscular part (Fig. 6). Through this septal defect the two ventricles communicate.

(3) This aperture is closed and the septum thus completed by tissue derived from the dorsal atrioventricular cushion in the neighbourhood of the attachment of the right bulbar ridge and the

FIG. 3.—Model of posterior part of the bulbus cordis and common ventricle. M.S., commencing muscular interventricular septum. D.C. and V.C., dorsal and ventral endocardial cushions. Remaining symbols as in Fig. 1.



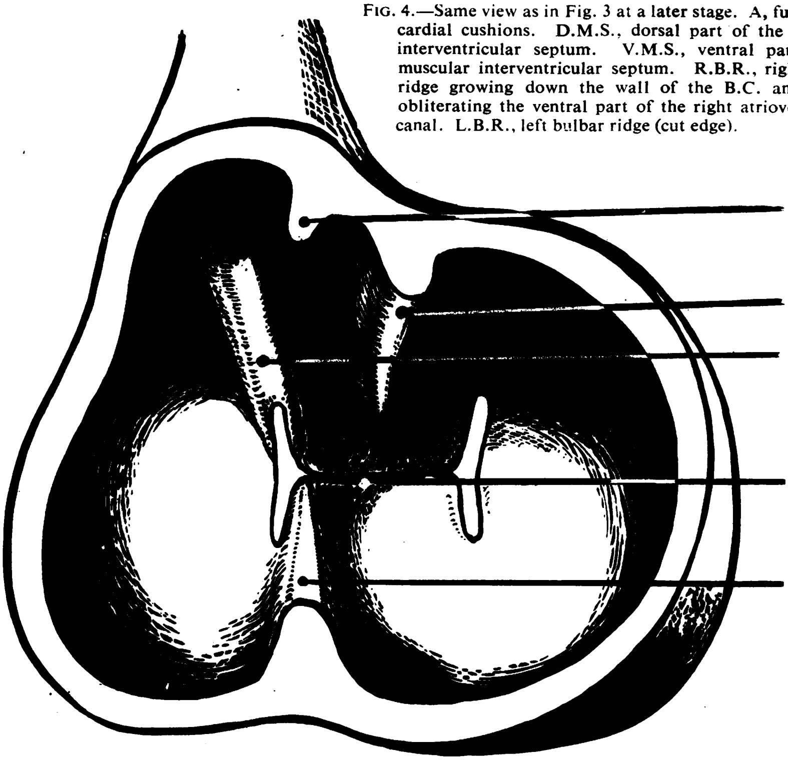


FIG. 4.—Same view as in Fig. 3 at a later stage. A, fused endocardial cushions. D.M.S., dorsal part of the muscular interventricular septum. V.M.S., ventral part of the muscular interventricular septum. R.B.R., right bulbar ridge growing down the wall of the B.C. and finally obliterating the ventral part of the right atrioventricular canal. L.B.R., left bulbar ridge (cut edge).

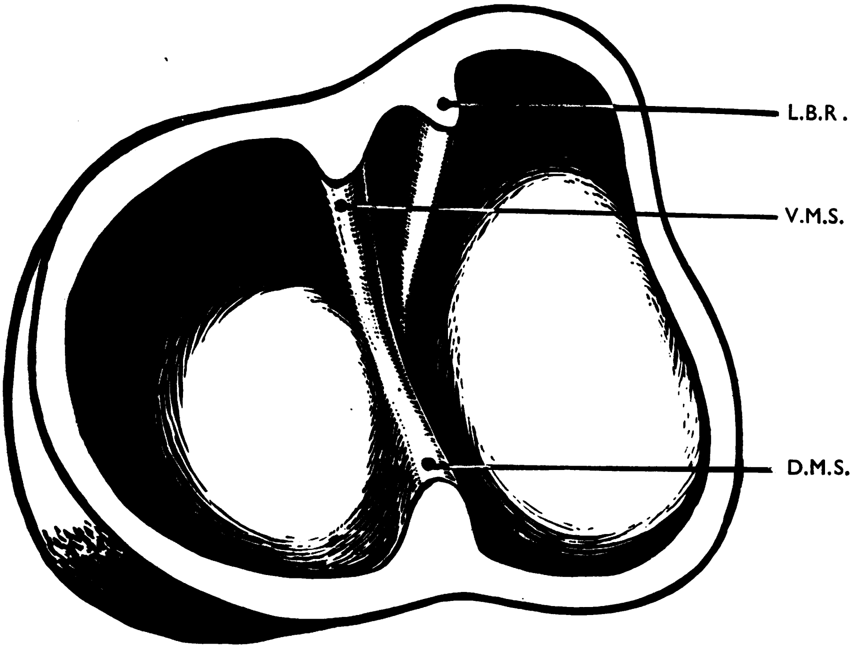


FIG. 5.—The anterior part of the same model as **Fig. 4**. Key as in **Fig. 4**.

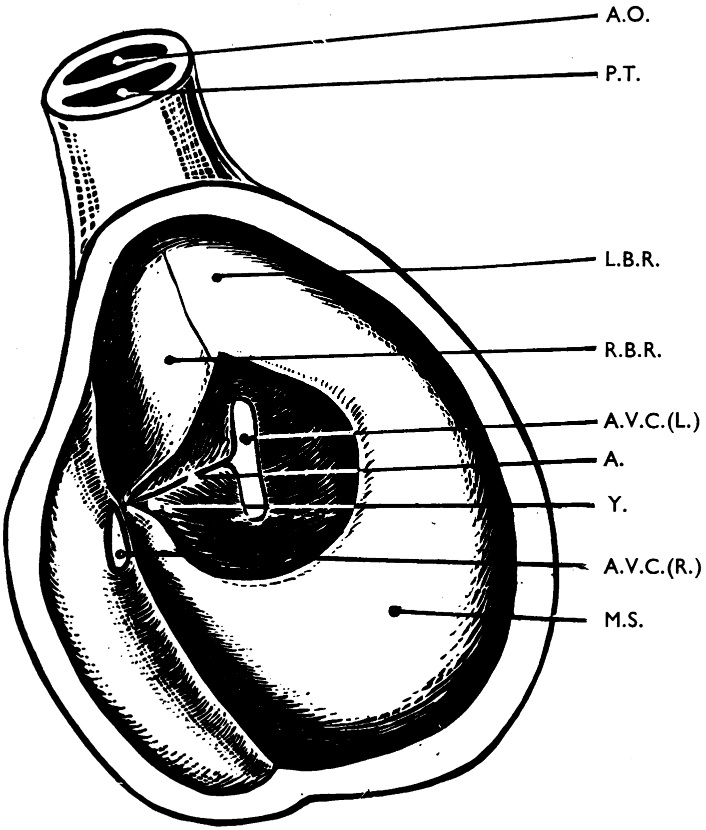


FIG. 6.—Model of a foetal heart at a later stage than Figs. 4 and 5. The bulk of the wall of the future right ventricle has been removed. P.T., pulmonary trunk. A.O., aorta. Y, site of origin of tissue from dorsal endocardial cushion which completes the interventricular septum. Other symbols as in Fig. 4.

dorsal end of the muscular septum (Fig. 6). This tissue grows along and becomes fused with the edges of the aperture from dorsal to ventral.

The Anatomical Situation of the Embryological Components in the Final Form of the Interventricular Septum

The Muscular Part.—This forms the bulk of the septum.

The Bulbar Septum.—This forms the division between the outflow channels and is continuous below with the anterior part of the muscular septum. As seen from the left ventricle it forms the part of the interventricular septum below the commissure of the two septal (coronary) cusps of the aortic semilunar valve and the adjacent parts of these cusps. This aspect of this part of the septum contains no ventricular muscle. From the right ventricular aspect this part is seen to form the upper anterior part of the interventricular septum which lies below the corresponding commissure in the pulmonary valve. On this side, the septum is muscular up to the semilunar valve. A needle passed through the septum in the commissure between the septal cusps of the aortic valve emerges into the right ventricle at the commissure between the corresponding cusps in the pulmonary valve (Figs. 7 and 8).

Part Formed from Dorsal Atrioventricular Cushion.—This forms the interventricular part of the pars membranacea septi. It lies anterior to the atrioventricular part of the pars membranacea septi and the whole pars membranacea septi lies below and behind the bulbar septum and above the middle of the upper border of the muscular septum (Figs. 7 and 8). As seen from the left ventricle, the pars membranacea septi lies below the commissure between right septal and non-septal cusps of the aortic valve and extends forwards below the adjacent half of the right septal cusp (Fig. 7).

The anterior part of the attached border of the septal cusp of the mitral valve crosses the pars membranacea septi between the atrioventricular and interventricular parts (Figs. 7 and 8).

Other Features of the Right Ventricular Surface of the Interventricular Septum

Crista Supraventricularis.—From the point of view of classifying septal defects the important structure is the crista supraventricularis. This is a smooth ridge of myocardium in the anterior wall of the right ventricle lying parallel and close to the attachment of the large anterior cusp of the tricuspid valve. It enlarges as it travels towards the left and ends by fusing with the interventricular septum between the part formed from the bulbar ridges and the interventricular part of the pars membranacea septi.

Conus Muscle.—Arising from the septum just below the attachment of the crista supraventricu-

FIG. 7.—Outflow region of left ventricle. Rod A passes through septum separating the outflow channels of the right and left ventricles between the septal cusps of the aortic valve in the line of fusion of the bulbar ridges. This is the site of type (*a*) defect. Rod B marks the line of attachment of the septal cusp of the tricuspid valve to the opposite side of the septum. It divides the pars membranacea septi into a larger atrioventricular part (*c*) and a smaller interventricular part (*d*); where the latter joins the muscular septum (*x*) is the site of type (*b*) defects. E, septal cusp of the mitral valve.

laris are a group of papillary muscles to which are attached the chordae tendinae of the adjacent parts of the anterior and septal cusps. One of these is usually larger than the rest, and this is then called the conus muscle.

CONDUCTING SYSTEM

ATRIOVENTRICULAR BUNDLE.—Arising from the atrioventricular node, the bundle passes into and through the trigonum fibrosum dexter and thence into the lower border of the atrioventricular septum, which lies just anterior to the trigone. It passes from the atrium into the ventricle at the junction of the atrioventricular septum and interventricular part of the pars membranacea septi and runs in the latter at its fusion with the muscular septum or on either side of the upper border of the muscular septum.

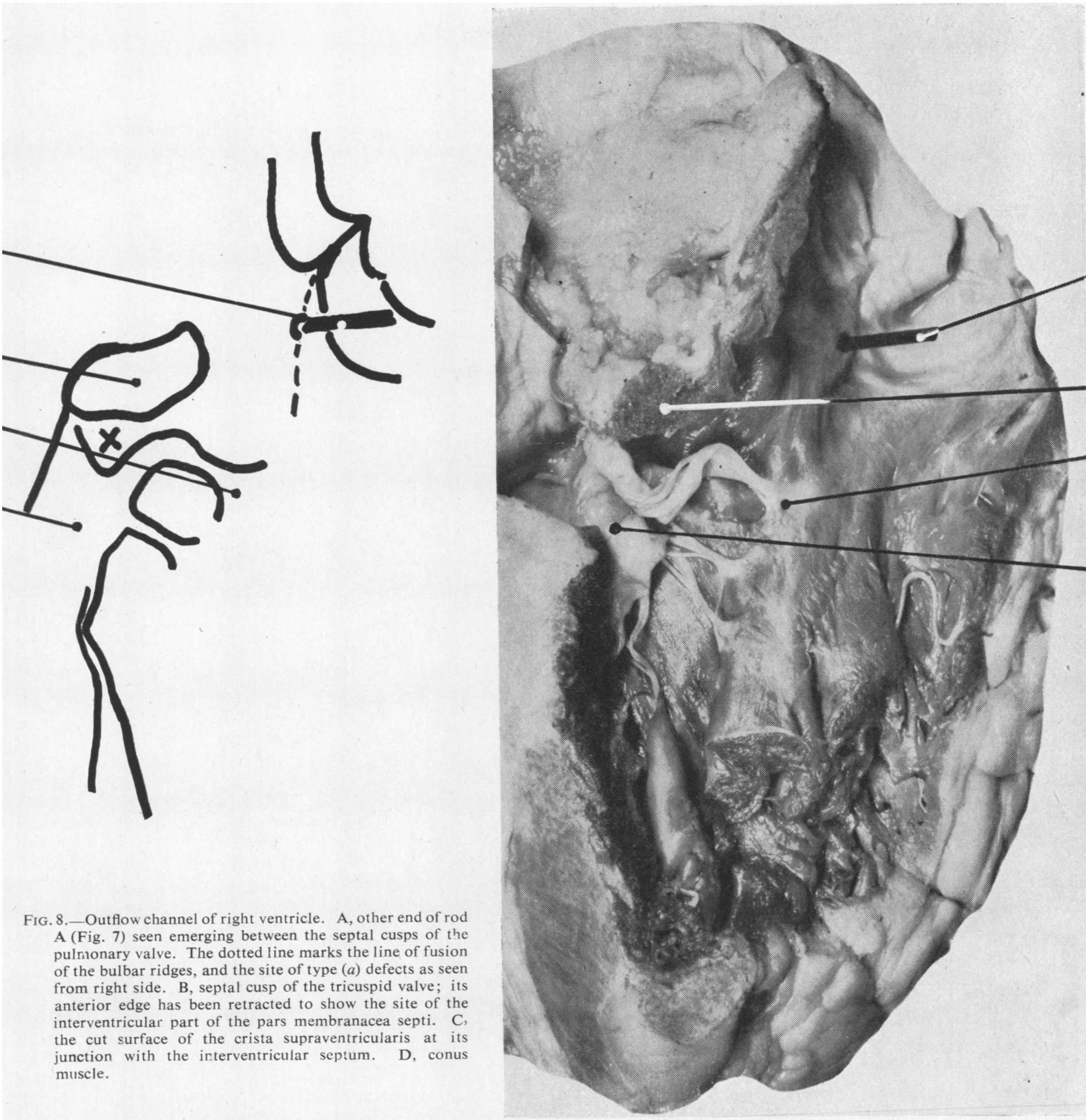


FIG. 8.—Outflow channel of right ventricle. A, other end of rod A (Fig. 7) seen emerging between the septal cusps of the pulmonary valve. The dotted line marks the line of fusion of the bulbar ridges, and the site of type (*a*) defects as seen from right side. B, septal cusp of the tricuspid valve; its anterior edge has been retracted to show the site of the interventricular part of the pars membranacea septi. C, the cut surface of the crista supraventricularis at its junction with the interventricular septum. D, conus muscle.

Right Branch.—The right branch is a direct continuation of the bundle and curves downwards towards the apex, either subendocardially or buried in the muscle. In this part of its course it runs dorsal to the conus muscle and in some hearts can be traced into the moderator band.

Left Branch.—The left branch arises from the atrioventricular bundle at varying sites from the point where it emerges from the trigonum to its end. It usually forms a flat subendocardial band of parallel fibres of paler colour than the true myocardial tissue and running in a different direction. The fibres fan out and two bands can sometimes be seen, one going to the neighbourhood of each papillary muscle.

Development

The conducting tissue can be recognized as differentiating from the cardiac musculature

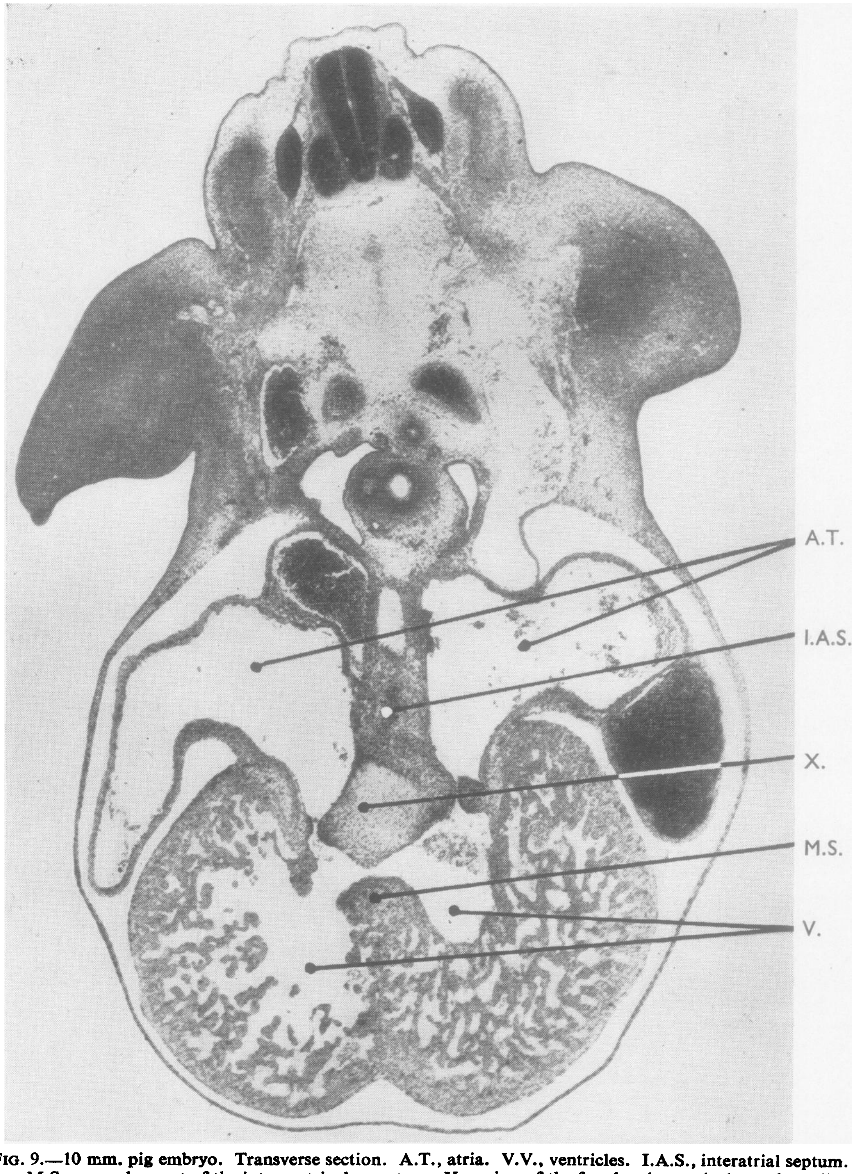


FIG. 9.—10 mm. pig embryo. Transverse section. A.T., atria. V.V., ventricles. I.A.S., interatrial septum. M.S., muscular part of the interventricular septum. X, region of the fused atrioventricular endocardial cushion which forms the atrioventricular part of the pars membranacea septi.

during the sixth week (C.R.L. 7–9 mm.) and rapidly extends, then the atrioventricular node is recognizable in the posterior wall of the atrium and the bundle extends along the dorsal wall of the atrioventricular canal under the dorsal atrioventricular cushion into the upper border of the dorsal horn of the muscular septum, where it divides into a right and left branch. It is therefore *in situ* before the final stage of the septum is complete and is then related to the posterior and inferior borders of the foramen which still exists.

TYPES OF UNCOMPLICATED DEFECTS

These may occur in the following sites:

(*a*) In the septum separating the aortic and pulmonary outflow, i.e., in that part of the septum formed from the bulbar ridges; as seen from the right ventricle they occur above the crista supraventricularis and from both aspects they are situated. below the commissure of the septal cusps of the semilunar valves. Their site is therefore consistent with the bulbar ridges not fusing.

(*b*) In the region of the interventricular part of the pars membranacea septi and adjacent muscular septum: in general these defects as seen from the right ventricle lie between the attachment of the septal cusp of the tricuspid valve and the septal attachment of the crista supraventricularis.

The crista supraventricularis therefore separates type (*a*) from type (*b*), the former lying above and the latter below and behind it (Fig. 8).

(*c*) In the muscular part of the septum: these usually lie near the apex and are sometimes multiple, but may occur in the upper part of the septum posteriorly, under the posterior part of the septal cusp of the tricuspid valve. In this purely muscular defect the atrioventricular bundle and branches will probably lie anterior to and above the defect.

ORIGIN OF THE DEFECTS.—By analogy with the known aetiology of congenital defects of other parts of the body it seems likely that septal defects may result either from failure of fusion of the several parts contributing to the septum, or from a breakdown of the tissue once formed. It seems reasonable to assume that type (*c*) is formed by the latter method. Of types (*a*) and (*b*), it is impossible to say more than that they are in sites compatible with a failure of fusion.

FREQUENCY OF DIFFERENT TYPES OF DEFECT

In a series of 156 cases of ventricular septal defects reported by Warden, DeWall, Cohen, Varco, and Lillehei (1957) and Kirklin, Harshbarger, Donald, and Edwards (1957) six (3.8%) were of type (*a*) and 145 (91.7%) were of type (*b*).

Class (*b*) is thus the most common defect in these series, and this is what might be expected from a consideration of the stages in the development of the septum. This class of defect is compatible with a failure of the final stage in the formation of the septum, that is, the closure of the temporary interventricular foramen by a growth of tissue from the dorsal atrioventricular cushion, and it is in the final stages of a complex embryological process that developmental errors most commonly occur. This leads to a further reflection, namely, that when there are associated congenital defects of the heart the ones most commonly found are those with which a ventricular septal defect is combined to make up the clinical entity of Fallot's tetralogy. In 120 cases of ventricular septal defect in the series of Warden *et al.*, 45 were associated with other structural abnormalities of the heart. In 33 (73.3%) of these cases the associated defects completed the complex of Fallot's tetralogy. In this condition the division of the outflow channel has been completed by the fusion of the bulbar ridges. The stage of development of the interventricular septum which is at fault in this condition is the final stage and the type of interventricular defect associated with it is therefore class (*b*). It seems reasonable to suggest that the final closure of the temporary interventricular foramen by tissue derived from the dorsal atrioventricular cushion represents a critical stage in the development of the heart. Its failure leads not only to the commonest type of uncomplicated interventricular septal defect, but also contributes to the most commonly occurring complex of defects (Fallot's tetralogy). In this condition the other defects arise at a later stage in development than the septal defect which accompanies them.

SUMMARY

The steps in the development of the interventricular septum have been described. Interventricular defects have been simply classified, and the relevant anatomical features of the ventricles have been described.

The possible relationship between the types of defect described and the steps in the development of the interventricular septum have been indicated.

Finally, other congenital defects of the heart frequently associated with interventricular septal defects are briefly discussed. A short bibliography is given which should enable any aspect to be followed up in more detail.

I wish to express my gratitude to Professor D. V. Davies for help and advice, and to Miss Dew for the drawings in Figs. 1 to 6 and to Mr. A. H. Wooding for the photographs of Figs. 7 to 9.

BIBLIOGRAPHY

EMBRYOLOGY

Arey, L. B. (1954). *Developmental Anatomy*, 6th ed. Saunders, Philadelphia.
Frazer, J. E. (1953). *Manual of Embryology*, 3rd ed. Baillière, Tindall and Cox, London.
Hamilton, W. J., Boyd, J. D., and Mossman, H. W. (1952). *Human Embryology*, 2nd ed. Heffer, Cambridge.
Kramer, T. C. (1942). *Amer. J. Anat.*, **71**, 343.
Odgers, P. N. B. (1938). *J. Anat. (Lond.)*, **72**, 247.
Tandler, J. (1912). *Manual of Human Embryology*, Vol. 2, ed. Keibel, F., and Mall, G. P. Lippincott, Philadelphia.

ANATOMY

Johnston, T. B., and Whillis, J. (1954). *Gray's Anatomy*, 31st ed. Longmans, Green, London.
Walmsley, T. (1929). In Quain's *Elements of Anatomy*, 11th ed., Vol. IV, Pt. III. Longmans, Green, London.

CONDUCTING SYSTEM

Field. E. J. (1951). *Brit. Heart J.*, **13**, 129.
Muii, A. R. (1954). *J. Anat.* (*Lond.*), **88**, 381.
Walls, E. W. (1945). Ibid., **79**, 45.
—— (1947). Ibid., **81**, 93.
Widran, J., and Lev, M. (9151). *Circulation*, **4**, 863.

SEPTAL DEFECTS

Abbott, M. E. (1936). *Atlas of Congenital Cardiac Disease.* American Heart Association, New York.
Becu, L. M., Fontana, R. S., DuShane, J. W., Kirklin, J. W., Burchell, H. B., and Edwards, J. E. (1956). *Circulation*, **14**, 349.
Kirklin, J. W., Harshbarger, H. G., Donald, D. E., and Edwards, J. E. (1957). *J. thorac. Surg.*, **33**, 45.
Rokitansky, C. von (1875). *Die Defecte der Scheidewände des Herzens.* Braumuller, Vienna.
Spitzer, A. (1923). *Virchows Arch. path. Anat.*, **243**, 81.
Warden, H. E., DeWall, R. A., Cohen, M., Varco, R. L., and Lillehei, C. W. (1957). *J. thorac. Surg.*, **33**, 21.