Double inlet right ventricle

Two pathological specimens with comments on embryology

Luis Muñoz-Castellanos, María V. de la Cruz, and Andrzej Cieśliński

From the Department of Embryology, Instituto Nacional de Cardiología de México, Av. Cuauhtémoc No. 300, Mexico

This paper describes two pathological specimens of congenital heart disease with double inlet right ventricle in which the ventricular chamber receives the right atrioventricular ostium and partially the left atrioventricular ostium, the two atrioventricular ostia being completely separated.

The published reports are reviewed and only cases of double inlet left ventricle have been found.

An ontogenetic explanation for the malformation described, based on the study of normal human embryos, is presented. Double inlet right ventricle represents a deviation from the normal course of the development of the heart in which the process of expansion of the atrioventricular canal from left to right has been exaggerated, leading to the connexion of the left atrium with the right ventricle. Both hearts had transposition of the great vessels.

An appreciable number of congenital cardiac abnormalities appear to arise from alterations of morphogenetic processes which affect normal development of the cardiovascular system, giving rise to abnormal morphologies. The cases presented in this paper support this concept (De la Cruz and Da Rocha, 1955, 1956; De la Cruz *et al.*, 1959, 1967, 1971b; Saxén and Rapola, 1969).

Two pathological specimens showing a rare cardiac malformation involving the atrioventricular connexions are presented; they were selected from necropsy specimens of the Department of Embryology of the Instituto Nacional de Cardiología de México. The central object of this paper is the malformation which we have named double inlet right ventricle and which is characterized by the right ventricle containing the right atrioventricular ostium and partially or totally the left atrioventricular ostium as well, the two atrioventricular ostia being completely separated. This congenital abnormality is important from a theoretical point of view because it clearly shows an anatomical-embryological correlation.

In the ventricular chambers two areas can be distinguished: one related to the atrioventricular valves, the inflow tract, compressed between the

tricuspid or mitral valvular orifices and the apex, and the other, the outflow tract, located between the apex and the aortic or pulmonary valve cusps. The inflow areas are posterior and related to the atria, the outflow areas are anterior and are related to the emergence of both great vessels.

It is important to point out that the cardiac chambers should not be designated according to their valvular apparatus nor should the incoming or outgoing vessels and neither should they be classified according to the kind of blood contained in them, because these elements are greatly variable in congenital heart disease. The cardiac chambers must be named according to their morphology. That is why the denominations right atrium or ventricle and left atrium or ventricle refer to those cardiac chambers with right or left morphological characteristics, regardless of the position they occupy in space (Lev, 1954; De la Cruz *et al.*, 1971a).

The two malformed hearts are described in detail in order to facilitate comparison with subsequent material related to this type of malformation.

Material

Case 1

The specimen 3315 belonged to a 3-year-old child. The heart formed part of a situs solitus. The ventricles are

FIG. 1 Photographs showing the anatomical features in both cases of double inlet right ventricle. A-A', inside view of the right chambers of the heart. Note how the right atrium opens completely into the right ventricle and the left atrium opens partially into this cavity (probe). B-B', inside view of the left chambers of the heart. A probe has been placed to point out the overriding of the mitral orifice (M) on the ventricular septum, thus, the left atrium communicates with both ventricles. Abbreviations: RA, right atrium; LA, left atrium; RV, right ventricle; LV, left ventricle; T, tricuspid valve; M, mitral valve.

normally situated, the right one is very hypertrophied and the left one has a small cavity, but its walls are normal in thickness. The aorta arises from the right ventricle in front of the crista supraventricularis; it runs parallel and ventral with respect to the pulmonary artery which emerges from the right ventricle also, behind the crista supraventricularis. The pulmonary trunk is of diminished calibre. This vessel presents valvular stenosis and has two sigmoid cusps. There is an interventricular septal defect in the basal portion of the ventricular septum extending from behind the crista supraventricularis to the posterior margin of the ventricular septum; there is a persistent ductus arteriosus.

The right atrium communicates with the right ventricle through the tricuspid orifice. The left atrium opens into both ventricles (Fig. 1A). The mitral orifice overrides the ventricular septum, and most of this valvular orifice is related to the right ventricle (Fig. 1B). Both tricuspid and mitral orifices are completely separated and there is no cleft in the septal leaflet of the tricuspid or in the mitral valves. The septal leaflet of the mitral valve is inserted completely in the right ventricle by means of fine tendons in the papillary muscle of the conus and in the septal surface of this ventricular chamber. The external leaflet is partially inside the left ventricle in both groups of papillary muscles which are small and

partially inside the right ventricle at the septal surface (Fig. 1B).

Anatomical pathological diagnosis Double inlet right ventricle; transposition of the great vessels with stenosis of the pulmonary artery, both vessels arising from the right ventricle, ventricular septal defect, and persistent ductus arteriosus.

Case 2

The anatomical specimen No. 2463 belonged to a 6-year-old girl. The heart formed part of a situs solitus. The ventricles are normally situated. The right ventricle is hypertrophied and the left ventricle has a small cavity but its walls are of normal thickness. The aorta arises from the right ventricle in front of the crista supraventricularis, and the pulmonary artery also emerges from the right ventricle but behind the crista supraventricularis, this vessel being of diminished calibre. It has two sigmoid cusps. There is valvular stenosis. The crista supraventricularis is abnormally thick and muscular. It is very similar to the previous case; there is a large ventricular septal defect which entirely occupies the basal portion of the septum. The right atrium opens into the right ventricle through the tricuspid and the left atrium communicates with both ventricles; this atrium overrides the ventricular septum (Fig. 1A'), and most of the mitral orifice opens into the right ventricle (Fig. 1B'). Both tricuspid and mitral orifices are completely separated and there is no cleft in the septal leaflet of the tricuspid or in the mitral valves. The septal leaflet of the mitral valve inserts inside the right ventricle on a well-developed papillary muscle, located on the septal surface, and the external leaflet inserts on the one hand into the external wall of the left ventricle in both groups of papillary muscles which are small, and, on the other hand, into the right ventricular septal surface (Fig. 1B'). There is a patent foramen ovale and persistent ductus arteriosus.

Anatomical pathological diagnosis Double inlet right ventricle; transposition of the great vessels with stenosis of the pulmonary artery, both vessels arising from the right ventricle; patent foramen ovale; and persistent ductus arteriosus.

Discussion

Double inlet right ventricle exists when this cardiac chamber receives the tricuspid orifice and partially or totally the mitral orifice. This definition excludes therefore cases of tricuspid or mitral atresia, any type of atrioventricular canal defect, atrioventricular accessory valve, double mitral, or tricuspid valve, since these do not constitute true atrioventricular orifices which open into the right ventricle. The accessory orifice is only a slit formed during development of the tricuspid or mitral valve.

When both atria open into the right ventricle, this cardiac chamber can be identified by its typical

anatomical characteristics, consisting of the presence of the anterior papillary muscle, the grossly trabeculated surface of the interventricular septum, the crista supraventricularis constituted by the parietal and septal bands, the latter related to the moderator band, and the muscular infundibulum (Fig. 1A-A'). In this condition, this ventricle is enlarged, and the left ventricle, though small, has all its typical morphological elements well constituted (Fig. 1B and B'). The interventricular septum is well developed and separates both ventricular chambers (Fig. 1A and A', B and B'). The definition of double inlet right ventricle is concerned only with atrioventricular connexions and does not specify the relation of the great arteries which emerge from the heart.

Both cases have striking similarities. The right ventricle receives the whole tricuspid valve and part of the mitral valve, the latter overriding the interventricular septum. This septum and the interatrial one are not aligned in the same plane; the second is located to the right of the first. This lack of alignment between both septa gives rise to a great interventricular septal defect located at the basal portion of the interventricular septum. Attention is called to the crista supraventricularis; in both cases it is atypical, and is very thick.

Among the developmental disorders affecting the atrioventricular canal, double inlet right ventricle is closely related to double inlet left ventricle since both entities originate from alterations in the morphogenesis of the atrioventricular connexions (Mehrizi *et al.*, 1966; De la Cruz and Miller, 1968; Libberthson *et al.*, 1971). For this reason reference to double inlet left ventricle will mean the entity which has been included by other authors in the heterogeneous group of common ventricle or cor triolulare biatriatum (Keith, Rowe, and Vlad, 1958; Van Praagh, Ongley, and Swan, 1964; Fontana and Edwards, 1962; Elliot, Anderson, and Edwards, 1964). It is considered that double inlet left ventricle constitutes a well-established condition which must be removed from the common ventricle group because it has two ventricular chambers with their respective anatomical elements which are separated by the septum, the face of which is more developed on the side of the morphologically left ventricle, this cavity receiving both AV ostia (De la Cruz and Miller, 1968).

By these criteria our double inlet right ventricle cases, and similar ones which may be reported, should also be removed from the common ventricle group, because they constitute an independent entity.

We consider common ventricle is properly defined as the entity in which the interventricular septum does not exist or is represented by a small ventricular crest, and in which there is a single

FIG. 2 Diagrammatic representations that summarize the normal development of the human heart. Frontal sections have been made in a ventral plane in A, B, and C, and in a dorsal plane in D and E (A, B, and C modified from Kramer (1942); D and E from Patten (1953)). Streeter's horizons: A, horizon XIII; B, horizon XVI; C, horizon XVII; D, horizon XIII; E, horizon XVI. Abbreviations: TA, truncus arteriosus; C, conus; BC, bulbus cordis; PV, primitive ventricle; RA, right atrium; LA, left atrium; RV, right ventricle; LV, left ventricle; 1 and 2, ventral and dorsal cushions of the atrioventricular canal; 3 and 4, truncoconal ridges; 5, conoventricular flange; AC, atrioventricular canal; Ao, aorta; P, pulmonary artery; T, tricuspid; M, mitral; VS, ventricular septum.

chamber into which the atria open, and from which the great arteries arise (Anselmi *et al.*, 1968).

In reviewing the published reports, we have not found any similar cases of double inlet right ventricle which fit the requirements stated in our definition; double inlet left ventricle therefore appears to be more frequent. This is probably due to the fact that this cardiac malformation represents the persistence of a normal developmental stage in which both atria are connected to the left ventricle (De la Cruz and Miller, 1968), whereas double inlet right ventricle represents an alteration in normal development of the atrioventricular connexions.

Normal embryology of the heart related to this malformation

In discussing the ontogenetic explanation for this cardiac malformation, it is necessary to review the principal developmental events of the embryonic

heart. Davis, studying early human embryos, identified the following primitive cardiac cavities: the atria, the primitive ventricle, the bulbus cordis, and the bulbus aorticus (Davis, 1927). In addition, he described two endocardial plates formed by endothelial trabeculae extended toward the myocardium, one in the bulbus cordis and the other in the primitive ventricle. Streeter discovered that they give rise to the trabeculated portions of the right and left ventricles, respectively (Streeter, 1942, 1945, 1948). The bulbus cordis and its cephalic portion, called the conus, give rise to all of the right ventricle, comprising its inflow portion and, in addition, the outflow tracts of both ventricles. The primitive ventricle forms only the inflow tract of the left ventricle. This chamber receives its outflow tract when the truncus conus shifts from right to left, owing to the disappearance of the conoventricular flange (Fig. 2).

During the formation of the primitive cardiac

tube, the atria occupy a caudal position; they are connected to the primitive ventricle. When the bulboventricular loop has formed (Streeter's XIII Horizon) (Streeter, 1945), both atria are still connected to the primitive ventricle (future left ventricle) (Fig. 2A). At this stage, the atria occupy a cephalic and dorsal position with respect to both

ventricles. The widening of the atrioventricular canal from left to right begins in the XIII horizon of Streeter and it continues during Streeter's XV horizon (Streeter, 1948). At this stage, the atria are still connected to the left ventricle and the partition of the truncus conus which forms the aortic and pulmonary channels begins. In the XVI horizon the development of the atrioventricular orifices begins (Streeter, 1948). It is at this point that the right atrium connects to the bulbus cordis (future right ventricle), due to the widening and shifting of the atrioventricular canal from left to right. The left atrium remains connected to its proper ventricle (Fig. 2B). The separation of the atrioventricular canal is completed during horizon XVII and the normal atrioventricular connexions are established (Streeter, 1948) (Fig. 2C and E). From the beginning of blood circulation and during horizon XV, the flow of blood follows a route throughout the heart passing from the atria to the left ventricle, then to the right ventricle and to the truncus conus. During the stages in which the right atrium is still connected to the left ventricle, the right ventricular chambers remain small in spite of giving rise to the truncus conus. This fact suggests to us that the left ventricle provides the motile force power which propels blood flow, and the right ventricle is only an outlet chamber. When the right atrium is connected to the right ventricle, this later develops and enlarges rapidly (Fig. 2C and E).

FIG. 3 Drawings that illustrate several stages during which the hypothetically abnormal development processes occur, leading to double inlet right ventricle. Frontal sections have been made in a ventral plane in A and B; and in a dorsal plane in a and b. C = schematic representation showing the most relevant characteristics in double inlet right ventricle. Notice the overriding of the mitral valve on the ventricular septum having the greater part of its area related to the right ventricle and both transposed great vessels arising from this chamber. Streeter's horizons: A, a, horizon XIII; B, b, horizon XVI.

Anatomical-embryological correlation

Embryologically, double inlet right ventricle originates from a precocious and prolonged widening of the atrioventricular canal from left to right. This process does not stop at the time when the interatrial complex septum is aligned with the interventricular septum, but it is continued exaggeratedly to the right (Fig. 3B and b). This abnormal process determines that the right ventricle not only receives the right atrium with which this ventricular chamber improves its development, but partially receives the left atrium as well (Fig. 3B and b).

This abnormal process would prevent the normal alignment between both the interatrial and the interventricular septa, the first located to the right of the latter. In this manner, a ventricular septal defect is originated (Fig. 3b).

The right ventricle is hypertrophied and dilated, and receives blood coming from the right atrium and partially blood from the left atrium, due to the fact that the mitral ring overrides the interventricular septum (Fig. 3C). Most of its area opens on the right ventricle. This abnormal connexion with its

altered haemodynamics conditions the under-developed left ventricle. Theoretically there could be cases in which both AV ostia open completely onto the right ventricle. These cases would appear if the widening of the atrioventricular canal from left to right is prolonged in an exaggerated manner, the mitral orifice remaining completely inside the right ventricle.

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Requests for reprints to Dr. María V. de la Cruz, Department of Embryology, Instituto Nacional de Cardiología de México, Av. Cuauhtémoc No. 300, México 7, D.F.