Developmental anatomy of the membranous part of the ventricular septum in the human heart

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SUMMARY The anatomy of the membranous part of the ventricular septum is described in 25 hearts from patients ranging in age from 15 weeks of gestation to the ninth decade of adult life. Both atrioventricular and interventricular components were recognised in all the adult subjects, and the atrioventricular component was evident in all 25. The interventricular membranous septum was present in only 1 of the fetal hearts and 4 of the infant subjects. We consider that these findings indicate that the transformation of the membranous septum into atrioventricular and interventricular components occurs in the late fetal and early postnatal period rather than during closure of the embryonic interventricular foramen. It is associated with the liberation of the medial leaflet of the tricuspid valve from the muscular ventricular septum.

The morphology of the membranous part of the ventricular septum is well described, particularly its division into atrioventricular and interventricular components (Walmsley, 1930; Odgers, 1938). However, can we be sure how these components are produced? Odgers (1938), endorsed by Goor et al. (1970), argued that the atrioventricular component resulted from fusion of the right bulbar ridge with the right lateral atrioventricular cushion, while the interventricular component was formed by proliferating tubercles so as to obliterate the embryonic interventricular foramen. While this may be the mechanism of closure of the foramen, it is hard to envisage it producing two components of the membranous septum. This is because the septum is divided into its portions by the annular attachment of the tricuspid valve leaflets, and these leaflets are as yet unformed at the time of closure of the secondary interventricular foramen. This fact has important consequences, because defects of the two components of the membranous septum are explained on the basis of different anomalous growth pattern (Goor and Lillehei, 1975). If the tricuspid leaflets are indeed formed late, this explanation would not be possible because any hole in the position of the membranous septum would be atrioventricular. Presence of an interventricular defect would be dependent upon the secondary formation of the tricuspid annulus and its relation to the membranous septum. In an attempt, therefore, to elucidate the mode of formation of the components of the membranous septum, we have studied its morphology in fetal, infant, and adult human hearts.

Subjects

Twenty-five hearts were studied. Five were from fetuses of 15 to 26 weeks’ gestation, 10 were from infants from stillbirth to 1 year of age, and the remaining 10 were from subjects aged from 3 years to 85 years. This latter group was designated ‘adult’, though 3 hearts were from children aged 3, 5, and 8, respectively. These were considered as juvenile adults for the purpose of this study. None of the subjects had died from heart disease but coronary artery disease was evident in some of the elderly subjects. The fetal hearts were studied by histological sectioning, as were the neonatal hearts. The hearts were embedded in their entirety in paraffin wax and serial sections of 10 μm thickness were prepared. One section in each 25 was mounted and stained with Masson’s trichrome technique. The adult hearts were opened to expose both left and right aspects of the membranous septum. The hearts were then photographed from both left and

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right sides. The specimens were pinned on a cork board, with the area to be illustrated over a circular hole, 6.5 cm in diameter, cut out of the cork. They were illuminated from behind with one lamp of a Schott KL 150B fibreoptic lamp operated at one-third to one-half of its strength.

Results

(1) FETAL HEARTS
The atrioventricular component of the membranous septum was evident from gross examination in each case. Only 1 of the 5 had an interventricular component which was small, but this structure could not be identified in the remaining 4. Microscopy confirmed these findings (Fig. 1). The anteroseptal commissure of the tricuspid valve was attached directly to the muscular crest of the ventricular septum. The annular attachment of the valve overlaid the penetrating atrioventricular bundle, placing the entire membranous septum in the atrioventricular position.

(2) INFANT HEARTS
The anatomy of the membranous part of the septum varied considerably in the infant hearts (Fig. 2 A, B, C). Two hearts possessed both atrioventricular and interventricular components. In both, the atrioventricular component was large, while the interventricular part, beneath the medial leaflet of the tricuspid valve, was rudimentary. The medial leaflet itself was 'fetal' in appearance, being still

Fig. 1 Photomicrograph of the region of the membranous septum from a 30-week gestation fetus. The membranous septum is placed solely between the aortic outflow tract (AOT) and the right atrium (RA). It is solely atrioventricular membranous (AVMS), because the origin of the tricuspid valve (TVO) has yet to be liberated from the interventricular septum (IVS). Note the location of the atrioventricular bundle (AVB).

Fig. 2 A series of sections of the membranous septal area in infant hearts. (A) The origin of the tricuspid valve (TV) placed the membranous septum in an atrioventricular position. (B) The origin is a little higher but still the septum is atrioventricular, the interventricular component being filled by the atrioventricular bundle (AVB). (C) There is virtually no membranous septum because the atrial septum comes almost down to the ventricular septum. IAS, interatrial septum; Ao, aortic outflow tract. Others as before.
The membranous septum

Fig. 3  Further sections of infant hearts showing the membranous septal origin. All sections are at the entire extent of the membranous septum. (A) and (B) A small interventricular component is illustrated. (C) However, the membranous septum is atrioventricular.

partially attached to the endocardium of the muscular septum (Fig. 3). In the remaining hearts, the annulus of the tricuspid valve was positioned so as to place the entire membranous septum in an atrioventricular position except in 2 hearts where a membranous septum as such was not identified, the musculature of the right atrium overlying that of the ventricular septum (Fig. 4).

(3) ADULT HEARTS
Both atrioventricular and interventricular components were present in each heart, but because the topography of the membranous part of the septum was slightly different in the juvenile hearts they are described separately from the mature adult specimens.

(a) Young subjects
When transilluminated, the atrioventricular component appeared as a triangle, with the commissure of the inferior and medial tricuspid leaflets as its base (Fig. 5A). The apex was thinly overlaid with
Fig. 5 Photographs from a child aged 5 years illustrating the components of the membranous septum. (A) A view from the right side with the membranous septum transilluminated from the left. The membranous septum has both atrioventricular (AVMS) and interventricular (IVMS) components, the two separated by the insertion of the tricuspid valve. S, septal leaflet; AS, anterosuperior leaflet of tricuspid valve; ASC, anteroseptal commissure; MPM, medial papillary muscle; TSM, trabecula septomarginalis; RA, right atrium; RV, right ventricle. (B) the left ventricular aspect transilluminated from the right. The membranous septum (MS) is beneath the right (RCC) and non (NCC) coronary cusps of the aorta (Ao). LV, left ventricle; MV, mitral valve.

Fig. 6 (A) and (B) Photographs of the membranous septum region in a 45-year-old man. By this age both components are well formed. The specimen has been transilluminated as for Fig. 5. The shadow is that of a wire passed beneath the medial tricuspid leaflet to differentiate the atrioventricular and interventricular components of the membranous septum.
atrial muscle fibres. The atrioventricular portion of the membranous septum measured 9 to 10 mm. The interventricular component of the membranous part of the septum occupied the area beneath the commissure of the inferior and septal leaflets of the tricuspid valve. It extended anteriorly and inferiorly to the medial papillary muscle. All 3 child hearts had secondary chordae tendineae attaching the ventricular surface of the medial tricuspid leaflet to the interventricular membranous septum.

When seen from the left ventricle, the membranous part of the septum appeared between the middle of the right aortic cusp and the posterior (non-coronary) aortic cusp (Fig. 5B). The septum was again triangular in shape, ranging in size from 7 × 5 mm in the 3-year-old to 11 × 7 mm in the 8-year-old.

(b) Mature subjects
In younger adults the atrioventricular septum was not well seen without transillumination, but was a conspicuous feature in subjects over 45 years old (Fig. 6A and B). In one of the oldest hearts, a fairly large artery traversed the atrioventricular membranous septum. Measurements of the atrioventricular septum indicated that it varied considerably in size from 7 × 3 mm to 18 × 12 mm.

The interventricular membranous septum lay beneath the tricuspid valve as in the juvenile hearts, but was in less intimate relation to the medial papillary muscle, especially in those over 60 years of age. In the 2 oldest subjects (80 plus), the septal leaflet was elaborately scalloped, producing a distinct cleft between its superior and inferior components (Fig. 7). The interventricular membranous septum was usually triangular or, in younger adults, pear-shaped, and varied in size from 4 × 5 mm to 10 × 10 mm.

When viewed from the left ventricle, the membranous septum was variable in size and measured from 10 × 5 mm to 16 × 8 mm. It lay between the middle of the right aortic cusp to the middle of the posterior cusp, as in the children's hearts. However, in some adults, irrespective of age, the membranous part of the septum originated posterior (to the left) of the right aortic cusp, and extended posteroinferiorly to the base of the anterior commissure of the mitral valve. The atrioventricular component of the septum was consistently larger than the interventricular component.

Discussion
Our findings show unequivocally that in the majority of fetal and infant hearts the membranous septum has only an atrioventricular component. The conversion of this infant arrangement to the pattern described by Walmsley (1930), and more usually illustrated in textbooks of anatomy (Walmsley in Quain, 1929; Gray, 1973), is dependent upon undermining of the tricuspid valve leaflets in the region of the septum. This process results in the annular attachment of the valve extending from the crest of the muscular septum to a position where it crosses the membranous septum, converting it into its typical atrioventricular and interventricular components (Fig. 6B). The evidence of this undermining is to be found in the constant presence of chordae tendineae attaching the ventricular aspect of the septal leaflet of the tricuspid valve to the interventricular membranous septum in all the adult specimens.

It is evident, therefore, that the division of the membranous septum into its components cannot be dependent upon separate processes of development, as suggested by Odgers (1938) and endorsed by Kramer (1942) and Goor et al. (1970). The different mechanisms invoked by these investigations may well be instrumental in closing the interventricular
foramen, though this is also a contentious point. It is not always appreciated that the foramen which is closed to bar the aorta from the right ventricle is the secondary interventricular foramen, the primary foramen becoming the aditus to the aortic outflow tract (Frazer, 1931; Van Mierop et al., 1963). Neither is this precise origin of the tissue which finally closes the secondary foramen agreed upon (Odgers, 1938; Wenink, 1974). However, the nature of closure of the foramen is clearly a separate process from undermining of the tricuspid valve leaflets, since at the time of closure, which all agree to be at about Horizon XVIII (that is about 6 weeks of gestation), there is no evidence of formation of the septal leaflet of the tricuspid valve. Until the septal leaflet is formed and undermined relative to the membranous septum, there can be no justification for referring to atrioventricular and interventricular components of the septum.

This point has major significance with regard to the nomenclature of defects of the ventricular septum. Defects in the region of the ventricular component of the membranous septum are commonly referred to as 'membranous' defects. Warden and his colleagues (1957) previously indicated quite rightly that most so-called 'membranous' defects were considerably larger than the area of interventricular membranous septum observed in the human heart. Our findings of absence of this component in the majority of fetal and infant hearts give added weight to their contention that 'membranous' is an inappropriate term for such defects. Our morphological studies (unpublished observations) suggest that defects result either from a deficiency of the muscular septum adjacent to the membranous component, or else to malalignment of the aorta with the left ventricle. For these reasons we suggest that 'perimembranous septal defect' would be a more appropriate name for defects confluent with the pars membranacea septi. Our findings are also pertinent to the morphology of defects which exist between the left ventricular outflow tract and the right atrium. These defects are frequently explained on the basis of absence of the atrioventricular component of the membranous septum (Goor and Lillehei, 1975). This should not be taken to indicate that the interventricular component of the septum is normally formed and intact. In a current study of over 200 hearts with isolated ventricular septal defects (Soto, B., Becker, A. E., Moulaut, A., Lie, J. T., and Anderson, R. H., unpublished observations), the only hearts we observed with right atrial to left ventricular communications possessed typical perimembranous defects but associated with a wide anteroseptal commissure of the tricuspid valve. The absence of a tricuspid attachment in the region of the commissure placed the defect in direct communication with the right atrium, a possibility envisaged by Rosenquist and Sweeney (1975) following study of normal hearts, and also described by Warden et al. (1957). The question is therefore raised as to whether the right atrial—left ventricular communication warrants a separate category when considering the nosology of septal defects. Only further surgical-anatomical studies will clarify this point.

References


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