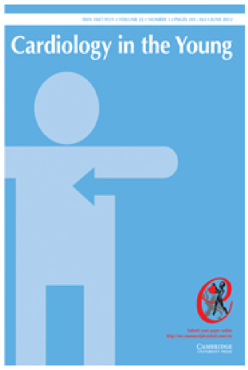

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Original Article

Transthoracic three-dimensional echocardiography for the assessment of straddling tricuspid or mitral valves

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Abstract *Background:* The advent of 3D echocardiography has provided a technique which, potentially, could afford significant additional information over conventional cross-sectional echocardiography in the assessment of patients with straddling atrioventricular valves prior to surgical correction. *Methods:* Eight patients, aged from 1 month to 9.2 years, were examined with 3D echocardiography. All but three had discordant ventriculoarterial connections or double outlet right ventricle. Data suitable for reconstruction was acquired with transthoracic scanning. Right and left ventricular volumes were calculated in the 3D dataset. *Results:* 3D echocardiography proved capable of defining the exact degree of straddling by imaging the proportion of tension apparatus attached to either side of the ventricular septum. It was able also to display the atrioventricular junction "en face", thus permitting identification of the precise site of insertion of the muscular ventricular septum relative to the atrioventricular junction. This made it possible first, to calculate the degree of valvar override, and second, to predict the location of the penetrating atrioventricular bundle. End-diastolic volume of the right ventricle in those with straddling tricuspid valves was 73 (61–83)% of normal, and, of the left ventricle in those with mitral valvar straddling 71 (40–97)% of normal. *Conclusions:* 3D echocardiography can aid in planning the optimal surgical procedure in patients with straddling or overriding atrioventricular valves, as it provides diagnostic information superior to standard cross-sectional techniques. It also allows for exact measurement of the volumes of the respective ventricles.

Keywords: 3D echocardiography; cross sectional echocardiography; straddling atrioventricular valves

AN ATRIOVENTRICULAR VALVE STRADDLES WHEN its tension apparatus inserts on both sides of the ventricular septum.[1] This arrangement, of major surgical significance,[2,3] may or may not be associated with overriding of the atrioventricular junction guarded by the straddling valve.[1] Because of the surgical significance,[2] exact preoperative diagnosis is mandatory.[3] In this regard, cross-sectional echocardiography has been shown to provide better information than angiography for diagnosis and characterization of straddling atrioventricular valves.[4] In this study, we assessed the utility of the recently available new imaging technique of 3D echocardiography[5] to ascertain if it could improve still further the diagnostic yield. Specifically, we evaluated whether new "cutplanes" could be reconstructed which are not provided by cross-sectional echocardiography, and whether the end-diastolic volumes could accurately be calculated for each of the ventricles.

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Methods

We examined eight patients who on the basis of a previous cross-sectional echocardiographic examination, were thought to have straddling atrioventricular valves. Their median age was 2.4 years, ranging from 10 days to 9.2 years (Table 1). We used a commercially available Vingmed 800 (GE Vingmed Horten, Norway) annular array sector scanner, interfaced with a Tomtec (Tomtec Munich, Germany) computer to generate 3D reconstructions from the cross-sectional images.

Table 1. Morphology of the heart and great vessels in patients with straddling atrioventricular valves

Patient	AV Valve Abnormality	Ventriculoarterial Connections	Great Vessel Morphology
1	Tricuspid straddle – with overriding	Concordant	Normal
2	Tricuspid straddle – with overriding	Pulmonary atresia	
3	Tricuspid overriding – without straddling	Pulmonary atresia	
4	Tricuspid overriding – without straddling	Discordant	Subpulmonary stenosis
5	Tricuspid straddle – with overriding	Discordant	Subpulmonary stenosis
6	Mitral Straddle – without overriding	Double outlet right ventricle	Aortic coarctation
7	Mitral Straddle – with overriding	Double outlet right ventricle	Aortic coarctation
8	Mitral Straddle – with overriding	Double outlet right ventricle	Subpulmonary and valvar pulmonary stenosis

For acquisition of data suitable for reconstruction, we used either fan-like[5] or rotational scanning[6] with electrocardiographic and respiratory gating.[7] The same software is used for reconstruction irrespective of the mode of acquisition of the data. Restless patients were sedated with 70 mg/kg chloralhydrate. In 3 patients, data was acquired in the catheterization laboratory, where patients in the Royal Brompton Hospital are routinely given general anaesthesia. In 1 patient, data was acquired in the operating room immediately after induction of general anaesthesia. After completion of acquisition of data, we reviewed the acquired cross-sectional slices of the heart. These could then be rotated in any orthogonal plane. When a desired cross-section had been found, the computer began 3D reconstruction. Three dimensional effects were achieved by assigning different gray-scale values to various cardiac structures.[8] The reconstructed dataset can be dynamically displayed and stored on standard 0.5 inch videotapes. In all the patients with overriding tricuspid and mitral valves, the overall diameter of the valve was determined, together with the parts of the overriding valvar orifice committed to each ventricle. From the dataset, we calculated right and left ventricular volumes using a previously described and validated technique.[9]

The quantitation is based on a technique of multiple slicing.[10] Firstly, the longest axis of the respective ventricle is defined in the appropriate cross-section of the dataset. Along the long axis, perpendicular 2 mm thick slices are displayed on the monitor as cross-sectional images. These are then manually outlined to calculate the area of each slice. The calculated area is multiplied with the thickness of the slice to obtain the volume of each slice. The respective volumes are summed to obtain the volume of the ventricle. Measurements were obtained in end-diastole, and expressed in mls/sqm body surface area. According to the literature, the end-diastolic volume of the normal right ventricle is 70 mls/sqm,[11] and that for the normal left ventricle is 60 mls/sqm.[12]

Results

3D reconstruction was possible for all datasets acquired. Reconstruction took between 40 and 240 minutes. All standard views of the heart obtainable with transthoracic conventional cross-sectional echocardiography could be reconstructed, as well as significant new views. Thus, the information obtained by 3D reconstruction of a conventional four chamber view is similar to that provided by conventional cross-sectional echocardiography (Fig. 1). For the tricuspid valve, this shows the malalignment between the atrial and ventricular septal structures which is the key to diagnosis. In the case of the mitral valve, the reconstructions showed that the valvar leaflets straddled through a defect opening to the outlet components of the right ventricle (Fig.2). In the hearts with override of the left atrioventricular junction, therefore, the atrial and ventricular structures are normally aligned at the crux of the heart. From the conventional cross-sections, we were able to reconstruct "en-face" views of the atrioventricular valves, permitting them to be viewed as seen by the surgeon working from the atrium (Figs 3,4,5).This reveals the fashion in which the valvar leaflets are connnected to the right and left ventricles, respectively (Table 2). While these measurements could not be directly validated at surgery in a non-beating heart, inspection in the patients subsequently undergoing surgery revealed no differences between the preoperative diagnosis of the extent of straddling and overriding made by 3D echocardiography and the findings in the operating room.

Volumetry of the ventricles (Table 3) permitted quantitation of the disproportionate sizes of the ventricles compared to hearts with normal atrioventricular junctions. In all 5 patients with

Figure 1.
3D reconstruction (middle), display of one cross-section of the dataset (right side) in a patient with a concordant ventriculoarterial connections, a ventricular septal defect, and straddling as well as overriding of the tricuspid valve. An anatomic specimen (not from the same patient) is shown on the left. The 3D reconstruction of a conventional 4-chamber view adds little information to the information provided by conventional cross-sectional echocardiography. The arrow in the reconstructed view, and in the specimen, points to the tension apparatus of the tricuspid valve which inserts on left ventricular side of the septum. (RA=right atrium, LA=left atrium, VS=ventricular septum, RV= right ventricle, LV= left ventricle).

straddling of the tricuspid valve, the right ventricle was hypoplastic, with an end-diastolic volume of 73 (61–83)% of the expected norm. The left ventricular volume in these 5 patients was 114 (107–122)% of normal. The smallest right ventricular volume was measured in a patient with both overriding and straddling of the tricuspid valve. In the 3 patients with straddling of the mitral valve, left ventricular end-diastolic volume was 71 (40–97)% of normal, while the right ventricular volume was 118 (103–139)% of normal.

Discussion

Our study has shown that 3D echocardiography can offer important and new information in patients with straddling tricuspid or mitral valves. Specific advantages are, first, the provision of the "en-face" view. This allows for precise determi-

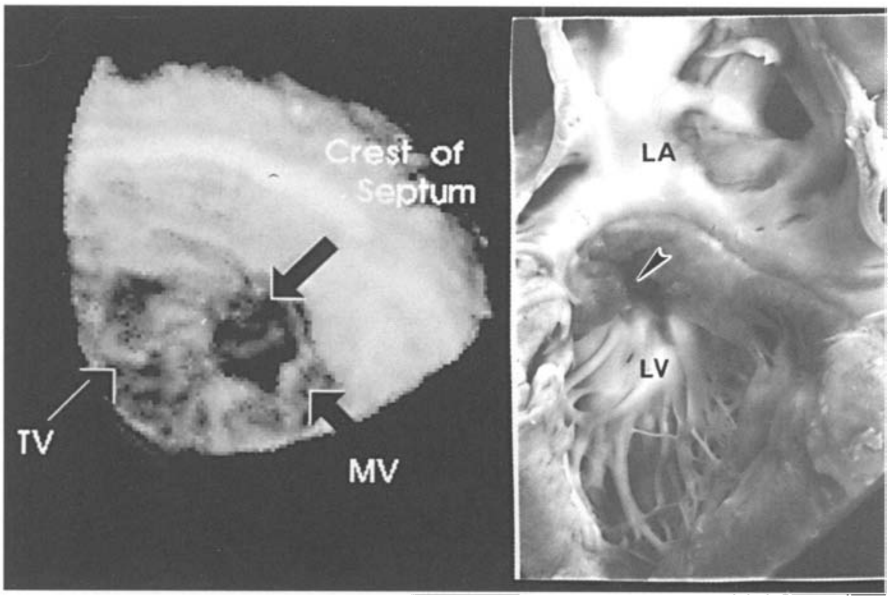

Figure 2.
3D reconstruction in a patient with double outlet right ventricle and subpulmonary ventricular septal defect (Taussig-Bing heart) complicated by straddling and overriding of the mitral valve. The reconstruction of the "en-face" view (left side) visualizes the crest of the septum (black arrow). On the right side an anatomical specimen (not from the same patient) is shown of a Taussig-Bing malformation with straddling of the mitral valve. The specimen has been cut in a way such to match the three-dimensional reconstruction, and is seen in a view similar to that obtained by the surgeon during inspection of the mitral valve. (TV=tricuspid valve, MV=mitral valve).

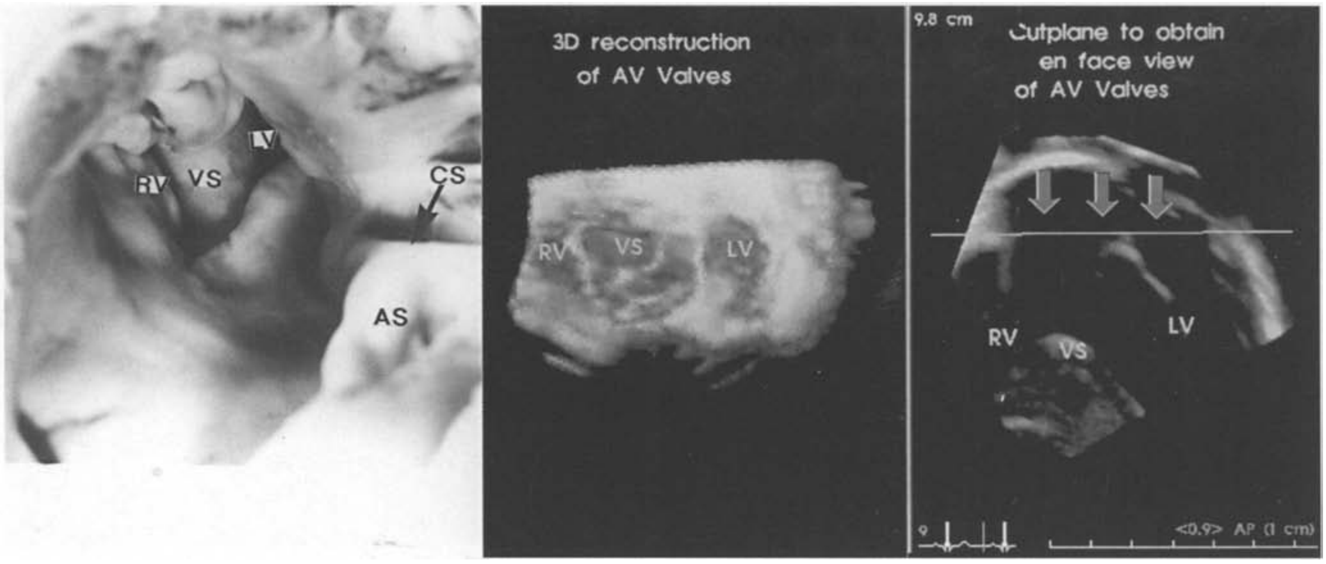

Figure 3.
3D reconstruction (middle), and display of one cross-section of the dataset (right side) in the same patient as shown in Figure 1. The specimen shown on the left side is not from the same patient. The arrows in the cross-section displayed on the right indicate the position and direction of view of an observer in the atrium looking downwards onto the orifice of the valve to obtain the "en-face" view of the atrioventricular junction. The 3D reconstruction of this viewplane illustrates better than the conventional four-chamber view the insertion of tricuspid valvar cords in the left ventricle. It also demonstrates the overriding of the valvar orifice. The crest of the ventricular septum is seen, together with the part of the tricuspid valve committed to the left ventricle (VS=ventricular septum, RV= right ventricle, LV= left ventricle, AS=atrial septum, CS=coronary sinus).

nation of the relationship of the overriding atrioventricular junction to the ventricular septum. Secondly, 3D echocardiography is helpful in measuring accurately ventricular volumes, particularly those of the right ventricle.[9] This has been difficult using conventional cross-sectional echocardiography.[13] We have previously validated such volumetric measurements using 3D echocardiography in vitro,[9] and have compared measurements of right ventricular volumes with the "gold standard" of magnetic resonance imaging.[14]

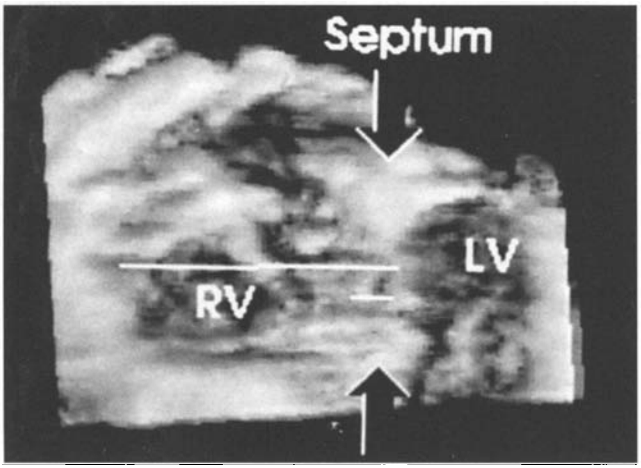

Figure 4.
Reconstruction from the same patient as shown in figures 1 and 3. In this "en face" view of the atrioventricular junction, we have put 2 lines of measurement. The upper line shows the whole tricuspid valve orifice in diastole, the lower short line, the part of the valve which is straddling the ventricular septum.

Information on anatomy of straddling

The key feature in the diagnosis of straddling of the morphologically tricuspid valve is the malalignment between the atrial and ventricular septal structures.[1,3] This is because the morphologically tricuspid valve straddles and overrides the inlet component of the muscular ventricular septum. The morphologically mitral valve, in contrast, straddles and overrides through an interventricular communication leading to the outlet component of the right ventricle.[15] When the mitral valve straddles, therefore, the atrial and ventricular septal structures are normally aligned at the crux of the heart.[15]

This information is crucial in predicting the location of the atrioventricular conduction axis.[15] All that information, of course, can usually be well displayed by conventional cross-sectional scanning.[16] The important information for the surgeon is the extent of straddling, specifically whether the tendinous cords are attached merely to the septal crest, to the wrong side of the septum, or to the parietal wall of the other ventricle.[17–19] In addition, the surgeon needs to know the precise

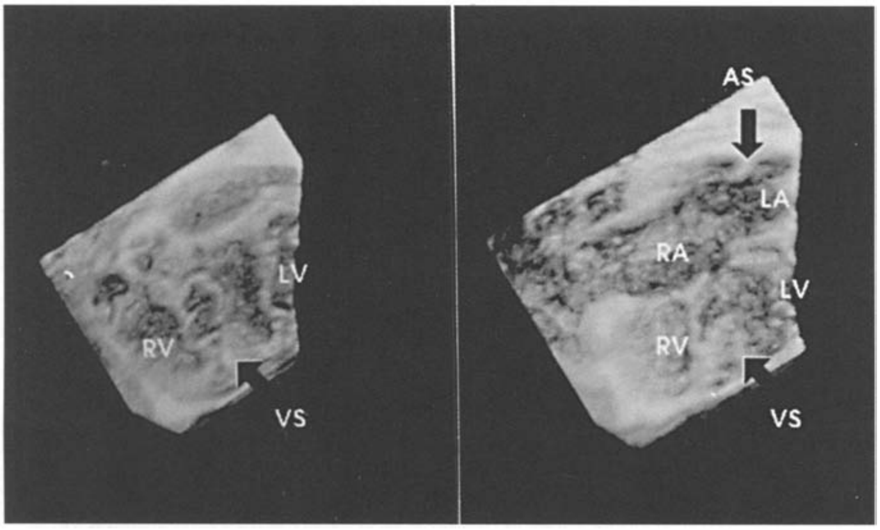

Figure 5.
3D reconstructions from a patient with concordant atrioventricular and discordant ventriculoarterial connections, ventricular septal defect, subpulmonary stenosis, and overriding of the tricuspid valve without straddling of its tension apparatus. On the right side is shown a view similar to the four-chamber cut, while on the left an "en-face" view of the atrioventricular junction is reconstructed. The malalignment between the atrial (AS) and ventricular septum (VS) is well seen. The fact that the tricuspid valve tension apparatus inserts into the right ventricle can be best seen in the "en face" view. (RA = right atrium, LA = left atrium, RV = right ventricle, LV = left ventricle).

point at which the muscular ventricular septum makes contact with the atrioventricular junction, since this position indicates the location of the atrioventricular conduction axis. Again, these important morphological details have previously been diagnosed accurately by cross-sectional echocardiography,[16] but 3D reconstruction offers

Table 2. Measurements of diameter of tricuspid and mitral valve total diameter and segment of diameter overriding the ventricular septum (mms)

Patient	Total diameter of atrioventricular valve	Segment of diameter of valve committed to contralateral ventricle
1	32	12
2	22	4
3	24	6
4	35	15
5	26	5
6	20	0
7	22	2
8	25	7

Table 3. Measurements of right and left ventricular enddiastolic volumes (ml/sqm body surface area)

Patient	Right ventricular volume	Left ventricular volume
1	54	66
2	58	64
3	43	73
4	48	72
5	52	68
6	72	58
7	78	46
8	90	24

the additional benefit of displaying the heart in a view which replicates the intraoperative appearance.[20] Before a decision can be made concerning the most appropriate form of surgical repair, be that biventricular, univentricular, or 1 and 1/2 ventricular, however, information is needed concerning the volume of the ventricle, which is necessarily incomplete because of the overriding atrioventricular junction.[19]

Ventricular volumes in straddling

The cavitary size of the incomplete and rudimentary ventricle is, in many ways, the crucial piece of information for deciding the optimal surgical repair. While 3D echocardiography can accurately assess ventricular volumes irrespective of their geometric shape,[9,10] we do not yet know the exact limit of cavitary hypoplasia which precludes biventricular repair.[3,19] In a previous study of unbalanced atrioventricular septal defects, where similar problems exist in respect to the committment of the atrioventricular orifice to one dominant ventricle, with concomitant underdevelopment of the second ventricle,[21] we measured ventricular volumes by angiography. In this study,[21] we could not determine the ventricular size representing the limits of normality. The same holds true for the current investigation. Although by analogy to the data available for repair of unbalanced atrioventricular septal defect,[22] we might anticipate that a volume of the rudimentary ventricle of four-fifths of normal should be acceptable for biventricular repair, it is not established with certainty whether this holds true for patients with straddling valves and complex anomalies of atrioventricular or ventriculoarterial connections.[18,23] Only increasing experience will answer this question.

Limitations of this study

With the currently available hard- and software, thickening of all the imaged cardiac structures during reconstruction of closely sequential cross-sectional slices remains a problem. Thus, valvar leaflets, as well as their tension apparatus, appear thickened. Thickening of the sometimes rather delicate tension apparatus[10] may lead to overestimation of the amount of atrioventricular tension apparatus located in the wrong ventricle. Because all patients were examined with conventional cross-sectional echocardiography before data suitable for subsequent reconstruction were acquired, we did not perform a double-blind study. We were unable, therefore to evaluate the incremental information of 3D over conventional cross-sectional echocardiography. With the new equipment of real-time 3D echocardiography such a study may be possible. With our equipment as presently used, nonetheless, it is difficult to blind the person acquiring the dataset to the cross-sectional images visible on the screen of the ultrasonic scanner.

The substantial time still needed to achieve a 3D reconstruction in these complex hearts remains a serious limitation, thus precluding further clinical application of this new imaging technique. It also remains difficult to illustrate the 3D findings in a two-dimensional format, especially in a still-frame picture. Because of this, we have thus produced moving images which can be viewed on the homepage of the Journal (www.greenwich-medical.co.uk). While advances in soft- and hardware have facilitated acquisition of data, frequently obviating the need for sedation, and have considerably shortened the period required for calculations of volume,[24,25] the clinical utility of 3D echocardiography still remains limited, confining the technique to evaluation of patients with complex hearts in whom decision-making is frequently difficult and time-consuming.[26] Despite these limitations, we have shown that 3D reconstruction offers important additional information on the morphology and cavitary size of patients with straddling atrioventricular valves. If replicated in the clinical setting, the technique should serve to determine the best options for surgical correction.

Internet Site

You can dowload a QuickTime™ movie illustrating the 3D findings. Please access www.greenwich-medical.com and click on "Journals" and "Cardiology in the Young" to view the movie and to read further details.

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