Comparison of three dimensional echocardiographic findings with anatomical specimens of various congenitally malformed hearts

M Vogel, S Y Ho, R H Anderson

Abstract
Objective—To compare the reconstructions obtained by three dimensional echocardiography with the anatomical specimens used to generate the echocardiograms.

Design—The heart specimens were immersed in a water bath and imaged with a 5 MHz echocardiographic transducer mounted into a scan frame which allowed the transducer to travel a total distance of 4-4 cm in steps of 0-25 mm. The transducer records a tomographic slice at each incremental level thus producing 176 parallel slices of the heart to form the dataset. Reconstruction of the anatomical structures of the heart in a three dimensional format is achieved by means of different grey scales.

Materials—72 specimens of either normal or various congenitally malformed hearts.

Results—Good quality echocardiographic pictures were obtained, permitting three dimensional reconstructions in each heart. The cardiac chambers and valves could be displayed in a three dimensional format which accurately displayed the internal anatomy of the specimens. No artefacts, such as spurious septal defects, were produced in specimens with intact septums. The atrioventricular valvar leaflets, however, appeared thicker in the images than they were in the specimens.

Conclusions—Three dimensional echocardiography accurately displays the anatomy of normal and congenitally malformed hearts.

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Keywords: echocardiography; three dimensional reconstruction; congenital heart disease

Three dimensional echocardiography is a newly available technique which, in many children, can produce three dimensional reconstructions of the heart when an ultrasound probe is used via either subcostal or transthoracic approaches.1 Initial experience suggests that this new imaging modality may offer clinically useful data,2 and may yield additional information over two dimensional cross-sectional echocardiography in deciphering the precise anatomy of some congenital heart malformations.3 The purpose of this study was to examine whether the anatomy of the heart, especially when it is congenitally malformed, is accurately displayed by the three dimensional reconstructions.

Materials and methods

ECHOCARDIOGRAPHIC EQUIPMENT

A commercially available Vingmed 725 or 800 (Vingmed Ultrasound, Horten, Norway) phased array sector scanner was used interfaced with a Tomtec (Tomtec Imaging Systems, Munich, Germany) computer to generate three dimensional reconstructions derived from cross-sectional images. The transducer is mounted inside a scan frame so that it moves longitudinally over a distance of 4-4 cm in 0-25 mm steps. Its movement is controlled by a stepper motor. At each step a tomographic slice of the heart is recorded producing a dataset of 176 parallel slices when the transducer is moved from the apex of the heart to the outflow tracts.4 For this study the external scan frame containing the transducer was positioned on a tripod placed over a bucket filled with water. A non-echogenic fish-net was used to suspend the heart specimen inside the bucket. The temperature of the water was kept between 35 and 40°C, this being found by experience to produce optimal echocardiographic images of the specimens. The distance between the transducer and the specimen in the bucket was between 1 and 5 cm depending on the size of the hearts. The computer used for processing the images reconstructs the structures of the heart in a three dimensional format by means of different grey scales. It then allows for viewing the reconstructed heart in multiple planes. In this way it can reconstruct a three dimensional image of the heart from any desired viewpoint.

HEART SPECIMENS

We examined 72 heart specimens with either normal anatomy or a variety of congenital malformations (table). All hearts were from

<table>
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<th>Cardiac anatomy of the examined specimens</th>
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<tr>
<td>Anatomy</td>
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<tr>
<td>Normal heart</td>
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<tr>
<td>Ventricular septal defect</td>
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<td>Atrioventricular septal defect</td>
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<td>Double inlet ventricle</td>
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<td>Subaortic stenosis</td>
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<td>Miscellaneous</td>
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the anatomical collection of the National Heart and Lung Institute.

Results
We were able to acquire good quality echocardiographic pictures in all specimens. Three dimensional reconstruction of the images took between 10 and 60 min depending on the complexity of the underlying anatomy. Most of the time taken in reconstruction is required for choosing the optimal view suitable for three dimensional reconstruction within the dataset. The computing time for reconstruction of the chosen view plane is 3–8 min. The various lesions within the heart could be displayed in views similar to those obtained by a surgeon while performing a heart operation. The three dimensional reconstructions showed that atrial morphology could correctly be identified on the basis of the extent of pectinate muscles within the appendages. The atrioventricular valves were seen in great detail: the “scalloping” of the valvar leaflets together with insertion of the tension apparatus being clearly visible. In many studies three dimensional echocardiography displayed the leaflets of atrioventricular valves as thicker structures than was the case in the specimen. The ability of three dimensional echocardiography to visualise the moderator band and coarse trabeculations of the right ventricle in contrast to the smooth septum and fine trabeculations of the left ventricle permitted ventricular morphology to be detected. Arterial valves were well seen, and the junction of the sinuses of the muscle supporting the leaflets with the ascending component of the muscle itself could be well defined. Ventricular septal defects could be viewed from both ventricular aspects, their location determined, and size assessed relative to the diameters of both arterial valves. Throughout the studies we encountered no artefacts such as echocardiographic drop outs mimicking ventricular septal defects.

We have chosen five cases to illustrate the ability of three dimensional echocardiography to display cardiac anatomy correctly.

In a specimen with a supravalvular mitral membrane (fig 1) we chose to display the anatomy in an “en face” view so as to simulate, as near as possible, the view seen by the surgeon through a left atriotomy. A specimen with Ebstein’s malformation of the tricuspid valve (fig 2) has been cut in a plane replicating...
the typical four chamber section. A specimen with fixed subaortic stenosis and the corresponding three dimensional reconstruction illustrate the extension of the tissue obstructing the left ventricular outflow tract on to the anterior (aortic) leaflet of the mitral valve (fig 3).

An atrioventricular septal defect with common orifice has been cut in such a way to provide an “en face” view of the common atrioventricular valve in the fourth specimen (fig 4). Thickening of the bridging and mural leaflets in the reconstruction can be compared with the true size of the leaflet in the specimen. The final specimen (fig 5) with a restrictive ventricular septal defect in a heart with absence of the right atrioventricular connexion (tricuspid atresia) illustrates that analysis of the three dimensional dataset by rotating the dataset around its vertical axis can yield useful information concerning the size of the ventricular septal defect.

Discussion
Our study demonstrates that three dimensional reconstruction of parallel slices of heart specimens imaged by echocardiography is feasible, and that the reconstructions obtained display accurately the underlying anatomy. The reconstruction process, with off line analysis of the acquired echocardiographic data, is still cumbersome, nonetheless, involving arbitrary definition of blood-tissue interfaces by assigning various grey scales to the images. Incorrect assignments of grey scale intensity of cardiac tissue, especially to the atrial or ventricular septum, could potentially lead to artefactual drop outs and a false diagnosis of atrial or ventricular septal defect. In reality this was not a problem in our study in which all reconstructions were performed by an examiner experienced in the use of the hard and software needed for three dimensional reconstruction. One problem that was encountered with three dimensional reconstruction, is that it falsely displays cardiac structures, especially the atrioventricular valves, as being thickened. Thus far, in clinical studies, this has not led to false positive diagnosis of endocarditis but nor did it prevent us from correctly diagnosing a supramitral membrane (fig 1). The spurious thickening of the atrioventricular valvular leaflets, nonetheless, may lead to potential diagnostic problems in congenitally malformed hearts, as it may be difficult to distinguish the extent of thickening due to the methods of imaging and that reflecting a true pathological process.

Apart from the ability to display the
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Figure 5. (A-C) Three dimensional echocardiographic reconstruction and (D) photograph of a heart specimen with absence of right atrioventricular connexion (tricuspid atresia) with a restrictive ventricular septal defect. By turning the three-dimensional dataset (A-C) around its vertical axis the size of the ventricular septal defect can be appreciated. The arrows in the anatomical specimen point to the ventricular septal defect. LA, left atrium; LV, left ventricle; RV, right ventricle.

anatomy of heart correctly, three dimensional echocardiography offers the possibility to display the cardiac anatomy in a lesion orientated way. The prospective diagnosis of supramitral ring has been difficult by standard cross-sectional echocardiography. The exact anatomy of the supravalvular lesion can be appreciated by using a cut through the three dimensional dataset which displays the floor of the left atrium "en face" together with the orifice of the mitral valve. Ebstein's malformation represents a complex malformation of the tricuspid valve, which involves all three leaflets. Previous echocardiographic studies had mainly focused on the morphology and displacement of the septal leaflet. The nature of the distal attachment of the anterosuperior leaflet can be readily shown by three dimensional echocardiography as can the hinge point of the mural leaflet, the key to accurate diagnosis. The four chamber equivalent displays the anatomy of the atrioventricular junction and identifies the atrialised portion of the right ventricle. Although standard cross-sectional echocardiography has been shown to be of value in the prospective diagnosis of subaortic stenosis, the accurate delineation of the extent of the obstructive tissue relative to the aortic leaflet of the mitral valve can be provided only by three dimensional reconstruction. Three dimensional echocardiography is also helpful in assessing the size of ventricular septal defects and identifying their surrounding tissues, as illustrated in our case with absent right atrioventricular connexion.

There are, nonetheless, several limitations to our study. Perhaps most importantly, we did not examine in a blind fashion the ability of three dimensional echocardiography to display the anatomy, the anatomical diagnosis being known to the person performing the three dimensional reconstruction. Second, high quality three dimensional reconstructions are much easier to obtain in heart specimens in a water bucket than in patients with moving hearts. Depending on the heart rate of the patient, the datasets, which are triggered to the electrocardiogram and respiration in an
attempt to minimise motion artefact, are 10–15 times bigger than datasets obtained in non-moving specimens. Thus, manipulation of the dataset to choose optimal view planes, as well as the computing time needed to generate three dimensional studies, are considerably longer. In clinical studies, some patients have been shown to have poor echo windows, which did not allow three dimensional reconstruction of the acquired cross-sectional echocardiographic data. Taking into account that image quality in patients may not always be as good as in non-moving specimens, we, nonetheless, submit that three dimensional echocardiography displays correctly the anatomy of the heart, and that lesion specific display of congenitally malformed hearts facilitates understanding of their anatomy.

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