Dynamic Three-Dimensional Reconstruction of the Heart by Transesophageal Echocardiography

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Objective *– To evaluate echocardiography accuracy in performing and obtaining images for dynamical three-dimensional (3D) reconstruction.*

Methods *– Three-dimensional (3D) image reconstruction was obtained in 20 consecutive patients who underwent transesophageal echocardiography. A multiplanar 5 MHz transducer was used for 3D reconstruction.*

Results *– Twenty patients were studied consecutively. The following cardiac diseases were present: valvar prostheses – 6 (2 mitral, 2 aortic and 2 mitral and aortic); mitral valve prolapse – 3; mitral and aortic disease – 2; aortic valve disease – 5; congenital heart disease – 3 (2 atrial septal defect –ASD- and 1 transposition of the great arteries -TGA); arteriovenous fistula – 1. In 7 patients, color Doppler was also obtained and used for 3D flow reconstruction. Twenty five cardiac structures were acquired and 60 reconstructions generated (28 of mitral valves, 14 of aortic valves, 4 of mitral prostheses, 7 of aortic prostheses and 7 of the ASD). Fifty five of 60 (91.6%) reconstructions were considered of good quality by 2 independent observers. The 11 reconstructed mitral valves/prostheses and the 2 reconstructed ASDs provided more anatomical information than two dimensional echocardiography (2DE) alone.*

Conclusion *– 3D echocardiography using a transesophageal transducer is a feasible technique, which improves detection of anatomical details of cardiac structures, particularly of the mitral valve and atrial septum.*

Keywords: three-dimensional echocardiography, ultrasonography, valvar disease

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Three-dimensional (3D) reconstruction of the heart through conventional 2DE imaging is a new technology with potential clinical applications.

Reconstruction through transthoracic echocardiography is often limited in some patients by small number of acoustic windows and poor imaging quality. In addition, the device coupled to transthoracic transducer is too large and heavy to allow for proper handling during the exam, resulting in a great number of artifacts, which interfere with the analysis and with making the correct diagnosis.

When transesophageal echocardiography (TEE) was first used clinically in 1980, a new window to the heart appeared. In 1986, Martin et al [1-3] used a micromanipulator for the TEE transducer for the 3D echocardiogram. Due to the high quality of images obtained by the transesophageal access, 3D reconstruction of the heart, using transesophageal imaging emerged as a promising technique that offers a stable site from which to obtain multiple images from several sections.

Thus, the purpose of this study was to evaluate the feasibility of performing and obtaining images of good diagnostic quality using TEE for 3D reconstruction.

Methods

Images for 3D reconstruction were obtained during routine transesophageal studies in 20 outpatients in sinus rhythm referred to our echocardiography laboratory. Patients with poor apical echocardiographic window (best plane for image acquisition), and those on atrial fibrillation (when it is difficult to gate to the R-R interval) were excluded. Topic anesthesia with lidocaine spray and slight sedation with intravenous midazolan were used.

After 2DE with conventional Doppler was performed, a 5 MHz multiplanar transducer (Vingmed CFM 800) was used to obtain several images for 3D reconstruction. The echocardiograph was coupled to a 3D reconstruction system (Echoscan Tomtec GmbH).

Table I – Clinical characteristics of the group

Nº	Gender	Age	Diagnosis	ROI
1	M	43	Arteriovenous fistula	VM
2	M	23	ASD	SIA
3	F	55	Ao stenosis + AoR	AoV, MV
4	F	25	ASD	AS, AoV
5	F	67	Mitral stenosis + AoR	MV
6	M	38	d-TGA	AoV, MV
7	M	68	Mitral + aortic prosthesis	AoV, MV
8	F	68	MVP + MR	MV
9	M	46	AoV abscess	AoV
10	F	51	IE of the MV + Ao prosthesis	MV
11	F	60	AoV thickening	AoV
12	M	60	Mitral prosthesis	MV
13	M	75	MVP	MV
14	F	60	Mitral + aortic prosthesis	MV
15	F	43	Aortic stenosis	AoV
16	F	76	Mitral prosthesis	MV
17	M	72	MVP + MR	MV
18	F	69	Ao prosthesis + MV thickening	AoV, MV
19	F	75	Aortic stenosis	AoV
20	M	50	IE + AoR	AoV

ROI- region of interest; M- male; F- female; ASD- atrial septal defect; AS - atrial septum; AoV- aortic valve; AoR- aortic regurgitation; IE – infective endocarditis; MV- mitral valve; MVP- mitral valve prolapse; MR- mitral regurgitation; d-TGA- d transposition of the great arteries.

Data were triggered with the electrocardiogram (ECG) and the patient's respiration and a DE images were acquired in the apical view, digitized and stored in a disk. The operator had to locate the center of the axis around which the multiplanar transducer rotated in intervals from 2º to 180º, activated by a motor and controlled by the software. Ninety sequential series from 0º to 180º were obtained during each cardiac cycle. Average time for calibration, acquisition, processing and reconstruction ranged from 40 to 50 minutes.

In the present study, we used the *volume-rendered* reconstruction visualization method in which, from any section plane, different algorithms were applied to represent space information. Several gray scales, distance, texture and gradient scales, as well as a threshold to differentiate cardiac structures from blood and image background were used to give depth perception. Different degrees of brightness and opacity were also used to help give this perception.

Twenty consecutive patients were studied; 9 were male and 11 female and age ranged from 23 to 75 years (mean age = 56±16). Clinical aspects are described in table I.

All patients were in NYHA functional class I and in sinus rhythm. Two patients had an ASD, three mitral valve prolapse (MVP), three aortic stenosis, three infective endocarditis, six valvar prosthesis, one had arteriovenous fistula, one TGA, one mitral stenosis and one aortic valve fibrosis.

Results

Transesophageal echocardiography was well tolerated and acquisition and reconstruction were possible in all patients. A total of 48 acquisitions were obtained (15 patients with one and five with two acquisitions).

Twenty five cardiac structures were acquired and 60 reconstructions were obtained (28 mitral valves, 14 aortic valves, 4 mitral regurgitations, 7 aortic regurgitations and 7 atrial septal defects).

In seven patients, color flow jets were also acquired and reconstructed: five mitral and two aortic regurgitations.

Valves could be seen in several three-dimensional views and lesions could be seen in different aspects. These structures were projected in several planes and observed in different phases of the cardiac cycle.

Among the 60 reconstructions, 55 (91.6%) were considered of good diagnostic quality by two independent observers. Eleven reconstructed mitral valves and two reconstructed ASDs provided more anatomic information than did 2DE alone.

Mitral valve prolapse – Anatomic information from valvar leaflet was obtained in three patients through the *volume rendered* method, which was performed on several sections at the mitral valve level, in long and short axis. Due to the fact that the left atrium (LA) is very well visualized by TEE, 3D reconstruction gives an excellent vision from the top of the prolapsed mitral valve leaflets [4]. The advantage of this image view modality is the excellent acoustic window obtained when the LA is dilated by associated mitral regurgitation, which thus helps visualize the morphology of the mitral valve components. A example of MVP is shown in figure 1.

Mitral regurgitation – In five patients, 3D dynamic imaging allowed for a better visualization and understanding of the jet direction and size projection than could be obtained by 2DE with color flow mapping alone. Mitral regurgitation is seen in figure 2, where a central jet is clearly seen on the atrial perspective.

Six patients were studied for evaluation of different kinds of mitral and aortic prostheses (7 mechanical and one biological). 3DE images did not provide additional information when compared with those obtained by 2DE, because 3DE disk evaluation was not adequate, even after using different thresholds with brightness and opacity adjustments, due to the excess of echoes that jeopardized the correct analysis. Figure 3 shows disk prosthesis in systole.

Aortic stenosis – 3D reconstruction of aortic valve was obtained in three patients and the aortic cusps were seen from above. In the dynamic mode, valve opening and closing could be observed. A stenotic aortic valve in diastole can be seen in figure 4.

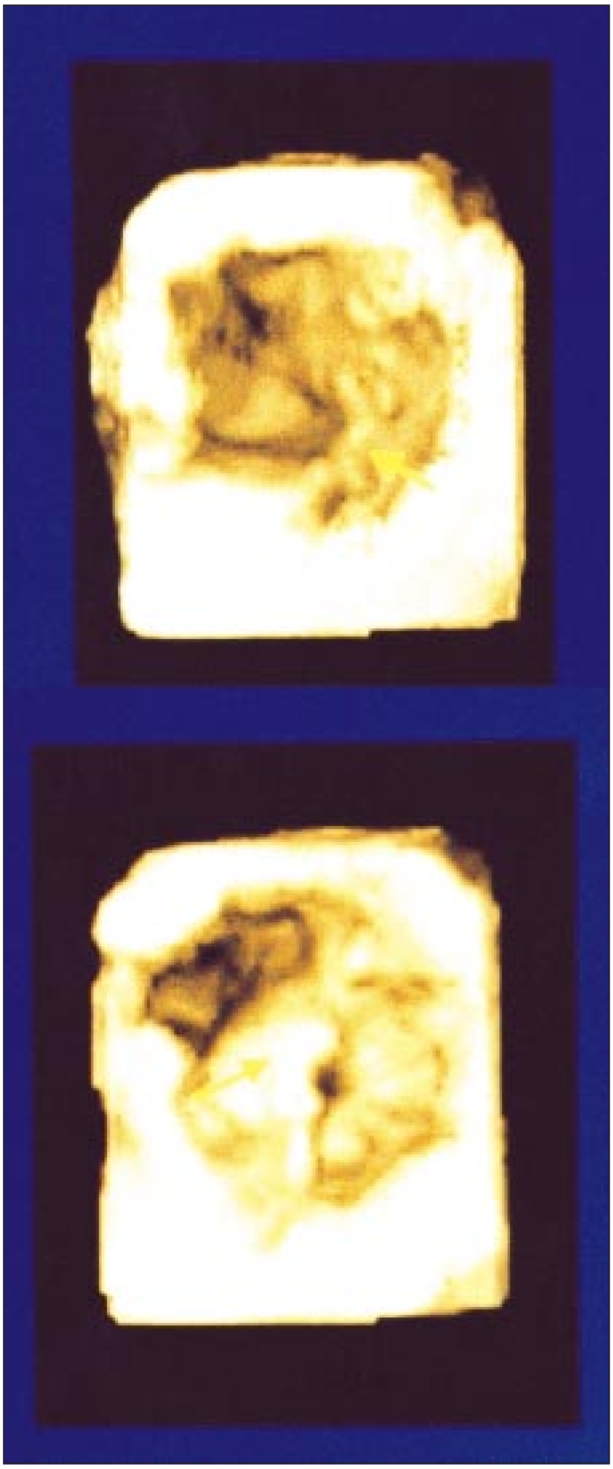

Fig. 1 – 3D reconstruction in a patient with mitral valve prolapse: A) mitral valve seen from the ventricular perspective. B) systolic prolapse of the anterior leaflet of the mitral valve seen from the atrial perspective, towards the observer.

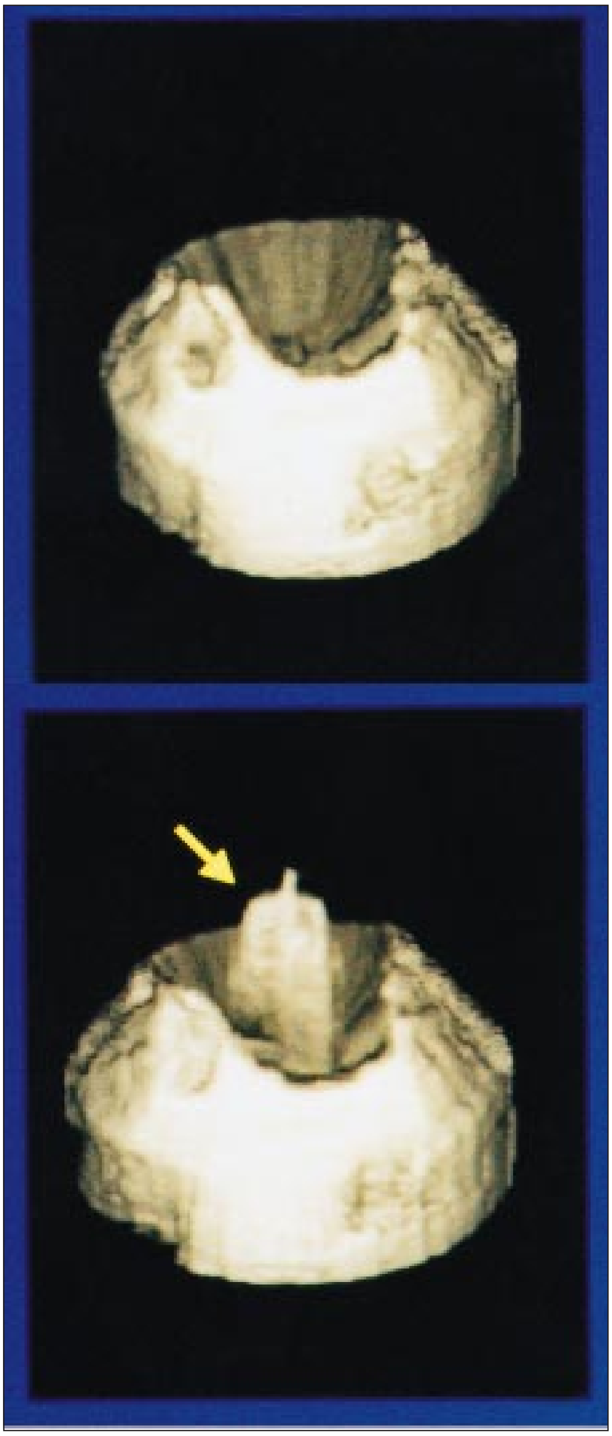

Fig. 2 - 3D reconstruction of the mitral valve in a patient with mitral regurgitation. Central jet is well visualized from the medium portion of the left atrium.

Atrial septal defect – In two patients, 3D reconstruction of the defect was performed and direct view of its size and geometry was obtained, as well as its relationships to other cardiac structures, which could be visualized from both sides of the atrial septum. It was also possible to defect systo-diastolic variation in the size of the defect, which could be visualized only when 3DE was used.

Figure 5 shows a large atrial septal defect from the perspective of the left atrium. Right atrium could be seen through the large defect.

Infective endocarditis – Three patients with infective endocarditis were studied and in one (case 9), a better anatomical definition of an aortic perivalvular abscess was obtained. In the two remaining patients, vegetation had already been identified by 2DE.

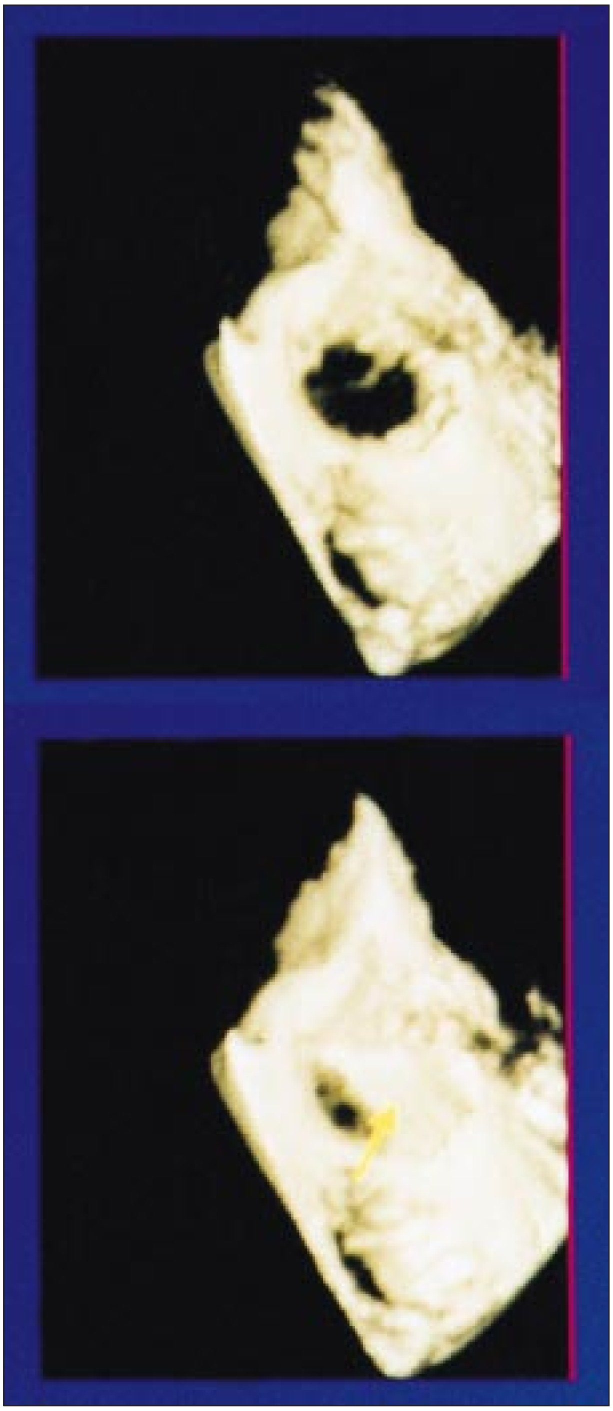

Fig. 3 - 3D reconstruction of a mechanical aortic prosthesis: A) opened disk in systole can be seen. B) closed disk is seen in diastole.

Discussion

3DE may become the best method for studying cardiac anatomy and pathology. In the last few years, 3D reconstruction has been performed using different methods for image acquisition. Up to now, conventional 2DE has always been used for 3D reconstruction.

Rotational acquisition technique offers advantages during a multiplanar transesophageal study due to the excellent quality of the obtained image when the transesophageal approach is used [5-9]. When the region of interest is centralized, the transducer is held in a stable position and then the motor makes it spin around the axis. This technique is relatively easy to perform but there is a learning curve, since the apparatus coupled to the transducer is large and heavy.

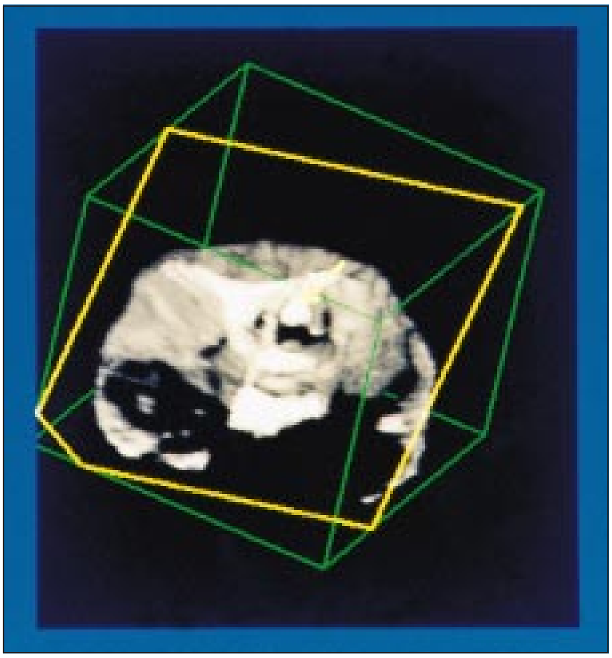

Fig. 4 - 3DE reconstruction of the aortic valve. The stenotic aortic valve is seen in diastole.

TEE, specially with a multiplanar transducer, has become a widely used procedure in many centers, because it can be easily employed in different clinical situations. Because the esophagus is posterior to the heart, it is a stable site for placing the multiplanar transducer, and this provides advantages for rotational acquisition of good quality images, when compared with other methods.

The greatest 3D reconstruction advantage consists of the possibility of visualizing structures in unique perspectives, due to the sections that can be obtained in any desired plane.[10] It is very helpful in the evaluation of valvar structure (subvalvular apparatus, valvular ring and leaflet thickening which can be visualized in different sections). Defect size and magnitude in different points and angles from those available in 2DE can be obtained in a perspective similar to open heart surgery.

In addition, real time images offer the opportunity to better reproduce valvar movement, providing further information about leaflets mobility, commissures and valvar orifice size. Different aspects from different diseases can be appreciated, when compared with the still heart during surgery [11,12].

However, valvar prostheses can not be adequately reconstructed due to the multiple artifacts resulting from the prosthetic material that makes prosthetic evaluation difficult.

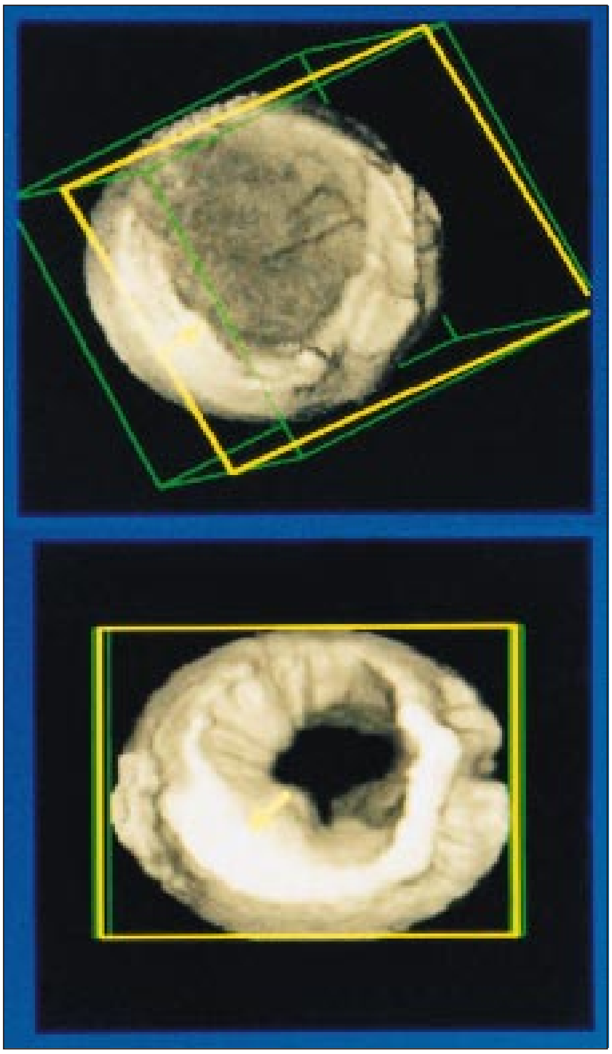

Fig. 5 – Section at the level of atrial septum helped to define atrial septal defect and its relationship with other structures.

Reconstruction image quality, considered adequate when complete deep view of the aimed structure is obtained, depends on the quality of 2DE images gathered during acquisition, which in turn, depends on the transducer stability, the patient's respiration and heart rate. Due to this fact, patients on atrial fibrillation, when it is difficult to obtain ECG gating, have been excluded, as well as those with respiratory distress, which greatly prolongs image acquisition time.

Several factors are crucial for 3D reconstruction. Selection of gains and threshold in post-processed image are major steps for *volume-rendered* imaging. When not properly adjusted, they may result in artifacts and limit diagnosis.

Another major point needs to be emphasized: the possibility of the patient moving the transducer during acquisition. This limitation has been overcome by providing adequate instruction to the patient to remain still during acquisition.

Finally, the greatest limitation for the 3DE is the amount of time spent for data processing, which is still too long to be used routinely.

In conclusion, this study shows that dynamic 3D reconstruction by multiplanar TEE is possible and improves the recognition of the anatomical details of the cardiac structures, particularly of the mitral valve and the atrial septum.

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