Evaluation of prosthetic valve dysfunction by three-dimensional echocardiography

ABSTRACT

Background: Three-dimensional (3D) echocardiography (echo) and transesophageal echo images enable visualization of valvular anatomy from unique orientations with improved spatial relationships not previously seen with two-dimensional (2D) echo.

Materials and Methods: Patients who fulfilled the criteria had undergone detailed evaluation of prosthetic valve dysfunction. Prosthetic valve dysfunction patients with stable hemodynamic were included and 3D echo findings were compared with 2D echo.

Results: A total of 10 males and 25 females were evaluated in the study. Two females and one male had bioprosthetic, three males and two females had tilting disc valve, while 21 females and six males had bileaflet mechanical valve. 3D echo had shown abnormal motion of leaflets in seven male and 21 female patients compared to 2D echo. Abnormal valvular calcification was demonstrated in a total of 23 patients on 3D echo. Valve sewing-ring integrity and motion were found abnormal in two male and two female patients in 3D echo. Prosthetic valve dehiscence and thrombus were better seen in five and 15 patients, respectively, on 3D echo. On 3D echo, pannus was better seen in one male and two females. 3D echo defined exact site and size of vegetation better than 2D echo in two female patients.

Conclusions: Real-time 3D imaging allows clinically useful visualization of prosthetic valve components such as leaflets, rings, and struts of all prosthetic valves, irrespective of position. “En face” view of the valve has proven useful in the assessment of prosthetic valve endocarditis, paravalvular regurgitation, and prosthesis dysfunction. 3D echo imaging plays an important role in device closure.

Keywords: Prosthetic valve dysfunction, three-dimensional echocardiography, two-dimensional echocardiography

INTRODUCTION

Approximately 280,000 valve substitutes are implanted worldwide each year. Of them, approximately half are mechanical valves and half are bioprosthetic valves.[1,2] Despite the marked improvements in valve technology and surgical skill, the outcome of patients undergoing valve replacement is affected by prosthetic valve hemodynamics, durability, and thrombogenicity.

Three-dimensional (3D) echocardiography (echo) with Doppler is the method of choice for noninvasive evaluation of prosthetic valve function. By their design, almost all replacement valves are obstructive compared with normal native valves. The degree of obstruction varies with the type and size of the valve. Thus, it may be difficult to differentiate obstructive hemodynamics due to valve design from that due to mild obstruction as observed after pathologic changes and from prosthesis-patient mismatch. Further, because of shielding and artifacts, the insonation of valve and, in particular, of regurgitant jets associated with the valve may be difficult.[3-6]

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While these earlier techniques enabled an improved visualization of valvular anatomy, acquisition of images was tedious and time-consuming compounded by the requirement of extensive postprocessing to generate images. Further, the image quality was poor and was frequently affected by artifacts, thereby limiting its use.

Recent advancements in 3D have enabled the visualization of valvular anatomy from unique orientations with improved spatial relationships not previously possible with two-dimensional (2D) echo.

This study aims to assess whether 3D mode can provide an incremental diagnostic and descriptive value over 2D mode in the assessment of prosthetic valve function.

MATERIALS AND METHODS

This prospective, observational study was conducted at U N Mehta Institute of Cardiology and Research Centre after approval by the Institutional Ethics Committee. From March 2012 to March 2014, 60 patients were identified to have prosthetic valve dysfunction. Of 60 patients, 25 had unstable hemodynamic condition, so they were excluded from the study. The remaining 35 patients who fulfilled the inclusion criteria underwent detailed evaluation by both 2D echo and 3D echo for prosthetic valve dysfunction. The findings were then compared.

Inclusion criteria for the study

For prosthetic aortic valve dysfunction, one or more of the following 2D echo criteria were used:

1. Mean gradient: ≥ 20 mmHg
2. Acceleration time: ≥ 80 ms
3. Effective valve orifice area (EOA) (cm²) ≤ 1.2
4. Doppler velocity index (DVI) < 0.30
   a. (velocity time integral [VTI] left ventricular outflow tract [LVOT]/VTI prosthetic aortic valve)
5. Presence of regurgitation jet > 5 cm long or its base at origin > 1 cm at prosthetic valvular leak or paravalvular aortic regurgitation.

For prosthetic mitral valve (pr.MV) dysfunction, one or more of the following 2D echo criteria were used:

1. Peak early velocity (m/s) ≥ 1.9
2. Mean gradient (mmHg) > 5
3. Pressure half-time (ms) ≤ 130
4. DVI: VTI pr.MV/VTI (LVOT) ≥ 2.2
5. EOA (cm²) < 2.0
6. Presence of regurgitation jet > 4 cm at prosthetic valvular leak or paravalvular mitral regurgitation effective regurgitant orifice area (cm²) ≤ 0.20.

Exclusion criteria

The patients of prosthetic valve dysfunction having unstable hemodynamics are excluded from this study.

Equipment

For echo, we have used Philips iE33 equipment with 2D and 3D transthoracic echo (TTE) probe (X5-1), 2D and 3D transesophageal echo (TEE) probe (X7-2t).

All the statistical calculations were carried out using SPSS program version 20.0 (Chicago, IL, USA); the result of Chi-square test of categorical data was expressed as frequency and percentage.

RESULTS

The echo findings of 35 patients who underwent detailed evaluation by both 2D and 3D echo were analyzed for prosthetic valve dysfunction. Table 1 shows the different characteristic of study population. Of 35 patients in the study, there were 10 males (28.6%) and 25 females (71.4%). There were 16 (45.7%) young patients (age range 20–40 years) comprising 3 out of 10 males (30%) and 13 out of 25 females (52%).

Among the 35 patients, 3 (8.57%) had aortic valve prosthesis, 25 (71.43%) had mitral valve prosthesis, and 7 (20%) had both aortic and mitral valve prosthesis.

Table 1: Different characteristics of the study population

<table>
<thead>
<tr>
<th>Variables</th>
<th>Total</th>
<th>Male (n=10),  n (%)</th>
<th>Female (n=25),  n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age group among study population</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20-40</td>
<td>16</td>
<td>3 (30)</td>
<td>13 (52)</td>
</tr>
<tr>
<td>&gt;40</td>
<td>18</td>
<td>7 (70)</td>
<td>12 (48)</td>
</tr>
<tr>
<td>Site of prosthetic valve among the study population</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aortic valve</td>
<td>3</td>
<td>1 (10)</td>
<td>2 (8)</td>
</tr>
<tr>
<td>Mitral valve</td>
<td>25</td>
<td>7 (70)</td>
<td>18 (72)</td>
</tr>
<tr>
<td>Both</td>
<td>7</td>
<td>2 (20)</td>
<td>5 (20)</td>
</tr>
<tr>
<td>Type of prosthetic valve amongst the study population</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bioprosthetic valve</td>
<td>3</td>
<td>1 (10)</td>
<td>2 (8)</td>
</tr>
<tr>
<td>Mechanical valve bileaflet</td>
<td>27</td>
<td>6 (60)</td>
<td>21 (84)</td>
</tr>
<tr>
<td>Mechanical valve tilting disc</td>
<td>5</td>
<td>3 (30)</td>
<td>2 (8)</td>
</tr>
<tr>
<td>Mechanical valve ball and cage</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>LV function data among study population</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal</td>
<td>32</td>
<td>7 (70)</td>
<td>25 (100)</td>
</tr>
<tr>
<td>Abnormal</td>
<td>3</td>
<td>3 (30)</td>
<td>0</td>
</tr>
</tbody>
</table>

LV: Left ventricular
Of the total prosthetic valves, 3 (8.5%) patients (2 females and 1 male) had bio pr.MV; 5 (14.2%) patients (2 females and 3 males) had tilting disc mechanical prosthetic valve; 27 (77.1%) patients (21 females and 6 males) had bileaflet mechanical prosthetic valve.

In this study, only 3 (30%) male patients had abnormal left ventricular function, and thus, majority of patients in this study had normal left ventricular function.

Thirty (85.71%) patients had adequate TTE acoustic window. Only 5 (14.3%) patients had inadequate transthoracic acoustic window. Two patients had chronic obstructive pulmonary disease and three patients had obesity; however, even with inadequate 2D imaging window in these five patients, we could get necessary information by 3D echo.

Table 2 highlights that during evaluation of prosthetic valve dysfunction using echo, 3D mode provides superior visualization than 2D mode. As compared to 2D mode echo, prosthetic valve dehiscence was better visualized in five patients (1 male and 4 females) on 3D mode. On 3D mode, thrombus was seen in 15 patients (4 males and 11 females) which was not seen on 2D mode echo. As compared to 2D mode echo, on 3D mode, pannus was better visualized in three patients (1 male and 2 females). Vegetation was seen in 2 (8%) female patients by both 2D and 3D echo. 3D echo defined exact site and size of vegetation better than 2D echo. Pseudoaneurysm was not seen in any of the cases in this study. In the present study, anticoagulation status among the study population was 6 (66%) male patients and 12 (52%) female patients had subtherapeutic prothrombin time.

Table 3 demonstrates that valve leaflet motion was abnormal in 28 patients (7 male and 21 female patients) on 3D echo as compared to 2D echo which showed abnormality in 21 patients (6 males and 15 females). Abnormal valvular calcification was demonstrated in 23 patients on 3D echo. While on 2D echo only 9 patients were found to have abnormal valvular calcification. Valve sewing-ring integrity and motion was found abnormal in four patients on 3D echo which was not visualized on 2D echo.

**DISCUSSION**

Real-time (RT) 3D imaging allows clinically useful visualization of prosthetic valve components such as the leaflets, rings and struts of all prosthetic valves, irrespective of position. This is especially useful for the assessment of mechanical mitral and aortic valves where 2D images are often of poor quality due to acoustic shadowing. In particular, the RT3D allows visualization of ventricular side of mitral prosthetic valves.

**Table 2: Prosthetic valve dysfunction mechanisms**

<table>
<thead>
<tr>
<th>Variables</th>
<th>Male (n=10), n (%)</th>
<th>Female (n=25), n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2D</td>
<td>3D</td>
</tr>
<tr>
<td>Dehiscence</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Not seen</td>
<td>10</td>
<td>9 (90)</td>
</tr>
<tr>
<td>Seen</td>
<td>1 (10)</td>
<td>3 (12)</td>
</tr>
<tr>
<td>Thrombosis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Not seen</td>
<td>7 (70)</td>
<td>3 (30)</td>
</tr>
<tr>
<td>Seen</td>
<td>3 (30)</td>
<td>7 (70)</td>
</tr>
<tr>
<td>Pannus formation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Not seen</td>
<td>10</td>
<td>9 (90)</td>
</tr>
<tr>
<td>Seen</td>
<td>1 (10)</td>
<td>2 (8)</td>
</tr>
<tr>
<td>Pseudoaneurysm formation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Not seen</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Seen</td>
<td>2 (8)</td>
<td>2 (8)</td>
</tr>
</tbody>
</table>

2D: Two-dimensional, 3D: Three-dimensional

**Table 3: Prosthetic valve apparatus evaluation in the study population**

<table>
<thead>
<tr>
<th>Variables</th>
<th>Male (2D)</th>
<th>Female (2D)</th>
<th>Male (3D)</th>
<th>Female (3D)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motion of leaflets (%)</td>
<td>4 (40)</td>
<td>10 (40)</td>
<td>3 (30)</td>
<td>4 (16)</td>
</tr>
<tr>
<td>Normal</td>
<td>6 (60)</td>
<td>15 (60)</td>
<td>7 (70)</td>
<td>21 (84)</td>
</tr>
<tr>
<td>Abnormal</td>
<td>7 (70)</td>
<td>19 (76)</td>
<td>3 (30)</td>
<td>9 (36)</td>
</tr>
<tr>
<td>Presence of calcification (%)</td>
<td>3 (30)</td>
<td>6 (24)</td>
<td>7 (70)</td>
<td>16 (64)</td>
</tr>
<tr>
<td>Normal</td>
<td>10 (100)</td>
<td>25 (100)</td>
<td>8 (80)</td>
<td>23 (92)</td>
</tr>
<tr>
<td>Abnormal</td>
<td>0</td>
<td>0</td>
<td>2 (20)</td>
<td>2 (8)</td>
</tr>
</tbody>
</table>

2D: Two-dimensional, 3D: Three-dimensional

**Prosthetic valve endocarditis**

While TTE has relatively high specificity for detecting vegetations, its sensitivity lies between 40 and 80%. RT3D has been shown to provide additional information in the evaluation of prosthetic valve endocarditis [Figures 1-3].

One study patient presented with postbio-pr.MV replacement before 8 years was presented with history of prolong fever and dyspnea NYHA Class 3 for the last 4 months. On 3D echo [Figures 1-3], vegetation and mitral valve effective regurgitation orifice were seen very clearly as compared to 2D echo.

Particularly, the “en face” view of prosthetic valves has been useful in the assessment of prosthetic valve endocarditis as it allows the identification of discrete valvular dehiscence together with associated regurgitation jets. The ability to
display valvular images in a surgical perspective allows for better communication with surgeons.

RT3D images can also assist in the differentiation of vegetation versus loose suture material, and the rocking motion of a partially dehisced valve is better appreciated on RT3D imaging.

Paravalvular regurgitation
The incidence of significant prosthetic paravalvular regurgitation causing heart failure and hemolytic anemia is 1%–5%, and the majority of prosthetic leaks generally occur in the 1st year postvalve replacement.

RT3D TEE plays an important role in (1) the evaluation of paravalvular regurgitation (size and location); (2) guidance during interventions to treat significant paravalvular regurgitation; and (3) postinterventional assessment.

Assessment of paravalvular regurgitation
2D TEE can miss significant findings as it only presents images from a thin imaging plane through the heart. 3D TEE provides 3D images that can display the entire prosthetic valve, especially those in the aortic or mitral positions. Specifically, the 3D zoom modality can provide en face views of both the mitral and aortic valves.

Dehiscence sites can be identified, with special attention to their location, shape, size, and area. Using multiplanar imaging, it is possible to quantify the area of the dehiscence [Figures 4-6]. Full-volume acquisition provides wider angle images with higher temporal resolution. After data acquisitions, data sets can be rotated, manipulated, and cropped to obtain optimal exposure of paravalvular leaks. The presence of paravalvular orifices can be confirmed with the use of three dimensional color flow.

One of the study patients presented with history of dyspnea for the last 2 months after 6 months of mitral mechanical valve replacement. Prosthetic valve regurgitation was seen moderate on 2D TTE [Figure 4], and severe on 2D TEE [Figure 4], but site of regurgitation was not clearly defined.

On 3D echo [Figure 5], real anatomical site and dimension of paravalvular regurgitation were defined. Patients had undergone surgical correction and successfully treated
on 3D echo color Doppler [Figure 6]; we can differentiate paravalvular regurgitation from echo drop out.

It has been recently described that mitral valve dehiscences occur mainly in the posterior or lateral region and are very rarely located anteriorly.[10]

Prosthetic valve thrombosis versus pannus

Although thrombus formation is frequently associated with valve obstruction, regurgitation, or embolism, it may be an incidental finding during imaging.[9]

The distinction between thrombus and pannus as the underlying etiology of obstruction is essential if thrombolytic therapy is contemplated. Recently, fibrinolytic therapy has emerged as an alternative to surgical treatment for obstructed left-sided prosthetic valves and is considered the treatment of choice for tricuspid valve thrombosis.[11‑14] A thrombus area on TEE <0.85 cm² confers a lower risk for embolic phenomena or death associated with thrombolysis.[15]

Compared with pannus formation, obstruction due to thrombus is associated with a short duration of symptoms and with a history of inadequate anticoagulation (international normalized ratio <2).

The combination of findings of a soft density on the prosthesis and an inadequate international normalized ratio has reported positive and negative predictive values of 87% and 89%, respectively, for thrombus formation.[16]

Thrombi are in general larger and have a soft ultrasound density, similar to that of the myocardium. 3D echo evaluation better defines thrombus size and exacts location of thrombus as compared to 2D echo. Specific features for pannus formation include a small dense mass that in 30% of cases may not be distinctly visualized. Pannus formation is more common in the aortic position [Figure 7].

One study patient had undergone cinefluoroscopy [Figure 8] due to dyspnea NYHA Functional Class II and abnormal prosthetic valvular hemodynamic data, suggesting bileaflet prosthetic valve with stuck one leaflet. An image of this patient was displayed showing 3D echo advantage over 2D echo evaluation in prosthetic valve dysfunction.

Limitations

This study is prospective, observational study; we had included patients who had presented with prosthetic valve dysfunction and in hemodynamic stable condition. This study population is very small, so large sample study is required.

Limitations of 3D TEE include poor visualization of anterior structures of the heart such as the aortic and tricuspid valve,
There are a few limitations to RT3D imaging such as poor visualization of anterior cardiac structures, poor temporal resolution, and poor image quality in patients with arrhythmias and tissue dropout.

This is the initial learning experience of 3D echo in our institute. In the future with experience, this technology will be helpful for guiding interventional therapy for structural heart diseases.

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**Conflicts of interest**
There are no conflicts of interest.

**REFERENCES**

