Doppler echocardiographic assessment of TTK Chitra prosthetic heart valve in the mitral position

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Aims TTK Chitra heart valve prosthesis (CHVP), a tilting disc mechanical heart valve of low cost and proven efficacy, has been in use for the last 15 years. Although various studies substantiating its long-term safety and efficacy are available, no study had assessed its echocardiographic characteristics. The purpose of this study was to determine the normal Doppler parameters of CHVP in the mitral position and to assess whether derivation of mitral valve area (MVA) using the continuity equation (CE) and more commonly used pressure half-time (PHT) method is comparable in the functional assessment of this tilting disc mitral prosthesis.

Methods and results Doppler echocardiography was performed in 40 consecutive patients with CHVP in the mitral position. All patients were clinically stable, without evidence of prosthetic valve dysfunction such as significant obstruction or regurgitation, endocarditis, left ventricular dysfunction (ejection fraction, 40%), or significant aortic regurgitation. Valve sizes studied included 25, 27, and 29 mm. Mitral valve area was derived both by the PHT method and by the CE, using the stroke volume measured in the ventricular outflow tract divided by the time–velocity integral of CHVP jet. The peak Doppler gradient ranged from 5 to 21 (mean 11.0) mmHg, and the mean gradient ranged from 1.7 to 9.2 (mean 4.1) mmHg. Mean gradient negatively correlated with an increase in the actual orifice area (AOA) derived from the valve orifice diameter given by the manufacturer (r = -0.45, P = 0.004). Mitral valve area calculated by both PHT and CE increased significantly with an increase in the AOA (r = 0.42, P = 0.007 and r = 0.32, P = 0.046, respectively). Mitral valve area by the CE averaged 1.55 ± 0.36 cm² (range 0.85 cm² for a 25 mm valve to 2.41 cm² for a 29 mm valve) and was smaller by the PHT method (mean 2.04 ± 0.41 cm², range 1.40–3.14 cm²; P = 0.0001; t-test), irrespective of whether PHT is less than or >110 ms.

Conclusion The Doppler parameters obtained with CHVP in the mitral position are comparable with those obtained with the different prosthetic valves in common use. In the selected group of patients with CHVP, assessment of MVA by the PHT method is comparable with that by the CE. Areas by both methods were smaller than the AOA provided by the manufacturer, as seen in other similar design valves.

Introduction

TTK Chitra heart valve prosthesis (CHVP) is a tilting disc artificial heart valve designed and developed by Sree Chitra Tirunal Institute for Medical Sciences and Technology (SCTIMST).1 It has an ultra-high-molecular-weight polyethylene disc, Haynes-25 alloy (Haynes International Inc., USA) cage, and polyester suture ring. Since its first implant on 6 December 1990, more than 15 000 valves have been implanted in various institutions in India. Because of its low cost and proven efficacy, it has a high potential for more widespread use in developed countries. Although various studies substantiating its long-term safety and efficacy are available,2–4 no study had assessed its echocardiographic characteristics.

Transthoracic Doppler echocardiography has been the predominant tool for the evaluation of prosthetic valve function since early 1980s.5 As the occluder disc is radiolucent, this
assumes particular relevance in the evaluation of prosthetic valve dysfunction of CHVP. Doppler echocardiography can provide information on the gradients across and the mitral valve area (MVA), which are comparable with those obtained at invasive cardiac catheterization.6,7 Two Doppler methods, the pressure half-time (PHT) method proposed by Hatle et al.8 and the method based on the equation of continuity (CE)9–10 were used to estimate the stenotic MVA non-invasively, and its accuracy in varying haemodynamic conditions had been studied previously.11–20 In general, although more commonly used in clinical practice, the method based on PHT was considered less reliable than the application of CE in the assessment of MVA in mechanical prosthetic valves.17–20

We studied the Doppler echocardiographic parameters of the normally functioning CHVP in the mitral position to make reference for these parameters and to assess whether derivation of MVA using the CE and the method based on PHT was considered less reliable than the application of CE in the assessment of MVA in mechanical prosthetic valves.

Methods
Study population
The study population consisted of 40 consecutive patients with a normally functioning CHVP at the mitral position, who were subjected to a routine follow-up echocardiographic examination. Those patients with a short-term follow-up, i.e. <3 months of valve replacement, evidence of prosthetic valve dysfunction such as significant obstruction or regurgitation, endocarditis, left ventricular dysfunction (ejection fraction <40%), significant aortic regurgitation, or unsatisfactory echocardiographic windows were not included in this study. Indications for MVR were rheumatic heart disease in 95% (38 patients) and mitral valve prolapse in 5% (2 patients).

A complete transthoracic echocardiographic examination was performed with Vivid 7 echocardiographic system (GE Vingmed Ultrasound A/S, GE Healthcare, Horten, Norway) in these patients to assess the prosthetic valve function and left ventricular function initially. Two-dimensional and Doppler echocardiographic studies were performed later and parameters were derived. Colour flow Doppler imaging was also performed to assess the degree of regurgitation.

Doppler evaluation of mitral prostheses
The following parameters were assessed to evaluate the prosthetic valve in the mitral position: peak velocity, peak gradient, mean gradient, and MVA derived by PHT and the CE. Flow velocity across the mitral prosthesis was recorded with continuous-wave Doppler guided by colour flow. Measurements were made from the view with the least angulation with flow, most commonly from the apical window. Colour flow Doppler was used in evaluating the direction of flow into the left ventricle and optimizing Doppler recordings of jet velocity. From the tracing of prosthetic inflow velocity, maximal velocity, peak gradient, and mean gradient were measured. Pressure half-time was measured from the tracing of prosthetic inflow velocity as the time required for the peak gradient is reduced by one-half. Mitral valve area is derived as 220/PHT. Mitral valve area using the CE is derived as stroke volume through the prosthesis divided by the velocity-time integral of the mitral jet velocity. Stroke volume through the mitral valve is substituted for that through the left ventricular outflow. In patients with atrial fibrillation, 10 beats were averaged to obtain the representative measurements. The actual orifice area (AOA) is calculated from the valve orifice diameter (VOD) provided by the manufacturer as π · VOD²/4.

Statistical analysis
All continuous data were reported as mean ± standard deviation. Subgroup analysis was performed for each size of the valve implanted. One-way analysis of variance was used to compare continuous variables between multiple groups. Bivariate correlation analysis was used to assess the correlations between each variable and AOA. Discrete variables were compared using the χ² test. A P-value of less than 0.05 was considered significant. The analysis was performed using SPSS version 14.0 for Windows.

Results
Out of the 40 patients studied, 23 had mitral valve replacement alone, whereas the remaining 17 had associated aortic valve replacement also. None had triple valve replacement, whereas 9 had associated tricuspid valve repair. Baseline characteristics of the patients studied are given in Table 1.

The sizes of valves studied were 25, 27, and 29 mm. None of the patients had 23 and 31 mm size valves implanted. An adequate recording of the mitral jet velocity through the prosthetic valve was obtained in all patients. The normal values for the peak velocity, peak and mean gradients, and MVA by PHT and CE of each valve size are shown in Table 2. Mean and peak gradients did not show significant correlation with MVA by PHT (r = −0.22 and −0.05, respectively). Similarly, no correlation was noted between mean and peak gradients and MVA by the CE (r = −0.23 and −0.3, respectively). Peak gradient did not correlate well with AOA (r = −0.26, P = 0.15). However, the mean gradient decreased significantly with an increase in the AOA (r = −0.45, P = 0.004 and r = −0.39, P = 0.014, respectively). The MVA calculated by both PHT and CE increased significantly with an increase in the AOA (r = −0.42, P = 0.007 and r = −0.32, P = 0.046, respectively) (Figures 1 and 2).

Table 1 Baseline characteristics of the patients

| Total number of patients, n | 40 |
| Age (years) | 38.8 ± 10.5 |
| Sex | Male 23 (57.5%), Female 17 (42.5%) |
| Diagnosis | Rheumatic 38 (95%), Mitral valve prolapse 2 (5%) |
| NYHA class | 1 22 (55%), 2 18 (45%) |
| Mean interval of evaluation from implant | 50.1 (3–180) months |
| Rhythm | Sinus rhythm 23 (57.5%), Atrial fibrillation 17 (42.5%) |
| Echo parameters at evaluation | LVIDD (mm) 48.5 ± 6.4, LVIDS (mm) 33.4 ± 5.7 |
| EF (%) | 66.1 ± 8.0 |
| LA (mm) | 46.4 ± 9.0 |
| Distribution of valve size | Valve size 25, 27, 29, No. of patients 13, 22, 5 |

Figures 1 and 2.
Table 2  Doppler echocardiographic parameters of Chitra valve in the mitral position

<table>
<thead>
<tr>
<th>Valve size (mm)</th>
<th>No. of patients</th>
<th>Peak velocity (ms^{-1})</th>
<th>Peak gradient (mmHg)</th>
<th>Mean gradient (mmHg)</th>
<th>Actual orifice area (cm²)</th>
<th>Mitral valve area by PHT (cm²)</th>
<th>Effective orifice area (cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>13</td>
<td>1.74 ± 0.33 (1.17–2.30)</td>
<td>12.6 ± 4.5 (5.5–21.0)</td>
<td>5.09 ± 1.93 (2.1–9.2)</td>
<td>3.14</td>
<td>1.80 ± 0.25 (1.40–2.32)</td>
<td>1.42 ± 0.35 (0.85–1.91)</td>
</tr>
<tr>
<td>27</td>
<td>22</td>
<td>1.60 ± 0.21 (1.14–1.97)</td>
<td>10.3 ± 2.7 (5.2–15.5)</td>
<td>3.72 ± 1.01 (1.7–5.9)</td>
<td>3.8</td>
<td>2.12 ± 0.36 (1.50–3.10)</td>
<td>1.56 ± 0.29 (1.04–2.26)</td>
</tr>
<tr>
<td>29</td>
<td>5</td>
<td>1.54 ± 0.38 (1.12–2.06)</td>
<td>10.0 ± 4.9 (5.0–17.0)</td>
<td>3.26 ± 0.62 (2.5–4.0)</td>
<td>4.52</td>
<td>2.30 ± 0.71 (1.70–3.14)</td>
<td>1.81 ± 0.59 (1.15–2.41)</td>
</tr>
<tr>
<td>Total</td>
<td>40</td>
<td>1.64 ± 0.28 (1.12–2.30)</td>
<td>11.0 ± 3.7 (5.0–21.0)</td>
<td>4.11 ± 1.50 (1.7–9.2)</td>
<td>2.04</td>
<td>2.04 ± 0.41 (1.40–3.14)</td>
<td>1.55 ± 0.36 (0.85–2.41)</td>
</tr>
</tbody>
</table>

Values given as mean ± standard deviation with range in parentheses.
The MVA by PHT showed a significant linear correlation with MVA derived by CE ($r = 0.041$, $P = 0.009$). However, the MVA calculated by PHT tended to be higher than that calculated by the CE, and this difference was statistically significant ($P < 0.001$, t-test). This difference was irrespective of whether PHT is less or more than 110 ms (Table 3). The subgroup analysis between groups with PHT less or more than 110 ms showed no difference in the mean or peak mitral gradients. Calculation by CE also showed no difference for calculated MVA between the two groups. The MVA calculated by CE and PHT showed comparable homogeneity in the distribution of MVA (Figures 3 and 4).

On colour Doppler imaging, 36 patients (90%) showed minimal-to-mild intravalvular mitral regurgitation, which was of grade 1 in 26 patients (65%) and grade 2 in 10 patients (25%). They were equally distributed among the various valve sizes.

### Discussion

This study is unique being the first one to provide the data on Doppler echocardiographic parameters for normally functioning CHVP in the mitral position. The use of CHVP is particularly relevant in developing countries due to its low cost with proven efficacy. We have obtained data on three sizes of CHVP at the mitral position—25, 27, and 29 mm. Although 23 and 31 mm valves are available, they are infrequently implanted. The normal Doppler parameters of CHVP in the mitral position as derived in this study are compared with the published data on commonly used prosthetic valves in Table 4.

### Doppler-derived gradients

Data on peak velocity and peak and mean gradients of various prosthetic valves at the mitral position show a poor correlation with the valve size. Studies have shown a wide range of normal values for the velocities and gradients of different valve types.21 In our study, peak gradients showed no correlation with valve area, despite optimizing confounding flow parameters such as mitral and aortic regurgitation, left ventricular dysfunction, and so on. The possibility of a correlation may have been reduced by the narrow range of valve sizes and the flow dependency. However, there was a significant relationship between the mean gradient and AOA.

### Mitral valve area by continuity equation

Valve areas by the CE are normally smaller than those derived by PHT and relate to valve size. In studies on bioprosthetic and St Jude Medical valves, this index relates well to area by the hydraulic equation and anatomic valve area.17,18 Our study also showed significant correlation between the valve area derived by CE and AOA, similar to published studies of other valves.22 The valve area calculated by the CE tended to be smaller than that calculated by PHT, irrespective of the PHT.

### Mitral valve area by pressure half-time

There was a significant correlation between AOA and PHT in our data. The concept of PHT was initially derived from studies on native mitral valve stenosis,8 and its use in prosthetic mitral valve is controversial.23 Pressure half-time is known to show poor correlation with valve size as it is affected by factors such as net atrioventricular compliance,

<table>
<thead>
<tr>
<th>Pressure half-time</th>
<th>MVA by continuity equation</th>
<th>MVA by pressure half-time method</th>
<th>$P$-value</th>
<th>Peak gradient</th>
<th>Mean gradient</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;110 ms ($n = 17$)</td>
<td>$1.57 \pm 0.36$</td>
<td>$2.41 \pm 0.36$</td>
<td>0.003</td>
<td>$10.5 \pm 3.1$</td>
<td>$3.7 \pm 1.0$</td>
</tr>
<tr>
<td>&gt;110ms ($n = 23$)</td>
<td>$1.33 \pm 0.15$</td>
<td>$1.77 \pm 0.16$</td>
<td>0.005</td>
<td>$11.4 \pm 4.1$</td>
<td>$4.4 \pm 1.7$</td>
</tr>
<tr>
<td>NS ($P = 0.475$)</td>
<td>Significant ($P = 0.005$)</td>
<td>NS ($P = 0.14$)</td>
<td>NS ($P = 0.034$)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

NS, not significant.
peak transmural gradient, and stroke volume. Most of the studies comparing the methods by PHT and CE in prosthetic valves had patients with these confounding factors in the study population. However, these haemodynamically confounding variables were minimized in our study by excluding immediate post-operative cases and those with suspected prosthetic valve dysfunction or significant aortic regurgitation (AR). This might have accounted for the relatively better homogeneity in PHT, and the better correlation of MVA derived by the PHT method with AOA in our study.

No Doppler echocardiographic method to assess the functional orifice area in mitral prosthesis is without fallacies. Mitral valve area by the CE is theoretically justified. However, the absence of correlation against manufacturer’s area has been reported and it is known to underestimate AOA. Valve resistance is useful in native mitral stenosis, but its role in prosthetic mitral valves has not been evaluated.24,25 Colour flow imaging provides good qualitative or semi-quantitative information and together with continuous wave Doppler imaging provides good qualitative or semi-quantitative information. The Gorlin formula and the CE are both pressure- and flow-dependent and are primarily related to the effective area occupied by flow rather than to the anatomic area of the valve.24

**Limitations**

Possible limitation of our study is the absence of cardiac catheterization and derivation of MVA by the Gorlin formula as the standard for comparison. Mitral valve area derived from the VOD and the AOA in our study tend to overestimate the physiological MVA of the tilting disc prosthesis. However, in the absence of invasive catheterization, this should be the next best option as the standard for comparison, as used in some previous studies. Secondly, valve sizes of 23 and 31 mm were not included in the study as they were infrequently used.

**Conclusions**

Our Doppler echocardiographic study provides normal values for pressure gradients and MVA derived by the PHT method and CE of all commonly used sizes of CHVP in mitral position. The data collected should act as a guide for the assessment of prosthetic valve dysfunction in clinical practice. The Doppler parameters obtained with CHVP in the mitral position are comparable with those obtained with the different prosthetic valves in common use. In this selected group of patients with CHVP, assessment of EOA by the PHT method is comparable with that found by the CE. However, areas by both methods were smaller than the AOA provided by the manufacturer.

**Conflict of interest:** none declared.


