Three-Dimensional Echocardiographic Assessment of the Repaired Mitral Valve

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Objective: **This study examined the geometric changes of the mitral valve (MV) after repair using conventional and three-dimensional echocardiography.**

Design: **Prospective evaluation of consecutive patients undergoing mitral valve repair.**

Type of hospital: **Tertiary care university hospital.**

Participants: **Fifty consecutive patients scheduled for elective repair of the mitral valve for regurgitant disease.**

Interventions: **Intraoperative transesophageal echocardiography.**

Measurements: **Assessments of valve area (MVA) were performed using two-dimensional planimetry (2D-Plan), pressure half-time (PHT), and three-dimensional planimetry (3D-Plan). In addition, the direction of ventricular inflow was assessed from the three-dimensional imaging.**

Main Results: **Good correlations ($r = 0.83$) and agreement (-0.08 +/− 0.43 cm^2) were seen between the MVA measured with 3D-Plan and PHT, and were better than either compared to 2D-Plan. MVAs were smaller after repair of functional disease repaired with an annuloplasty ring. After repair, ventricular inflow was directed toward the lateral ventricular wall. Subgroup analysis showed that the change in inflow angle was not different after repair of functional disease (168 to 171 degrees) as compared to those presenting with degenerative disease (168 to 148 degrees; $p < 0.0001$).**

Conclusions: **Three-dimensional imaging provides caregivers with a unique ability to assess changes in valve function after mitral valve repair.**

KEY WORDS: echocardiography, mitral valve repair, mitral regurgitation, three-dimensional imaging

THE GOAL of mitral valve repair is to return the valve toward normal function, which most commonly is defined by its competency and patency. In addition to acting as a one-way valve for blood flow between the left atrium and ventricle,[1,2] the mitral apparatus influences the direction of blood flow into and within the left ventricular cavity,[3-6] which, in turn, has an effect on the efficiency of ventricular ejection and the closure of the mitral valve during ventricular systole.[7]

The purpose of this investigation was to assess the geometry of the mitral valve apparatus and function of the mitral valve before and after repair, using intraoperative 3D transesophageal echocardiography (TEE) to report on changes in the shape of the mitral valve.[1–6,8–10] Comparisons were made for all patients pre- and post-repair and between patients presenting with degenerative mitral regurgitation (MR) and functional disease. It was hypothesized that geometric changes occur after mitral valve repair and that these changes affect the ability to assess valve function, and the direction of blood flow into the left ventricle.

METHODS

After approval from the Institutional Review Board, the authors performed a retrospective analysis of intraoperative TEE data from patients scheduled for mitral valve repair. As this was a retrospective analysis, the IRB did not require informed consent. The authors had no conflicts of interest with any of the devices employed during this investigation. All patients had severe MR without evidence of mitral stenosis prior to surgery. Patients were excluded if they were not in an atrioventricular (AV) sequential rhythm. The surgical procedure was determined by the surgeon, and based on preoperative and intraoperative echocardiographic studies. For all patients, an annuloplasty ring was placed. Based on visual inspection, the surgeon determined the size of the annuloplasty ring. When necessary, additional valve repair consisted of leaflet repair or resection, plication, and/or commissuroplasty of abnormal leaflets.

Intraoperative hemodynamics were monitored from invasive arterial and pulmonary artery catheters. All patients during the intraoperative period were either in sinus rhythm or being synchronously paced via atrial and ventricular pacing wires at a rate of 80-100 beats/min. The use of vasoactive medications was left to the discretion of the attending anesthesiologist. Post-cardiopulmonary bypass (CPB) hemodynamic management was per divisional protocol to achieve pre-specified goals: Mean arterial pressure between 60-90 mmHg, central venous pressure ≤15 mmHg, pulmonary artery pressures within 25% (+/-) of pre-CPB values, and cardiac index ≥2.5 L/min/m^2.

Immediately after CPB, all patients were in an atrio-ventricular sequential rhythm (either sinus rhythm or some atrio-ventricular sequentially paced rhythm [DDD, AOO, or DOO]) with an AV interval of ≤150 m/sec. Intraoperative TEE data were obtained during periods of hemodynamic stability, as guided by divisional protocols.

Prior to and after CPB, a comprehensive TEE exam (IE 33 with 3D TEE probe, Philips, Andover, MA) was performed by experienced cardiac anesthesiologists and echocardiographers. Mitral valve assessment was performed per American Society of Echocardiography (ASE) guidelines for the assessment of native valve stenosis[6] and for prosthetic valves.[7] Mitral valve area (MVA) was calculated or measured using 3 methods; 2 directly from intraoperative data, and

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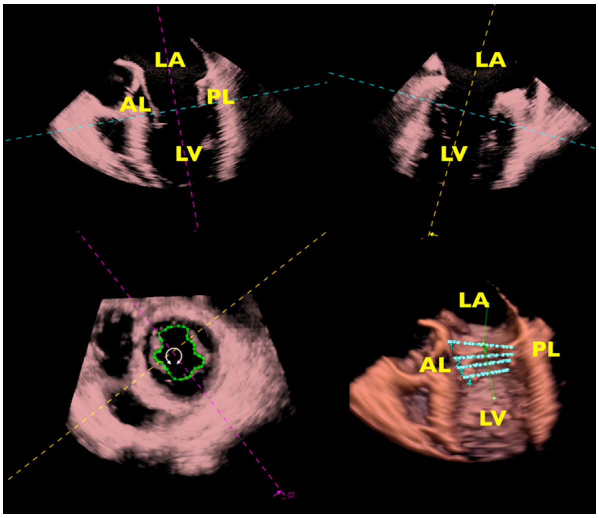

Fig 1. Volumetric Data Analysis: Using the volumetric data set and the Tom-Tec software (TomTec software and 4D CardioView analysis (TomTec Imaging Systems GmbH, Germany), successive short-axis views of the mitral apparatus from the annulus to the leaflet tips, were obtained, and planimetry was performed to measure the area of each level. The top 2 images are perpendicular to each other to align the cursors and optimize the short-axis image (bottom left) of the valve at a particular level within the apparatus. The right lower panel is the result of the successive short-axis measurements. AL, anterior leaflet; LA, left atrium; LV, left ventricle; PL, posterior leaflet.

using the 3D volume data set and reconstructed 3D images. The first 2 included 2-dimensional planimetry (2D-PLAN) and the pressure half-time (PHT) methods. 2D-PLAN was obtained from a transgastric 2-dimensional cross-sectional view of the mitral valve.[11,12] PHT was measured from continuous wave (CW) or high pulse repetition frequency (HPRF) Doppler interrogation depending on the trans-valvular velocity to obtain a clear and distinct Doppler velocity profile across the mitral valve. Data were obtained from the mid-esophageal windows.[11,13] Using the PHT, an MVA was calculated:

$$MVA = 220/PHT \qquad \text{(equation 1)}$$

All measures were obtained in triplicate and averaged. For patients with irregular rhythms, 5 measurements were obtained and averaged. Data were collected during brief periods of apnea.

Three-dimensional full-volume echocardiographic data were obtained from mid-esophageal imaging. From these data, off-line assessment of the mitral apparatus was performed using TomTec software and 4D CardioView analysis (TomTec Imaging Systems GmbH Munich, Germany).

Data from 4 successive short-axis views of the mitral inflow apparatus were obtained from the annular plane to the leaflet tips (Fig 1). The areas were measured by tracing the inner edges of each successive short-axis view (Fig 1).

A 3D view of the mitral valve was reconstructed from the 3D volume data set. The image then was rotated to allow visualization from a left ventricular vantage point. From this view, the inner edges of the leaflets were traced directly during its peak excursion in diastole to yield a true, enface MVA (3D-PLAN) (Fig 2).[8]

From the 3D volumetric data, the direction and angle of ventricular inflow were assessed. These were obtained by connecting 2 perpendicular lines, 1 through the annular plane and the other at the level of the leaflet tips. The angle of LV inflow then could be measured (Fig 3).

Paired t-tests and ANOVA were used to determine if significant differences existed between the geometric data prior to and after CPB and between different subgroups, degenerative *v* functional disease and those who did and did not have anterior leaflet procedures performed. Mitral valve areas, obtained from the methods described above, were compared using correlation and agreement statistics (Bland-Altman; Bias Analysis). These areas included those using PHT, 2D-PLAN, and 3D-PLAN. Analyses were performed using StatView (Statview, San Francisco, CA).

RESULTS

Fifty consecutive patients were studied. All patients demonstrated an atrio-ventricular sequential rhythm whether it was their native conduction or paced. All fifty patients had suitable data for analysis. All had successful repair of the mitral valve without significant MR (≤1+) or the occurrence of systolic anterior motion (SAM) or evidence of left ventricular outflow tract obstruction (LVOTO). Demographic and procedural data are listed in Table 1. In the immediate postoperative period, during echocardiographic assessment, all but 2 patients received vasoactive medications to meet hemodynamic goals.

Prior to repair, 10 patients had functional (normal leaflet appearance) mitral regurgitation, and 40 had degenerative (myxomatous) disease. For functional disease, the mitral valve was repaired with an isolated annulopasty in all but 1 patient who had partial resection of the posterior leaflet. For 40 degenerative cases, procedures included leaflet resection or plication (n = 39), repair (n = 14), and peripheral commissuroplasties (n = 14). All had an annulopasty ring placed. Immediately after valve repair, there was less than 1+ MR in all cases. There was no significant TR or AI (≤1+) after CPB.

Three-dimensional imaging and off-line analysis were feasible in all patients. Pressure half-time (PHT) was feasible in 46/50 (92%) patients. In 4 patients, a discernible 'E' wave to measure PHT was not obtained. 2D planimetry from the transgastric view (during 2D imaging) could be performed in 36/50 (72%) of patients. For 5 of these 15 patients, transgastric imaging was limited due to a hiatal hernia. For 10 patients, a short-axis view of the repaired mitral valve was difficult to obtain due to an inability to visualize the full circumferential extent of the leaflet edges.

Mitral valve areas decreased after repair (Table 2). From the 3D volumetric data set, the pre-repair annular and the leaflet tip areas were 8.7 cm^2 and 6.9 cm^2, respectively. The pre-repair

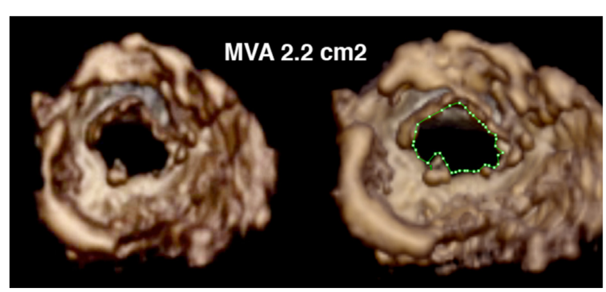

Fig 2. Three-dimensional planimetry (3D Plan): Planimetry of short-axis obtained during 3-dimensional imaging. The volumetric data set was analyzed offline using the Tom-Tec software (TomTec software and 4D CardioView analysis [TomTec Imaging Systems GmbH Germany]). Adjusting the 3-dimensional image to view the largest mitral orifice from the left ventricular side allows planimetry of the mitral opening at the leaflet tips and determination of the mitral valve area (MVA).