Quantitative Modeling of the Mitral Valve by Three-Dimensional Transesophageal Echocardiography in Patients Undergoing Mitral Valve Repair: Correlation with Intraoperative Surgical Technique

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Background: Mitral valve (MV) repair is the procedure of choice for patients with degenerative MV disease (DMVD) with severe mitral regurgitation. The aim of this study was to identify specific quantitative MV parameters from preoperative three-dimensional (3D) transesophageal echocardiography that are associated with the length of the mitral annuloplasty band implanted and the performance of leaflet resection in patients with DMVD undergoing MV repair.

Methods: Ninety-four patients (mean age, 60 ± 11 years; 68% men) referred for MV surgery with adequate-quality preoperative 3D transesophageal echocardiographic studies were retrospectively identified. Parametric maps of the MV were generated using semiautomated MV modeling software. Annular and valvular parameters were measured and indexed to body surface area. The implanted annuloplasty band size and leaflet resection were determined on the basis of surgical reports.

Results: Three-dimensional annular circumference correlated best ($r = 0.74$) with the implanted annuloplasty band length and remained an independent predictor on multivariate linear regression analysis. A third of our cohort ($n = 33$) had posterior leaflet resection. On receiver operating characteristic curve analysis, P2 segment length ≥ 20 mm (area under the curve, 0.86; sensitivity, 88%; specificity, 74%) and P2 leaflet area ≥ 3.4 cm^2 (area under the curve, 0.84; sensitivity, 85%; specificity, 74%) best discriminated the need for leaflet resection.

Conclusions: In DMVD, quantitative 3D annular circumference obtained from semiautomatically generated parametric maps of the MV from 3D transesophageal echocardiographic data was associated with the surgically implanted annuloplasty band length, while P2 leaflet length ≥ 20 mm and area ≥ 3.4 cm^2 were associated with the performance of leaflet resection. These parameters should be further investigated for preoperative planning in patients with DMVD undergoing MV repair. (J Am Soc Echocardiogr 2015;■:■-■.)

Keywords: Degenerative mitral valve disease, Three-dimensional transesophageal echocardiography, Quantitative valve modeling, Leaflet resection, Annuloplasty

Degenerative mitral valve (MV) disease (DMVD) affects approximately 2% of the population and is the leading cause of mitral regurgitation (MR) in developed countries.[1] In patients requiring surgery for severe MR due to DMVD, American and European societal guidelines recommend valve repair over replacement, provided that the valve is suitable and that the institution has surgeons with appropriate expertise.[2,3] Valve repair as opposed to replacement is associated with improved event-free survival.[3] Two important aspects of MV repair are the choice of mitral annuloplasty ring or band size and the decision regarding leaflet modification. These decisions are most often made intraoperatively on the basis of surgical experience and judgement.[4] This reduces reproducibility. Several tools such as ring sizers have been used to help make this process more objective, but they too have limitations.[4]

Echocardiography is the modality of choice for the assessment of MV disease. Specifically, three-dimensional (3D) transesophageal echocardiography (TEE) allows superior visualization of the MV anatomy and morphology, allowing better assessment of the lesion, its complexity, and its suitability for repair compared with two-dimensional (2D) TEE.[5] In addition, 3D MV modeling generates

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Abbreviations
ALPM = Anterolateral-posteromedial
DMVD = Degenerative mitral valve disease
ICD = Intercommissural distance
ITD = Intertrigonal distance
LV = Left ventricular
MR = Mitral regurgitation
MV = Mitral valve
SAM = Systolic anterior motion
TEE = Transesophageal echocardiography
3D = Three-dimensional
2D = Two-dimensional

a plethora of quantitative measurements of the MV obtained in its physiologic state.[6-8] This offers an opportunity for preoperative surgical planning and individualizing the surgical approach to the patient. However, before using 3D MV modeling for surgical planning, it is important to first demonstrate associations between measurements obtained by preoperative 3D modeling and components of the surgical technique. The aim of our study was to identify specific quantitative parameters on a preoperative 3D TEE using a semiautomated MV modeling technique that would correlate with the annuloplasty band length used and the performance of leaflet resection in patients with DMVD who underwent MV repair. We hypothesized that mitral annular and leaflet parameters commonly measured and used intraoperatively along with novel 3D parameters can be obtained by 3D TEE–based semiautomated MV modeling preoperatively and will correlate with the annuloplasty band length used and the performance of leaflet resection during the surgery.

METHODS

Patients

We retrospectively identified all adult patients referred to an expert surgeon (T.D.), who underwent MV repair for severe MR secondary to DMVD between 2010 and 2013 at Toronto General Hospital (Toronto, Ontario, Canada). Patients who had diagnostic-quality pre- or intraoperative 3D TEE, received annuloplasty bands, and underwent predischarge echocardiography were included. The study protocol was approved by the institutional research ethics board.

Echocardiography

All patients underwent preoperative transthoracic echocardiography. Left ventricular (LV) volumes and ejection fraction were measured using the biplane Simpson method.[9] The severity of MR was graded per American Society of Echocardiography guidelines[10] using a multiparametric approach. All patients then underwent clinical 2D TEE using an iE33 system (Philips Medical Systems, Andover, MA) equipped with an X7-2t transesophageal probe. Three-dimensional assessment of the MV was performed using full-volume (median volume rate, 20 volumes/sec; interquartile range, 16–26 volumes/sec) or real-time (median volume rate, 9 volumes/sec; interquartile range, 7–13 volumes/sec) 3D acquisitions of the MV from either the midesophageal four- or three-chamber view. Four-beat gated acquisitions were used for the full-volume data sets. Withholding of respiration was performed whenever possible. All patients underwent predischarge transthoracic echocardiography from which the MV peak and mean gradients and residual MR were assessed by two level 3–trained echocardiographers (F.P., P.T.) using the integrative approach, as recommended by the American Society of Echocardiography.[10] The result of the surgical repair was considered optimal on the basis of a ≤5mm Hg mean transvalvular gradient, mild or less MR, and absence of systolic anterior motion (SAM) or LV outflow tract obstruction on predischarge echocardiography.

Three-Dimensional Quantitative Measurements

The 3D transesophageal echocardiographic data sets were first assessed for gating artifacts by examining the studies in a plane perpendicular to the plane of acquisition. Studies with gating artifacts were excluded. The studies were then analyzed offline by a single operator (A.C.) blinded to clinical, echocardiographic, and surgical findings using semiautomated valve software (eSie Valves; Siemens Medical Solutions USA, Inc, Mountain View, CA) which has been previously described in detail.[11] In brief, first 3D Digital Imaging and Communications in Medicine data were loaded. A midsystolic frame was chosen for analysis because it was where leaflet billowing and/or prolapse was best visualized, and on the basis of the annular dynamics, it was felt to represent the average measure of annular circumference (smallest circumference at early systole and largest at end-systole). The valve was segmented automatically using a machine learning algorithm.[11] The position of the valve and its orientation and dimension in the image are first detected. This forms a region of interest, within which key landmarks (e.g., trigones and commissures) as well as the annulus and leaflet free edges are detected. Then an average surface model of the anterior and posterior leaflets is fitted to the landmarks. These contours are then deformed to match the atrial side of the leaflets in the image (Figure 1A). To facilitate automated computation of complex measurements, the surface model returned by eSie Valves is represented uniformly. This is established from a landmark-based resampling procedure. Each vertex of the valve surface model is uniquely defined by two coordinates, the u-coordinate, tangential to the valve circumference, from anterior to posterior, and the v-coordinate, perpendicular to the valve circumference, from annulus to free edge (Figure 1B). Each stage of the automated valve modeling is performed by robust detectors trained on a large database of cases covering a wide range of normal and pathologic patient data. When computing the annular circumference, the application goes through the vertices of the anterior leaflet defined by a zero v-coordinate, creating the anterior perimeter, followed by the same process for the posterior leaflet. The total circumference is then the sum of the anterior and posterior perimeters. Leaflet segments are defined using geometric features to cope with the lack of clear image features. More precisely, the A1 to A3 and P1 to P3 segments were defined by dividing the leaflets at the u-coordinates 0 to 1/3, 1/3 to 2/3 and 2/3 to 1.

Once the valve is modeled, to confirm the predetermined landmarks and edit the segmented valve, different work-flow options were available. First, commonly used valve orientations (long axis through A2 to P2, commissural view, and en face view) are displayed for editing (Figure 2A). To view the model in more detail, parallel sagittal and coronal or rotational cut planes (which go through a 360° rotation of the valve) are used (Figures 2B and 2C). Using those planes, data sets in which shift and stitch artifacts interfered with the modeling were excluded. Quantitative parameters automatically generated from the geometric model included (1) 3D annular measurements: total area, anterior, posterior, and total circumference; (2) anteroposterior and anterolateral-posteromedial (ALPM)