Quantitative Analysis of Mitral Annular Geometry and Function in Healthy Volunteers Using Transthoracic Three-Dimensional Echocardiography

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Background: Quantitative assessment of the mitral annulus provides information regarding the pathophysiology of mitral regurgitation and aids in the planning of reparative surgery. Three-dimensional (3D) transthoracic echocardiographic data sets acquired with current scanners have enough spatial and temporal resolution to allow the quantitative analysis of the mitral annulus. Accordingly, the authors performed (1) a validation study to assess the agreement of quantitative analysis of the mitral annulus performed on 3D transthoracic echocardiography (TTE) and 3D transesophageal echocardiography (TEE) and (2) a normative study to obtain the reference values of 3D transthoracic echocardiographic parameters for mitral annular (MA) geometry and dynamics.

Methods: Mitral valve data sets were obtained by 3D TEE and 3D TTE in 30 consecutive patients with clinically indicated TEE (validation study) and 3D TTE in 224 healthy volunteers (aged 18–76 years) (normative study).

Results: In the validation study, MA measurements obtained by 3D TTE were similar to those obtained by 3D TEE (P = NS). In the normative study, MA analysis by 3D TTE was feasible (94.5%) and reproducible (intraclass correlation coefficient = 0.78–0.97). MA diameters, area, and circumference were correlated with body surface area ($r > 0.50$ for all) but not with age. Men had larger MA areas than women (4.9 ± 1.0 vs 4.5 ± 0.7 cm^2/m^2, P = .004). During systole, MA area decreased by $29 \pm 5\%$. This decrease was related mainly to anteroposterior diameter shortening ($20 \pm 7\%$).

Conclusions: MA quantitative analysis by 3D TTE was accurate compared with 3D TEE in unselected patients with mitral valve disease. In healthy subjects, it was highly feasible and reproducible. The availability of reference values for MA geometry and dynamics may foster the implementation of MA quantitative analysis by 3D TTE in clinical settings. (J Am Soc Echocardiogr 2014;■:■-■.)

Keywords: Three-dimensional echocardiography, Transesophageal echocardiography, Transthoracic echocardiography, Mitral annulus, Mitral valve, Reference values, Normal subjects

Transthoracic echocardiography (TTE) is the standard clinical tool for the initial assessment and longitudinal evaluation of patients with mitral regurgitation (MR).[1,2] Changes in the size, shape, and dynamics of the normal mitral annulus are closely related to the development of MR,[3-6] and mitral annuloplasty is the most common surgical procedure to repair a regurgitant mitral valve (MV).[7,8] Therefore, the quantitative assessment of mitral annular (MA) geometry seems to be important for a better understanding of MR pathophysiology and planning of reparative surgery.[9,10] However, MA size is only rarely reported in clinical routine, and according to current recommendations regarding the echocardiographic assessment of patients with MR, the characterization of MA geometry is limited only to the measurement of MA anterior-posterior (A-P) diameter.[1]

Linear or area measurements used to describe MA geometry using tomographic imaging techniques (e.g., two-dimensional [2D] echocardiography or cardiac magnetic resonance [CMR]) depend on the correct alignment of imaging planes and on the recognition of anatomic landmarks.[11] In addition, they are unsuitable to fully characterize the complex nonplanar geometry of the mitral annulus and mitral leaflets.[12] Conversely, three-dimensional (3D) echocardiography has the ability to provide anatomically sound images of the MV

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Dr Mihaila was a European Association of Cardiovascular Imaging Research Grant winner in 2011 and a European Society of Cardiology Training Grant winner in 2014. Drs Badano and Muraru are consultants for and have received equipment grants from GE Healthcare (Little Chalfont, United Kingdom) and TomTec Imaging Systems (Unterschleissheim, Germany).

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0894-7317/$36.00

http://dx.doi.org/10.1016/j.echo.2014.04.017

Abbreviations

ALA = Anterior leaflet area

AL-PM = Anterolateral-posteromedial

Ao-AP angle = Angle between the aortic valve and mitral annulus along the anterior-posterior direction

A-P = Anterior-posterior

BSA = Body surface area

CMR = Cardiac magnetic resonance

LV = Left ventricular

MA = Mitral annular

MR = Mitral regurgitation

MV = Mitral valve

MVC = Mitral valve closure

NPA = Nonplanarity angle

PLA = Posterior leaflet area

TEE = Transesophageal echocardiography

3D = Three-dimensional

TTE = Transthoracic echocardiography

2D = Two-dimensional

apparatus and to analyze the geometry and dynamics of the mitral annulus without geometric assumptions.[3-6,13-15] Indeed, measurements of MV anatomy using 3D transesophageal echocardiography (TEE) have been reported to be accurate compared with surgical measurements and superior to those obtained by 2D TEE.[16]

Until recently, MA quantitative assessment was feasible only with 3D data sets acquired from the transesophageal approach, so it was not practical for the routine assessment and follow-up of patients with MR.[3,17,18] Third-generation 3D scanners have significantly improved the spatial and temporal resolution of 3D data sets acquired by 3D TTE, making feasible both the qualitative and quantitative analysis of the mitral annulus by 3D TTE.[19,20] To the best of our knowledge, there are no data regarding the feasibility and accuracy of MA quantitative analysis performed on 3D transthoracic echocardiographic data sets, and data on reference values of MA parameters assessed using 3D TTE are quite limited.[14]

To address these issues, we designed two consecutive, prospective studies. In a validation study, we compared MA quantitative assessment by 3D TTE against the same measurements obtained by 3D TEE, and in a normative study, (1) we obtained reference values for static and dynamic MA analysis from a large cohort of healthy volunteers, (2) we analyzed the relationships of normal MA geometry with age, gender, and body size, and (3) we assessed the feasibility and reproducibility of quantitative analysis of MA geometry using 3D TTE.

METHODS

Study Population

Between July 2011 and October 2011, we enrolled consecutive patients in sinus rhythm with clinical indications for TEE to conduct the validation study.

To obtain normative values for MA size and geometry, healthy Caucasian volunteers were prospectively recruited among hospital employees, fellows-in-training, their relatives, and individuals who underwent medical assessments for driving or working licenses between October 2011 and February 2013. The inclusion criteria were age > 17 years, no history or symptoms of cardiovascular or lung disease, no cardiovascular risk factors (i.e., systemic arterial hypertension, smoking, diabetes, and hypercholesterolemia), normal results on electrocardiography and physical examination, and no cardio- or vasoactive treatment. Exclusion criteria were athletic training, pregnancy, body mass index > 30 kg/m^2, and a poor apical acoustic window. Blood pressure was measured in all subjects immediately before the echocardiographic examination. The study was approved by the University of Padua Ethics Committee (protocol no. 2380 P), and both patients and volunteers provided informed consent before the study.

Echocardiography

All examinations were performed using standardized protocols and a commercially available Vivid E9 system (GE Vingmed Ultrasound AS, Horten, Norway) equipped with 4V and 6VT probes for 3D TTE and 3D TEE, respectively.

In the validation study, 3D full-volume MV data sets were acquired by 3D TTE from the apical approach in all patients, immediately before TEE. TEE was performed according to the specific clinical indication by the same experienced operator (L.P.B. or D.M.), and at the end, a 3D full-volume MV data set was acquired using the 3D zoom option (Videos 1 and 2; available at www.onlinejase.com).

In the normative study, all 224 healthy subjects underwent complete TTE to exclude subclinical heart diseases and poor apical acoustic windows. Two 3D full-volume acquisitions (i.e., one for the MV and a separate one for the left ventricle) were recorded by combining six consecutive electrocardiographically triggered subvolumes during a breath-hold (Videos 3 and 4; available at www.onlinejase.com).

Image Analysis

Three-dimensional transthoracic and transesophageal echocardiographic data sets for the MV and the left ventricle were stored digitally in raw-data format for offline analysis. Quantification of 3D left ventricular (LV) volumes and ejection fraction and 3D longitudinal strain was performed using a commercially available software package (4D AutoLVQ, EchoPAC BT 12; GE Vingmed Ultrasound AS) previously described and validated against CMR.[21]

For the validation study, 3D transthoracic and transesophageal echocardiographic MV data sets were converted to Digital Imaging and Communications in Medicine format and analyzed using a dedicated software package for MV quantitative analysis (4D-MV Assessment version 2.3; TomTec Imaging Systems, Unterschleissheim, Germany) by a single observer, who performed the quantitative analysis of transesophageal and transthoracic echocardiographic data sets in random order, in a blinded fashion, with an interval of 1 week.

For the normative study, a single observer (S.M.) analyzed the 3D transthoracic echocardiographic MV data sets of the 224 healthy volunteers to obtain reference values for MA geometry and dynamics, using the same software package. The quality of MV data sets was judged subjectively as excellent, good, fair, or poor, considering the signal-to-noise ratio, the degree of blood-tissue contrast, and the quality of MA tracking. Poor-quality data sets were excluded from the study.

MA analysis on 3D transthoracic echocardiographic data sets started by identifying three time points: early systole (the frame after MV closure [MVC]), end-systole (the frame just before the MV begins to open, and mid-systole (the frame midway between MVC and end-systole). After adding anatomic landmarks for the mitral annulus, aorta, and leaflet coaptation point, the software created a static 3D model of the mitral annulus and leaflets at mid-systole. Afterward, the mitral annulus was tracked in each systolic frame (dynamic