Quantification of Mitral Regurgitation by General Imaging Three-Dimensional Quantification: Feasibility and Accuracy

Wugang Wang, MD, Qiongwen Lin, MD, Weichun Wu, MD, Yong Jiang, MD, Tingyu Lan, MD, and Hao Wang, PhD, MD, *Beijing, China*

Background: Mitral regurgitant volume (MRvol) is an important index of the severity of mitral regurgitation (MR), but MRvol measurement remains challenging. With the development of probe technology and software, General Imaging 3D Quantification (GI 3DQ) allows the direct measurement of MR jet volume. The aim of this study was to evaluate the feasibility and accuracy of MRvol by quantification of MR jet volume using GI 3DQ.

Methods: Ninety-three patients were included, 61 with functional MR and 32 with mitral valve prolapse. Patients with MR were also divided into those with central MR ($n = 41$) and those with eccentric MR ($n = 52$). MRvol was assessed using GI 3DQ and the proximal isovelocity surface area (PISA) method. MRvol using effective regurgitant orifice area by real-time three-dimensional echocardiography multiplied by the MR time-velocity integral was used as the reference method.

Results: MRvol measured by GI 3DQ and the PISA method had good correlation with MRvol by the reference method. A significant underestimation of MRvol using GI 3DQ and the PISA method was observed in the assessment of eccentric MR, but without a significant difference in the assessment of central MR.

Conclusions: Quantification of MRvol with GI 3DQ was feasible. Quantification of central MRvol using this methodology is accurate compared with the reference method. Quantification of MRvol with GI 3DQ has no significant difference from the currently recommended PISA method. (J Am Soc Echocardiogr 2014;27:268-76.)

Keywords: General imaging three-dimensional quantification, Mitral regurgitation, Real-time three-dimensional echocardiography, Proximal isovelocity surface area

Mitral regurgitation (MR) is common valvular lesion that ultimately progresses to irreversible heart failure with high morbidity and mortality.[1,2] Consequently, the timely diagnosis and accurate assessment of severity of MR are of significant importance for appropriate decision making and timing of surgical intervention.[3-5] Mitral regurgitant volume (MRvol) is a useful and important index of the severity of MR. MRvol calculation using effective regurgitant orifice area (EROA) by the proximal isovelocity surface area (PISA) method multiplied by the MR time-velocity integral (TVI) has been recommended.[6,7] However, pitfalls and limitations of this technique are well recognized.[7,8]

Now, with the development of probe technology and software, real-time three-dimensional (3D) echocardiography (RT3DE) is capable of acquiring and displaying 3D color flow Doppler imaging. With subsequent offline 3D color flow reconstruction and analysis, the General Imaging 3D Quantification (GI 3DQ) plug-in (Philips Medical Systems, Andover, MA) provides tools for manually tracing regurgitant jet contours, and MRvol is directly measured. Recently, a series of studies have confirmed that MRvol using EROA (direct planimetry of EROA by real-time 3D color Doppler echocardiography) multiplied by the MR TVI was highly accurate compared with MR volume measured by velocity-encoded cardiac magnetic resonance.[9-11] Therefore, the aim of this study was to evaluate the feasibility and accuracy of MRvol by the quantification of MR jet volume with GI 3DQ to compare MRvol derived from EROA by real-time 3D color Doppler echocardiography.

METHODS

Study Population

Our study was performed prospectively in 93 patients (57 men, 36 women; mean age, 47.9 ± 15.2 years) with varying degrees of MR of different etiologies on color Doppler echocardiography. The etiology of MR was ischemia in 22, idiopathic dilated cardiomyopathy in 39, mitral valve prolapse (MVP) in 32 (anterior MVP in 17, posterior MVP in 15). Patients with good acoustic windows and color Doppler quality were included in the study. Patients with atrial fibrillation,

From the Department of Echocardiography, Fuwai Hospital, Chinese Academy of Medical Sciences, Peking Union Medical College, Beijing, China.

Reprint requests: Hao Wang, PhD, MD, Department of Echocardiography, Fuwai Hospital, Chinese Academy of Medical Sciences, Peking Union Medical College, 167 Beilishi Road, Beijing, 100037, China (E-mail: fwanghao@aliyun.com).

0894-7317/$36.00

http://dx.doi.org/10.1016/j.echo.2013.11.015

Abbreviations

EROA = Effective regurgitant orifice area

GI 3DQ = General Imaging 3D Quantification

MRvol = Mitral regurgitant volume

MR = Mitral regurgitation

MVP = Mitral valve prolapse

PISA = Proximal isovelocity surface area

RT3DE = Real-time three-dimensional echocardiography

3D = Three-dimensional

TVI = Time-velocity integral

frequent atrial or ventricular premature beats, mitral stenosis, and congenital heart disease were excluded. Of 110 patients initially enrolled, 17 (15.5%) were excluded from further analysis because of technically difficult echocardiographic studies: inadequate 3D color Doppler images in 11 and an inability to obtain a continuous-wave Doppler profile of the mitral regurgitant jet in 6. According to mechanism, MR was divided into functional MR (n = 61) and MVP (n = 32) groups. Functional MR was defined as leaflet tethering and incomplete leaflet closure in the presence of normal mitral valve anatomy and regional or global left ventricular remodeling.[12] MVP was defined as systolic mitral leaflet motion of ≥2 mm beyond the mitral annulus of one or more leaflet segments with or without flail.[13] We also divided all patients into a central MR group (n = 41) and an eccentric MR group (n = 52) on the basis of the direction of regurgitant jet. All patients in the central MR group had functional MR, and the eccentric MR group included 20 patients with functional MR with eccentric jets and the 32 patients with MVP. The regurgitant jet direction was classified according to the initial direction of the jet immediately behind the point of mitral leaflet coaptation. Thus, eccentric jets were in close contact with the mitral leaflet behind the regurgitant orifice or impinged to the medial or lateral wall of the left atrium, whereas central jets were initially directed into the center of the left atrium and did not strike atrial walls or mitral valve leaflets.[14] The study was approved by our institutional review board, and all patients underwent echocardiography because of clinical indications and gave written informed consent.

Two-Dimensional Echocardiography: MRvol by PISA

Patients were imaged in the left lateral decubitus position using a commercially available system (iE33; Philips Medical Systems) equipped with a 3.5-MHz transducer. The proximal isovelocity surface of the mitral regurgitant jet was visualized in an image from the apical four-chamber view, using zoom mode. We optimized the appearance of the PISA by shifting the color Doppler aliasing velocity from 20 to 40 cm/sec (mean, 34.3 ± 3.6 cm/sec). For each cardiac cycle, the frame with the largest flow convergence region was selected as coinciding with maximal regurgitant flow. The maximal velocity of the regurgitant jet was determined using continuous-wave Doppler. EROA was calculated using the PISA method as $(2 \times \pi \times r^2 \times V_r)/V_{max}$, where r is the isovelocity radius, V_r is the aliasing velocity, and V_{max} is the maximal velocity of the regurgitant jet. MRvol by PISA was calculated as PISA-derived EROA multiplied by the MR TVI.

Real-Time 3D Color Doppler Echocardiography

Three-dimensional color Doppler data were acquired immediately after the two-dimensional transthoracic study using the same system equipped with an X3, fully sampled matrix transducer. Three-dimensional color Doppler data sets were obtained from the apical view within one breath hold, combining seven small real-time subvolumes in a larger pyramidal volume (approximately 60° × 60°). Nyquist limits were set between 40 and 60 cm/sec to avoid any overestimation or underestimation, and color gain was used that just eliminated random color speckles from nonmoving regions. All 3D color Doppler data sets were stored digitally, and quantitative analysis was performed offline.

3D Analysis: MRvol Derived from EROA by RT3DE: Direct Planimetry

Three-dimensional color Doppler data sets were analyzed offline using software (QLAB version 7.1; Philips Medical Systems). To measure EROA, the 3D color Doppler data sets were manually cropped by an image plane that was perpendicularly oriented to the jet direction, and the cropping plane was then moved along the jet direction as far as the smallest cross-sectional area[9,11,15] (Figure 1). The EROA was measured by manual planimetry of the color Doppler signal, tilting the image in an "en face" view and selecting the systolic frame with the largest MR jet (Figure 1)[16]; the MRvol was calculated as EROA multiplied by the MR TVI.

Direct Measurement of MRvol by GI 3DQ

GI 3DQ analysis was based on the same 3D color Doppler data sets, and the observer was blinded to the measurement results of MRvol derived from EROA (3D and PISA). In the QLAB workstation, we opened the 3D color Doppler data sets, entered the analysis plug-in GI 3DQ, and selected 15 slices in the "default slices" preference setting. The volumes of regurgitant jets were measured using 15 parallel slices through the regurgitant jet zones. First, we connected the initial and terminal points to get the length of the mitral regurgitant jet, then the 15 slices were displayed automatically. Second, we traced every slice of the regurgitant jet contour from the orifice to the distal plane, and 15 subvolumes were determined. Finally, the volume of the mitral regurgitant jet was calculated by the superposition of the 15 subvolumes (Figure 2). We adjusted the image view and moved the edge of the bounding box to present the complete regurgitant jet and selected the systolic frame with the largest MR jet for the measurement of the MRvol.

Fifteen patients were randomly identified to evaluate the interobserver and intraobserver reproducibility for the MRvol using the GI 3DQ method. Interobserver variability was evaluated by a second independent blinded observer who measured the MRvol with the described GI 3DQ method above on the same full-volume acquisition with the first observer. To test intraobserver variability, measurement of MRvol with GI 3DQ method was repeated by the same observer (the first observer) 1 month later.

Statistical Analysis

Continuous data are expressed as mean ± SD. Categorical data are expressed as absolute numbers or percentages. Pearson's correlation analysis was performed to evaluate the relation between GI 3DQ and PISA measurements of MRvol and those obtained using the reference method. Bland-Altman analysis was performed to evaluate the agreement between methods. Interobserver and intraobserver reproducibility of MRvol using GI 3DQ was evaluated using intraclass correlation coefficients. P values $< .05$ were considered statistically significant. SPSS version 16.0 (SPSS, Inc, Chicago, IL) was used for statistical analysis.