Clinical Implications of Three-Dimensional Real-Time Color Doppler Transthoracic Echocardiography in Quantifying Mitral Regurgitation: A Comparison with Conventional Two-Dimensional Methods

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Background: Automatic quantification of real-time three-dimensional (3D) full-volume color Doppler transthoracic echocardiography (FVCD) has been proposed as a feasible and accurate method for quantifying MR. We aimed to explore the clinical implications of real-time 3D-FVCD for mitral regurgitation (MR) with various clinical manifestations, in comparison with the conventional two-dimensional (2D) proximal isovelocity surface area (PISA) and volumetric method and cardiac magnetic resonance imaging (CMR) methods.

Methods: A total 186 patients with MR were enrolled prospectively. Based on exclusion criteria and image quality review, 152 patients were included in the final analysis for 3D-FVCD and 2D transthoracic echocardiography. Among them, 37 patients underwent subsequent CMR for the validation of 3D-FVCD.

Results: MR volume from 3D-FVCD demonstrated a better agreement ($r = 0.94$) with CMR than 2D-PISA or the 2D volumetric method (VM; $r = 0.87$ vs 0.56). Overall, 2D methods underestimated MR when compared with 3D-FVCD (35.4 ± 28.4 mL for 2D-VM vs 43.8 ± 24.6 mL for 2D-PISA vs 64.6 ± 35.1 mL for 3D-FVCD; $P < .001$). In subgroup analysis, multijet MR (odds ratio [OR], 6.30; 95% CI, 2.52–15.72) and dilated left ventricular end-systolic diameter ≥40 mm (OR, 2.90; 95% CI, 1.12–7.50) were predictors of significant difference in MR volume (>30 mL for primary MR and >15 mL for secondary MR) between 2D-PISA and 3D-FVCD. In identifying surgical candidates, patients with multijet MR (OR, 4.53, 95% CI, 1.99–10.35) demonstrated a higher risk of discrepancy between 2D-PISA and 3D-FVCD, which were consistent in both primary and secondary MR, respectively.

Conclusions: MR quantification with 3D-FVCD showed better correlation and agreement than conventional 2D methods. MR was underestimated by 2D methods, especially in multijet and dilated left ventricle. Multijet MR demonstrated higher risk of discrepancy for the identification of surgical candidate, regardless of MR etiology. (J Am Soc Echocardiogr 2017;■:■-■.)

Keywords: Mitral regurgitation, Three-dimensional echocardiography, Full volume color Doppler echocardiography, Proximal isovelocity surface area

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Abbreviations

2D = Two-dimensional

3D = Three-dimensional

AF = Atrial fibrillation

ASE = American Society of Echocardiography

CMR = Cardiac magnetic resonance imaging

EROA = Effective regurgitant orifice area

FVCD = Full-volume color Doppler transthoracic echocardiography

ICC = Intraclass correlation coefficient

LA = Left atrial

LV = Left ventricular

LVEDD = Left ventricular end-diastolic diameter

LVESD = Left ventricular end-systolic diameter

LVOT = Left ventricular outflow tract

MA = Mitral annulus

MR = Mitral regurgitation

MV = Mitral valve

OR = Odds ratio

PISA = Proximal isovelocity surface area

PW = Pulse wave

PWDF = Pulse-wave Doppler flow

SV = Stroke volume

TTE = Transthoracic echocardiography

VCW = Vena contracta width

VM = Volumetric method

VTI = Velocity-time integral

Mitral regurgitation (MR) is one of the most prevalent valvular heart diseases. Of greatest importance is the fact that the survival tends to decline in patients with significant MR irrespective of its etiology.[1-3] Quantitative assessment of MR severity is imperative because of its link to prognosis, and further still, surgical management is indicated in those who present with severe MR.[1,4,5]

There are several methods and parameters for assessing MR by two-dimensional (2D) transthoracic echocardiography (TTE). Proximal isovelocity surface area (PISA) by 2D-TTE is well validated and recommended for quantifying MR and is widely utilized in clinical practice.[4-6] The volumetric method (VM) and pulse-wave Doppler flow (PWDF) method use the difference of stroke volume (SV) from left ventricular (LV) and aortic forward flow volume. Despite its apparent utility, there are some potential pitfalls. For the PISA method, a multistep process with multiple assumptions may introduce significant error toward MR severity. VM is also known for the potential error on MR quantification due to its assumption on left ventricular outflow tract (LVOT) as a circular structure.[7-9]

The recent development and implementation of real-time three-dimensional (3D) full-volume color Doppler echocardiography (FVCD) has made it possible to quantify mitral inflow and aortic outflow SVs, in parallel with an automated quantification algorithm.[10-12] Notably, in prior validation studies,[12,13] the automated quantification of MR by 3D-FVCD was feasible and accurate. However, the significance of quantifying MR by 3D-FVCD in a clinical setting with various characteristics is yet to be established.

Therefore, we aimed to explore the differential impact of MR quantification by real-time 3D-FVCD in a wide spectrum of MR phenotypes, while comparing it with the conventional 2D and cardiac magnetic resonance imaging (CMR) methods.

METHODS

Study Population and Protocols

Initially, this study comprised 186 consecutive patients presenting with mild-to-severe native valve MR who were referred to Severance Hospital for TTE examination between December 2011 and March 2015. The severity of MR was defined by comprehensive assessment with LV remodeling, effective regurgitant orifice area (EROA), regurgitant volume by the VM and PISA methods, vena contracta width (VCW), jet characteristics, and the presence of systolic flow reversal in pulmonary veins according to the guidelines.[6,14] Patients with more than a mild degree of aortic regurgitation (n = 22), abnormal intracardiac shunt (n = 2), or significant arrhythmia including ventricular arrhythmia and poorly controlled atrial fibrillation (AF; heart rate > 100 beats/min and/or beat-to-beat variability > 30 beats/min, n = 6) were excluded. Hence, subsequent 3D-FVCD study was performed on the remaining 156 patients. After reviewing the image quality, four patients were further excluded due to poor image quality. A flow diagram of study population is summarized in Supplemental Figure 1.

The cause of MR was classified as primary or secondary. Primary MR was defined as MR related to intrinsic valvular abnormalities, and secondary MR was defined as leaflet tethering or incomplete coaptation of leaflets in the presence of regional or global LV remodeling without intrinsic valvular abnormalities.[4] MR was further classified by the jet direction (central vs eccentric) and by the number of jets (single vs multiple). The cardiac rhythm was classified as sinus rhythm or AF by electrocardiography. Candidates for mitral valve (MV) surgery were classified according to current guidelines based on the symptom, ejection fraction, chamber dimension, and MR severity.[4,14] The criteria for severe MR was EROA ≥ 40 mm^2 and MR volume ≥ 60 mL for primary MR and EROA ≥ 20 mm^2 and MR volume ≥ 30 mL for secondary MR.[14] Informed consent was obtained from all participants, and the study protocol was approved by the ethics committee at Severance Hospital.

Image Acquisition and MR Quantification

Each of the image acquisitions was obtained during the same day for all patients. In the event of AF, MR volume was quantified when the preceding and pre-preceding R-R intervals differed by less than 10%.

Two-Dimensional Echocardiography Image Acquisition and the MR Quantification

Two-dimensional TTE was performed using an ACUSON SC2000 ultrasound system (Siemens Medical Solutions USA Inc., Mountain View, CA) with a 4V1c phased-array transducer at a frequency of 4.5 MHz. Measurements for MR assessment was done according to American Society of Echocardiography guidelines.[6]

The VCW of the MR jet was measured at the narrowest portion of the regurgitant jet in zoom mode with an adapted Nyquist limit (59.3 cm/sec) and averaged from the measurements in the four-chamber and three-chamber views.

Two volumetric methods were used: (1) the PWDF method used quantitative Doppler using mitral and aortic SVs[15,16] and (2) the VM was calculated from the difference of SV, which measured from LV end-diastolic and end-systolic volume and aortic forward flow volume.[17] The PWDF method used the difference between MV inflow volume and LV SV, with measurements of multiple parameters. To obtain the Doppler spectral profiles of mitral annulus (MA) and LVOT, a pulsed-wave Doppler sample was carefully placed as parallel as possible (angle < 20°) to the blood flow in apical four-chamber and three-chamber views. The MA diameter was measured between the inner edges of the base of posterior and anterior leaflets