Accuracy of Three-Dimensional Versus Two-Dimensional Echocardiography for Quantification of Aortic Regurgitation and Validation by Three-Dimensional Three-Directional Velocity-Encoded Magnetic Resonance Imaging

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Quantitative assessment of aortic regurgitation (AR) remains challenging. The present study evaluated the accuracy of 2-dimensional (2D) and 3-dimensional (3D) transthoracic echocardiography (TTE) for AR quantification, using 3D 3-directional velocity-encoded magnetic resonance imaging (VE-MRI) as the reference method. Thirty-two AR patients were included. With color Doppler TTE, 2D effective regurgitant orifice area (EROA) was calculated using the proximal isovelocity surface area method. From the 3D TTE multiplanar reformation data, 3D-EROA was calculated by planimetry of the vena contracta. Regurgitant volumes (RVol) were obtained by multiplying the 2D-EROA and 3D-EROA by the velocity-time integral of AR jet and compared with that obtained using VE-MRI. For the entire population, 3D TTE RVol demonstrated a strong correlation and good agreement with VE-MRI RVol (r = 0.94 and −13.6 to 15.6 ml/beat, respectively), whereas 2D TTE RVol showed a modest correlation and large limits of agreement with VE-MRI (r = 0.70 and −22.2 to 32.8 ml/beat, respectively). Eccentric jets were noted in 16 patients (50%). In these patients, 3D TTE demonstrated an excellent correlation (r = 0.95) with VE-MRI, a small bias (0.1 ml/beat) and narrow limits of agreement (−18.7 to 18.8 ml/beat). Finally, the kappa agreement between 3D TTE and VE-MRI for grading of AR severity was good (k = 0.96), whereas the kappa agreement between 2D TTE and VE-MRI was suboptimal (k = 0.53). In conclusion, AR RVol quantification using 3D TTE is accurate, and its advantage over 2D TTE is particularly evident in patients with eccentric jets. **(Am J Cardiol 2013;112:560−566)**

Quantification of aortic regurgitation (AR) remains challenging in clinical practice. Currently, the proximal isovelocity surface area (PISA) method, using 2-dimensional (2D) Doppler echocardiography, is the recommended approach to estimate the regurgitation volume (RVol) and effective regurgitation orifice area (EROA).[1,2] However, several assumptions inherent in its derivation may hamper the accuracy of 2D PISA method to quantify AR, such as noncircular orifices[3] and eccentric jets.[4] Real-time 3-dimensional (3D) echocardiography permits direct visualization of the vena contracta and measurement of the EROA, without the need for additional computation or geometric assumptions.[5−8] In addition, 3D echocardiography is not restricted by any imaging plane, unlike 2D echocardiography, which is limited to quantify flow aligned along the ultrasound beam.[4,8] Therefore, quantification of AR would be more accurate using 3D than 2D echocardiography, and this would probably become more evident in patients with eccentric AR. Recently, 3D 3-directional velocity-encoded magnetic resonance imaging (VE-MRI) has been proposed as a more accurate method to assess transvalvular flow.[7,9,10] The current evaluation assessed the accuracy of 2D and 3D transthoracic echocardiography (TTE) for quantification of AR, using 3D 3-directional VE-MRI as the reference method.

Methods

Thirty-two patients with AR who were clinically referred for TTE and MRI to quantify AR, aortic root, and aortic dimensions were retrospectively evaluated. Patients with acute AR or concomitant valvular disease of more than mild severity, atrial fibrillation, or contraindications for MRI (i.e., implanted devices, claustrophobia) were not included. Clinical data including demographics and symptoms were collected in the departmental electronic patient file (EPD vision version 8.3.3.6; Leiden, The Netherlands) and retrospectively analyzed. All patients underwent standard 2D and

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See page 565 for disclosure information.

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http://dx.doi.org/10.1016/j.amjcard.2013.04.025

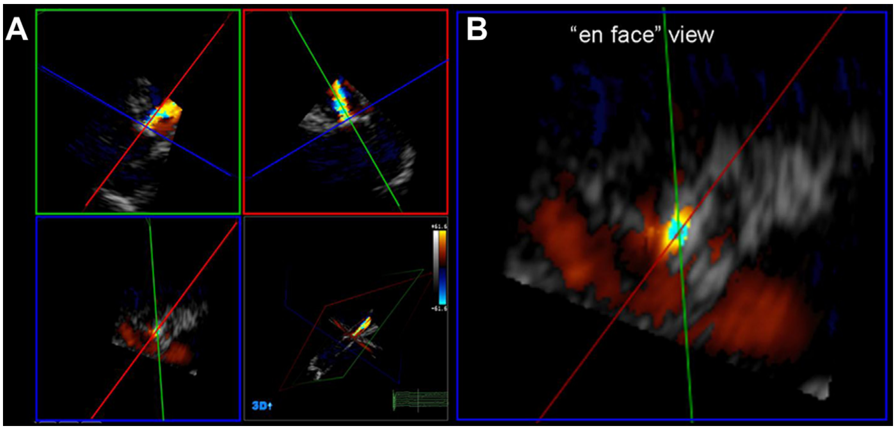

Figure 1. Three-dimensional transthoracic echocardiography for assessment of aortic EROA. First, the 3D color Doppler data set was manually cropped to provide a cross-sectional plane through the vena contracta of the regurgitant jet, perpendicular to the direction of the aortic regurgitant jet *(A)*. Next, from the en face view of the vena contracta, selecting the plane with the narrowest cross-sectional area of the regurgitant jet, the 3D-EROA was measured by manual planimetry of the color Doppler signal *(B)*. The figure provides an example of a patient with central and circular jet.

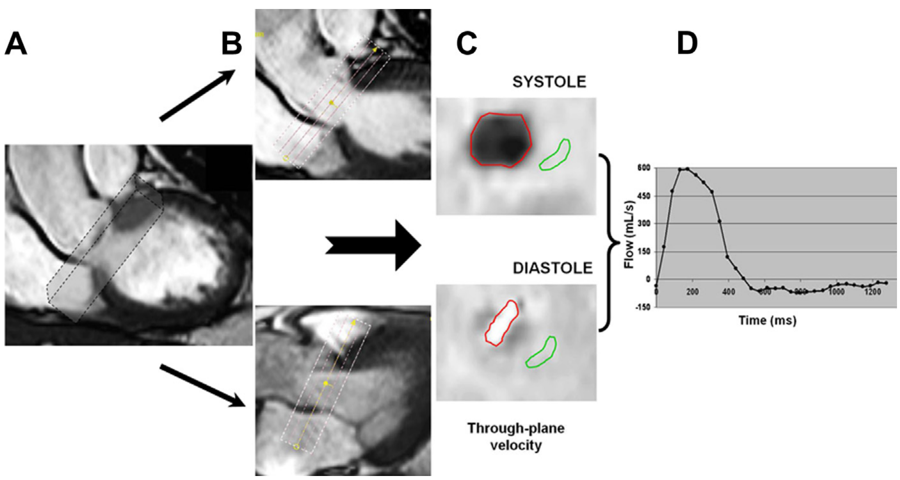

Figure 2. Postprocessing of aortic valve flow from 3D 3-directional VE-MRI data sets. The 3D acquisition volume was positioned at the level of the aortic valve, covering its full excursion during the entire cardiac cycle *(A)*. From the 2 orthogonal views of the aortic valve *(B)*, retrospective valve tracking and reformatting plane (with 5 parallel planes spaced at 5 mm) were reconstructed at the level of the aortic annulus, perpendicular to the aortic flow. The through-plane velocity-encoded images were thus obtained by reformatting in the center of the valvular plane in each cardiac phase *(C)*. During systole, the aortic forward flow was acquired (inner border of the aortic annulus was traced in *red* for flow analysis). During diastole, the regurgitant flow could be identified (*red line*). Region within the left ventricular wall was traced (*in green*) for correction of the myocardial motion, at the caudal-most reformatted plane where myocardial tissue was best visualized. *(D)* Finally, integration of the velocities over the aortic annulus, subtracted by the through-plane velocity of the myocardium, yielded the flow graph. The regurgitant volume was calculated by the Riemann sum of backward flow during diastole in the flow graph.

3D color Doppler TTE to quantify AR RVol and EROA. In addition, cardiac MRI was performed in all patients to assess left ventricular (LV) size and function, aortic valve morphology, AR severity, and aortic root and ascending aorta dimensions.[2] Severity of AR was assessed using 3D 3-directional VE-MRI data to quantify the AR Rvol.

Patients were imaged at rest in the left lateral decubitus position using a commercially available ultrasound system (iE33, Philips Medical Systems, Andover, Massachusetts) equipped with a S5-1 transducer. A complete 2D, color, pulsed, and continuous wave Doppler examination was performed according to the standard guidelines.[1,2,11] For AR quantification, color Doppler images of the aortic valve were acquired with optimized gain and Nyquist scale (50 to 60 cm/s).[1,2] From the zoomed color Doppler view of the AR jet, the vena contracta was identified as the narrowest portion of the regurgitant jet that occurred at or just downstream from the regurgitant orifice.[1,2] For a more quantitative assessment of AR, the PISA method was used. In brief, by shifting the baseline of the aliasing velocity toward the direction of the regurgitant jet (between 20 and 40 cm/s), a well-defined hemisphere of the convergence zone could be identified. From this, the maximal 2D-EROA could be estimated. Subsequently, the RVol was calculated as 2D-EROA multiplied by the velocity-time integral of the AR jet, from the continuous wave Doppler obtained either at the apical 5- or 3-chamber views.[1,2] AR severity was graded based on RVol: grade 1 (mild), <30 ml; grade 2 (mild-to-moderate), 30 to 44 ml; grade 3 (moderate-to-severe), 45 to 59 ml; and grade 4 (severe), ≥60 ml.[1,2]