Accuracy of 3D Transesophageal Echocardiography in the Quantitative Evaluation of Aortic Regurgitation

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Objective: This study evaluated the accuracy of three-dimensional transesophageal echocardiography (3D-TEE) and two-dimensional transesophageal echocardiography (2D-TEE) in assessing aortic regurgitation (AR) severity compared to magnetic resonance imaging (MRI). While three-dimensional transthoracic echocardiography (3D-TTE) is commonly used to assess eccentric regurgitant jets, transesophageal echocardiography (TEE) is recommended for detailed valvular evaluation.
Methods: A retrospective analysis of 24 AR cases compared regurgitant volume (Rvol) measured by 2D-TEE, 3D-TEE, and MRI. Bland-Altman analysis assessed Rvol concordance, while severity grading agreement was analyzed using the Kappa coefficient.
Results: Rvol measured by 3D-TEE correlated better with MRI than 2D-TEE. However, 3D-TEE tended to overestimate AR severity. Agreement in severity grading between 3D-TEE and MRI was low (κ = 0.418) but improved significantly (κ = 0.822) after correcting for 3D-TEE overestimation (4.5 mL/beat).
Conclusion: 3D-TEE slightly overestimated regurgitant flow but, after correction, showed strong agreement with MRI in AR severity grading. This suggests 3D-TEE is a valuable tool for quantitative AR assessment, with adjustments enhancing accuracy.

Key words: aortic regurgitation, 3D transesophageal echocardiography, quantitative assessment, severity assessment

INTRODUCTION

The quantification of aortic regurgitation (AR) remains challenging in clinical practice. Currently, the proximal isovelocity surface area (PISA) method, using two-dimensional (2D) transthoracic Doppler echocardiography, is the recommended approach to estimate the regurgitant 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 three-dimensional (3D) transthoracic echocardiography (TTE) permits direct visualization of the vena contracta area without the need for additional computation or geometric assumptions [5–8]. In addition, 3D-TTE is not restricted by any imaging plane, unlike 2D-TTE, which is limited to quantifying flow aligned along the ultrasound beam [4, 8]. Therefore, quantification of AR is more accurate using 3D than 2D TTE, and this would 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 for assessing transvalvular flow [7, 9–11]. This study aimed to assess the accuracy of 2D and 3D transesophageal echocardiography (TEE) for quantification of AR, using 3D 3-directional VE-MRI as the reference method.

MATERIALS AND METHODS

This study was performed in accordance with the Declaration of Helsinki and followed all the prevailing guidelines and regulations. This study protocol was approved by the Research Ethics Committee of St. Marianna University. Twenty-four patients with AR who were clinically referred for TTE, TEE, and MRI to quantify the AR, aortic root, and aortic dimensions were retrospectively evaluated. Patients with concomitant valvular disease of more than moderate severity and contraindications to MRI (i.e., implanted devices and claustrophobia) were excluded. Clinical data, including demographics and symptoms were collected and retrospectively analyzed. All patients underwent standard 2D and 3D color Doppler TTE and TEE to quantify the aortic 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]. AR severity was assessed using 3D 3-directional VE-MRI data to quantify the aortic RVol. Patients were imaged at rest in the left lateral decubitus position using a commercially available ultrasound system (iE33; Philips Medical Systems, Andover, Massachusetts, USA). A complete 2D, color, pulsed, continuous-wave Doppler examination was performed according to standard guidelines [1, 2, 12, 13]. For

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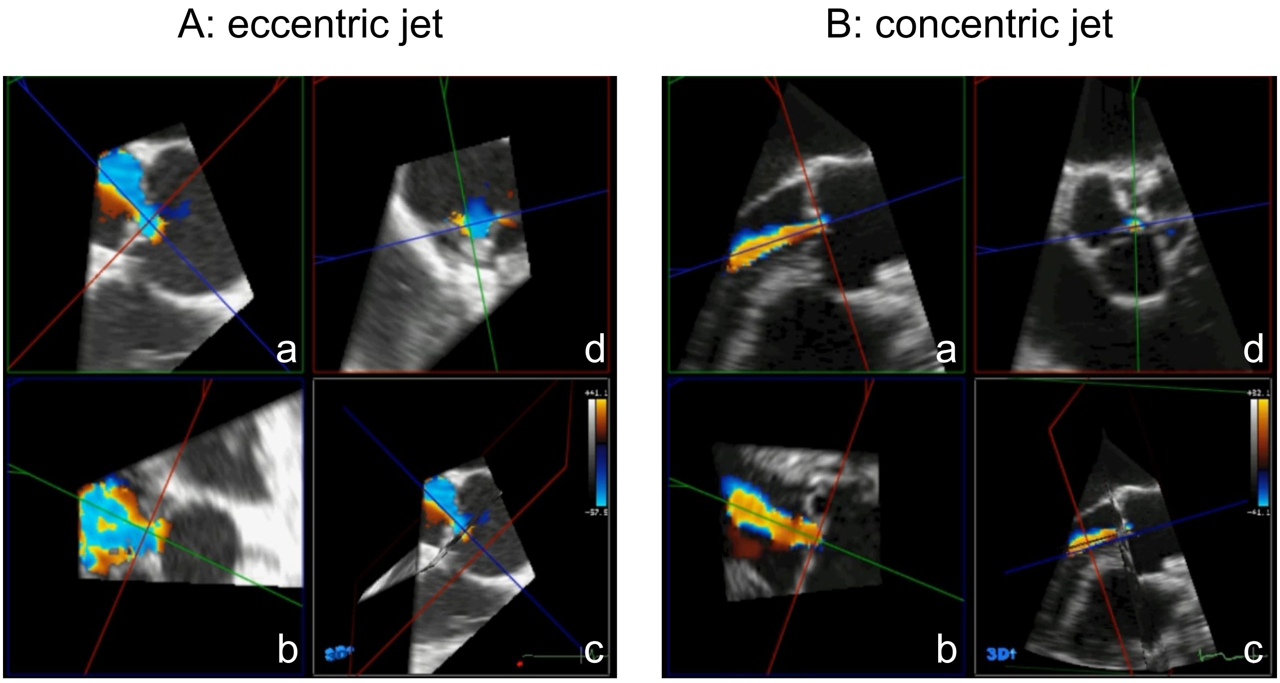

Fig. 1 Three-dimensional transthoracic echocardiography for assessing aortic EROA
The figures show three-dimensional echocardiographs of a patient with an eccentric jet (A) and a central jet (B). The 3D color Doppler dataset is manually cropped to provide a cross-sectional plane through the vena contracta of the regurgitant jet perpendicular to the direction of the aortic regurgitant jet (c). Subsequently, from the "en face" view of the vena contracta, selecting the plane with the narrowest cross-sectional area of the regurgitant jet (a and b), the 3D-EROA is measured by manual planimetry of the color Doppler signal (d).
3D, three-dimensional; EROA, effective regurgitation orifice area

AR quantification, color Doppler images of the aortic valve were acquired with optimized gain and Nyquist scale (50 to 60 cm/s) [1, 2, 12]. 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 immediate downstream from the regurgitant orifice [1, 2, 12]. 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. Thus, the maximal 2D-EROA could be estimated. Subsequently, RVol was calculated as the 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 the RVol: grade 1 (mild), < 30 mL; grade 2 (moderate), 30–59 mL; and grade 3 (severe), > 60 mL [1, 2, 12]. The 3D TEE was performed using the same ultrasound system (the iE33 system). Apical and parasternal full-volume color Doppler datasets of the AR jets were obtained using electrocardiographic gating over seven consecutive heartbeats to obtain seven small real-time subvolumes in a larger pyramidal volume. To minimize stitch artifacts, acquisition was performed during 3–5 s of breath-holding. The color gain and scale were set as previously described. All images were digitally stored and analyzed offline (Q-Lab 3DQ; Philips Medical Systems). To measure the 3D-EROA, multiplanar reconstruction of the 3D datasets and manual cropping were performed. First, a cross-sectional plane through the vena contracta of the regurgitant jet, perpendicular to the direction of the AR jet, was obtained. Subsequently, from the en face view of the vena contracta, the 3D-EROA of the narrowest cross-sectional area of the regurgitant jet was measured by manual planimetry from the diastolic frame with the most relevant lesion size (Fig. 1). Regurgitant volume was derived as PISA x aliasing velocity x time velocity integral of AR/peak AR velocity [3]. MRI was performed using a 1.5-T scanner (Philips Medical Systems, Best, The Netherlands) equipped with a 5-element cardiac synergy coil. First, from a series of short-axis images encompassing the LV from the apex to the base and throughout the entire cardiac cycle, quantification of LV volumes and ejection fraction were obtained using ziostation2 (Ziosoft, Inc., Tokyo, Japan) with contour segmentation of the epicardial and endocardial borders [14]. 3D 3-directional VE-MRI was used for AR quantification. A detailed description of the 3D VE-MRI acquisition protocol has been provided previously [9, 10]. In brief, freebreathing 3D phase-contrast acquisition was used with velocity encoding in three orthogonal directions. Echoplanar imaging was performed with a factor of 5, resulting in a scan duration of approximately 5 min. The velocity encoding was initially set to 150 cm/s in all three directions. However, an additional 2D VE-MRI of the aortic valve was used to determine whether a higher maximal velocity was required, and the optimized velocity was then applied to 3D VE-MRI in all three directions. Two orthogonal views of the aortic valve were used for retrospective valve tracking and a reformatting plane (with seven parallel planes equally spaced at 4 mm apart) was marked at the level of the valve annulus in every cardiac phase, perpendicular to the aortic regurgitant flow (Fig. 2). Subsequently,

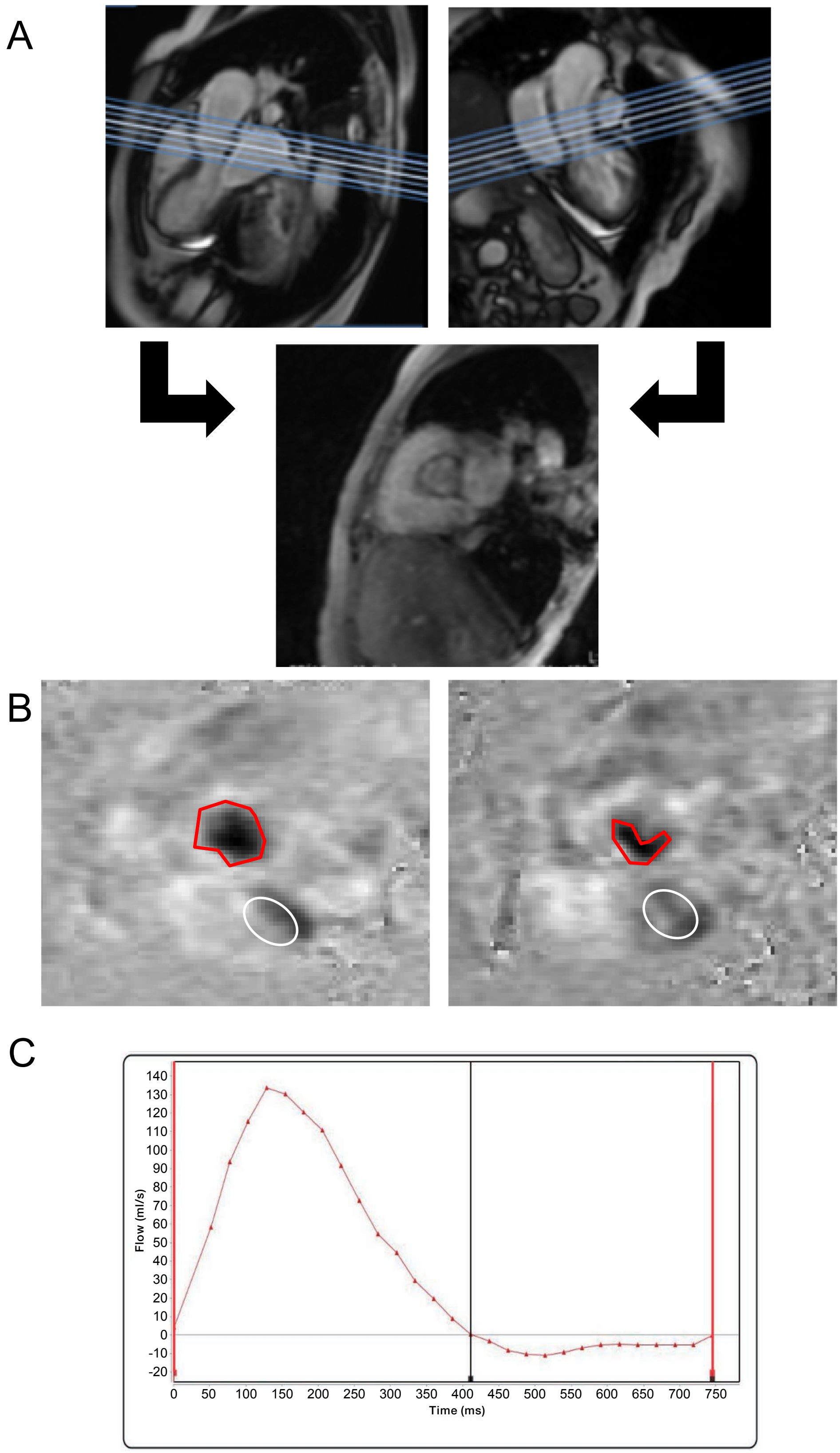

Fig. 2 Postprocessing of the aortic valve flow from 3D 3-directional VE-MRI data sets
The 3D acquisition volume is positioned at the level of the aortic valve, covering its full excursion during the entire cardiac cycle. From the two orthogonal views of the aortic valve, retrospective valve tracking and reformatting planes (with seven parallel planes spaced 4 mm apart) are reconstructed at the level of the aortic annulus perpendicular to the aortic flow (A). Through-planevelocity-encoded images are obtained by reformatting the center of the valvular plane in each cardiac phase (B). During systole, the aortic forward flow was acquired (the inner border of the aortic annulus is traced in red for flow analysis). During diastole, the regurgitant flow can be identified (red line). The region within the right atrium is traced (white) for correction of cardiac motion. Finally, the integration of the velocities over the aortic annulus subtracted by the through-plane velocity of the myocardium yielded a flow graph. The regurgitant volume is calculated by the Riemann sum of backward flow during diastole in the flow graph (C).
3D, three-dimensional; VE-MRI, velocity-encoded magnetic resonance imaging

the 3D-velocity data were reformatted at the center of the valvular plane to generate one-directional through-plane velocity-encoded images. If aliasing occurred in any of the velocity directions as a result of high-velocity regurgitant jets, the phase unwrapping option of the software was used to correct the velocity data and avoid underestimation of regurgitation. Background correction was performed to correct for the through-plane motion of the myocardium in the basal-to-apical direction and local phase offset [10]. The background region of interest was placed in the most caudal plane (10 mm from the central plane in the LV anterior wall). Finally, the transvalvular volume flow was obtained by integrating the resulting velocities over the annular area. The MRI RVol was obtained by calculating the Riemann sum of the backward flow during diastole in the flow graph (Fig. 2). The reformatting process required 5 min, and the subsequent image analysis required 5–10 min.

STATISTICAL ANALYSIS

Continuous data are presented as mean ± standard deviation, and categorical variables as absolute numbers (percentages). Chi-squared or Fisher's exact tests were used to compare categorical variables, as appropriate. Linear regression analysis (Pearson's correlation) for continuous variables was performed to evaluate the relationship between the RVol measurements derived from 2D TEE, 3D TEE, and MRI. Bland–Altman plots were used for agreement analysis between 2D TEE, 3D TEE, and MRI-derived RVol measurements [15]. In 10 randomly selected patients, interobserver reproducibility for 3D TEE-derived measurements was performed by two independent, blinded observers and evaluated using the intraclass correlation coefficient (ICC). To evaluate intra-observer reproducibility, the same observer repeated the measurements at two time points. Good agreement was defined as an ICC > 0.8.

The kappa coefficient (κ) is a statistical measure of inter-rater agreement for categorical items. It accounts for the agreement that could occur by chance.

Formula for Kappa coefficient (κ):

$\kappa = (Po - Pe)/(1 - Pe)$

where:

Po = Observed agreement (proportion of cases where raters agree)

Pe = Expected agreement (proportion of agreement expected by chance)

All statistical analyses were performed using SAS for Windows version 9.1 (SAS Institute Inc., Cary, Illinois, USA).

RESULTS

Table 1 summarizes the clinical characteristics and parameters of the patients. Fig. 1 shows examples of central and eccentric AR jets. For the entire population, the mean aortic RVol obtained by 2D TEE, 3D TEE, and VE-MRI were 53.6 ± 19.8, 59.7 ± 15.7, and 55.2 ± 14.9 mL/beat, respectively. There was a significant but modest correlation between the RVol as assessed by 2D TEE and VE-MRI ($r = 0.75$, $p < 0.0001$), and RVol quantification by 3D TEE showed a strong correlation with VE-MRI (r. 0.95, $p < 0.0001$; Table 2). When Bland–Altman plots were used for entire population, the 3D TEE-derived RVol showed a large bias (-4.5 mL/beat) and narrow limits of agreement (-2.5 to -6.6 mL/ beat) compared with the VE-MRI-derived RVol. In contrast, the bias between 2D TEE- and VE-MRI-derived RVols were small, and the limits of agreement was large (1.58 mL/beat and 7.1 to -3.9 mL/beat, respectively; Fig. 3). The bias of 2D TEE-derived RVol was positive (0.59) and that of 3D TEE-derived RVol was negative (-4.54), indicating that the measurement by 3D TEE was slightly larger than that by MRI, and the measurement by 2D TEE was

Table 1 Patient characteristics

	Patients (n = 24)
Age (years)	64.4 ± 12.7
Male	19 (79%)
Female	5 (21%)
Body surface area (m^2)	1.61 ± 0.19
Systolic blood pressure (mmHg)	137.7 ± 19.3
Diastolic blood pressure (mmHg)	67.7 ± 16.3
New York Heart Association functional class	
Ⅰ	19 (79.2 %)
Ⅱ	3 (12.5 %)
Ⅲ	2 (8.3 %)
Co-morbidities	
Hypertension*	15 (62.5 %)
Hypercholesteroaemia*	4 (16.7 %)
Diabetes mellitus	3 (12.5 %)
Coronary artery disease	3 (12.5 %)
Peripheral artery disease	2 (8.3 %)
Chronic kidney disease	4** (16.7 %)
Aortic regurgitation direction	
concentric	7 (29.2 %)
eccentric	17 (70.8 %)
Aortic regurgitation etiology	
Calcific degeneration	8 (33.3 %)
Bicuspid	6 (25 %)
Idiopathic dilatation of the aorta	8 (33.3 %)
Previous infective endocarditis	1 (4.2 %)
Other***	1 (4.2 %)
MRI RVol (ml)	55.2 + 14.9
TEE RVol 3D (ml)	59.7 ± 15.7
TEE RVol 2D (ml)	53.6 ± 19.8
LV ejaction fraction (%)	55.1 ± 14.5
Aortic annulus (mm)	25.4 ± 8.2
Aortic sinus (mm)	37.6 ± 5.7
Sinotubular junction (mm)	31.5 ± 5.1
Ascending aorta (mm)	37.2 ± 5.5

data was expressed as mean ± SD or as number (%).

* Hypertension was defined as blood pressure ≥ 140/90 mm Hg or on antihypertensive medication for hypertension. Hypercholesterolaemia was defined as a serum low-density lipoprotein.

cholesterol > 140 mg/dl or on lipid-lowering medication for hypercholesterolaemia.

** 1 patient undergoing artificial dialysis is included in Chronic kidney disease.

*** Regurgitation etiology was right coronary cusp bending.

Table 2 Relationship between aortic regurgitant volume measured by echocardiography and magnetic resonance imaging

	all	concentric	eccentric
2D TEE vs VE-MRI			
Pearson correlation coefficient (r)	0.75	0.66	0.77
r --- 95% confidence interval	0.50---0.89	-0.06---0.96	0.45---0.91
p value	< 0.0001	0.0657	0.0003
3D TEE vs VE-MRI			
Pearson correlation coefficient (r)	0.95	0.95	0.96
r --- 95% confidence interval	0.89---0.98	0.66---0.99	0.88---0.98
p value	< 0.0001	0.0013	< 0.0001
2D TEE vs 3D TEE			
Pearson correlation coefficient (r)	0.72	0.77	0.72
r --- 95% confidence interval	0.45---0.87	0.04---0.96	0.37---0.89
p value	< 0.0001	0.0428	0.0011

TEE: transesophageal echocardiography, VE-MRI: velocity-encoded magnetic resonance imaging.

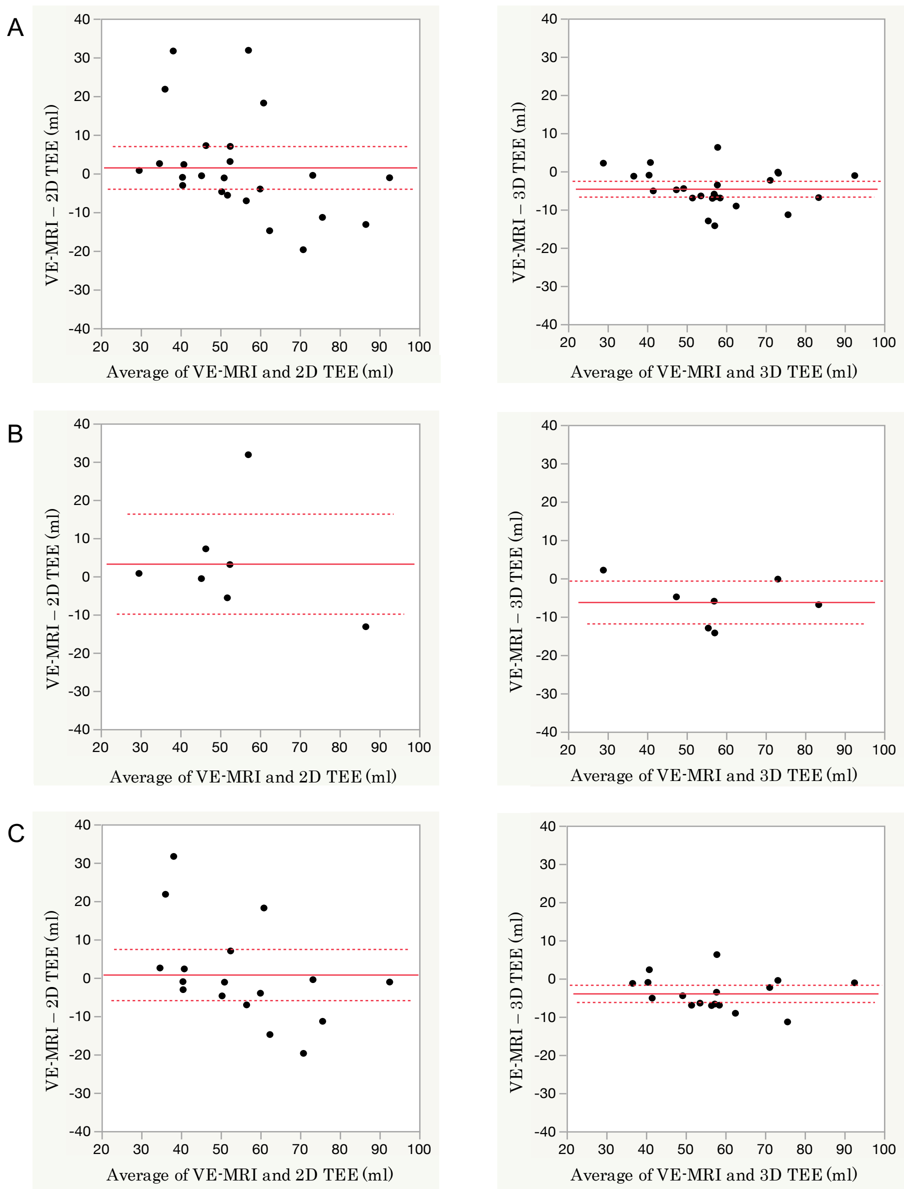

Fig. 3 Scatter plots of Bland–Altman analysis for 2D and 3D TEE measurements of the aortic regurgitant volume vs. the 3D VE-MRI reference values for overall population (A), central (B), and eccentric (C) jets
2D, two-dimensional; 3D, three-dimensional; VE-MRI, velocity-encoded magnetic resonance imaging

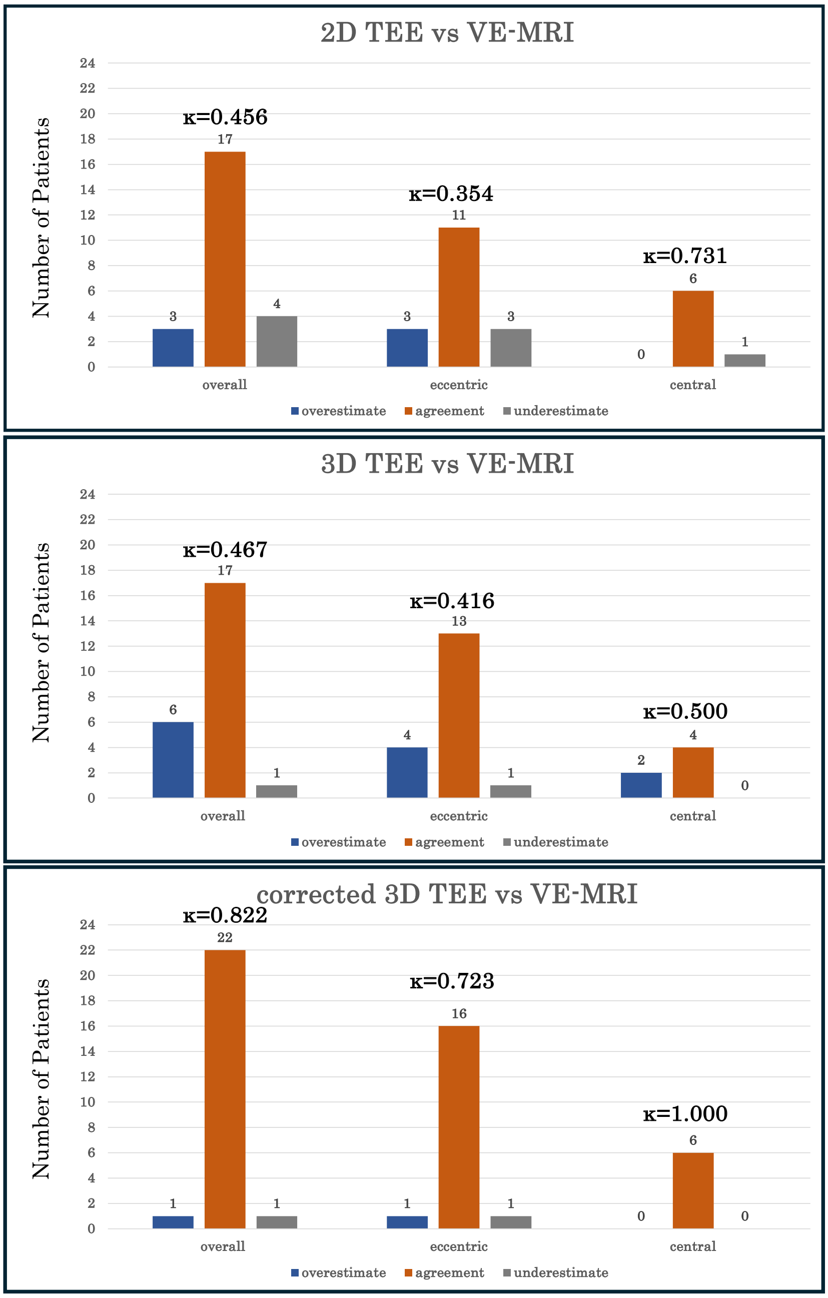

Fig. 4 Severity agreement between 2D and 3D TEE vs.the 3D VE-MRI as the reference method
2D, two-dimensional; 3D, three-dimensional; TEE, transesophageal echocardiography; VE-MRI, velocity-encoded magnetic resonance imaging, corrected 3D TEE; Rvol measured by 3D TEE was corrected to 4.5 mL smaller.

smaller than that by MRI. In patients with central jets, 2D TEE demonstrated a relatively weak correlation with VE-MRI in the assessment of RVol ($r = 0.72$, $p = 0.0657$); however, this correlation could be improved by using 3D TEE ($r = 0.95$, $p = 0.0013$). Similarly, in patients with eccentric jets, the correlation between the RVols, as assessed by 2D TEE and VE-MRI, was weak ($r = 0.77$, $p = 0.0003$), whereas that between the 3D TEE- and VE-MRI-derived RVols was strong ($r = 0.96$, $p < 0.0001$; Table 2). In the Bland–Altman analysis, the 3D TEE-derived RVol had the best agreement with VE-MRI, regardless of the direction of the AR jet (central or eccentric), with the narrowest limits of agreement (Fig. 3). Particularly for eccentric AR, 3D TEE demonstrated a good agreement with VE-MRI, with a small bias (-3.871 mL/beat) and narrow limits of agreement (-6.1 to -1.6 mL/beat). AR severity was graded based on the RVol measurements derived from 2D and 3D TEE and VE-MRI [1, 2]. There was a moderate agreement, in terms of AR severity grading, between 2D TEE and VE-MRI (kappa index = 0.456). In 70.8% of the patients, including those with central (n = 6) and eccentric (n = 11) jets, 2D TEE and VE-MRI provided a concordant grading (Fig. 4). Of the seven patients who were differently graded by 2D TEE, the majority had eccentric (n = 6) instead of central jets (n = 1; 86% vs. 14%). In one patient with central AR who was misclassified by 2D TEE, the AR severity was marginally underestimated (from severe to moderate). Among the eccentric AR cases with incorrect grading, 2D TEE underestimated AR severity in three patients compared with VE-MRI, misclassifying grade 1 instead of 2 (n = 2) and grade 2 instead of 3 (n = 1). In the remaining three patients, 2D TEE overestimated AR severity compared with VE-MRI, misclassifying grade 3 instead of 2 (n = 3). Similarly, there was moderate agreement between 3D TEE and VE-MRI in terms of the AR severity grading (kappa index = 0.467). In 66.7% of the patients, including central (n = 5) and eccentric (n = 11) jets, 3D TEE and VE-MRI provided a concordant grading (Fig. 4). Of the eight patients who were differently graded by 3D TEE, the majority had eccentric (n = 6) instead of central jets (n = 2; 75% vs. 25%). In patients with central AR who were misclassified by 3D TEE, the AR severity was marginally overestimated (from moderate to severe, n = 2). Among the eccentric AR with incorrect grading, 3D TEE underestimated AR severity in two patients compared with VE-MRI, misclassifying grade 1 instead of 2 (n = 1) and grade 2 instead of 3 (n = 1). In the remaining four patients, 3D TEE overestimated AR severity compared with VE-MRI, misclassifying grade 3 instead of 2 (n = 4). In the Bland-Altman analysis, although a bias of 4.5 mL/beat was observed between 3D TEE and VE-MRI, the limits of agreement were narrow. Therefore, an analysis with bias correction was performed. After bias correction, the agreement rate was high (κ = 0.822), and in cases of central jets, a perfect agreement was achieved (κ = 1.0) (Fig. 4).

DISCUSSION

The present evaluation showed that quantification of AR with 2D TEE is challenging, particularly in eccentric regurgitant jets. In contrast, quantification of AR by direct measurement of the vena contracta area using 3D TEE is feasible, and the measurement of aortic RVol shows good correlation and agreement with 3D 3-directional VE-MRI, the reference standard. In addition, the measurement of the 3D TEE-derived aortic RVol showed high interobserver and intraobserver reproducibility. Accurate assessment of the severity of valvular regurgitation is paramount for the prognosis and clinical management of patients with AR [16, 17]. However, the accuracy of the severity assessment of AR was not improved, despite the accurate quantification and understanding of valve structure. This procedure is primarily performed using echocardiography, with the integration of multiple parameters, including the hemodynamic consequences of AR on the LV [1, 2]. AR severity is usually assessed using both quantitative and semiquantitative echocardiographic criteria [1, 2, 12, 13]. However, Messika-Zeitoun *et al.* have shown that the commonly used semiquantitative methods in AR assessment such as pressure half-time, diastolic flow reversal, and LV cardiac output lack sensitivity [18]. In contrast, the quantitative assessment of AR using RVol and EROA not only supersedes the semiquantitative markers of AR severity but also has prognostic clinical implications in patients with AR [19]. They also mentioned that semiquantitative parameters should be integrated into the comprehensive evaluation of AR severity, but severe AR should not be excluded based only on semiquantitative criteria [19]. Thus, a quantitative assessment of AR should always be performed, as recommended [1, 2, 12]. The present evaluation shows the superior accuracy of 3D TEE to quantify AR compared with 2D TEE, particularly in eccentric regurgitant jets. The 3D TEE-derived aortic RVol exhibited the best agreement with that obtained using 3D 3-directional VE-MRI. It is not surprising that 3D TEE provides a more accurate quantification of AR than the 2D PISA method because direct planimetry of the AR vena contracta can be performed without any geometric or flow assumptions or multiple computation steps [1, 5–8]. It is necessary to understand the limitations of 2D TTE and 3D 3-directional VE-MRI before discussing the effectiveness of 3D TEE. Pouleur *et al.* measured the PISA-derived RVols obtained using 2D TTE and MRI in 50 patients with AR, including 21 with central AR jets and 29 with eccentric jets, and investigated the correlation. A stronger correlation was observed in patients with concentric AR jets (r = 0.92) than in those with eccentric jets (r = 0.69). This study demonstrated that in eccentric jets, the differences between 2D TTE-derived PISA and MRI-derived RVol could be nullified by imaging from the left parasternal window because of the geometric anatomy. Thus, this study highlights the limitations of 2D TTE in aligning eccentric jets with an ultrasound beam [4]. The present evaluation, using multiplanar reconstruction of the 3D full-volume data set, has the advantage of unlimited plane orientation, allowing the exact shape and size of the true cross-sectional view of the regurgitant orifice to be measured accurately. In addition, the use of 3D 3-directional VE-MRI sequences as a reference method with retrospective valve tracking [7, 9, 10] further strengthens the results of the present evaluation because the 3D VE-MRI sequence permits direct measurement of through-plane transaortic blood flow, taking into consideration the valve and heart motion throughout the cardiac cycle. Moreover, MRI is the reference standard for evaluating LV size and function (a measure of the hemodynamic consequences of AR) and the dimensions of the thoracic aorta [20], all of which are important parameters to consider in clinical decision-making for managing patients with AR [16, 17]. The present evaluation demonstrated that 3D TEE permitted accurate quantification of AR, even in the presence of an eccentric jet. Moreover, the non-planar flow convergence angle, commonly observed in patients with AR with concomitant aneurysmal dilatation of the ascending aorta, could represent another source of error in AR quantification using the PISA-derived method [21]. However, this could not be considered if a 3D TEE approach was used. The present evaluation also demonstrated the high accuracy of using 3D TEE to quantify AR, especially in patients with eccentric jets, whereas 2D TEE was less precise for AR quantification in these patients. However, severity agreement using 3D TEE, despite the highly accurate quantification of RVol, could not be improved compared with using 2D TEE. Hooi Ewe *et al.* reported that AR severity agreement using 3D TTE and 3D 3-directional VE-MRI was better than that using 2D TTE, especially in patients with eccentric AR (kappa index = 0.96 vs 0.53) [11]. These results indicate that 3D TEE was useful for a more detailed evaluation of the anatomical positional relationship and RVol compared with 3D TTE. The tendency of 3D TEE to overestimate in this study is not clear, but correction for this resulted in an extremely high concordance rate with MRI assessment. TEE generally visualizes the left ventricular outflow tract (LVOT) well and is highly sensitive even to trivial degrees of regurgitation. The width of the vena contracta (as well as the jet width in the LVOT immediately below the vena contracta) correlates with AR severity and the jet width/LVOT diameter, which is another parameter of AR severity [2]. These parameters are generally more difficult to measure accurately in the presence of an eccentric jet; however, 3D TEE enables the measurement of these parameters more accurately. Willett *et al.* reported that the width and area of the vena contracta measured using TEE correlated well with the regurgitant fraction and RVol as measured with a flow probe at the time of surgery [22]. TEE is generally a more invasive test than TTE; it is not the preferred choice for solely determining the severity grade in patients with AR. However, TEE helps in elucidating the mechanism of AR, which may have implications for surgical management. Therefore, it is recommended that the present evaluation be performed for a more detailed understanding of the anatomical positional relationship in preoperative patients, especially those with AR of the eccentric jet. There are scant data on the comparative value of TEE and TTE in measuring the severity of AR, including in this study. However, in patients who require more detailed information with limited acoustic windows, the AR severity may be best evaluated by combining and integrating available data from TTE and TEE.

This study had some limitations. As a small number of patients who underwent TTE, TEE, and MRI with a complete dataset were included in this study, selection and information biases could not be excluded completely. Use of 3D TEE for the quantitative grading of AR severity resulted in superior accuracy and correlation with 3D VE-MRI. While more accurate anatomical and geometric information could be obtained using 3D TEE, the determination of severity grade was not affected compared with 2D TEE. In addition, TTE is a more appropriate choice for determining the severity grade of AR because of its adequate accuracy and minimal invasiveness compared with TEE. Quantitative evaluation using 3D TEE has limitation, as mentioned, but should be performed in addition to conventional evaluation to obtain detailed information in preoperative patients with AR. The present evaluation precluded the investigation of the clinical and prognostic implications of these findings because it was designed as a retrospective and single-center study, which should be further evaluated in prospective studies.

CONCLUSION

Three-dimensional transesophageal echocardiography (3D TEE) tended to slightly overestimate reverse flow, and the agreement rate for severity assessment was low. However, when the overestimation was uniformly corrected, the severity rating agreed with MRI at a high rate.

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