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Original Article

Comparison of the Mitral Regurgitation Volume Derived From Transthoracic Echocardiography Between the HeartModel and Continuity Equation Methods in Patients With Severe Mitral Regurgitation

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ABSTRACT

Background: We compared the mitral regurgitation (MR) volume measured between 2 methods: the 2D continuity equation transthoracic echocardiography (2D CE-TTE) and the 3D HeartModel transthoracic echocardiography (3D HM-TTE).

Methods: Thirty-five patients at a mean age of 53.31 years (SD=15.16) were enrolled. All the patients were diagnosed with severe MR via transesophageal echocardiography. For the comparison of the MR volumes yielded by the 2 methods, the Bland–Altman chart and linear regression analyses were conducted.

Results: The Bland–Altman analysis showed a mean difference of −89.30 mL between the MR volume measurements of the 2 methods, and the linear regression resulted in a standardized coefficient β of −0.831 (P<0.001). Hence, the analysis showed a significant proportional bias between 2D CE-TTE and 3D HM-TTE.

Conclusions: Overall, we observed that 2D CE-TTE overestimated the MR volume measured by 3D HM-TTE by about 30%. ***(Iranian Heart Journal 2023; 24(1): 62-68)***

KEYWORDS: Transthoracic echocardiography, HeartModel, Continuity equation, Mitral regurgitation

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Mitral regurgitation (MR) is one of the most prevalent forms of valvular heart disease. Severe MR, even asymptomatic, causes a 5-year mortality rate of 14% if left untreated. Surgery has made a significant impact on MR treatment, increasing life expectancy. Nonetheless, an accurate diagnosis is a primary step for patients to be nominated for MR surgery and evaluate the postoperative prognosis. [1] On the other hand, coronary artery disease is the leading cause of morbidity and mortality in adults, and diabetes mellitus is a major risk factor for

the development of coronary artery disease, accounting for the increased incidence of heart failure, myocardial infarction, and cardiac death. [7,8]

Conventional 2D echocardiography is the most widespread diagnostic tool for MR measurement so far. Data gathered via 2D transthoracic echocardiography (TTE) are further processed using algorithms, which in the present study, the algorithm of interest is continuity equation (CE), [2] to obtain desired volumes. In 2D TTE, volumetric reconstructions rely greatly on geometric assumptions, rendering poor volumetric estimations. [3] It should, therefore, come as no surprise that 2D TTE usually underestimates or overestimates MR volume. The situation worsens in severe MR cases, especially those with asymmetrical orifices and eccentric MR. [4] One might blame this suboptimal volume estimation on inter and intraobserver variations since this conventional method relies significantly on the cardiologist's expertise. Additionally, the mitral valve anatomy is so complex that it renders a precise interpretation of echocardiographic data challenging. Furthermore, as 3D TTE measures volumes directly and without geometric assumptions, not only does it confer more accuracy in quantifying the heart chambers but also it helps investigate the location of the mitral valve, possible prolapses, and possible commissural lesions. [2,5,6]

Although 3D TTE has an apparent superiority over 2D TTE, manual data processing is complicated and takes significant time, energy, and expertise. Thus, automated quantification software programs have been designed to overcome these complications. HeartModel (HM) is a newly developed heart-chamber quantification software (HeartModel[A.I.]; Philips Healthcare, Andover, MA, USA) used to rapidly and fully automatically interpret 3D TTE data. [7,8]

The current study aimed to compare MR volume measurements between 2D CE-TTE and 3D HM-TTE among patients diagnosed with severe MR.

METHODS

Thirty-five patients diagnosed with severe MR at Rajaie Cardiovascular Medical and Research Center, affiliated with Iran University of Medical Sciences, Tehran, Iran, were enrolled in the present study between March and September 2021. The study protocol was approved by the Research and Ethics Committee of Rajaie Cardiovascular Medical and Research Center and adhered to the Helsinki Declaration. Informed written consent was obtained from all the patients.

The inclusion criteria were severe MR diagnosis via 2D transesophageal echocardiography (TEE) without any concomitant valvular disease. The exclusion criterion was a refusal to continue study participation at any stage. All echocardiographic images were taken by a single echocardiography fellow.

The study population's demographic characteristics and underlying etiologies are presented in Table 1. First, all the patients underwent 2D TEE (the X8-2T Probe, Philips EPIQ -7, Philips Healthcare, Andover, MA, USA), and severe MR was confirmed by color flow and Doppler indices according to the MR severity criteria in the guideline published in *American Society of Echocardiography*. [9] Then, MR volume was measured via the CE method [2] (ie, calculating MR volume by subtracting the regurgitant mitral valve stroke volume (derived using the diameter of the annulus and velocity time integral) and the competent mitral valve stroke volume [9] in 2D TTE (the X5-1 Probe, Philips EPIQ-7). Next, the patients underwent 3D TTE (the X5-1 Probe, Philips EPIQ -7), and the measurement was carried out using the HM method [3] (ie, calculating MR volume by the automated measurement

of the left ventricular end-diastolic and end-systolic volumes and ejection fraction with the HM software). [8] Thus, in the current investigation, MR volume and fraction were measured via 2 methods: 2D CE-TTE and 3D HM-TTE.

The statistical variables were reported as the mean ± the standard deviation (SD) and numbers (percentages) for continuous and categorical data, respectively. Correlations were compared between the measurements using the linear regression analysis and the agreement between them using the Bland–Altman analysis. The mean difference between the 2 methods concerning the systematic error and the limit of agreement was reported using 2SD. The significance level was considered a *P* value of 0.05. The statistical analyses were conducted using the SPSS software, version 25.

RESULTS

The baseline characteristics of the patients are presented in Table 1. The mean age of the study population was 53.31 years (SD=15.16). Of the 35 patients, 15 (42.9%) were female, and 20 (57.1%) were male. Twenty-two patients (62.9%) were diagnosed with flail mitral valves, 8 (22.9%) with Barlow's disease, 2 (5.7%) with ruptured mitral valves, 2 (5.7%) with rheumatic mitral valves, and 1 (2.9%) with functional MR.

The mean MR volumes measured were 51.10 (SD=15.81) and 140.10 (SD=51.89) by 3D HM-TTE and 2D CE-TTE, respectively, with the difference being significant (*P*<0.001).

The Bland–Altman plot, used to determine the average of the 2 methods against the difference between them, indicated a poor concordance between the 2 methods. The mean bias was −89.30 mL, and the limits of agreement (2SD) were 16.80 mL and −195.40 mL (Fig. 1).

The linear regression analysis of the mean difference yielded an unstandardized coefficient β of −1.59 and a standardized coefficient β of −0.831 with a *P* value <0.001, showing that the difference between these 2 methods was significant and proving a proportional bias between them.

Table1: patients' characteristics

Variable			
Age, y, mean (SD)		53.31 (SD=15.16)	
Sex, n (%)		Female	15 (42.9%)
		Male	20 (57.1%)
Etiology	Flail MV, n (%)	22 (62.9%)	
	Barlow's disease, n (%)	8 (22.9%)	
	RHD, n (%)	2 (5.7%)	
	IE ruptured valve, n (%)	2 (5.7%)	
	Functional MR, n (%)	1 (2.9%)	
MR volume, mL	HM, mean (SD)	51.10 (SD=15.81)	
	CE, mean (SD)	140.40 (SD= 51.90)	
MR volume fraction, %	HM, mean (SD)	0.51 (SD=0.10)	
	CE, mean (SD)	0.72 (SD=0.07)	

MR, Mitral regurgitation; MV, Mitral valve; HM, HeartModel method; CE, Continuity equation method; RHD, Rheumatic heart disease; IE, Infective endocarditis

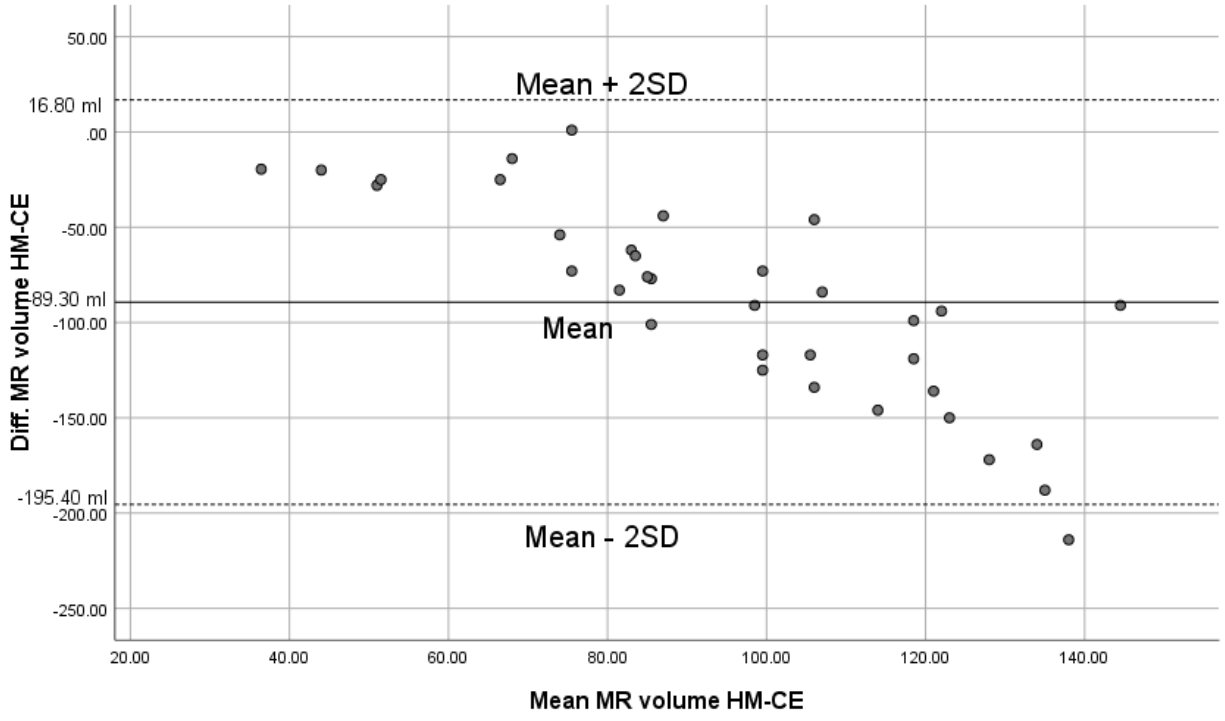

Figure 1: The image depicts the Bland-Altman analysis of the mitral regurgitant volume of the patients.

HM, HeartModel; CE, Continuity equation

DISCUSSION

The last decade has witnessed the emergence of numerous software programs for the quantification of echocardiographic results. The fully-automated HM software was developed to measure the 3D evaluation of the heart chambers' volumes. In a study by Tamborini et al, [3] the accuracy and reproducibility of the HM method were approved by a high correlation with the reference standard, cardiac magnetic resonance imaging (MRI), and the conventional 3D full-volume method, nominating this method as a potentially valid alternative for the measurement of heart volumes.

Feng et al [7] compared the fully-automated 3D HM-TTE and the conventional manual quantitative 3D TTE method. They measured the left atrial and left ventricular volumes with these 2 methods by dividing 156 patients into 3 groups: normal, left ventricular remodeling, and left atrial remodeling. They observed relatively high correlations between left ventricular end-diastolic and end-systolic volumes and ejection fraction and left atrial end-systolic volume measured by the 2 methods (r= 0.72 vs r=0.97). Overall, they concluded a significantly strong correlation between 3D HM-TTE and 3D manual-TTE and stated that 3D HM-TTE was a feasible method in left atrial and ventricular volume measurements.

Two-dimensional echo-Doppler is the conventional method for evaluating MR by assessing its severity and determining its pathology. In most cases, a simple grading of the severity in a range of mild, moderate, and severe provides the clinical evidence required for a further treatment plan. Nevertheless, quantitative approaches might be necessary for certain patients for whom

the exact regurgitation volume might be desired where there is an inconsistency between the assessment and other clinical findings. Accordingly, quantitative 2D echo-Doppler examinations are supplemented with a calculation technique yielding the effective regurgitant orifice area (EROA) and subsequently the regurgitant volume with geometric assumptions through formulas, the most famous of which is the CE. The most frequently employed method in assessing the regurgitant volume in MR patients is 2D echo-Doppler CE. [2]

De Agustin et al [10] compared the 2 methods of estimating MR volume by recruiting 33 patients with MR. They measured the volume using the 2D proximal isovelocity surface area (2D PISA) method and the 3D PISA method. The 2D PISA method employs a geometric assumption to measure EROA, whereas 3D PISA avoids this assumption and instead directly measures PISA without geometric assumptions and calculation of EROA. A significant proportional bias was observed between the 2 methods since 2D PISA significantly underestimated the regurgitant volume compared with 3D PISA. Consequently, the authors concluded that 3D PISA was more accurate than 2D PISA.

In a similar study, Ashikhmina et al [11] compared the 2 methods concerning the evaluation of PISA in patients with functional MR. They recruited 24 functional MR patients undergoing surgery and made intraoperative evaluations using 3D TEE and the conventional 2D TEE. The 2D TEE method assumes a hemispheric shape for PISA to calculate EROA and MR volume. However, 3D TEE can directly measure PISA. Since the typical shape of PISA is usually asymmetric and not hemispheric, and 3D TEE does not employ a geometric assumption, the method yields more accurate results. Subsequently, Ashikhmina and colleagues compared the results of the 2 methods regarding the cross-sectional area at the vena contracta, a well-established reference measure of functional MR. The results indicated that 3D PISA yielded a significantly smaller difference than did 2D PISA. Further, the directly measured 3D PISA was significantly larger than the calculated 2D PISA. They concluded that 2D TEE significantly underestimated EROA and, hence, PISA, since it applied geometric assumptions. Ultimately, 3D TEE confers much more accurate results. In a setting similar to the latter 2 studies, Izumo et al [5] reported an underestimation of the mitral valve prolapse quantification by 2D TEE compared with 3D TEE. They recruited 102 patients with mitral valve prolapse, measured the prolapse gap and width using the 2 methods, and calculated their difference. They concluded that based on the significant difference observed, 3D TEE provided much more reliable and precise results.

Several studies have evaluated the TEE quantification of MR in comparison with the reference standard, cardiac MRI. Shanks et al [12] compared MR quantification between 2D and 3D TEE by measuring EROA and cardiac MRI. In their study, 30 patients with MR underwent 2D TEE, 3D TEE, and cardiac MRI. Based on their results, 2D TEE, in comparison with 3D TEE and cardiac MRI, underestimated the regurgitant volume by 21.6% and 21.3%, respectively. Therefore, 3D TEE was more accurate than 2D TEE in measuring MR volume.

In a similar study by Hamada et al [13] on 43 MR patients, the accuracy of 3D TEE was evaluated based on the reference method, cardiac MRI, and the results showed the superiority of 3D TEE over 2D TEE compared with cardiac MRI measurements. Likewise, Marsan et al [14] reported the significant accuracy and high consistency of 3D TEE in assessing MR volume compared with cardiac MRI in 64 functional MR

patients. These results were later repeated and approved by a study carried out by Brugger et al [15] on 60 MR patients, concluding that 3D PISA calculated by 3D TEE, compared with the conventional 2D TEE, conferred more accurate measurements consistent with the reference method, cardiac MRI.

CONCLUSIONS

In our study, consistent with the studies mentioned above, we observed a significant proportional bias between 3D HM-TTE and 2D CE-TTE. Our results demonstrated that the volumes measured by 2D CE-TTE differed from those measured by 3D HM-TTE, with the difference constituting statistical significance. Given the accuracy of the HM method confirmed through comparisons with cardiac MR in previous studies and according to the results of the current study, we conclude that the conventional 2D CE-TTE method overestimates MR volume by around 30% compared with 3D HM-TTE. Since a relatively small sample size was the salient limitation of our study, further studies on more patients are needed to confirm our results.

Conflict of Interest

None declared.

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