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Original Article

Left Ventricle Study via 3D Full-Volume and Heart-Model Software in Mitral Valve Prolapse With Severe Mitral Regurgitation

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ABSTRACT

Background: Most patients with mitral valve prolapse (MVP) are asymptomatic with a normal life expectancy; however, between 5% and 10% of them have progression to severe mitral regurgitation (MR). Because of this silent progression, the size and ejection fraction of the left ventricle are very important in decision-making for surgery in asymptomatic patients with MR. A 3D assessment of LV volumes and ejection fraction is preferred to 2D echocardiography because of its accuracy and reproducibility.

Methods: Between April 3, 2018, and February 20, 2019, the present study enrolled 50 patients suffering from MVP with relatively severe MR undergoing transesophageal echocardiography at Rajaie Cardiovascular, Medical, and Research Center, affiliated with Iran University of Medical Sciences. The ejection fraction was analyzed via the visual 2D method, in addition to 3 other methods: the Simpson biplane, 3D full volume, and 3D heart model.

Results: Of the 4 measurement methods, the 3D heart model had the highest agreement with the Simpson biplane method (ICC: 0.859, 95% CI: 0.745 to 0.922). The agreement rate between the 3D heart model and the 3D full volume was 72% and between the 3D heart model and the visual 2D method was 64%. In the measurement of the end-diastolic volume, there was a remarkable agreement between the 3D heart model and both the Simpson biplane and 3D full-volume methods (98% and 95%, respectively). Similarly, in the measurement of the end-systolic volume, the rate of agreement between the 3D heart model and both the Simpson biplane and 3D full-volume methods was 91% and 92%, correspondingly.

Conclusions: This study showed that the use of the 3D heart model and the Simpson biplane method was more accurate in the study of the left ventricular ejection fraction than that of the visual 2D and 3D full-volume methods. It appears that the use of all 3 methods (ie, the Simpson biplane, 3D full volume, and 3D heart model) in the measurement of the end-systolic and end-diastolic volumes is reliable. ***(Iranian Heart Journal 2020; 21(2): 41-47)***

KEYWORDS: Mitral regurgitation, 3D echocardiography, Ejection fraction, Simpson, Heart model, Full volume

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Any incompetency in each part of the mitral valve (MV) apparatus may produce regurgitation from the left ventricle (LV) to the left atrium in systole. The prevalence of mitral regurgitation (MR) is greater than 10% in adults older than 75 years. [1] The second most common form of valvular disease that requires surgery is MR (31.5%). [1]

In primary MR, there is intrinsic leaflet pathology; and in secondary MR, the main problem is LV or left atrial remodeling, which results in changes in the MV apparatus. [2]

Myxomatous degeneration (mitral valve prolapse [MVP]) is the main reason for primary MR. [2] MVP is a spectrum of diseases from fibroelastic deficiency, which refers to focal segmental pathology with thin leaflets, to the Barlow disease with the diffuse thickening and redundancy of multiple segments of both leaflets and chordae. [2]

The prevalence of MVP is approximately 2% to 3% of the general population in the United States. [3] Most patients with MVP are asymptomatic with a normal life expectancy, but between 5% and 10% of them are liable to progress to severe MR. [4]

Patients with severe MR who develop a left ventricular ejection fraction (LVEF) of 60% or less or a left ventricular end-systolic volume (LVESV) of 40 cc or greater suffer LV systolic dysfunction. [5] Because of this silent progression, the guidelines of the American College of Cardiology and the European Society of Cardiology recommend that LV size and LVEF are very important in decision-making for surgery in asymptomatic patients with MR. [6]

The MIDA (Mitral Regurgitation International Database) registry is a multicenter registry of MR with flail leaflets. [7] This registry enrolled 739 patients with flail MR and reported that 10 years' survival was higher among patients with a left ventricular end-systolic diameter (LVESD) of less than 40 mm than those with LVESD of 40 mm or greater (64% vs 48%; $P < 0.001$). Additionally, LVESD of 40 mm or greater independently predicted overall mortality (HR: 1.95, 95% CI: 1.01 to 3.83) and cardiac mortality (HR: 3.09, 95% CI: 1.35 to 7.09) with noninvasive management. Mortality risk increased linearly in patients with LVESD of greater than 40 mm (HR: 1.15, 95% CI: 1.04 to 1.27 per 1-mm increment). During the follow-up of the patients, including those that underwent surgery, LVESD of 40 mm or greater independently predicted overall mortality (HR: 1.86, 95% CI: 1.24 to 2.80) and cardiac mortality (HR: 2.14, 95% CI: 1.29 to 3.56).

These findings indicated that the best preservation of survival was achieved in the patients that underwent surgery before LVESD reached 40 mm. In this regard, a precise evaluation of LVEF and LV volume is very important in proper decision-making for surgery, especially in asymptomatic patients. Although 2D echocardiography is routinely used for the evaluation of LV function and size in valvular diseases such as MR, this modality has some limitations.

Limitations of 2D Echocardiography Assessment

In spite of the routine use of 2D echocardiography to evaluate LV volume and function, there are important limitations in terms of LV imaging such as foreshortening, malrotation, and angulation. If the acquisition of 2D images is suboptimal, volumetric measurement may not be precise. [8]

In 3D, volumetric evaluation is done by using landmarks such as LV apex and MV annulus and by including LV trabeculations and papillary muscles in LV cavity. [8] This measurement is rapid, accurate, and reproducible and its accuracy is similar to magnetic resonance imaging (MRI). [9] There is an interobserver agreement regarding the

EF between 64-row computed tomography (CT), MRI, and 3D echocardiography (intraclass correlation coefficient > 0.8).[10]
Currently, 3D transthoracic echocardiographic (TTE) assessment of LV volume and EF is preferred to 2D echocardiography because of its accuracy and reproducibility.[8]
Datasets of 3D echocardiography can be viewed by using different software tools including volume rendering, surface rendering, wireframe, and 2D tomographic slicing.
In the new version of Philips Vender (Epic 7), there are 2 different software tools for the evaluation of LV volume and EF in 3D: full volume and the heart model.
The 3D full-volume mode has the largest acquisition sector. The main limitation of this software is operator dependency in border detection. The 3D heart model is another new software tool. With 1-button simplicity, the 3D heart model overcomes the complexity and time it takes to perform 3D TTE. The 3D heart model confers robust 3D quantification to everyday clinical practice. This anatomically intelligent cardiac application automatically detects segments and quantfies the LV and the left atrium from a live 3D volume.

METHODS

From April 3, 2018, to February 20, 2019, a total of 80 patients with MVP and moderate-to-severe or severe MR at Rajaie Cardiovascular, Medical, and Research Center, affiliated with Iran University of Medical Sciences, for advanced diagnostic tests (transesophageal echocardiography [TEE]) were prospectively studied. Thirty patients were excluded because of atrial fibrillation rhythms, coronary artery disease, the presence of other valvular problems (more-than-mild disease), and LVEF of less than 45%. Thus, 50 patients were evaluated in the current study. The study protocol was approved by the institutional ethics committee, and written informed consent was obtained from all the participants prior to their inclusion in the study.

Echocardiography

After the patients' general information such as age, sex, functional capacity, and body surface area was collected, standard TTE study was performed with a Philips EPIQ 7 ultrasound system for cardiology equipped with the xMATRIX ultrasound transducer technology by a single echocardiologist. The calculation of LVEDV, LVESV, and LVEF (eyeball global and the Simpson biplane) was done in 2D. Thereafter, with the use of 3D full volume and heart model software, LV volumetric and function study was acquired. Next, with the aid of TEE, other parameters such as regurgitation severity, jet direction in the left atrium, and involved leaflets and scallops were recorded.

Statistical Analysis

All the continuous variables were expressed as the mean and the standard deviation. The normal distribution was tested using the Kolmogorov–Smirnov test. The continuous variables were compared using the independent–samples *t*-test or the one-way analysis of variance (ANOVA). A *P* value of less than 0.05 was considered statistically significant. The reproducibility was assessed in 2 independent observers in 10 patients for the 2D, 3D, and TEE analyses. All the statistical analyses were performed using the SPSS, version 22 for Windows. The agreement rate between the different 2D and 3D methods in the LVEF analysis and volumetric indices is shown in the Bland–Altman plot (Difference plot).

RESULTS

The general information of the study population is summarized in Table 1.

Table 1: General information on the study population

Mean age (y)	46.5±15.2
Male sex –NO (%)	33 (66%)
Mean body surface area (m^2)	1.79±0.21
Function Class- NO (%)	
I:	15 (30%)
II:	32 (64%)
III:	3 (6%)
Mitral Regurgitation Severity -NO(%)	
severe	42 (84%)
moderate to severe	8 (16%)
Etiology (1)-NO(%)	
Barlow	43(86%)
fibroelastic deficiency	7 (14%)
Etiology (2) – N0(%)	
flail	29(58%)
non-flail	21(42%)
Mean Ejection Fraction(%)±SD	
2D	55.5±4.0
Simpson	60.1±6.5
3D heart model	58.2±6.8
3D full volume	55.7±6.8
Mean Left Ventricular End-Diastolic Volume (cc)±SD	
Simpson	147.4±49.1
3D heart model	146.5±49.0
3D full volume	141.8±45.3
Mean Left Ventricular End-Systolic Volume (cc)±SD	
Simpson	55.8±19.8
3D heart model	58.7±21.8
3D full volume	61.5±18.5

The majority of the patients were men (66%), and the mean age of the study population was 46 ± 15.2 years. Most of the patients (64%) had minor limitations in activity (FC II). Valve involvement was mostly Barlow (86%), and then fibroelastic deficiency (14%). Flail involvement was more prevalent than non-flail (58% vs 42%). The agreement rate between the different 2D and 3D methods in the LVEF analysis and volumetric indices in the patients with MVP with moderate-to-severe and severe MR is shown in the Bland–Altman plot (difference plot).

In the EF study, the 3D heart model enjoyed a greater agreement with the Simpson biplane method than with the visual 2D (85% vs 64%) (Fig. 1 & 2).

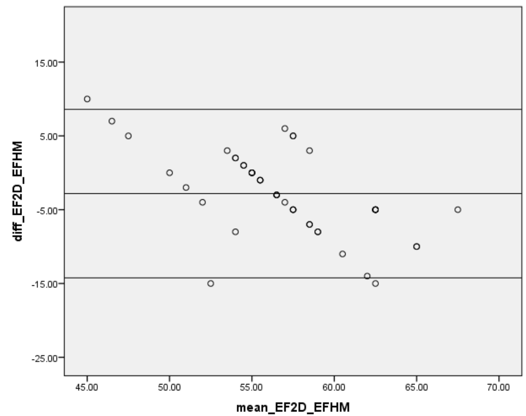

Figure 1: Agreement diagram between the visual 2D and 3D heart model (HM) methods in measuring the left ventricular ejection fraction (ICC: 0.641, 95% CI: 0.351 to 0.801)

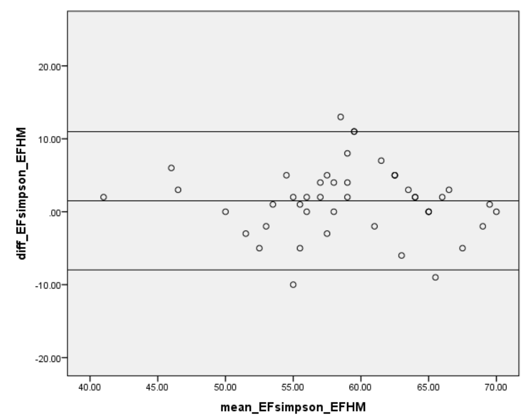

Figure 2: Agreement diagram between the Simpson biplane and 3D heart-model (HM) methods in measuring the left ventricular ejection fraction (ICC: 0.859, 95% CI: 0.745 to 0.922)

As is shown in Figure 3, the agreement between the 3D full-volume and Simpson biplane methods was lower than that between the Simpson biplane and 3D heart-model methods shown in Figure 2 (62% vs 85%).

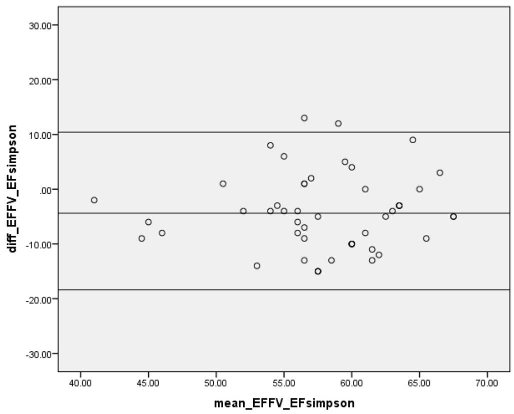

Figure 3: Agreement diagram between the Simpson and 3D full-volume (FV) methods in measuring the left ventricular ejection fraction (ICC: 0.627, 95% CI: 0.342 to 0.788)

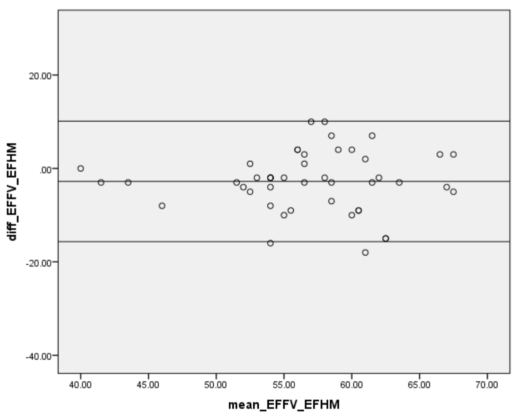

Figure 4: Agreement diagram between the 3D full-volume (FV) and 3D heart-model (HM) methods in measuring the left ventricular ejection fraction (ICC: 0.720, 95% CI: 0.494 to 0.845)

Concerning LVEDV, the results showed that the 3D heart model had an appropriate agreement with the Simpson biplane and full-volume methods (98% and 95%) (Fig. 5 & 6).

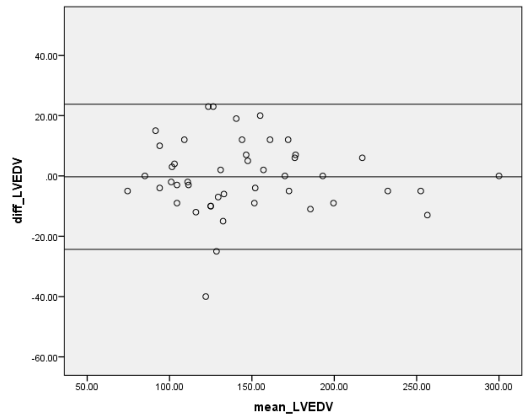

Figure 5: Agreement diagram between the Simpson and 3D heart model (HM) methods in measuring the left ventricular end-diastolic volume (LVEDV) (ICC: 0.985, 95% CI: 0.946 to 0.983)

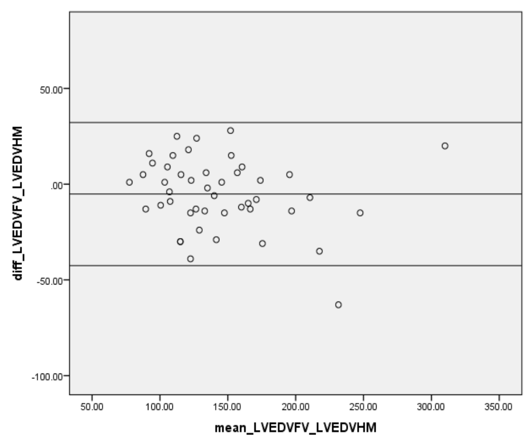

Figure 6: Agreement diagram between the 3D full-volume (FV) and 3D heart model (HM) methods in measuring the left ventricular end-diastolic volume (LVEDV) (ICC: 0.959, 95% CI: 0.927 to 0.978)

The examination of LVESV indicated that the 3D heart model enjoyed a good agreement with the Simpson and full-volume methods (91% and 92%) (Fig. 7 & 8).

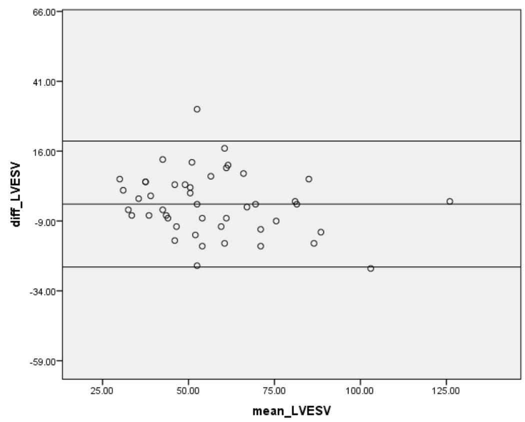

Figure 7: Agreement diagram between the Simpson and 3D heart-model (HM) methods in measuring left ventricular end-systolic volume (LVESV) (ICC: 0.919, 95% CI: 0.854 to 0.955)

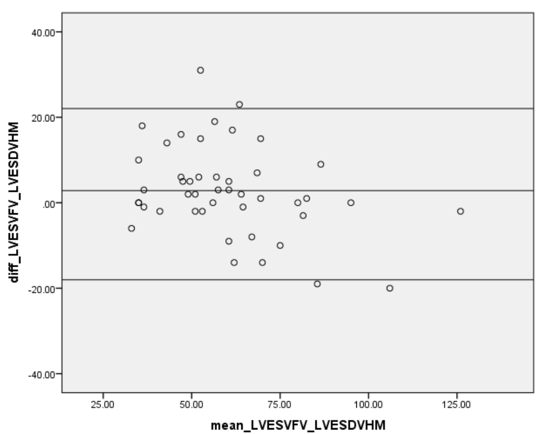

Figure 8: Agreement diagram between the 3D full-volume (FV) and 3D heart model (HM) methods in measuring left ventricular end-systolic volume (LVESV) (ICC: 0.929, 95% CI: 0.871 to 0.961)

DISCUSSION

In this study, the EF analysis was performed using the visual 2D method, in addition to 3 other methods—namely Simpson biplane, 3D full volume, and 3D heart model. Of the 4 measurement methods, the heart model had the highest agreement with the Simpson biplane (ICC: 0.859, 95% CI: 0.745 to 0.922). The agreement rate between the heart model the and full volume was 72%, and with visual 2D was 64%. In the 3D full-volume method, due to the manual contouring of LV internal border, which is often not very clear, the measurements did not appear to be accurate enough; therefore, it had less agreement with the heart model (ICC: 0.720, 95% CI: 0.494 to 0.845). Moreover, because of the dependency of the visual 2D method on the operator's experience, it had less agreement with the 3D heart model in estimating LVEF (ICC: 0.641, 95% CI: 0.351 to 0.801).

In a study published in the American College of Cardiology Journal, the intraclass correlation between the different methods of measurement was examined and the results revealed that both 2D and 3D methods had a significant agreement with CT and MRI (> 80%). [11] We did not CT and MRI in the current investigation. Nonetheless, not only has the 3D heart model already been validated with MRI but also it is automated with minimal hand involvement. Given that the 3D heart-model method boasts high precision, accuracy, and speed, it can show relatively similar results to the Simpson biplane and full-volume methods. [9, 12]

In the measurement of LVEDV, we observed a remarkable agreement between the 3D heart model and both Simpson and full volume (98% and 95%, respectively) (Fig. 5 & 6). Similarly, in the measurement of LVESV, the agreement rates between the 3D heart model and both Simpson and full volume were 91% and 92% (Fig. 7 & 8). It appears that the use of the Simpson biplane, 3D full-volume, and 3D heart-model methods in measuring LVESV and LVEDV is reliable. [13-14]

CONCLUSIONS

Given the vital importance of LVEF and LVESV in patients with severe MR in the setting of MVP, the use of reliable and advanced methods that are more accurate than conventional ways is essential in tracking these patients and determining the exact time of surgery—especially in asymptomatic patients. The results of the present study showed that the use of 3D heart-model and Simpson biplane methods was more accurate in the EF study than the use of the visual 2D and 3D full-volume methods. Apropos of LVEDV, all 3 heart-model, full-volume, and Simpson methods can be applied with acceptable accuracy. Considering the high speed and precision in the use of the 3D heart-model method and minimal manual intervention in the measurement, we would recommend that this method be employed, along with the Simpson biplane, as an acceptable method for measuring LVEF and LVEDV in patients with severe MR. In cases where the machine is not equipped with this method, the Simpson biplane method is preferred to the visual assessment and the 3D full-volume method. However, the use of the full-volume method requires more experience and optimal images with acceptable contours.

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