Original Article

Accuracy of mitral valve annulus measurements by two- and three-dimensional transesophageal echocardiography, compared to intraoperative measurements in patients undergoing mitral valve replacement surgery

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Abstract

Introduction: Transthoracic echocardiography (TTE) is the most beneficial diagnostic modality for mitral valve (MV) diseases. However, it is not accurate enough for MV annular sizing. Recent evidence has demonstrated the superiority of transesophageal echocardiography (TEE) over TTE. The present study aimed to evaluate the accuracy of two-dimensional TEE (2D-TEE) and three-dimensional TEE (3D-TEE) in preoperative measuring of MV size and specifications.

Methods: This cross-sectional study evaluated patients with mitral valve replacement (MVR) surgery at Shahid Madani Heart Center of Tabriz university of Medical Sciences, Tabriz, Iran, in 2020. Thirty-eight patients admitted for MVR surgery were enrolled in this study. Demographic, electrocardiogram (ECG), and echocardiographic studies -including TTE, 2D, and 3D TEE- were performed preoperative for each patient. The accurate size and the specifications of the studied structure were measured by a surgical gauge caliper during the surgery, which was considered the gold standard value. The correlations between obtained parameters were evaluated using Pearson's correlation coefficient. The data obtained from individual were entered into the SPSS software. Significance was set at $P < 0.05$.

Results: The mean age of patients was 55.89 ± 11.81 years, and 65.8% were male. Most patients (68.4%) had sinus rhythm. The strongest correlation with the gold standard was observed in mitral annulus circumference measured by the three-dimensional multiplanar reconstruction (3D MPR) method in all patients ($r = 0.758$, $P < 0.001$), [($r = 0.723$, $P < 0.001$) for patients with sinus rhythm, and ($r = 0.825$, $P = 0.001$) for patients with atrial fibrillation (AF)]. The minor difference between the echocardiographic measurements and the surgical rule was related to the short axis (SA) in the 3D MPR method (3.3 mm).

Conclusion: This study illustrated a high correlation between 3D-MPR TEE measured MV annulus and intra-operative measurements using a surgical gauge caliper as the gold standard.

Introduction

Valvular heart disease (VHD) is characterized by distorted intra-cardiac valve structure(s), resulting in diminished physiologic cardiac functioning. It causes a prominent impairment in patient's quality of life and imposes high annual costs on healthcare system.[1] Amongst VHDs, mitral valve (MV) disease is the most common in the developed countries.[2] The culprit is that the MV's complex structure makes it more vulnerable to insults.[3]

Surgical repair of the diseased valve will improve the outcome in some cases.[4] Meanwhile, choosing a proper method, case selection, and accurate timing for intervention are crucial for reaching a desirable outcome. The latter is unachievable unless the physicians are able to obtain thorough and precise information on MV apparatus anatomy and function prior to the surgery.[5,6]

Transthoracic echocardiography (TTE) is the primarily used modality for patient evaluation in this regard. The type of lesion, the severity of the disease, the functional status of the valve, and the burden of the disease on overall cardiac function are somehow evaluable by TTE.[7] However, transesophageal echocardiography (TEE) has higher sensitivity and can provide more accurate information compared to TTE. Therefore, the TEE study is recommended for all patients with VHD who do not have any contraindications.[8]

On the other hand, considering the different modes of echocardiographic studies, three-dimensional (3D) images are superior to two-dimensional (2D) and provide comprehensive data from the study object (MV apparatus

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in this case).[9-11] Thus, 3D TEE study has been suggested as a complementary modality for all patients with MV disease. It has been stated that the 3D TEE can provide valuable preoperative information for both the surgeon and the cardiologist. [6, 9] However, a few comparative studies have been conducted so far in this regard.[12] Since the precise measuring of the valve annulus is crucial before MV replacement surgery,[13] besides the lack of sufficient studies comparing the pros and cons of the preoperative 3D TEE over the conventional echocardiographic studies; we aimed to conduct this study. The primary objective of the present study is to find out which echocardiographic methods (2D and 3D) represents more accurate results in measuring MV annulus size and specifications.

Methods

This cross-sectional study was conducted at Shahid Madani Heart Center of Tabriz University of Medical Sciences, Tabriz, Iran, in 2020. Thirty-eight patients over 18 years with MV disease who were selected for mitral valve replacement (MVR) surgery were enrolled in this study. The indication for surgery was determined according to relative guidelines, regardless of the present study's design. Individuals were selected using the convenience sampling method and based on the inclusion criteria. All patients had undergone MVR surgery due to MV regurgitation, valve stenosis, or endocarditis as a direct consequence of MV disorder. Following recruitment, the demographic data of the individuals, including age, body surface area (BSA), and the etiology of their MV disease, were recorded on each patient's chart. BSA was calculated using the BSA calculator. Each patient was stratified into one of the following groups of: rheumatic, functional, prolaptic, degenerative, and infective valve disease according to the etiology of their disease. Combined pathologies were also labeled as a separate etiological classification.

Written informed consent was obtained from all participants, ensuring their information could be used for medical research. The collected information and the results of the statistical analysis remained confidential.

Afterward, electrocardiogram (ECG), as well as conventional 2D TTE studies, were performed for all patients. Left ventricular end-diastolic diameter (LVEDD), left ventricular end-systolic diameter (LVESD), left ventricular ejection fraction (LVEF), left atrial volume index (LAVI), and pulmonary artery pressure (PAP) were measured, and charted for each individual. Further on, all patients were studied by 2D TEE in order to measure MV annulus. The measurements were performed at three echocardiographic views (1) Mediolateral (Zero-degree angle), (2) Commissural (75-to-90-degree angle), and (3) Antero-posterior (120-degree angle). The mid-diastolic size of the valve annulus, which is the largest physiological diameter, was the measure of interest for the investigators. At the final stage, 3D TEE in zoom mode and mid-esophageal level (60-to-75-degree angle) was performed

to fulfill the pre-operative survey of the study participants. All acquired data were then summoned and inserted into QLAB software for offline analysis.

MV annulus diameter -at both short and long axis- as well as MV surface area and circumference were calculated for each patient using 3D multiplanar reconstruction and 3D direct methods. The mean of the three and five separate beats measures was considered the final value in patients with normal sinus rhythm and atrial fibrillation (AF), respectively.

All echocardiographic studies were performed utilizing a Philips® EPIQ 7 ultrasound machine. Mathematical values were calculated using the QLAB software, following the adjustment of the depth and gain of the obtained images (Figure 1). Patients with severe mitral annulus calcification and/or inadequate quality of echocardiographic images were excluded from the study.

In order to address the investigator bias, all echocardiographic studies were carried out by two highly trained echocardiologists. Both observers were kept blind to each other's results. Inter-observer agreement (IOA) was then calculated using the kappa coefficient.

Intra-operative MV annulus size was considered the gold standard in order to compare the echocardiographic results. For this purpose, the mitral annulus was measured at its maximal diameter on an unloaded state using a surgical gauge caliper. Mitral annulus area (MAA) and mitral annulus circumference (MAC) were calculated based on the obtained diameter.

First, the researchers explained the design and objective of the study to the eligible participants and asked them to read and sign the written informed consent if they wish to participate in the study. Patients were told that they are free to leave the study at any stage if they were reluctant to carry on with the study team.

Statistical analysis

The data were analyzed using IBM SPSS Statistics for Windows version 22.0 (IBM Corp. 2013. Armonk, NY: IBM Corp). The descriptive analysis was expressed as numbers, frequencies, and mean ± standard deviation (SD). The categorical variables were compared using the Chi-square test. The normal distribution of data was evaluated using the Shapiro-Wilk test, which showed normal distribution of all numeric variables. Therefore, the statistical associations between the values were compared using paired t-test and Pearson's correlation coefficient. Also, the correlation was calculated according to the patients' BSA. A $P < 0.05$ was considered to be statistically significant.

Results

A total of 38 patients diagnosed with end-stage mitral regurgitation (MR) or mitral stenosis (MS), according to the American Heart Association and American College of Cardiology (AHA/ACC) guidelines, completed this
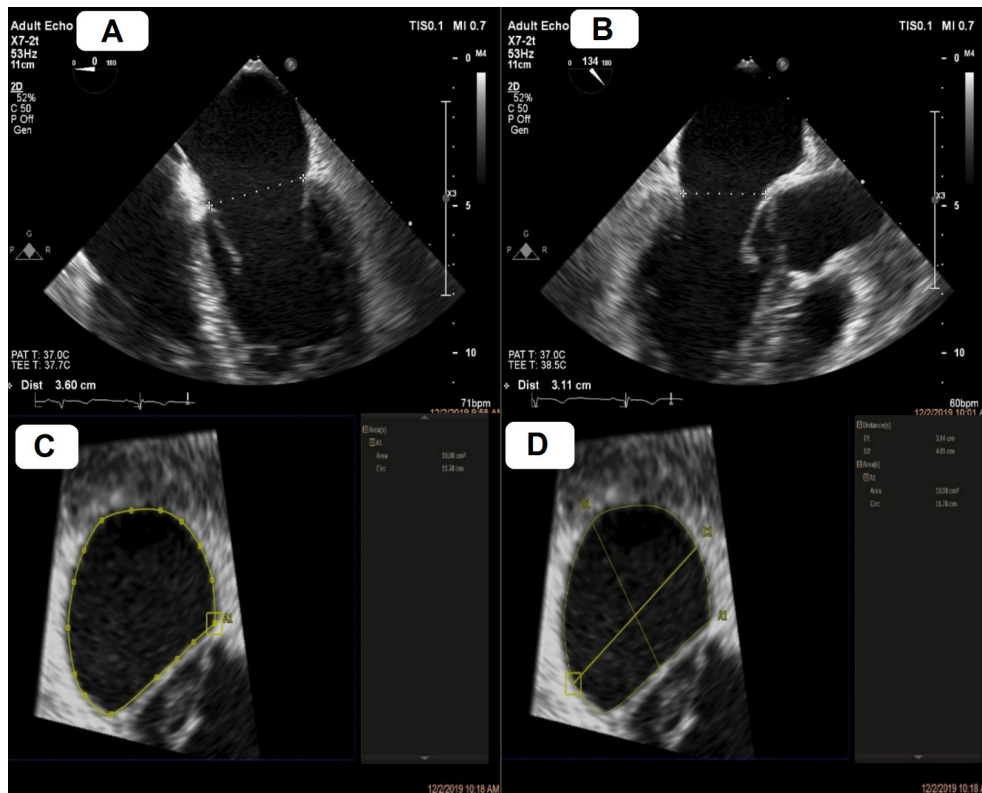
Figure 1. Mitral annulus sizing using two– and three–dimensional transesophageal echocardiography (2D and 3D TEE) software. A, mediolateral annulus by 2D TEE. B, anteroposterior annulus by 2D TEE. C, annulus area and circ by 3D multiplanar reconstruction. D, Long axis (LA) and short axis (SA) by 3D multiplanar reconstruction.

study. All participants were successfully treated with metallic MVR surgery later in the course of the study. Coronary bypass surgery grafting (CABG) was performed simultaneously for 10 out of 38 study participants.

Since the echocardiographic studies were performed by two independent echocardiologists, the IOA was evaluated which revealed a kappa value of 0.87. Besides, data were normally distributed, according to the Shapiro-Wilk statistical analysis.

Regarding the patients' demographic information, the mean age and BSA of patients were 55.89 ± 11.81 years and 1.81 ± 0.17 m², respectively; and 13 (34.2%) were female. Considering the etiology of the valvular disease, rheumatic valve disease with the incidence of 21 out of 38 patients (55.3%) was on top of our list followed by functional (13.2%, n = 5), prolaptic (10.5%, n = 4), degenerative-functional (7.9%, n = 3), degenerative (5.3%, n = 2), prolaptic-infective endocarditis (5.3%, n = 2), and infective endocarditis (2.6%, n = 1)

According to the ECG data, most patients had sinus rhythm (68.4% n = 26). Table 1 depicts the data regarding the mitral annulus diameter (MAD), MAA, and MAC stratified according to the measuring method.

The correlation of the data obtained from 2D and 3D TEE compared to the surgical gold standard is displayed in both Table 2 and Figure 2. The strongest correlation with the gold standard was observed in the MAC values when it was measured using the 3D MPR method

Table 1. The measurements of transthoracic echocardiographic, two– and three–dimensional transesophageal echocardiography

Type of test	Measurements	Mean ± SD
Two–dimensional transesophageal echocardiography	Mediolateral annulus, mm	38.27 ± 4.03
	Commissure–commissure annulus, mm	37.51 ± 4.39
	Anteroposterior annulus, mm	36.93 ± 4.07
Three–dimensional transesophageal echocardiography	LA (3D MPR), mm	39.38 ± 4.61
	SA (3D MPR), mm	31.91 ± 3.19
	Area (3D MPR), cm²	10.26 ± 2.1
	Circ (3D MPR), cm	11.82 ± 1.22
	LA (3D Direct), mm	37.92 ± 4.56
	SA (3D Direct), mm	31.54 ± 3.62
	Area (3D Direct), cm²	9.92 ± 1.98
	Circ (3D Direct) cm	11.48 ± 1.14
Echocardiographic measurements	LVEDD, mm	51.61 ± 8.61
	LVEDDI, mm/m²	28.41 ± 4.54
	LVESD, mm	36.31 ± 9.71
	LVESDI, mm/m²	19.91 ± 4.95
	EF%	46.93 ± 8.29
	LAVI, cc/m²	73.36 ± 36.99
	PAP, mmHg	51.05 ± 22.14

Abbreviations: LA; long axis, 3D; three–dimensional, MPR; multiplanar reconstruction; SA; short axis, Circ; circumference, LVEDD; left ventricular end-diastolic diameter, LVEDDI; left ventricular end-diastolic dimension index, LVESD; left ventricular end-systolic dimension, LVESDI; left ventricular end-systolic dimension index, EF; ejection fraction, LAVI; left atrial volume index, PAP; pulmonary artery pressure.

Table 2. The Pearson's correlation between mitral valve annulus diameters, area, and circumference of two– and three–dimensional transesophageal echocardiography with the surgical ruler

Variables	Measurements	Total		Sinus rhythm		Atrial fibrillation	
		r	P value	r	P value	r	P value
Diameter	Mediolateral annulus	0.477	0.001	0.440	0.01	0.407	0.168
	Commissure–commissure annulus	0.451	0.002	0.425	0.014	0.390	0.188
	Anteroposterior annulus	0.468	0.001	0.452	0.008	0.287	0.341
	LA (3D MPR)	0.493	<0.001	0.480	0.005	0.346	0.248
	SA (3D MPR)	0.507	<0.001	0.479	0.005	0.400	0.175
	LA (3D Direct)	-0.234	0.157	0.014	0.946	-0.766	0.006
	SA (3D Direct)	-0.06	0.722	0.175	0.383	-0.678	0.022
Area	Area (3D MPR)	0.587	<0.001	0.561	0.001	0.524	0.066
	Area (3D Direct)	-0.188	0.258	0.034	0.867	-0.728	0.011
Circ	Circ (3D MPR)	0.758	<0.001	0.723	<0.001	0.825	0.001
	Circ (3D Direct)	-0.179	0.282	0.061	0.764	–0.688	0.019

Abbreviations: LA; long axis, 3D; three–dimensional, MPR; multiplanar reconstruction; SA; short axis, Circ; circumference.
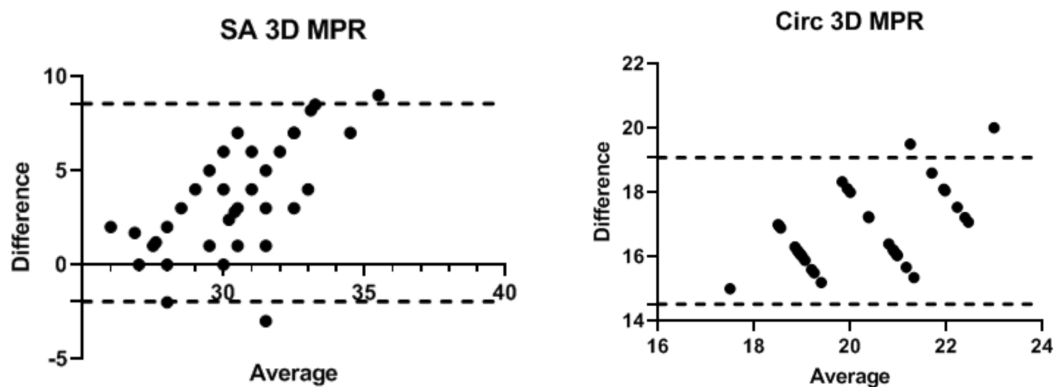
Figure 2. The correlation of SA 3D MPR and circ 3D MPR with the surgical ruler

($r=0.758$, $P<0.001$). The latter statistical significance was also discretely verifiable within the population of patients with sinus rhythm ($r=0.723$, $P<0.001$) and AF rhythm ($r=0.825$, $P=0.001$).

However, none of the indices of the 3D direct planimetry were significantly correlated with the surgical gold standard ($P>0.05$).

As depicted in Table 3, the mitral annulus values measured by 2D and 3D TEE methods revealed a significant correlation with the surgical gold standard among the patients with sinus rhythm. Meanwhile, apart from the mediolateral annulus size, long-axis diameter of the annulus, and annulus circumference, the other measured values did not show a significant correlation with gold standard observation in AF patients (Table 3).

According to the data presented in Table 4, the most accurate echocardiographic values compared to the gold standard belong to the SA when they were measured using the 3D MPR method. Other echocardiographic values and their deviation from the gold standard are shown in Table 4. All patients completed this study successfully and uneventfully.

Discussion

The results of this study revealed a positive correlation in the values of MAD, MAA, and MAC, measured by 2D and 3D TEE-MPR methods, compared to the actual numbers obtained following valvectomy. The P value for these observations was less than alpha, hence considered significant. These results express a high diagnostic accuracy for 2D and 3D TEE in order to scrutinize the MV annulus prior to the MVR surgery, which is crucial in terms of patient and device selection, as well as choosing the proper implant size and surgical technique. However, 3D direct planimetry measurements were not precise enough in this regard. This might have happened due to the difficulty in accurately locating the distorted borders of the valve's annulus in the setting of degenerative and rheumatic valve diseases.

The superiority of the 3D TEE in assessing the MV annulus over the conventional 2D methods has been suggested by several studies. They related their findings to the spatial saddle shape of MV, which is not accurately comprehensible in conventional 2D plan images.[9-11,14]

Furthermore, 3D TEE has been shown to exhibit MV morphology in high consistency with computed

Table 3. The Pearson's correlation between diameters, area, and circumference of two– and three–dimensional transesophageal echocardiography with surgical ruler based on patients' body surface area

Variables	Total		Sinus rhythm		Atrial fibrillation	
	r	P value	r	P value	r	P value
Mediolateral annulus	0.744	0.001	0.754	0.001	0.616	0.033
Commissure–commissure annulus	0.679	0.001	0.728	0.001	0.398	0.201
Anteroposterior annulus	0.737	0.001	0.756	0.001	0.567	0.055
LA (3D MPR)	0.670	0.001	0.651	0.001	0.619	0.032
SA (3D MPR)	0.735	0.001	0.749	0.001	0.568	0.054
Area (3D MPR)	0.694	0.001	0.716	0.001	0.438	0.154
Circ (3D MPR)	0.788	0.001	0.824	0.001	0.590	0.043

Abbreviations: LA; long axis, 3D; three–dimensional, SA; short axis, Circ; circumference.

Table 4. The difference between transesophageal echocardiographic measurements with the surgical ruler

Variables	Measurements	Mean ± SD	Difference	P value
Diameter	Surgical ruler	28.60 ± 1.71	-	
	LA (3D MPR)	39.38 ± 4.61	-10.78	<0.001
	SA (3D MPR)	31.90 ± 3.19	-3.3	<0.001
	LA (3D Direct)	37.92 ± 4.56	-9.23	<0.001
	SA (3D Direct)	31.54 ± 3.62	-2.85	<0.001
	Mediolateral	38.27 ± 4.03	-9.66	<0.001
	Commissure–commissure	37.51 ± 4.39	-8.91	<0.001
	Anteroposterior	36.93 ± 4.07	-8.32	<0.001
Area	Surgical ruler	6.05 ± 1.15	-	-
	Area (3D MPR)	10.26 ± 2.10	-4.21	<0.001
Circ	Surgical ruler	8.98 ± 0.56		
	Circ (3D MPR)	11.82 ± 1.22	-2.84	<0.001

Abbreviations: LA; long axis, 3D; three–dimensional, MPR; multiplanar reconstruction; SA; short axis, Circ; circumference.

tomography (CT) images that makes it a perfect and safe alternative for CT scans.[15] However, the quantitative comparison of diagnostic accuracy of pre-surgical 2D and 3D TEE compared to surgically determined MV parameters has rarely been studied. In a retrospective study on 94 patients with degenerative MV disease undergoing 3D TEE, MAC demonstrated the strongest correlation with the implanted annuloplasty band's length ($r = 0.74$).[12] The study performed by Calleja and colleagues[12] declares a set of results consistent with the present study, which remark the strong correlation between MAC and the gold standard. However, their methods of collecting reference standard and inclusion criteria were different from the present study.[1] Another study that compared 2D and 3D TEE results with the intraoperatively obtained measures yields sensitivities of 97.7% and 92.9%, respectively, and a remarkable specificity of 100% for both methods. These results are consistent with the present study confirming a high correlation with intraoperative gold standard value for both 2D and 3D TEE methods.[16]

Although intraoperative sizing is the conventional and prevalently used method for determining the MV implant size, comprehending this value prior to the surgery can add tremendous leeway for surgeons to properly prepare themselves for the operation.[8,15] Therefore, the availability of a method capable of preoperatively and accurately visualizing the MV apparatus, would be valuable in this regard.[7,16]

In a study by Ender et al, the researchers studied 35 patients with MV diseases who were selected for elective surgical valve repair. According to their results, the correlation between real-time 3D TEE measures performed before the surgery, and the intra-operatively measured actual valve's ring size was 0.91. In the same way, this correlation for the inter-commissural distance and the height of the anterior MV leaflet were 0.55 and 0.75, respectively. Moreover, the statistical correlation coefficient regarding the relativity of the implanted ring size and the postoperative MV assessment, as well as the intercommissural distance and the height of the anterior MV leaflet were 0.96, 0.92, and 0.79, respectively.[17] These results indicate the high statistical correlation running between the real-time 3D TEE and surgically obtained MV measures, consistent with the present study.

The significant impact of the MAD, MAA, and MAC on prognosis of patients with MV disease persuaded us to opt these parameters.[18,19] We also suggest further studies focusing on these parameters.

Subgroup analysis in the present study also showed that the observed significant correlation between the MV annulus circumference measured by the 3D MPR method compared to the gold standard, is valid for both groups of patients with sinus and AF rhythm. However, most other statistical correlations were exclusively attainable among patients with sinus rhythm. The recent finding might have happened due to the small sample size of the current study. Though, all correlations remained significant after considering BSA in the subgroup analysis. These results confirm high levels of correlation running between 2D/3D TEE findings and the surgical measurements independent of patients' BSA and rhythm (in the case of MV annulus circumference), which is contrary to the previous studies.[19-22]

Regarding the mean difference of the values obtained

by 2D and 3D TEE measures compared to the intra-operative standard, all values were significantly different, with the slightest difference observed in the SA 3D MPR images. The difference between echocardiographic and surgical measures could happen due to the dissimilar hemodynamic status during each of these methods. Since the intra-operative measurements were performed on a non-beating heart, echocardiographic studies were carry out under physiologic conditions.[19] Studies utilizing intra-operative echocardiography can be beneficial in order to understand the source of this difference.[23] However, further investigation is needed to support this hypothesis.

Limitations

In addition to the accuracy of three independent study methods compared to the surgical gold standard values, the prospective design of the present study is its other strength. However, this study also has some limitations. A major limitation of the present study is the small sample size. Although information related to different variables had been collected throughout this study's course, the small sample size hampered the subgroup analysis in specific areas, such as the etiology of the disease and patients' age.

Furthermore, because the researchers did not evaluate live (intraoperative) TEE, they could not establish whether the different MV annulus measures regarding the methods were related to the difference in patients' hemodynamics and other conditions before and during the operation or it did primarily occur due to the imaging methods itself.

Conclusion

This study showed a high correlation between 2D/3D TEE measured MV annulus and intraoperative using a surgical ruler as the gold standard method. Also, it has been concluded that the mitral annulus circumference in 3D–MPR TEE demonstrated the strongest correlation with intra-operative measures. Considering the lack of high quality studies on this subject, and the limitations of the present study, further studies should be performed for definite conclusions in this regard.

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Writing-original draft: Elnaz Javanshir.

Study Highlights

What is current knowledge?
- It is well known that preoperative assessment using TEE is crucial for surgical planning in patients with MV disease. Both 2D and 3D TEE have been shown to correlate strongly with intraoperative findings, allowing for better preparation and surgical outcomes.

What is new here?
- The present study highlights the differences in accuracy and reliability between 2D and 3D TEE measurents compared to the gold standard surgical ruler measurements. It suggests that 3D TEE, especially the 3D multiplanar reconstruction (MPR) method, shows a stronger correlation with intraoperative measures than 2D TEE.

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