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Evaluation of Mitral Annulus Diameter by Three-Dimensional Transesophageal Echocardiography and Its Correlation with Surgical Techniques

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ABSTRACT

Background: Mitral Valve (MV) disease is responsible for a considerable number of open cardiac surgeries. Selecting a befitting prosthetic valve is a matter of consideration. Thus, accurate definition of mitral apparatus characteristics, particularly mitral annulus dimensions, preoperatively can shed some light on the situation. The less invasive nature of three-dimensional Transesophageal Echocardiography (3D-TEE) can turn it into a practical modality for preoperative investigation of mitral anatomy.

Objectives: The present study aimed to investigate the correlation between the size of mitral annulus attained through 3D-TEE and intraoperative size as well as the valve or ring size finally placed in mitral position.

Methods: The study was conducted on 28 patients suffering from MV disease who were candidates for MV surgery. All the patients underwent 3D-TEE. Mitral annulus diameters including anteroposterior and intercommissural diameters were measured delicately by using the Mitral Valve Navigation (MVN) tool. In the midst of surgery, a mitral ring sizer was utilized in order to suggest the proper prosthesis size.

Results: The study results demonstrated that the sizer instrument was strongly associated with the inserted prosthesis size and moderately with echocardiographic annulus diameters. The correlation between the deployed prosthesis size and annulus size obtained by intraoperative sizer and 3D echocardiography was assessed, as well. The results indicated that ring sizer showed a strong positive relationship with the intercommissural echocardiography diameter and a moderate positive relationship with the anteroposterior echocardiography diameter.

Conclusion: The results revealed a good correlation between the echocardiography measurements and intraoperative examination along with the deployed prosthesis size. Thus, 3D-TEE could be considered a practical modality for the preoperative investigation of mitral anatomy.

1. Introduction

Mitral Regurgitation (MR) is one of the most common valvular heart abnormalities that is classified into primary (organic or degenerative) and secondary (functional) types (1-3). Ring annuloplasty is a surgical procedure for the reconstruction of the mitral annulus geometry, which has currently become an essential part of Mitral Valve Repair (MVr) irrespective of the underlying pathology (4-6). Choosing the best treatment strategy for individuals with Mitral Valve (MV) disease requires information about the anatomic properties of MV as well as a rough estimation of mitral apparatus measurements preoperatively (7, 8). In line with heterogeneous MR pathophysiology, various techniques such as two-dimensional (2D) and three-dimensional (3D) echocardiography have been developed to evaluate MV diseases (9, 10). Different preoperative

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echocardiographic methods make it possible to study the functional anatomy and dynamic structure of the MV (11-13). The superiority of 3D echocardiography has been documented over 2D echocardiography in terms of evaluating different parameters of the mitral annulus (14). There is still a debate on the modality that can bring a more accurate assessment of MV annulus diameter and can, consequently, serve as a guide for choosing the best-suited valve or ring size.

Up to now, few studies have compared echocardiography techniques with intraoperative findings.

1.1. Objectives

The present study aims to assess the relationship between mitral annular size obtained by 3D echocardiography and intraoperative diameter as well as the inserted valve (or ring) size. The results can be of great help for cardiac surgeons to determine the appropriate valve or ring size to insert.

2. Methods

2.1. Study Population and Study Design

This study was conducted on patients with MV pathology who were about to undergo cardiac surgeries involving MV procedures in Imam Khomeini Hospital, Jundishapur University of Medical Sciences, Ahvaz, Iran from June to December 2020. Patients with a history of prior cardiac surgery, aortic or mitral prosthetic valves, atrial fibrillation rhythm, congenital heart disease, and severe mitral annular calcification were excluded. This study was approved by the review board of Ahvaz Jundishapur University of Medical Sciences. Besides, written informed consent forms were obtained from all patients.

2.2. Echocardiography

Transthoracic Echocardiography (TTE) as well as 2D and 3D Transesophageal Echocardiography (TEE) were performed for all the patients 24 hours before surgery using a Philips EPIQ 7 ultrasound system, version 10 (Philips Ultrasound, Bothell, WA, USA) equipped with X8-2t transesophageal probe. 3D MV image acquisition was done utilizing 3D zoom mode by a single cardiologist specialized in echocardiography. Echocardiography clips were recorded at three cardiac cycles. Subsequently, offline analysis of 3D data was carried out via the Mitral Valve Navigation (MVN) software.

2.3. 3D Analysis by Mitral Valve Navigation Software

After automatic display of the three orthogonal views of mitral annulus including commissural, long axis, and short axis views, planes were manually adjusted in the mid-systole frame. In the next step, anterior (A), posterior (P), anterolateral (AL), and posteromedial (PM) annulus reference points were defined on the long axis and commissural views. After that, annulus editing was executed frame by frame for precise border delineation of the saddle-shaped annulus. The extra steps were as follows: commissure editing, leaflet editing, border editing, and papillary tip selection. Finally, the software automatically rendered MV apparatus in the 3D model and provided manifold data in terms of MV apparatus including anteroposterior annulus diameter and intercommissural annulus diameter (Figure 1).

2.4. Surgical Technique

MV surgery was conducted by a single expert cardiac surgeon who was blind to the echocardiographic data. The underlying etiology of the mitral disease was also marked down during surgery. Observing valve leaflet anatomy directly and its potential for being saved, the surgeon went through MVr or MV Replacement (MVR) on a case-by-case basis. Conventionally, "sizer" instruments were placed in the mitral annulus tissue to make the annulus sizing a bit objective. Given the fact that there is no consensual sizing strategy for mitral annulus, the ring or valve size was chosen by considering the sizer result and the surgeon's assumption, although it might seem rather arbitrary.

2.5. Statistical Analysis

The study data were statistically analyzed using the SPSS 26 software. Normality of the data was checked using Kolmogorov-Smirnov test and QQ plot. Then, one-way ANOVA was used to compare the differences in quantitative and qualitative variables. Additionally, Spearman's correlation test was performed to determine the relationship between the mitral annular size in 3D echocardiography and surgical measurements. Finally, Interclass Correlation

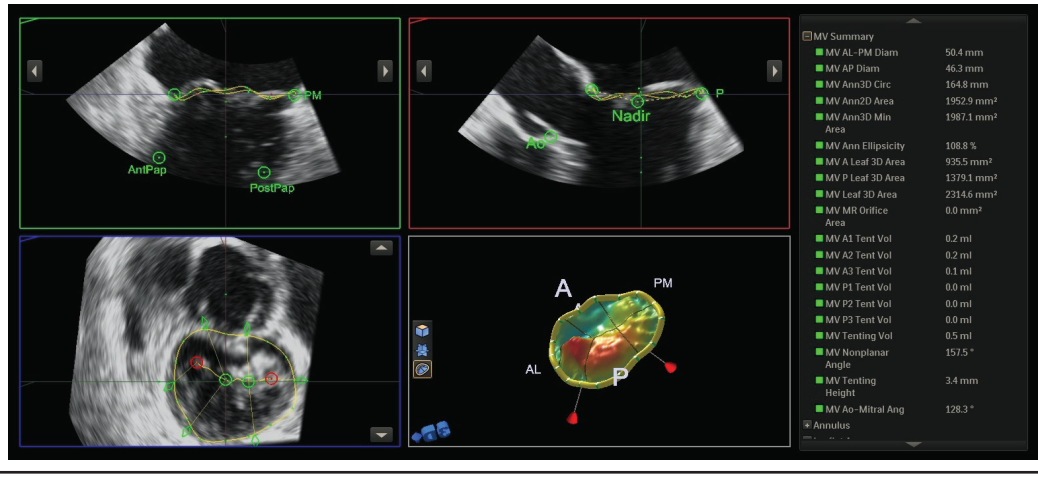

Figure 1. Mitral Annulus Analysis Provided by the Mitral Valve Navigation Software

Coefficient (ICC) was measured to obtain inter-observer and intra-observer reliability**.** $P < 0.05$ was considered statistically significant.

3. Results

This study was conducted on 28 patients who met the study criteria. The patients' baseline characteristics have been presented in Table 1. The mean age of the patients was 48 ± 11.7 years and the majority of them were female (67.9%). MV involvement leading to surgery was severe MR in 75% of the cases compared to 10.7% of the cases with severe Mitral Stenosis (MS). Additionally, four patients (14.3%) had a combination of both severe MR and severe MS. The underlying etiology was rheumatic fever in three patients and primary MV tumor in one. The most common causes of MR were rheumatic fever (44%) and myxomatous prolapse (32%) followed by secondary (ischemic) etiology (16%). All the patients who underwent surgery for pure severe MS were female and were affected by rheumatic heart disease. The 3D-TEE assessment of the mitral annulus dimensions using MVN revealed the anteroposterior diameter of 38.6±5.4 mm and intercommissural diameter of 39.4 ± 4.2 mm.

Among the patients, 92.9% underwent MV replacement, while MV repair was performed in two patients. Besides, 71% of the patients had at least one concomitant surgery; one patient underwent both Aortic Valve Replacement (AVR) and Tricuspid Valve Repair (TVr) and another patient experienced simultaneous TVr and Left Atrium Appendage (LAA) occlusion surgery. The average mitral annulus size that was obtained by ring sizer intraoperatively was 33 ± 3 mm. In addition, the mean size of the inserted valve (or ring) was 30.3 ± 2.1 mm.

Table 1. Baseline Characteristics of the Study Population

Variable	Values
Clinical data	
Age (years)	48.1 ± 11.7
Sex, male	9 (32.1)
Echocardiographic data	
Mitral valve involvement	
Pure severe MR	21(75)
Pure severe MS	3(10.7)
Severe MR + severe MS	4(14.3)
LVEF (%)	48.7 ± 8.0
SPAP (mmHg)	47.0 ± 14.0
LA area (cm^2)	29.3 ± 10.4
RVD (mm)	33.0 ± 5.6
LVEDD (mm)	48.9 ± 7.7
LVESD (mm)	34.2 ± 6.3
3D- mitral annulus AP diameter (mm)	38.6 ± 5.4
3D- mitral annulus IC diameter (mm)	39.4 ± 4.2
MR etiology	
Primary	
Rheumatic	11(44)
Prolapse myxomatous	8(32)
Endocarditis	1(4)
Tumor	1(4)
Secondary	4(16)
MS etiology	
Rheumatic	6(85.7)
Tumor	1(14.3)
Surgical data	
Mitral valve procedure	
MVR	26(92.9)
MVr	2(7.1)
Concomitant surgery	20(71.4)
TVr	8(36.3)
AVR	3(13.6)
CABG	6(27.2)
LAA occlusion	5(22.7)
Valve or ring size	30.3 ± 2.1
Annulus size by ring sizer	33.0 ± 3.0

Abbreviations: MR, mitral regurgitation; MS, mitral stenosis; LVEF, left ventricular ejection fraction; SPAP, systolic pulmonary artery pressure; RVD, right ventricular diameter; LVEDD, left ventricular end-diastolic diameter; LVESD, left ventricular end-systolic diameter; AP, anteroposterior; IC, intercommissural; MVR, mitral valve replacement; MVr, mitral valve repair; TVr, tricuspid valve repair; AVR, aortic valve replacement; CABG, coronary artery bypass graft; LAA, left atrium appendage. Values have been presented as mean ± SD or n (%).

Table 2. The Correlation between the Mitral Annulus Diameter Achieved by Sizer and Echocardiographic Data and the Inserted Valve (or Ring) Size

Variable	Correlation	P-value
Anteroposterior diameter by 3D-TEE	0.61	0.001
Intercommissural diameter by 3D-TEE	0.64	< 0.001
Valve (or ring) size	0.77	< 0.001

Abbreviations: 3D-TEE, three-dimensional transesophageal echocardiography. P-values ≤ 0.05 were considered statistically significant.

Table 3. The Correlation between the Inserted Valve (or Ring) Size and the Annulus Diameters Obtained from the 3D Echocardiography and Ring Sizer

Variable	Correlation	P-value
Anteroposterior diameter by 3D-TEE	0.61	0.001
Intercommissural diameter by 3D-TEE	0.705	< 0.001
Annulus diameter by sizer	0.779	< 0.001

Abbreviations: 3D-TEE, three-dimensional transesophageal echocardiography. P-values ≤ 0.05 were considered statistically significant.

This study evaluated the preciseness of the 3D echocardiographic measurement of the mitral annulus compared to the diameter determined by intraoperative ring sizer. The results showed a strong correlation between the surgical annulus size and the valve (or ring) size selected by the surgeon. Furthermore, a moderate positive correlation was noticed regarding the echocardiographic data. The same correlation was also obtained for both anteroposterior and intercommissural dimensions (Table 2). In addition, the study aimed to explore the level of correspondence between the valve (or ring) size chosen by the surgeon and the sizes obtained from 3D echocardiography and ring sizer. The chosen valve (or ring) size depicted a strong positive relationship with the intraoperative annulus size and echocardiographic intercommissural diameter, while it presented a moderate correlation with the echocardiographic anteroposterior annulus diameter (Table 3).

In the end, reproducibility of 3D echocardiography measurements was quantified in five random patients. The ICCs of the intra-observer variability for anteroposterior and intercommissural annulus dimensions were calculated as 0.92 and 0.88, respectively. The ICCs of the inter-observer reliability were also 0.89 and 0.84, respectively. These measures indicated good agreements between the observations.

4. Discussion

During MV surgery, there is no single consensual approach when it comes to deciding on the prosthetic MV size. The fact that the surgeon's judgment is still the mainstay of this decision underscores its unreproducible essence (15, 16). The paucity of objective measurement tools in this regard makes the search for the practical and accurate sizing tool clinically imperative. The widespread use of ring sizer intraoperatively has been of great help, although its limitations as a non-physiological measurement means is well known (17, 18).

Echocardiography, particularly 3D methods, offers a premier perception of MV anatomy, function, and disorders (19, 20). Additionally, thanks to complex 3D echocardiography navigators, MV annulus diameters can be appraised in a physiological state (21). The present study aimed to look into the agreement among the annulus measurements derived from 3D echocardiography, intraoperative annulus size demonstrated by ring sizer, and the valve (or ring) size chosen by the surgeon. It is worth mentioning that a limited number of studies have been done on the correlation between echocardiographic MV annulus size and deployed valve size.

Discovering the best predictor of mitral prosthetic size in patients undergoing minimally invasive MV replacement, Vo et al. reported that mitral diameters measured on TTE and Computed Tomography (CT) scan could predict mitral prosthetic size (22). Furthermore, Calleja et al. put the 3D echocardiography data to the test in a population with degenerative mitral disease who were candidates for MV repair. As a result, 3D annular circumference obtained from 3D TEE was associated with implanted annuloplasty band length, emphasizing the potential role of 3D echocardiography in preoperative surgical planning of those cases (23). Moreover, Ender et al. demonstrated a marked preoperative correlation between the deployed annuloplasty ring size and intercommissural distance on the basis of echocardiography results in candidates for MV repair (24), which was in agreement with the current study findings.

Overall, it is speculated that the potent correlation observed between the echocardiographic data and the deployed valve size in MV surgeries implicates the notable role of 3D echocardiography, as a complementary method, in preoperatively predicting the mitral valve (or ring) size best suited for a given case. There are also other known clinical applications of 3D TEE in patients affected by MV disease. Defined in advance, emergence of 3D methods has provided the ground for discovering MR etiologies in a precise manner (25). As a case in point, in the current study, the most frequent underlying MR etiology turned out to be rheumatic involvement followed by prolaptic changes using 3D echocardiography.

4.1. Limitation

The main limitation of the present study was its small

sample size, which is needed to be alleviated in future studies. Secondly, the study population was an amalgam of MR and MS patients and the majority of the cases experienced MVR compared to the limited MVr procedures done. Thirdly, lack of postoperative echocardiographic data might put constraints on making deductions about the clinical utilization of 3D echocardiography outputs throughout the MV surgery. In other words, due to the inability to match the correlation findings with the mitral prosthesis competence, it was hardly possible to predict if patients would end up with a better clinical course by reliance on 3D echocardiography data at the time of choosing the valve size.

4.2. Conclusion

In patients undergoing MV surgery, the chosen MV (or ring) demonstrated a robust correlation with intercommissural diameter obtained by 3D MVN method. On the other hand, the annulus size by ring sizers was moderately proportional to intercommissural and anteroposterior echocardiography measurements. Nevertheless, studies encompassing patient follow up including symptoms as well as post-operative echocardiography data could illuminate whether choosing the MV (or ring) size according to physiological 3D echocardiography measurements would form a better clinical course for patients in comparison with non-physiological ring sizers.

4.3. Ethical Approval

The study protocol was approved by the Ethics Committee of Ahvaz Jundishapur University of Medical Sciences, Ahvaz, Iran (IR.AJUMS.HGOLESTAN.REC.1399.079).

4.4. Informed Consent

The informed consent form has been uploaded in the supplementary files during submission.

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Authors' Contribution

Study concept and design: N.A. and H.M.; data acquisition: N.A., H.M., M.A.S, B.G, and R.R.K.; analysis and interpretation of data: N.A. and H.M; drafting of the manuscript: S.Z.K. and Sh.A.; critical revision of the manuscript: Sh.A., H.M., M.A.S., B.G., and R.R.K.; statistical analysis: Sh.A. and S.Z.K.

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