

Dynamic changes in the ischemic mitral annulus: Implications for ring sizing

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ABSTRACT

Objectives: Contrary to the rest of the mitral annulus, inter-trigonal distance is known to be relatively less dynamic during the cardiac cycle. Therefore, intertrigonal distance is considered a suitable benchmark for annuloplasty ring sizing during mitral valve (MV) surgery. The entire mitral annulus dilates and flattens in patients with ischemic mitral regurgitation (IMR). It is assumed that the fibrous trigone of the heart and the intertrigonal distance does not dilate. In this study, we sought to demonstrate the changes in mitral annular geometry in patients with IMR and specifically analyze the changes in intertrigonal distance during the cardiac cycle. **Methods:** Intraoperative three-dimensional transesophageal echocardiographic data obtained from 26 patients with normal MVs undergoing nonvalvular cardiac surgery and 36 patients with IMR undergoing valve repair were dynamically analyzed using Philips Qlab[®] software. **Results:** Overall, regurgitant valves were larger in area and less dynamic than normal valves. Both normal and regurgitant groups displayed a significant change in annular area (AA) during the cardiac cycle ($P < 0.01$ and $P < 0.05$, respectively). Anteroposterior and anterolateral-posteromedial diameters and inter-trigonal distance increased through systole ($P < 0.05$ for all) in accordance with the AAs in both groups. However, inter-trigonal distance showed the least percentage change across the cardiac cycle and its reduced dynamism was validated in both cohorts ($P > 0.05$). **Conclusions:** Annular dimensions in regurgitant valves are dynamic and can be measured feasibly and accurately using echocardiography. The echocardiographically identified inter-trigonal distance does not change significantly during the cardiac cycle.

Key words: Ischemic mitral regurgitation; Mitral annulus; Mitral valve repair; Three-dimensional echocardiography

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INTRODUCTION

The mitral annulus is dynamic and undergoes conformational changes during the cardiac cycle to optimize diastolic left ventricular filling, maintain systolic competence, and minimize leaflet stress.^[1,2] The timing, magnitude, and structural selectivity of these changes have been a source of considerable debate. Being a part of the fibrous skeleton, the anterior portion of the annulus was assumed to be relatively rigid whereas the posterior annulus was considered flexible and mostly responsible for the observed dynamism. However, recent studies have shown that, under normal circumstances, the entire annulus (anterior and posterior) demonstrates dynamic motion.^[3] Hence,

the inter-trigonal distance is assumed to be relatively constant during the cardiac cycle and used for annuloplasty ring size selection.^[3,4] Whether the trigones dilate and the intertrigonal

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distance increases in patients with ischemic mitral regurgitation (IMR) has not been established.^[5]

It has been approved that the mitral annulus dilates and flattens in patients with IMR.^[2] These conformational changes affect both static dimensions and the magnitude of the dynamism during the cardiac cycle. Further, it has been shown that the inter trigonal distance demonstrates limited dynamism during the cardiac cycle.^[3] Surgical annuloplasty fixes the mitral annulus in an end-systolic conformation disregarding its dynamism.^[6] Since the inter-trigonal distance is used for ring sizing, knowledge of its enlargement in patients with IMR could impact ring sizing strategy for mitral valve (MV) repair for IMR. Hence, there is value in the knowledge of the exact extent, nature, and timing of possible changes in the ischemic mitral annular (MA) dimensions during the cardiac cycle. We hypothesized that during the cardiac cycle, valves with IMR demonstrate dynamic behavior, which should be accounted for during ring sizing. Availability of this information in hand can potentially impact surgical decision-making. Therefore, utilizing intraoperative data collected with real-time three-dimensional (3D) transesophageal echocardiography (TEE), we tracked and compared the dynamic geometry of the MA in patients with normal valves and those with IMR.

Subjects

The study was conducted after Institutional Review Board approval with a waiver of informed consent between July 2012 and June 2013. Data were collected from two cohorts: Twenty-six patients with normal MV function and 36 with IMR. Participants with normal MV function served as the control group and were selected from patients undergoing elective cardiac surgery and routine perioperative TEE examinations. Specific inclusion criteria for this group included patients undergoing coronary artery bypass graft surgery with normal biventricular systolic function and absence of any other valvular abnormalities. Patients with more than mild mitral regurgitation (MR), mild MA calcification, MA dilation, and those with any degree of leaflet restriction were excluded from the control group. Our test group was selected from patients undergoing coronary artery bypass grafting and MV repair surgery. Specific inclusion criteria included the presence of mild to moderate or more IMR with evidence of ischemic leaflet restriction. Patients with any degree of mitral stenosis, mild, or more MA calcification, ruptured/tethered chordae tendinae, congenital abnormalities, redo cardiac surgery, arrhythmias, paced rhythms, emergency surgery, and

those on a ventricular assist device were excluded from either of the two groups.

METHODS

The TEE examinations were conducted after induction of general anesthesia and before initiation of cardiopulmonary bypass (CPB). Studies were recorded on iE-33 ultrasound system with an X7-2t matrix 3D-TEE probe (Philips Medical Systems, Andover, MA). A comprehensive two-dimensional (2D) echocardiographic examination was conducted, and suitability of the patient for inclusion in the study was established. The 3D data collection was initiated with a 2D MV image with appropriate depth adjustment to include the entire MA on the data acquisition field. Images were acquired with R-wave gating over 4–6 heartbeats during a brief period of apnea in the absence of electrical interference or patient movement. Multiple (3–4) volumetric acquisitions were performed, and the most optimal data were selected for further analysis. For those patients who were in atrial fibrillation or in any other irregular rhythm, a single-beat full acquisition of the MV was performed.

The acquired data were exported to the on-cart 3D quantification software Qlab[®] Version 8.1.2 (Philips Medical Systems, Andover, MA). Within the Qlab[®] environment, the data were accessed through the 3D quantification software for alignment of the multi-planar reformatting (MPR) planes to obtain orthogonal annular images. With pivot and tilt controls, MPR was used to obtain a sagittal section of the MA. By scrolling the MPR planes in the sagittal plane, the trigones were identified with the help of the position of the aortic valve. The cine-loop function was used to identify the end-systolic and end-diastolic frames. End-systole (ES) was defined as the last frame before the MV starts to open and end-diastole (ED) was defined as the last frame before the MV starts to close. Two points in mid-systole and mid-diastole were also identified using the cine function. Two cardiac surgeons and an echocardiographer identified the trigones in the 3D data and agreed on the linear measure.

After image optimization, multiple linear measures were made at the reps-defined ES and ED frames of the MV. Measurements were also taken at two more points, midway between the opening and closure and vice-versa. Briefly, anteroposterior (AP) diameter, anterolateral-posteromedial (AL-PM) diameter, annular area (AA), anterior AA, posterior AA and inter-trigonal distance (ITD) distance were measured [Figure 1].

Statistical analysis

All data used in this study were analyzed offline and were not used for clinical decision-making. Data generated from the dynamic analysis of the MA were exported to Microsoft Excel for Mac 2011 (Microsoft Corp., Redmond, WA). Measures obtained throughout the cardiac cycle were averaged into 4-time points: Early systole/end diastole, mid-systole, end systole/early diastole, and mid-diastole. Analysis of time data was performed using SPSS, version 20.0 (IBM Corp, Armonk, NY, USA). Comparison between measurements was performed using linear repeated measures analysis of variance. Data are reported as mean \pm standard deviation, or percentage of the group, as appropriate. Percentage change of the measurements was calculated as compared to the early systolic value. Statistical significance was determined at $P \leq 0.05$.

RESULTS

A total of 62 patients were studied, the demographic characteristics and surgical description are shown in Table 1. Data on IMR valves demonstrated larger MA areas across all phases of the cardiac cycle when compared to nondiseased valves [Table 2a]. In both groups, total AA increased throughout systole, achieving a maximum area during early diastolic filling [Figure 2a and b]. Both groups displayed significant change over the course of the cardiac cycle in terms of AA ($P < 0.01$ and $P < 0.05$, respectively) [Figure 2a and b]. However, compared to normal valves we noted significantly less percentage area change in IMR valves ($P < 0.05$) [Figure 2a and b]. When examining the linear dimensions of the MV, we found that all three measures increased through systole ($P < 0.05$ for all)

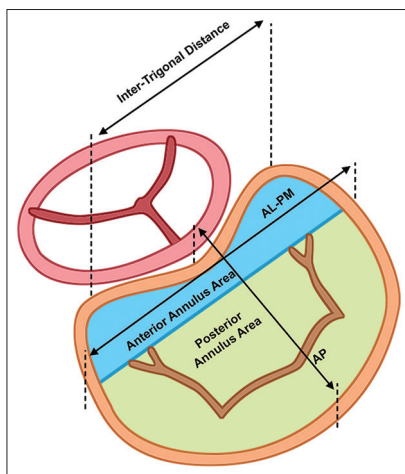


Figure 1: Diagram illustrating the area and linear measures that were obtained for each patient. AL-PM: Anterolateral-posteromedial; AP: Anteroposterior

in accordance with the valve area in patients with both normal and ischemic MVs [Table 2b, Figure 3a and b]. However, as shown in figures, intertrigonal distance showed the least percentage change across the cardiac cycle and its reduced dynamism was validated in both cohorts ($P > 0.05$).

DISCUSSION

The results of our study demonstrate that dynamism of the mitral annulus is relatively preserved in patients with IMR. However, the magnitude of changes in annular conformation in IMR patients is significantly less than the normal annuli. We were also able to measure the inter-trigonal distance feasibly using 3D TEE data. Of note, the echocardiographic inter-trigonal distance did not change significantly in either of the two groups (3.7% in normal and 2.2% in ischemic MVs). This finding may be especially important in the context of surgical annuloplasty ring sizing. We also observed significant dynamic changes in the AP and AL-PM dimensions across both IMR and control groups, pointing to cyclical conformational change even in the diseased state. In patients with IMR, the MA expanded 8.24% in the AP and 7.05% in the AL-PM dimensions. In terms of temporal sequence, valves with IMR were seen to expand and contract similarly to normal valves, achieving maximal area at the opening of the MV, with a progressive reduction during diastole and reaching smallest dimensions at ED.

Application of an annuloplasty device is an integral component of MV repair as it serves to restore normal shape and size of the MA to optimize MV structure and function.^[7] However, there is considerable variation in the intraoperative ring sizing strategy based on MA linear dimensions.^[8] Surgically, these dimensions (inter-trigonal distance, transcommissural diameter, anterior leaflet length) are made using commercial “valve sizers.”

Table 1: Patient characteristics

Parameter	Normal MV group (n=26)	IMR group (n=36)
Age (years)	66.4 \pm 6.8	67.1.4 \pm 5.9
Weight (kg)	85.1 \pm 12.1	82.3.1 \pm 13.2
Height (cm)	174.7 \pm 9.0	177.7 \pm 10.5
BMI (kg/m ²)	28.0 \pm 3.6	29.4 \pm 4.5
Gender (male/female)	22/4	20/16
Procedure	23 (CABG)/ 3 (AAA)	24 (MVR); 12 (CABG + IMR)

AAA: Abdominal aortic aneurysm, IMR: Ischemic mitral regurgitation, MV: Mitral valve, MVR: Mitral valve repair, BMI: Body mass index

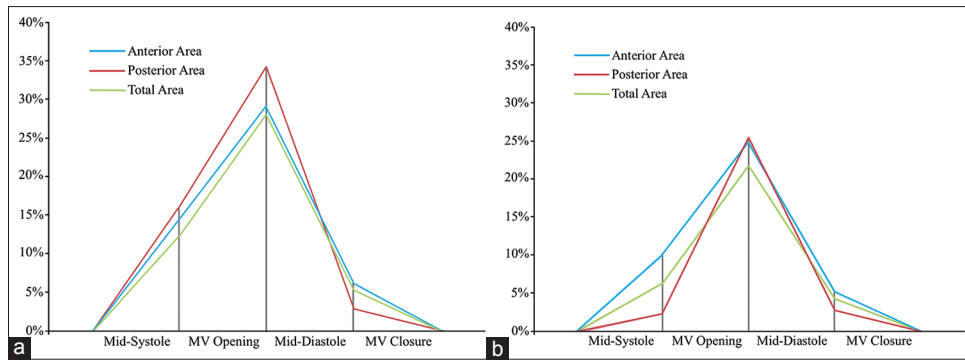


Figure 2: (a) Graph showing changes in the anterior, posterior and total, the annular area over the course of the cardiac cycle in patients with normal mitral valves. (b) Graph showing changes in the anterior, posterior and total annular area over the course of the cardiac cycle in patients with ischemic mitral regurgitation. Note that while the changes in area are similar in their temporal sequence, the percentage change is reduced in diseased valves compared to normal valves

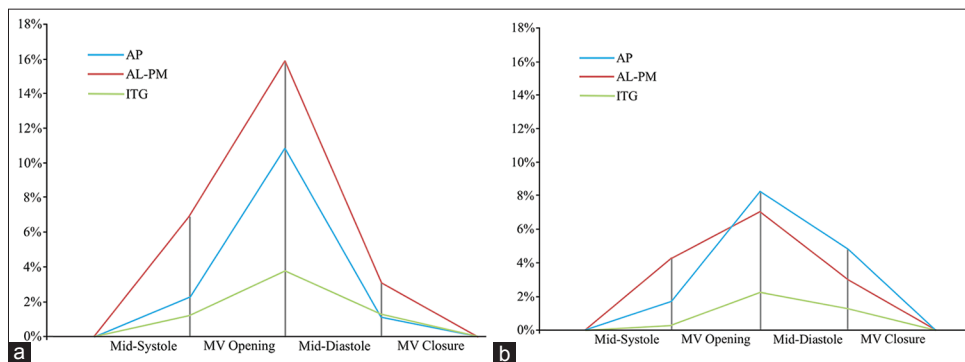


Figure 3: (a) Graph showing changes in linear dimensions including anteroposterior diameter, anterolateral-posteromedial diameter, and inter-trigonal distance (ITD) in normal mitral valves over the course of the cardiac cycle. (b) Graph showing changes in linear dimensions including anteroposterior diameter, anterolateral-posteromedial diameter, and inter-trigonal distance (ITD) over the course of the cardiac cycle in patients with ischemic mitral regurgitation. Note that the overall percentage change in diameters is depressed in ischemic valves compared to normal valves. However, the relative lack of change in inter-trigonal distance is consistent across both normal and diseased valves

Table 2a: Changes in linear dimensions across cardiac cycle for control group

Variable (n=26)	Early systole (end diastole)	Mid systole	End systole (early diastole)	Mid diastole
AP diameter (cm)	2.67±0.39	2.69±0.33	2.94±0.33	2.69±0.34
AL-PM diameter (cm)	3.52±0.45	3.82±0.39	4.08±0.57	3.63±0.44
Inter-trigonal distance (cm)	3.19±0.31	3.26±0.37	3.39±0.43	3.23±0.32
Anterior annulus area (cm ²)	4.11±0.83	4.60±1.11	5.24±1.24	4.56±1.06
Posterior annulus area (cm ²)	3.94±1.15	4.33±1.13	5.14±1.07	3.97±0.94
Total annulus area (cm ²)	8.14±1.71	9.14±1.90	10.43±2.09	8.56±1.70

AP: Antero-posterior, ALPM: Anterolateral-posteromedial

Table 2b: Changes in linear dimensions across cardiac cycle for ischemic mitral regurgitation patients

Variable (n=36)	Early systole (end diastole)	Mid systole	End systole (early diastole)	Mid diastole
AP diameter (cm)	2.91±0.62	2.96±0.79	3.15±0.75	3.05±0.64
AL-PM diameter (cm)	3.97±0.74	4.22±0.94	4.25±0.91	4.09±0.86
Inter-trigonal distance (cm)	3.13±0.51	3.14±0.54	3.24±0.56	3.17±0.54
Anterior annulus area (cm ²)	4.97±1.69	5.47±1.73	6.20±1.09	5.23±1.01
Posterior annulus area (cm ²)	4.76±1.90	4.87±1.12	5.97±1.36	4.89±1.91
Total annulus area (cm ²)	9.73±2.46	10.34±2.80	11.84±2.36	10.15±1.84

AP: Anteroposterior, ALPM: Anterolateral-posteromedial

The correlation of commercial valve sizers to actual anatomical dimensions lacks consensus and is based on manufacturer recommendations and subjective personal preferences.^[6] Moreover, intraoperative surgical valve analysis for ring size selection is performed on a paralyzed heart not exposed to the dynamic physiological loading conditions. In this process, the temporal variation in the MA structure is ignored, and the MA is fixed in a static position for measurement. This can lead to a discrepancy between the physiological and the observed dimensions of the MA. The high incidence of recurrent MR and mitral stenosis suggests that current ring sizing strategies merit reconsideration.^[9,10]

Considering the variations in ring sizing strategies, there is a need for a standardized and reproducible approach based on our physiological understanding of the heart. Moreover, in the case of devices that measure the IT distance, the precise location of the trigones is approximated on an arrested and physiologically inactive heart. Our study suggests that it is possible to identify trigones with 3D transesophageal echocardiographic data, which offers the opportunity to measure inter-trigonal distance in a physiologic state. Our results bring into question, the existing paradigm of quantitative analysis of MV geometry based on a static valve. It is logical to assume that dimensions such as AP, AL-PM, and AAs may be different depending on the point in the cardiac cycle they are measured at. Importantly, for echocardiographically measured inter-trigonal distance this assumption does not hold true. This makes it a suitable benchmark for categorizing valve sizes based on a single, static frame.

We can identify some limitations of our study. We have a small sample size, but our results were based on normal cardiac anatomy and function and conform to earlier descriptions of dynamic MA behavior. Therefore, we are confident of our results. The echocardiographic identification and measurement of the inter-trigonal distance could possibly be different from the actual measurement. However, this method provides a more objective approach and more accurate measurement since it is measured on a beating heart before the institution of CPB.

CONCLUSION

The entire MA displays dynamism during the cardiac cycle, in both normal as well as those patients with IMR. The magnitude of annular dynamism is relatively

reduced in patients with IMR. Echocardiographically acquired inter-trigonal distance demonstrated the least dynamism during the cardiac cycle. Therefore, echocardiographically identified and measured inter-trigonal distance can be possibly used for annuloplasty ring sizing.

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Conflicts of interest

There are no conflicts of interest.

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