ORIGINAL ARTICLE

Mitral annulus dynamics in myxomatous mitral valve disease

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Abstract: Myxomatous mitral valve disease (MVD) is a common disorder in which the entire mitral valve apparatus seems to be involved. Mitral valve repair is nowadays the method of choice for the correction of mitral regurgitation but the optimal shape and flexibility of the annuloplasty ring remain controversial. Considering that myxomatous MVD covers a wide spectrum from limited fibro-elastic deficiency to extensive Barlow disease, we presume that the mitral annulus morphological and functional changes are likely different in different types of myxomatous MVD. We analyze the 3-dimensional geometry and the dynamics of the mitral annulus in 110 patients with significant mitral regurgitation due to different types of myxomatous mitral valve disease and 40 normal subjects using 3D transesophageal echocardiography. The mitral annulus differs in patients with limited MVD, extensive MVD and in normal controls in terms of size, shape, and dynamics Patients with limited MVD have larger, flatter, dysfunctional and more mobile mitral annulus compared to normal, while patients with extensive MVD have even larger, flatter and more dysfunctional mitral annulus, with reduced mobility. The non-planar dynamics has different patterns during systole, according to the extension of MV disease. Our data may be important for the appropriate choose of annuloplasty mitral annulus in mitral valve repair, the current trend being to choose the ring according to the underlying pathology.

Keywords: mitral annulus, myxomatous mitral valve disease, mitral regurgitation, mitral annulus dynamics.

Rezumat: Boala mixomatoasă a valvei mitrale reprezintă o afecțiune relativ frecventă care implică întreg aparatul valvular mitral. Repararea valvei mitrale este în prezent metoda preferată pentru corectarea insuficienței mitrale, dar tehnica optimă de plastie și flexibilitatea inelului de anuloplastie rămân controversate. Având în vedere că boala mitrală mixomatoasă acoperă un spectru larg de la deficiența fibro-elastică limitată la boala Barlow, presupunem că modificările morfologice și funcționale ale inelului mitral sunt probabil diferite în funcție de tipul de afectare mitrală mixomatoasă. Am analizat folosind ecocardiografie transesofagiană 3D geometria tridimensională și dinamica inelului mitral la 110 pacienți cu insuficiență mitrală semnificativă cu diferite tipuri de boală mitrală mixomatoasă și 40 de subiecți normali. Inelul mitral este la diferit atât din punct de vedere al dimensiunii, formei, dar și al dinamicii la pacienții cu boală mixomatoasă limitată comparativ cu cei cu boală mixomatoasă extinsă și comparativ cu subiecții normali. Pacienții cu boală mixomatoasă limitată au inel mitral dilatat, aplatizat, disfuncțional dar mai mobil în comparație cu subiecții normali, în timp ce pacienții cu boală mixomatoasă extinsă au inel mitral cu dilatare mai importantă, mai aplatizat și mai disfuncțional dar cu mobilitate mai redusă. Dinamica non-plană are modele diferite în timpul sistolei, în funcție de extinderea bolii mitrale. Datele noastre pot fi importante pentru alegerea corespunzătoare a inelului de plastie în repararea valvei mitrale, tendința actuală fiind de a alege inelul în funcție de patologia de bază.

Cuvinte cheie: inel mitral, boală mitrală mixomatoasă, insuficiență mitrală, dinamica inelului mitral.

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INTRODUCTION

Myxomatous mitral valve disease (MVD) is a common disorder, affecting 2-3% of the general population[1]. Morphologically, it is characterized by fibromyxomatous changes, mucopolysaccharide accumulation and collagen alteration[2]. From an imaging standpoint, it is characterized by systolic displacement of abnormally thickened mitral leaflets[3] into the left atrium[4]. Although the morphological changes have been described initially only at the mitral leaflets' level, the entire mitral valve (MV) apparatus seems to be involved.

Mitral valve repair is nowadays the method of choice for the correction of mitral regurgitation (MR) in MVD[5], but the principles of MV repair have evolved together with the better understanding of MV anatomy and physiology[6]. Although the concept of consolidation of mitral ring annuloplasty introduced by Carpentier is generally accepted in MV repair[7,8], the optimal shape and flexibility of the annuloplasty ring remain controversial[9]. If the initially used mitral ring was flat and rigid[10], the current trend was to choose the ring according to the underlying pathology. The aim of MV repair is to achieve normal function in the long term rather than to replicate a structurally normal mitral valve.

The anatomy and function of the mitral annulus (MA) were previously analysed in normal subjects and in patients with MR using different imaging modalities: transthoracic and transesophageal 2D and 3D echocardiography, cardiac CT[11,12] or cardiac MRI[13]. However, previous studies have generally analysed all patients with myxomatous MVD as a single group, regardless of the extent and severity of valve impairment. Considering that myxomatous MVD covers a wide spectrum from limited fibro-elastic deficiency to extensive Barlow disease[14], the MA morphological and functional changes are likely different in different types of MVD.

Therefore, the aim of the study was to analyze the 3-dimensional geometry and the dynamics of the MA in patients with significant MR due to different types of myxomatous MVD.

METHODS

Study population

All symptomatic patients with a confirmed transthoracic echocardiography (TTE) diagnosis of significant MR (severe and moderate-to-severe) due to myxomatous MVD referred to our department for transesophageal echocardiography (TEE) were screened for inclusion. The exclusion criteria were known coronary artery disease, history of rheumatic fever/rheumatic valve disease, significant MA calcification, more than mild concomitant aortic or tricuspid valve disease, left ventricular (LV) systolic dysfunction or atrial fibrillation. A control group consisting of patients who had a clinical indication for TEE and in whom no significant cardiovascular disease was found were also analysed.

The following clinical data were collected for all patients: age, gender, history of hypertension, symptoms (e.g. dyspnea, chest pain, palpitations, syncope). The clinical status was defined according to the *New York Heart Association* (NYHA) classification. Physical exa-

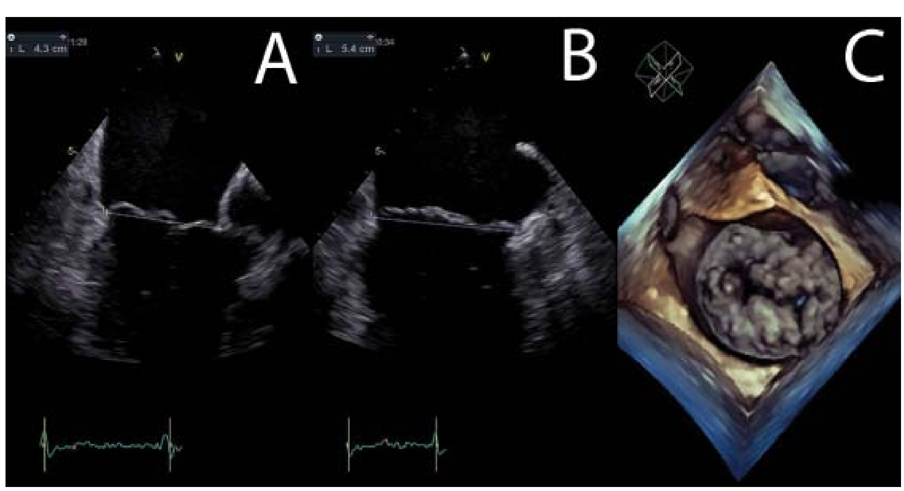

Figure 1. Transesophageal echocardiographic views for analysing the morphology of mitral valve (mid-systole still images) in a patient with extensive mitral valve mixomatous disease: mid-oesophageal long axis view for A2-P2 visualisation and measurement of antero-posterior annulus (A), bi-commisural view for P1-A2-P3 scallop visualisation and measurement of commissural diameter (B), „en-face" 3D visualisation of mitral valve (C).

mination and 12-lead electrocardiography were performed in all patients.

Transesophageal 2D and 3D echocardiography

All patients had a complete TEE examination (using the EACVI protocol) followed by 3D acquisition of the mitral valve (3D and color 3D). Electrocardiographically-gated full-volume loops were acquired over 4 cardiac cycles at a frame rate of 17 to 30 volumes/s. The volume for mitral valve was a multibit acquisition with ≥15 vol/second.

The MV morphology was first analysed by 2D TEE using six different views: mid-esophageal four chamber, five chamber, two chamber, modified two chamber with the probe rotated to the right, bi-commisural and long axis views[15] (Figure 1). The Carpentier classification was used to describe the components of each leaflet: the posterior leaflet is composed of three scallops: P1 (anterolateral), P2 (middle), and P3 (posteromedial), while the corresponding segments of the anterior leaflet are labelled A1, A2, and A3[13]. Each scallop of the MV was characterized as being normal, prolapsing, or flail. Prolapse was defined as supra-annular displacement of the free margins and flail was defined as orientation of mitral leaflet tip towards the left atrium during systole. The existence of ruptured chordae was noted. The morphology of each scallop was also evaluated by 3D echocardiography from the „surgical view" and from specific cut planes obtained from the volumetric dataset[16]. The data obtained by 3D echocardiography were considered the gold standard against which the 2D images were assessed[17].

Mitral regurgitation severity was estimated using qualitative, semi-quantitative and quantitative methods (effective regurgitant orifice area, EROA; and regurgitant volume, RV, estimated by the PISA method). Mitral regurgitation was considered moderate to severe

Table 1. Automatic mitral valve measurements (using 4D MV Assessment 2.0 TomTec imaging Systems)

Parameter	Definition	Unit
Antero-posterior diameter	Distance between the anterior and posterior point of mitral annulus.	cm
Anterolateral-posteromedial diameter	Longest distance between two points on the annulus that are derived by intersecting the annulus and a line perpendicular to antero-posterior diameter.	cm
Commissural diameter	Distance between two points on the annulus. Both points are derived by intersecting the annulus spline with a plane that goes through both end points of the coaptation and is perpendicular to the best fitting plane.	cm
Annulus circumference (3D)	Real length of annulus spline	cm
Annulus area (3D)	Size of core area	cm^2
Annulus area (2D)	Size of area derived by projecting the annulus spline onto the Best Fitting Plane.	cm^2
Non-planar Angle	Angle between the plane formed by anterior point of MA and commissural diameter and the plane formed by posterior point of MA and commissural diameter.	°

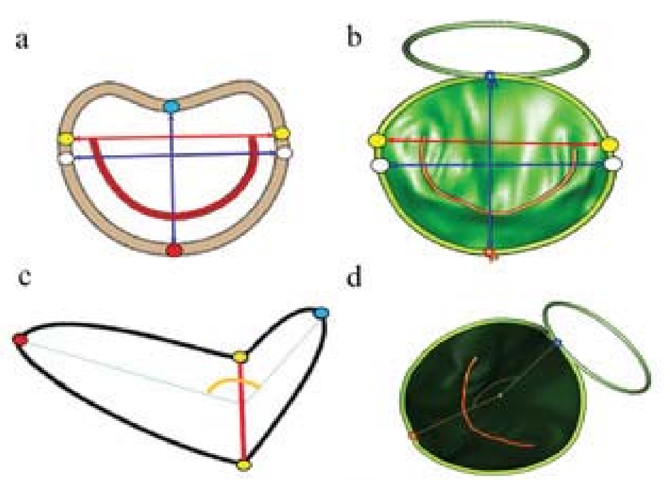

Figure 2. Mitral annulus measurements performed using 3D reconstructed model (b,d): antero-posterior diameter (between red and blue dots- a and b), anterolateral-posteromedial diameter (between white dots- a and b), bi-commissural diameter (between yellow dots), non-planar angle (c and d).

when EROA was 30-39 mm^2 and RV 45-59 ml, and severe when EROA was >40 mm^2 and RV >60 ml[18].

Imaging analysis

All 2D and 3D TEE images were analysed off-line. Parameters of mitral annulus (MA) geometry were first measured from 2D images: the antero-posterior diameter in mid-systole from the long axis view; the anterolateral-posteromedial diameter in mid-systole from the bi-commissural view; and the length of mitral valve leaflets in mid-diastole from the long axis view (Figure 1).

The mitral valve was reconstructed from the acquired 3D volume using a specific software (4D MV Assessment 2.0 TomTec Imaging Systems). The mathematical model illustrates the leaflet topology by colouring each point of the leaflet surface according to its distance to the best fitting plane of the mitral annulus. This plane is defined as the plane that fits the majority of points of mitral annulus and minimizes the distance to the points that are not in the plane. The points of mitral valve leaflet located above this plane, in the left atrium, are coded in red, the points located below this plane, towards the LV, are coded in blue, while the points located in this plane are coded in white. Therefore, the part of the mitral valve leaflets which is coloured in red is considered prolapsing. Automatic measurements of the mitral annulus and mitral valve leaflets were performed (Table 1, Figure 2).

To describe the mitral annulus dynamics all these parameters were measured in five systolic moments: beginning of systole, early-systole, mid-systole, late-systole, and end-systole.

The annular tracking using the semi-automated programme offers also a dynamic model with measurements of annular displacement and displacement velocity. Annular displacement (max) was defined as the longitudinal movement of the annular centroid and annular displacement velocity (max) as the first derivative of annular displacement. The annular area fraction was automatically calculated by using the formula: (maximum area - minimum area)/maximum area. We analysed the changes of these parameters during systole, which can be mainly described by the following four models: U-shape (decrease-increase), ascending shape, descending shape, and inverted-U shape (increase-decrease).

Statistical analysis

Continuous data are presented as mean +/- SD and nonparametric data as median and ranges. For testing the differences between the three groups we used one way ANOVA and for testing differences at each mentioned systolic moment we used repeated measurements MANCOVA. Variables between two groups were compared using Student's *t* test or the Mann-Whitney *U* test. The relationships between different parameters were assessed by correlation analysis: Pearson's method or Spearman's r method as appropriate.

Reproducibility of the 3D morphologic parameters was assessed in a randomly chosen subgroup of 15 patients. Intraobserver variability was assessed using repeated measurements performed by the same observer a month later, while interobserver variability was evaluated by repeating the analysis by a second independent observer, blinded to the results of all prior measurements.

Statistical analyses were performed using SPSS version 21.0 (SPSS, Inc., Chicago, IL). P values < .05 were considered significant.

Table 2. Demographic and clinical characteristics in normal subjects and patients with mitral regurgitation

	Normal subjects	Limited MVD	Extensive MVD	p*
Patients, n	38	58	41	
Age, y	54.9+/-10.6	58.5+/-9.1	56.11+/-10.33	0.55
Men, %	57.9	58.6	56.1	0.96
BSA, m^2	1.91+/-0.2	1.85+/-0.2	1.83+/-0.19	0.14
Symptoms				
• No symptoms	38			
• NYHA I		28	22	
• NYHA II		14	13	
• NYHA III		6	4	

*p value obtained by ANOVA among the three groups.

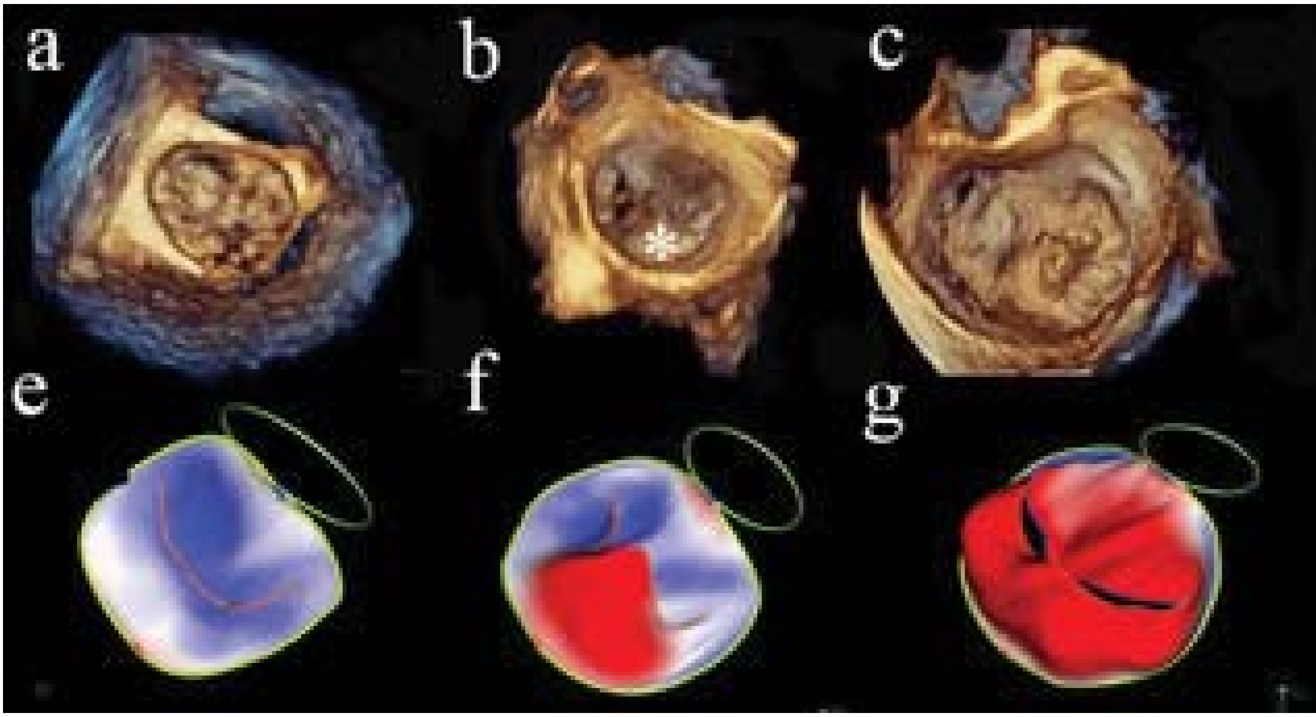

Figure 3. The three groups analysed in our study (3D atrial view of mitral valve- a, b and c and mathematical model- e, f and g): normal (a and e), limited mitral valve disease (b and f) and extensive mitral valve disease (c and g).

RESULTS

We included 110 patients in the mitral regurgitation group and 40 patients in the control group. Eleven patients were excluded from the MR group due to inadequate temporal resolution (<15 vol/s), associated atrial septal defect, or non-significant MR (regurgitant volume <45 ml based on the TEE examination). Two subjects were excluded from the control group due to inadequate temporal resolution. Thus, the final study group consisted of 99 patients with MR and 38 control subjects.

The clinical characteristics of the study groups are presented in Table 2.

The age (54.9+/-10.6 vs 58.3+/-11.7, p=0.12) and gender (57% men in both groups, p=0.9) distribution were similar in patients with MR and in control subjects.

Among patients with MVD, in 44% the valve was affected by prolapse without flail, while in 55% the flail of at least one scallop was noted. In 6% of patients the pathology involved only the anterior mitral leaflet, in 49% only the posterior mitral leaflet, and in 44% both leaflets were affected. In the MR group, 34% of patients had only one scallop affected by prolapse/flail, 24% had two scallops, 9% three scallops, 6% four scallops, 6% five scallops, and 20% had all the six scallops affected.

Based on the number of scallops affected we subdivided the group of patients with MR in:

1. limited MVD (LMVD: 1-2 scallops affected by prolapse/flail, 58 pts), and 2. extensive MVD (EMVD: 3-6 scallops affected by prolapse/flail, 41 pts) (Figure 3). Parameters of MR severity were not significantly different between these two MR groups: 0.6+/-0.2 cm^2 vs 0.48+/-0.23 cm^2 for EROA (p=0.7); and 76+/-32 ml vs 65+/-3 ml for RV (p=0.09) and 7+/-1.8 mm vs 6.6+/-1.4 mm for vena contracta (p=0.27). Left ventricular ejection fraction was not different in patients with LMVD compared to patients with EMVD (60+/-5% vs 61+/-7%, p=0.7).

COMPARISON BETWEEN 2D AND 3D DATA

The antero-posterior MA diameter measured by 2D TEE had moderate correlations with values of same diameter obtained by 3D geometrical reconstruction (r=0.39, p<0.001) while the anterolateral-posteromedial MA diameters had a better correlation (r=0.53, p<0.001). Moreover, the values of the MA antero-posterior diameter obtained by 2D and 3D echocar-

Table 3: Parameters of mitral valve apparatus geometry

	Normal	Limited MVD	Extensive MVD	p	p'
Patients (number)	38	58	41		
Antero-posterior diameter* (cm)	3+/-0.23	3.58+/-0.56	3,86+/-0.61	<0.001	0.008
Anterolateral-posteromedial diameter* (cm)	3.35+/-.31	3.84+/-0.55	4.27+/-0.7	<0.001	<0.001
MA circumference* (cm)	10,46+/-0,87	12,15+/-1,7	13.4+/-2.18	<0.001	<0.001
MA 2D area* (cm2)	8,08+/-1,35	11,14+/-3,3	13.53+/-4.53	<0.001	0.001
MA 3D area* (cm2)	8,3+/-1,38	11,33+/-3,36	13.66+/-4.2	<0.001	0.001
Intercommisural distance* (cm)	3,31+/-0.31	3,75+/-0.52	4.14+/-0.68	<0.001	<0.001
Anterior mitral leaflet area* (cm)	5,32+/-0,92	6,71+/-2,00	8.4+/-2.9	<0.001	<0.001
Posterior mitral leaflet area* (cm^2)	4,02+/-0,93	7,16+/-3,15	9.51+/-4.64	<0.001	0.001
Leaflets area reported to 3D MA area*	1.1+/-0.05	1.2+/-0.11	1.3+/-0.20	<0.001	0.005
Mitral-aortic angle* (degree)	120,91+/-10,50	122,09+/-12,33	119.73+/-25.66	0,936	0.74
Nonplanar angle- beginning systole	150,23+/-8,73	154,45+/-11.97	162.83+/-13.29	<0.001	<0.001
Nonplanar angle- early-systole	146,81+/-8,87	150,91+/-12,36	160.19+/-11.92	<0.001	<0.001
Nonplanar angle- mid-systole	147,13+/-7,92	152,29+/-10,01	158.21+/-10.70	<0.001	0.006
Nonplanar angle- late- systole	149,93+/-7,07	155,21+/-10.01	158.21+/-10.7	0,001	0.124
Nonplanar angle- end-systole	153,64+/-7,51	157,54+/-10,18	158.10+/-11.23	0,09	0.7
Nonplanar angle- mean value	149,55+/-7,23	153.48+/-10.18	159.46+/-10.3	<0.001	0.003

* the reported value is measured in mid-systole.
p value is obtained by ANOVA among the three groups and p' value is calculated using independent t-test between patients with limited and extensive mitral valve disease.

diography were significantly different (3.4+/-0.5 cm vs 3.5+/-0.6 cm, p=0.002).

THE MITRAL ANNULUS GEOMETRY

The mitral annulus dimensions were significantly different in the 3 study groups.

The MA dimensions (antero-posterior diameter, anterolateral-posteromedial diameter, MA circumference and MA area) are larger in the LMVD group compared to controls, and larger in the EMVD group compared to the LMVD. Similarly, the MA is flatter in the LMVD group compared to controls, and even flatter in the EMVD group, compared to the LMVD (Table 3).

Doppler parameters of MR severity (EROA and RV) had moderate correlations with structural MA parameters: antero-posterior diameter (r=0.46 and 0.47, p<0.005 for both), anterolateral-posteromedial diameter (r=0.41 and 0.43, p<0.001), 3D MA area (r=0.42 and 0.41, p<0.005), intercommisural distance (r=0.37 and 0.6, p<0.005), and weak correlations with the value of nonplanar angle (r=0.18 and 0.24, p<0.05). These parameters of MR severity are moderat correlated with the ratio between the non-planar angle and 3D MA area (r=0.46, p<0.001).

Comparing patients with flail vs. patients without flail, the only significantly different static parameter was the non-planar angle at the beginning of systole (152+/-12° for patients with flail vs 160+/-13 for patients without flail, p <0.05). Among patients with LMVD, those with flail had a significantly lower ratio between the sum of anterior and posterior mitral leaflet area divided by the 3D MA area compared to those without flail. This was the case for all the five systolic moments (p<0.005).

The antero-posterior diameter, anterolateral-posteromedial diameter, MA area and MA circumference were all larger in patients with EMVD compared to patients with LMVD and to controls. During systole, all mentioned parameters are increasing for all groups (Figure 4). The antero-posterior diameter, the anterolateral-posteromedial diameter, and the 3D MA area correlate with the number of segments affected by prolapse (r= 0.56, 0.57, 0.57, p< 0.001 for all).

The non-planar angle has also greater values in all the five systolic moments in patients with EMVD compared to patients with LMVD and to controls. The non-planar angle had weak correlations with parameters of MA dimensions (anteroposterior diameter: r=0.3; anterolateral-posteromedial diameter: r=0.2; MA area: r=0.3, p<0.01 for all).

The dynamic changes during systole have the following pattern: in control subjects the nonplanar angle initially decreases and ultimately increases, de-

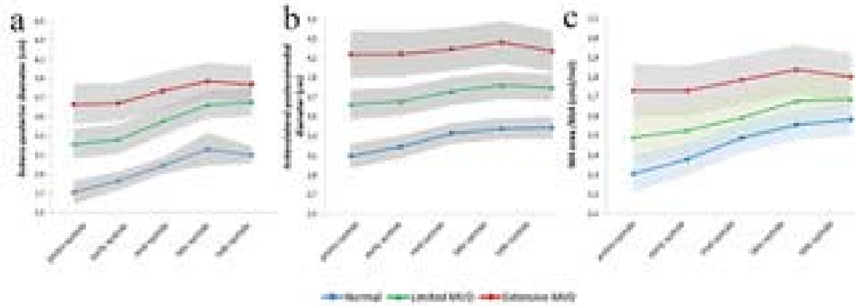

Figure 4. Static MA parameters dynamics among five systolic moments (beginning of systole of proto-systole, early systole, mid-systole, late systole and end of systole or tele-systole): the MA antero-posterior diameter is larger in patients with limited MVD (green) comparing to normal (blue) and even larger in patients with extensive MVD (red) and increases along systole in all groups but the increasing rate is higher in patients with limited MVD (a); the MA anterolateral-posteromedial diameter (b) and MA area (c) has the same characteristics as MA antero-posterior diameter.

scribing a U-shape; in patients with LMVD the nonplanar angle increases during systole describing an ascending shape; and in patients with EMVD the nonplanar angle decreases during systole describing a descending shape (Figure 5).

Intraobserver and interobserver variability reported as intraclass correlation coefficient and 95% confidence interval were 0.95 (0.82-0.98) and 0.91 (0.72-0.97) for non-planar angle, and 0.97 (0.89-0.99) and 0.91 (0.74-0.97) for 3D MA area; $p<0.001$ for all.

DYNAMICS OF MITRAL ANNULUS GEOMETRY

Mitral annulus function, as assessed by MA fractional area changes, was decreased in patients with LMVD compared to controls and even more decreased in patients with EMVD. The MA dynamics (assessed by annular displacement and annular velocity) was higher in patients with LMVD compared to controls, and lower in patients with EMVD compared to controls (Table 4).

DISCUSSION

The three-dimensional shape of the MA is a hyperbolic paraboloid 19-21 with two higher points: the anterior point (adjacent to the aortic valve) and the posterior point, located closer to the left atrium; and two lower points: the medial and the lateral points (adjacent to the commissures), located closer to left ventricle[22,23].

The mitral annulus is dynamic and changes its shape during the cardiac cycle[24]. During systole, the MA area decreases by augmenting its saddle shape mainly by decreasing the distance between the two higher points and increasing the MA height, and to a lesser extent by decreasing the distance between the two lower points[22]. Therefore, the minimum MA area is reached at the beginning of systole, with the peak MA area in diastole[25], followed by a presystolic contraction of the MA[26], apparently independent from the left atrium and LV contraction[27].

The MA is affected in patients with primary MR[28]: structurally it is dilated and flatter, and functionally its ability to contract at the beginning of systole is decreased[7,29].

Our study confirms that patients with significant primary MR have larger and flatter MA: the antero-posterior diameter, anterolateral-posteromedial diameter, MA 2D and 3D area, MA non-planar angle have greater values throughout systole in patients with MR compared to normal controls ($p<0.005$). The MA fractional area change was significantly lower in patients with MR compared to normal controls (14.3+/-8.2% vs 21.6+/-12%, $p<0.001$), whereas fractional change in the non-planar angle was not significantly different (7.4+/-0.4% vs .5+/-0.39%, $p=0.25$). This decreased ability to contract during systole suggests MA dysfunction in patients with MR[30].

The usefulness of 3D TEE in the correct identification of prolapsing scallops has been demonstrated previously[31,32], with an accuracy of more than 95% compared to intraoperative inspection[17]. The superiority of 3D was reported mainly for the examination of P1, A2 and A3 scallops[33]. In our study, the accuracy of 2D vs 3D TEE in diagnosing the prolapsing scallop was 98%, higher than previously reported, probably due to high-quality multiple views utilised for MV examination. Among the scallops reclassified as prolapsing after the 3D TEE analysis, A3 was involved in 10 cases, P1 in four cases, and A2 in 2 cases. The new method tested in our study was the identification of prolapsing scallops based on a colour coded mathematical model.

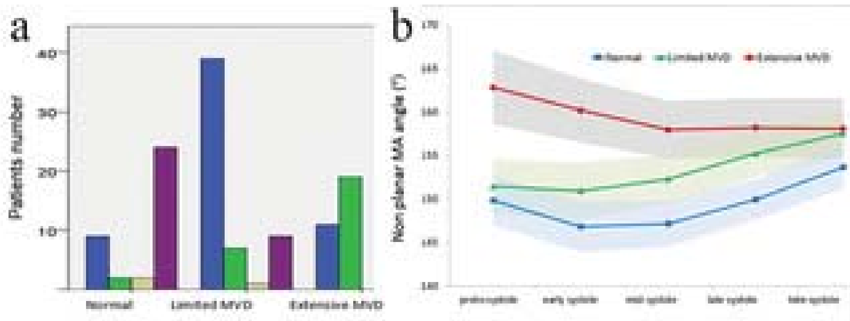

Figure 5. The graphic representation of MA non-planar dynamic evolution during systole (a): ascendant– blue, descendent – green, U turn yellow and U shape- purple; in the group of normal the U turn pattern is predominant while in the group of patients with limited mitral valve disease the predominant pattern is ascendant and in the group of patients with extensive mitral valve disease the predominant pattern is descending. Therefore, the MA non-planar angle dynamics describe an ascendant-descendent shape in normal group (blue), an ascendant shape in limited MVD group (green) and descendent shape in extensive MVD group (red).

Table 4. Parameters of mitral annulus dynamics

Parameter	Normal subjects	Limited MVD	Extensive MVD	p	p'
Annular displacement (mm)	8,01+/-2,66	8.83+/-2.88	6.42+/-2.76	0,000	<0.001
Annular velocity (mm/sec)	32,84+/-11,86	40.77+/-14.56	31.2+/-14.25	0,001	0.001
Antero-posterior diameter change (%)	15.03+/-1.6	13.9+/-6.5	9.8+/-0.05	0.004	0.007
Anterolateral-postero medial diameter change (%)	10.2+/-5.3	6.9+/-4.4	6.8+/-4.5	0.002	0.92
Fractional 3D MA area change (%)	21,59+/-12,36	16.06+/-8.41	11.89+/-7.3	0,000	0.033
Fractional non-planar MA angle change (%)	10,34+/-6,34	11.87+/-6.61	14.15+/-7.8	0,51	0.89

p value is obtained by ANOVA among the three groups and p' value is calculated using independent t-test between patients with limited and extensive mitral valve disease.

The differences between 3D TEE and the mathematical model are mainly due to the fact that the model considers the distance from every point of MV leaflets to the best fitting plane, and not to the MA plane. The use of this colour coded mathematical model may overcome the difficulties related to the proper diagnosis of prolapse[34,35] and may be very useful in clinical practice[36], especially for interpreters with limited experience[37]. The method needs further validation compared to intraoperative findings.

All the previous studies assessing MA dynamics in patients with organic MR had included all patients with mixomatous MVD in a single group. This study is the first one to report comparatively the changes in MA size, shape and function in two different groups of myxomatous MVD based on the extent of valve involvement: limited vs extensive MVD.

We conclude that patients with extensive MVD had larger and flatter, but less dynamic MA compared to patients with limited MVD. Another important finding is that MA dynamics is different: in patients with limited MVD the annulus becomes flatter at the end of systole, while in patients with extensive MVD the annulus is almost flat at the beginning of systole and tends to augment its saddle shape towards the end of systole.

We also analysed MA function (by MA area changes) and MA mobility (by MA displacement and velocity). We conclude that all patients with organic MR have decreased MA function. MA mobility is increased in patients with limited MVD and decreased in patients with extensive MVD despite significant MR, suggesting a 'stiff' annulus.

Clinical implications

Although a wide range of annuloplasty rings is available[38] the optimal mitral ring annuloplasty is still debatable. Data from *in vitro* studies have demonstrated the superiority of the annuloplasty ring which preserves the anatomical saddle shape compared to the flat rings[6,39]. However, trials have not confirmed the long-term superiority of flexible rings compared to the rigid ones[40,41]. Initially, the ideal ring was considered the one retaining the shape and dynamics of the normal MA[42], but currently the ring choice is mainly based on the cause of mitral regurgitation.

Thus, if the purpose is to prevent further MA dilatation – undersized stiff and flat rings are generally used[43]. If the goal is only remodelling, partially flexible rings or incomplete bands are preferred[44-46]. The importance of annuloplasty ring type became clearer in the context of newly developed repair techniques, in which leaflet resection is not performed and the valve is repaired using artificial chords and annuloplasty ring[47]. Therefore, knowing in detail the anatomy and function of the MA is of practical importance for the choice of the proper ring/technique to be used for annuloplasty.

The current study demonstrates that not all patients with MR due to myxomatous MVD have the same disease and that MA dynamics is different depending on the degree of valve involvement. Thus, a ring that preserves both the anatomical saddle shape and its flexibility will be able to restore the anatomy of the normal MA but will fail to mimic the dynamics of a normal ring, keeping the modified dynamic of a diseased annulus.

Therefore, the type of ring chosen should be adapted to the type of valvular lesion.

STUDY LIMITATIONS

The control group consisted of patients with no proven cardiac disease but with a clinical indication for TEE, which may have introduced a bias selection. However, the main results reported relate to the patients with MR, making this limitation less relevant. Patients were not followed clinically and intraoperative data (for those who underwent surgery) were not available. Thus, data about the mitral valve was obtained by echocardiography only, with no surgical or morphological confirmation.

CONCLUSION

The mitral annulus differs in patients with limited MVD, extensive MVD and in normal controls in terms of size, shape, and dynamics Patients with limited MVD have larger, flatter, dysfunctional and more mobile MA compared to normal, while patients with extensive MVD have even larger, flatter and more dysfunctional MA, with reduced mobility. The non-planar dynamics has different patterns during systole, according to the extension of MV disease.

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