Surgical treatment of functional mitral regurgitation

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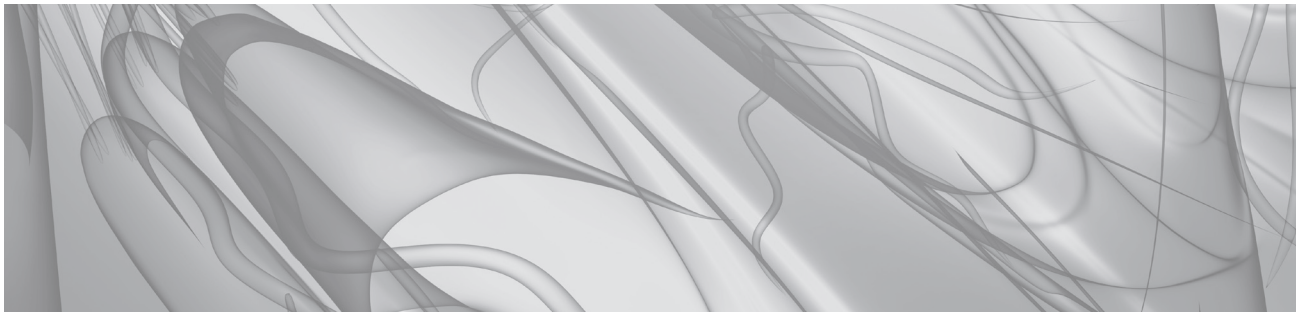

CHAPTER EIGHT

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Predictors of mitral regurgitation recurrence in patients with heart failure undergoing mitral valve annuloplasty

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Abstract

Restrictive mitral annuloplasty is a surgical treatment option for patients with heart failure (HF) and functional mitral regurgitation (MR). However, recurrent MR has been reported at mid-term follow-up. The aim of the present study was to identify the echocardiographic predictors of recurrent MR in patients with HF undergoing mitral annuloplasty. During a mean follow-up of 2.6±1.6 years, 109 patients with HF (49% ischemic and 51% idiopathic dilated cardiomyopathy) who had undergone mitral valve repair were followed (of 122 total patients). The severity of MR was quantified, and the following parameters were measured before intervention and at the mid-term follow-up examination: left ventricular (LV) and left atrial volumes and dimensions, LV sphericity index, mitral annular area, and mitral valve geometry parameters. At mid-term follow-up, 21 patients presented with significant MR (grade 2 to 4), and 88 patients had only MR grade 0 to 1. Both groups of patients had had a similar preoperative MR grade, mitral annular area, and LV volume and dimension. In contrast, patients with recurrent MR had had increased preoperative posterior and anterior leaflet angles, tenting height, tenting area, and LV sphericity index compared to the patients without recurrent MR. Of the different parameters of mitral and LV geometry, the distal mitral anterior leaflet angle (hazard ratio 1.48, 95% confidence interval 1.32 to 1.66, $P<0.001$) and posterior leaflet angle (hazard ratio 1.13, 95% confidence interval 1.07 to 1.19, $P<0.001$) were independent determinants of MR at mid-term follow-up. In conclusion, in patients with HF of ischemic or idiopathic etiology and functional MR, distal mitral leaflet tethering and posterior mitral leaflet tethering were associated with recurrent MR after restrictive mitral annuloplasty.

The mechanism of functional mitral regurgitation (MR) is complex, with mitral annular dilation and tethering of mitral leaflets contributing to the MR pathophysiology.[1] Some of these pathophysiologic issues, either related to left ventricular (LV) geometry or mitral valve geometry itself, could contribute to recurrent MR after mitral annuloplasty. Previous studies focusing on the mechanisms of recurrent MR have been conducted in separate series of patients with ischemic and idiopathic dilated cardiomyopathy.[2,3] The present study identified the preoperative echocardiographic predictors of mid-term recurrent MR after successful mitral valve annuloplasty in a cohort of patients with heart failure with idiopathic dilated or ischemic cardiomyopathy.

Methods

Patients

A total of 122 patients with heart failure and moderate to severe MR were included. The patients were scheduled for restrictive mitral annuloplasty, accompanied by coronary artery bypass grafting if indicated. In patients with heart failure with idiopathic cardiomyopathy, restrictive mitral annuloplasty was performed with concomitant placement of a CorCap (Acorn Cardiovascular, St. Paul, Minnesota) cardiac support device if significant LV dilatation (LV end-diastolic diameter >65 mm) was measured on the preoperative echocardiographic examination. All patients underwent surgery using a midline sternotomy with normothermic cardiopulmonary bypass and intermittent antegrade warm blood cardioplegia. The mitral valve was exposed through a transseptal approach. The ring size (Carpentier-Edwards Physioring, Edwards Lifesciences, Irving, California) was determined after careful measurement of the height of the anterior leaflet. Then, downsizing by 2 sizes was performed (i.e., when a ring size 30 was measured, the size of the annuloplasty ring was 26). The rings were inserted using 14 to 16 deep U-shaped simple horizontal sutures using Ethibond 2-0 (Ethicon, Inc, Somerville, New Jersey) or Ti-Cron 2-0 (Syneture, Norwalk, Connecticut). Tricuspid annuloplasty was performed with a Carpentier Edwards Classic or MC3 ring (Edwards Lifeseciences) in patients with tricuspid regurgitation exceeding grade 2 or in the presence of a dilated tricuspid annulus >40 mm (or 21 mm/m^2 indexed to body surface area) on the echocardiogram. In all patients, the results of mitral annuloplasty were assessed by intraoperative transoesophageal echocardiography. No residual MR and a mitral leaflet coaptation length of ≥8 mm at the A2-P2 level were the criteria for successful mitral valve repair. If these criteria were not fulfilled, additional downsizing was performed.

In patients undergoing surgical revascularization, coronary artery bypass grafting was performed before mitral valve annuloplasty. If a cardiac support device was used it was applied on the beating heart, and fixed by sutures to the dorsal base of the heart, along

the atrioventricular groove. After completion of the mitral valve repair, the extracorporeal circulation was weaned out and the final fitting of the CorCap was ensured on a full and beating heart with appropriate filling. The aim was to obtain a snug fit, without reduction of LV diameter of >10% (as measured by transesophagal echocardiography), compared to preoperative dimensions, as described earlier.[4]

Before surgical intervention, transthoracic echocardiography (System Five or Vivid 7, GE Norway, Horten, Norway) was performed and repeated at hospital discharge and mid-term follow-up (2.6±1.6 years). Transthoracic echocardiography at discharge was used to confirm the absence of MR, and the preoperative and mid-term follow-up echocardiographic examinations were used to perform measurements of LV and left atrial (LA) volumes and dimensions, geometric analysis of the left ventricle and mitral valve, and quantification of MR.

The severity of MR was quantitatively determined by proximal isovelocity surface area and by vena contracta method according to the current guidelines.[5] The effective regurgitant orifice and regurgitant volume were calculated according to the formula.[5] The vena contracta was defined as the narrowest part of the regurgitant jet recorded in the parasternal long-axis view. The LV and LA volumes and LV geometry were measured according to the recommendations of the American Society of Echocardiography and European Association of Echocardiography for chamber quantification.[6] In the parasternal long-axis view, LV end-diastolic diameter, LV end-systolic diameter, and LA diameter were measured. LV end-diastolic volume, LV end-systolic volume, and LV ejection fraction were estimated using Simpson's disk method from the apical 4- and 2-chamber apical views. The LA volume was assessed using the area-length method.[6] The systolic and diastolic LV sphericity indexes were calculated as the ratio between the LV short-axis diameter and the LV long-axis diameter at end-systole and end-diastole, respectively.[7]

To evaluate the apical displacement of mitral leaflets, the leaflet tethering lengths were measured in the apical 4- and 2-chamber views in mid-systole (Figure 1).[7] The end-diastolic and end-systolic frames were determined from the mitral leaflet closure and opening, respectively, and the middle frame was used for measurements in mid systole. In the apical 4-chamber view, the distance between the posterior papillary muscle and median portion of the mitral annulus was measured (posterior papillary muscle tethering length in the apical 4-chamber view; Figure 1). In the apical 2-chamber view, the distance between the anterior and posterior papillary muscles and the contralateral part of the mitral annulus were measured (anterior papillary muscle tethering length and posterior papillary muscle tethering length in the 2-chamber view, respectively; Figure 1).[7]

In the long-axis view, the coaptation-to-septum distance was measured in mid-systole, as the distance between the septum at the hinge point of the aortic valve cups and coaptation point of the mitral valve leaflets (Figure 1).[8] Evaluation of the geometry of the mitral valve was performed in mid-systole, as previously described.[3,9] In the parasternal long-axis view, tenting area, tenting height and coaptation length were measured. The tenting area was measured as the area enclosed between the annular line

and the mitral leaflets, and the tenting height was defined as the distance between the coaptation point and the annular line (Figure 1). The coaptation length was measured as the length of apposition of the anterior and posterior mitral leaflets.

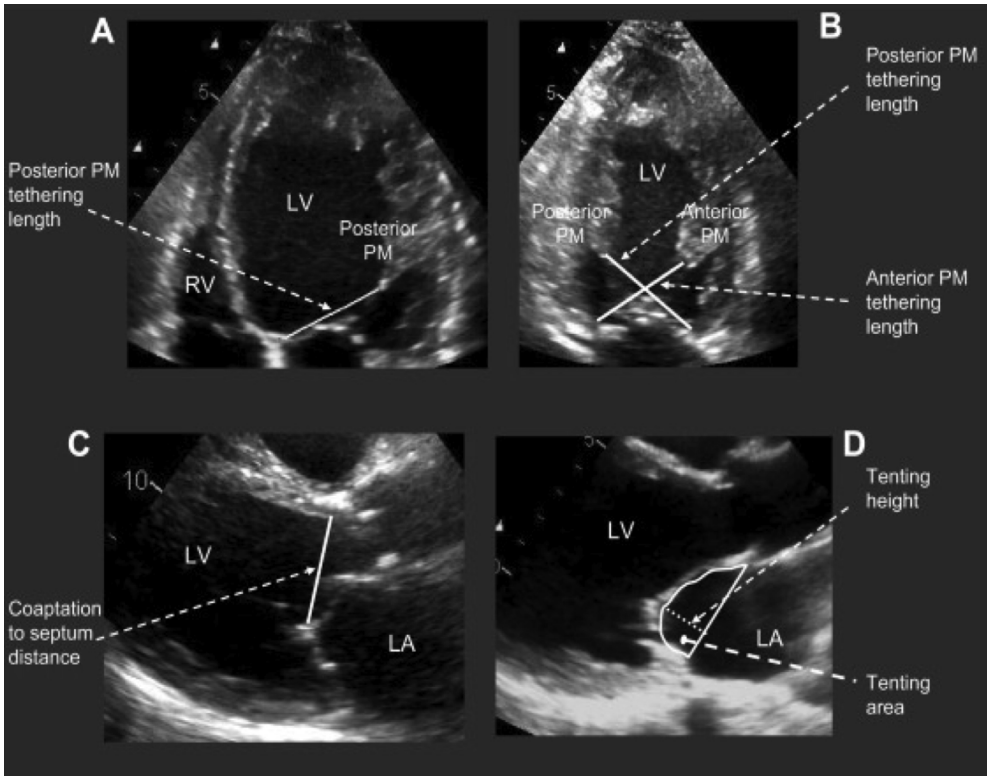

Figure 1. *Measurements of PM tethering lengths, mitral tenting area, and mitral tenting height. (A) White line represents posterior PM tethering length measured in apical 4-chamber view. (B) Measurements of papillary muscle tethering lengths, as measured in 2-chamber view. White lines represent anterior and posterior PM tethering lengths measured from head of anterior and posterior PM to contralateral part of mitral annulus, respectively. (C) White line represents measurement of coaptation-to-septum distance, defined as distance between septum at hinge point of aortic valve cups and coaptation point of mitral valve leaflets. (D) Measurements of mitral tenting area and tenting height in long-axis view. Tenting area depicted by continuous white line, and tenting height corresponds to dotted line drawn between coaptation point and mitral annulus in long-axis view..*

The tethering of mitral leaflets was estimated by calculation of the basal mitral anterior leaflet angle (ALA_{base}), the distal mitral anterior leaflet angle (ALA_{tip}), and the posterior mitral leaflet angle (PLA). The ALA_{base} was defined as the angle between the annular plane and the basal portion of the anterior leaflet, and the PLA was defined as the angle between the annular plane and the posterior leaflet (Figure 2). The ALA_{tip} was defined as the angle between the annular plane and the anterior leaflet tip distance (which

corresponded to the distance between the median part of the mitral annulus and the coaptation point; Figure 2). The angles were calculated according to previously reported formulas.[3,9] The mitral annular area was obtained from its dimensions in the 4- and 2-chamber views, using an ellipsoid assumption.[10]

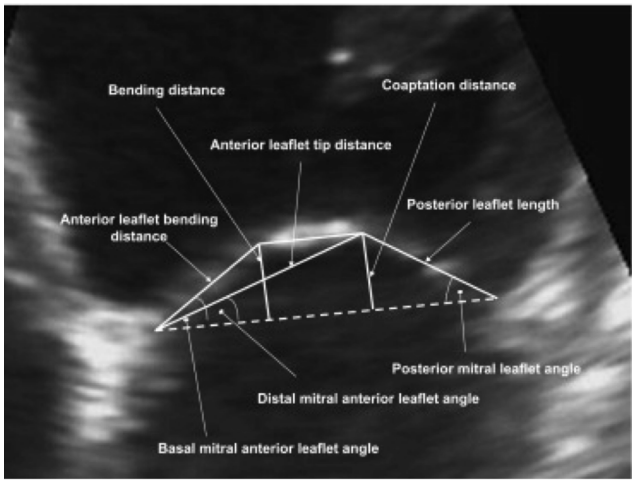

Figure 2. *Method of quantification of ALA_{base}, ALA_{tip}, and PLA. Measurements depicted on echocardiographic image of mitral valve in apical 4-chamber view in mid-systole.*
Formulas used for calculations of angles were as follows:

- *ALA_{base} = $sinus^{-1}$ (bending distance/anterior leaflet bending distance);*
- *ALA_{tip} = $sinus^{-1}$ (coaptation distance/anterior tip leaflet distance);*
- *PLA = $sinus^{-1}$ (coaptation distance/posterior leaflet length).*

Operative risk was calculated according to EuroSCORE.[11] Continuous data are presented as the mean ± SD and dichotomous as the number of patients (percentage), as appropriate. Patients were divided into 2 groups according to the presence of MR at mid-term follow-up: patients without recurrent MR if no or mild MR was observed—effective regurgitant orifice area <0.20 cm^2, regurgitant volume <30 mL/beat, and vena contracta <0.3 cm—and patients with recurrent MR if moderate or severe MR was observed—effective regurgitant orifice area ≥0.20 cm^2, regurgitant volume ≥30 mL/beat, and vena contracta ≥0.3 cm. The preoperative and mid-term follow-up echocardiographic measurements of the patients without recurrent MR were compared to those of the patients with recurrent MR. The differences in clinical and echocardiographic baseline (preoperative) characteristics between the patients with and without recurrent MR were evaluated using Student's t-test or the chi-square test, as appropriate. Changes (from baseline to follow-up) in echocardiographic data were analyzed by repeated measurements analysis of variance, and the interaction between the evaluation point (preoperatively vs. during follow-up) and group (patients with recurrent MR vs. patients without recurrent MR) was tested.
Univariate and multivariate Cox proportional hazard regression analysis were applied to further study the relation between baseline characteristics and recurrent MR. On multivariate analysis, the stepwise backward method was used to indentify predictors of MR, with significant univariate predictors entered as covariates. The variables were checked for colinearity, and, if the correlation coefficient between 2 variables was

>0.7, only one variable was retained in the model. A *P* value <0.05 was regarded as statistically significant. Statistical analysis was performed using the Statistical Package for Social Sciences for Windows, version 16.0 (SPSS, Chicago, Illinois).

Results

The demographic, clinical and surgical characteristics of the patients are listed in Table 1. The mean age was 62±11 years, and 61% of patients were men. Most patients (85%) had New York Heart Association functional class III or IV. Patients were receiving optimal medical treatment for Heart failure. No clinically relevant difference was found in the demographic or clinical characteristics between the patients with recurrent MR and those without recurrent MR at mid-term follow-up

In 37% of patients, the CorCap cardiac support device was implanted concomitantly with restrictive mitral annuloplasty (Table 1). The average mitral ring size used for annuloplasty was 26; in 53% of patients, tricuspid annuloplasty was also performed. Twelve patients had chronic atrial fibrillation and underwent a perioperative ablation procedure. No clinically relevant differences were found in the surgical characteristics between the patients with and without recurrent MR.

Preoperative echocardiographic quantitative analysis of MR revealed moderate to severe MR with a mean effective regurgitant orifice area of 0.33 cm^2, regurgitant volume of 47 mL, and vena contracta of 5.5 mm (Table 2)

Of 122 patients, 10 died during the peroperative period, 112 were discharged from the hospital (with MR grade 0 to 1) and 3 patients died before the mid-term echocardiographic follow-up examination. In the final analysis, 109 patients with heart failure were included (56 patients with dilated cardiomyopathy and 53 with ischemic cardiomyopathy). All 109 patients underwent echocardiographic and clinical follow-up. At mid-term follow-up, 88 patients (81%) continued to have MR grade 0 or 1, and MR grade 2 or greater was observed in 21 patients (19%). Of the patients with recurrent MR, grade 2, 3, and 4 MR was present in 14 (13%), 6 (5%) and 1 (1%), respectively.

The LV end-diastolic and end-systolic volume decreased from 217±72 mL to 167±61 mL and from 162±65 mL to 119±55 mL, respectively (*P*<0.001). LV end-diastolic diameter decreased from 66±8 mm to 60±10 mm (*P*<0.001), and LV end-systolic diameter decreased from 59±9 mm to 52±12 mm (*P*<0.001). A slight increase in LV ejection fraction was observed (from 27±9% to 31±12%, *P*<0.001).

The preoperative MR severity was similar in patients with and without recurrent MR (Table 2). In addition, no difference was noted in the preoperative LV and LA diameters or volumes (Table 3). Concerning mitral valve geometry, patients with recurrent MR had greater preoperative ALA_{base}, ALA_{tip}, and PLA than patients without recurrent MR (*P*<0.05; Table 4). In addition, patients with recurrent MR were found to have a significantly increased tenting area and tenting height before surgery, and the coaptation length was lower than that in patients without recurrent MR (*P*<0.05; Table 4).

TABLE 1

Preoperative Clinical and Surgical Characteristics

Variable	All (n=109)	MR at follow-up	
		No (n=88)	Yes (n=21)
Age (years)	62±11	62±11	62±12
Men	66 (61%)	54 (61%)	12 (57%)
Body surface area (m^2)	1.9±0.2	1.9±0.2	1.8±0.3
Systolic blood pressure (mmHg)	118±24	118±25	115±19
Diastolic blood pressure (mmHg)	72±11	72±12	70±10
NYHA functional class			
I	2 (2%)	1 (1%)	1 (5%)
II	14 (13%)	11 (12%)	3 (14%)
III	77 (70%)	63 (72%)	14 (67%)
IV	16 (15%)	13 (15%)	3 (14%)
Serum creatinine (µmol/L)	110±41	108±36	116±60
Glomerular filtration rate (mL/min)	61±22	62±22	58±23
Ischemic cardiomyopathy	53 (49%)	47 (53%)	9 (43%)
Hypertension	20 (18%)	17 (20%)	3 (14%)
Diabetes mellitus	28 (26%)	26 (30%)	2 (10%)
Chronic obstructive pulmonary disease	24 (22%)	20 (23%)	4 (19%)
Stroke	6 (6%)	6 (7%)	0%
Peripheral vascular disease	8 (7%)	5 (6%)	3 (14%)
Logistic EuroSCORE	13±11	14±12	10±7
Medications			
β Blockers	81 (74%)	66 (75%)	15 (71%)
Calcium antagonists	6 (6%)	6 (7%)	0%
ACE inhibitor or angiotensin receptor blocker	89 (82%)	73 (83%)	16 (76%)
Diuretics	92 (84%)	74 (84%)	18 (86%)
Spironolactone	41 (38%)	33 (38%)	8 (38%)
Surgical characteristics			
Mitral valve ring size	26±2	26±2	26±2
CorCap cardiac support device	40 (37%)	36 (41%)	4 (19%)
Tricuspid valve annuloplasty	58 (53%)	50 (57%)	8 (38%)
Cardiopulmonary bypass time (min)	155±45	151±42	166±54
Aortic cross clamp time (min)	93±39	93±38	95±41

NYHA, New York Heart Association; *ACE*, Angiotensin-converting enzyme

TABLE 2

Preoperative Mitral Regurgitation Severity

Variable	All (n=109)	MR at follow-up	
		No (n=88)	Yes (n=21)
Mitral regurgitation grade			
2	17 (15%)	14 (16%)	3 (14%)
3	67 (62%)	57 (65%)	10 (48%)
4	25 (23%)	17 (19%)	8 (38%)
Mean mitral regurgitation grade	3.1±0.6	3.0 ± 0.6	3.2±0.7
Effective regurgitant orifice (cm^2)	0.33±0.09	0.32±0.09	0.35±0.09
Regurgitant volume (mL)	47±13	46±13	50±12
Vena contracta (mm)	5.5±1.5	5.4±1.2	6.0±2.0

Furthermore, the systolic and diastolic LV sphericity indexes were greater in patients with recurrent MR than in those without recurrent MR (P<0.05; Table 4). The posterior and anterior papillary muscle tethering length and the coaptation-to-septum distance were similar in patients with and without recurrent MR. Finally, the mitral annulus area was similar in both groups of patients.

The LA volume and LV diameters and volumes decreased during follow-up in patients without recurrent MR (Table 3). In contrast, the LA and LV dimensions remained unchanged in patients with recurrent MR (P<0.05; Table 3). The LV ejection fraction decreased in patients with recurrent MR and increased in patients without recurrent MR (P<0.01; Table 3). The ALA_{base} and ALA_{tip} had decreased at mid-term follow-up in patients without recurrent MR but remained unchanged in patients with recurrent MR (Table 4). The PLA had increased in both groups, but this increase was more pronounced in patients with recurrent MR at follow-up. The tenting area decreased in a similar manner in both groups, but the tenting height decreased only in patients without recurrent MR. The coaptation length at mid-term follow-up had increased more in the patients without recurrent MR than in those with recurrent MR. The mitral annulus area had decreased more in patients without recurrent MR than in those with recurrent MR during follow-up.

The diastolic sphericity index decreased in both groups after restrictive mitral annuloplasty to a similar extent, but the systolic sphericity index decreased only in patients without recurrent MR. The posterior papillary muscle tethering length decreased in a similar manner in both groups. The anterior papillary muscle tethering length and coaptation-to-septum distance decreased to a larger extent in patients without recurrent MR than in the patients with recurrent MR.

Univariate Cox regression analysis revealed that ALA_{base}, ALA_{tip}, PLA, tenting height, tenting area, coaptation length, and sphericity index in diastole and systole were predictors of recurrent MR (Table 5). On multivariate analysis, ALA_{tip}, PLA, tenting

height, systolic sphericity index, and etiology of cardiomyopathy (ischemic or non-ischemic) were tested. On multivariate analysis, only the ALA_{tip} and PLA remained associated with recurrent MR at mid-term follow-up (Table 6). The ALA_{tip} and PLA remained associated with recurrent MR when cardiac support device use was included in the final model.

Discussion

The results of the present study have identified baseline echocardiographic predictors of mid-term recurrent MR after restrictive mitral annuloplasty for functional MR. In a cohort of patients with heart failure of ischemic or nonischemic origin, distal mitral anterior leaflet tethering, as estimated by the ALA_{tip}, and posterior leaflet tethering, as estimated by PLA, were independent predictors of recurrent MR after mitral annuloplasty.

The spherical shape of the left ventricle plays an important role in the pathophysiology of functional MR, because it provokes the displacement of the papillary muscles, which exert traction on the mitral leaflets and increase their tethering.[12] In previous studies, posterior mitral leaflet tethering was evaluated by PLA,[2,9] and anterior mitral leaflet tethering was estimated by measurement of 2 different angles: ALA_{tip} and ALA_{base}.[2,3,9] This dual evaluation of the anterior mitral leaflet tethering is because the chordae insertion at the anterior leaflet can be divided into the marginal chordae, which are inserted at the leaflet tip, and the basal chordae, which are inserted at the leaflet base.[13] The measurement of the ALA_{tip} permits one to not overlook the tethering of the distal mitral anterior leaflet, which can play a role in recurrent MR.[3] We found increased preoperative PLA, ALA_{base}, and ALA_{tip} in patients who developed MR at mid-term follow-up. On multivariate analysis, ALA_{tip} and PLA predicted recurrent MR at mid-term follow-up. To explain this finding, one should realize that mitral annuloplasty immobilizes the posterior mitral leaflet, but the anterior mitral leaflet must be sufficiently mobile to ensure adequate closure of the mitral valve.[14] Therefore, excessive distal anterior mitral leaflet tethering preoperatively will be prone to suboptimal leaflet closure postoperatively. Thus, unless the LV reverse remodeling attenuates the augmented anterior leaflet tethering, the risk of recurrent MR will increase with increasing distal anterior mitral leaflet tethering, as was confirmed by our study.

The role of heart failure etiology has been evaluated in previous studies, analyzing patients with ischemic and nonischemic cardiomyopathy who developed recurrent MR after annuloplasty separately.[2,3,9,15,16] Only one study analyzed the presence of recurrent MR in a group of patients, of whom ⅓ had nonischemic and ⅔ had ischemic cardiomyopathy.[17] According to the underlying etiology, different parameters of mitral valve geometry have been proposed to predict MR recurrence after restrictive annuloplasty.[2,3,9,15,16] In contrast, our study analyzed the predictors of recurrent MR after mitral annuloplasty in a mixed population of patients with ischemic and nonischemic

dilated cardiomyopathy. In our cohort of patients, distal mitral leaflet tethering and posterior mitral leaflet tethering were associated with recurrent MR after restrictive mitral annuloplasty, independently of the origin of the underlying cardiomyopathy. These findings are of clinical relevance because these parameters can be applied to patients with ischemic and nonischemic cardiomyopathy.

The present study also demonstrated the effects of restrictive mitral annuloplasty on the LV volume and function and the changes in mitral valve geometry. Patients who presented with recurrent MR at mid-term follow-up had no decrease in LV volume or diameter, but those without recurrent MR had a substantial decrease in LV volume and diameter. This observation was similar to what has been shown in other trials that demonstrated LV reverse remodeling in patients who successfully underwent mitral annuloplasty.[18–20] Accordingly, the LV ejection fraction increased slightly in patients without recurrent MR and decreased in patients with recurrent MR. In addition, the evolution of leaflet tethering before and after the intervention was similar to what has previously been described. The increase of PLA was noted in both groups, and ALA_{base} and ALA_{tip} decreased only in patients without recurrent MR and remained unchanged in patients with recurrent MR.[2,3] Patients without recurrent MR had a decrease in the tenting distance and tenting height, and those with recurrent MR presented with only a slight decrease in the tenting area and no decrease in tenting height. Finally, the LV sphericity index, posterior and anterior papillary muscle length, and coaptation-to-septum distance decreased in both groups. However, the magnitude of these changes was more pronounced in patients without recurrent MR and was related to LV reverse remodeling.

Some limitations of our study should be acknowledged. The present study was retrospective and included some patients who had undergone concomitant implantation of a cardiac support device. However, the cardiac support device was associated only with a trend toward a decrease in recurrent MR at mid-term follow-up. Also, after inclusion of the cardiac support device in the multivariate model, ALA_{tip} and PLA were still independent predictors of recurrent MR at mid-term follow-up.

In conclusion, in patients with heart failure of ischemic or idiopathic etiology and functional MR, distal mitral leaflet tethering and posterior mitral leaflet tethering were associated with recurrent MR after restrictive mitral annuloplasty.

TABLE 3

Evolution of Standard Echocardiographic Variables Measured Preoperatively and at Mid-term Follow-up

Variable	MR at follow-up				*P* Value (Time vs. Group comparison)
	No (n=88)		Yes (n=21)		
	Preoperative	Follow-up	Preoperative	Follow-up	
Left atrial diameter (mm)	45±7	44±7*	44±6	45±7	NS
Left atrial volume (mL)	93±43	78±38*	83±27	87±43	0.02
Left ventricular ejection fraction (%)	27±9	32±12*	28±9	26±8	<0.01
Left ventricular end-diastolic diameter (mm)	66±8	58±10*	67±10	66±9	<0.001
Left ventricular end-systolic diameter (mm)	59±8	51±12*	60±11	57±11	<0.01
Left ventricular end-diastolic volume (mL)	216±65	159±58*	218±92	201±66	<0.001
Left ventricular end-systolic volume (mL)	161±62	111±51*	164±82	151±59	<0.001

Analysis of variance time versus group comparison, $P<0.05$, signified that evolution of measured variable was different for patients with versus without recurrent MR in time (preoperatively vs. mid-term follow-up).

* Corresponded to $P<0.05$ versus preoperative measurement in patients without recurrent MR; no difference noted in preoperative variables between patients with and without recurrent MR (*P* values not shown)

TABLE 4

Evolution of Echocardiographic Geometric Measurements of Left Ventricle and Mitral Valve in Patients Without and With Recurrent Mitral Regurgitation at Mid-term Follow-up

Variable	MR at Follow-up				*P* Value (Time vs. Group comparison)
	No (n=88)		Yes (n=21)		
	Preoperative	Follow-up	Preoperative	Follow-up	
Mitral valve geometry					
Basal mitral anterior leaflet angle (°)	31±6	24±6*	38±5*	38±5	<0.001
Distal mitral anterior leaflet angle (°)	12±3	11±3*	19±3*	19±4	<0.05
Posterior mitral leaflet angle (°)	40±10	60±11*	54±9*	66±9†	0.01
Tenting area (cm^2)	2.1±0.3	1.4±0.4*	2.9±0.7*	2.1±0.5†	NS
Tenting height (mm)	10.2±1.2	9.1±1.4*	12.6±2.4*	12.0±1.9	NS
Coaptation length (mm)	5.5±1.2	8.7±1.2*	4.9±1.1*	6.7±1.5†	0.001
Mitral annulus (cm^2)	10.1±2.8	5.3±1.5*	10.8±2.9	7.0±2.5†	<0.001
Left ventricular geometry					
Sphericity index diastole	68±9	60±8*	75±8*	71±7†	NS
Sphericity index systole	65±9	57±9*	72±9*	69±8	NS
Posterior papillary muscle length 4-ch (mm)	41±5	36±5*	43±5	40±4†	NS
Posterior papillary muscle length 2-ch (mm)	40±6	33±5*	42±5	37±6†	NS
Anterior papillary muscle length 2-ch (mm)	40±5	34±5*	42±5	38±5†	<0.05
Coaptation-to-septum distance (mm)	40±5	35±5*	42±6	40±5†	<0.001

4-ch, 4-chamber view; *2-ch*, 2-chamber view

* P < 0.05 versus preoperative measurement in patients without MR at follow-up

† P < 0.05 versus preoperative measurement in patients with MR at follow-up.

TABLE 5

Univariate Cox Proportional Hazard Analysis of Predictors of Mitral Regurgitation Recurrence at Mid-term Follow-up

Variable	Hazard Ratio	95% Confidence Interval	*P* Value
Left atrial diameter (mm)	0.98	0.92–1.04	NS
Left atrial volume (mL)	1.00	0.99–1.01	NS
Left ventricular ejection fraction (%)	1.00	1.00–1.05	NS
Left ventricular end-diastolic diameter (mm)	1.03	0.97–1.09	NS
Left ventricular end-systolic diameter (mm)	1.03	0.97–1.09	NS
Left ventricular end-diastolic volume (mL)	1.00	0.99–1.01	NS
Left ventricular end-systolic (mL)	1.00	1.00–1.01	NS
Basal mitral anterior leaflet angle (°)	1.15	1.08–1.23	<0.001
Distal mitral anterior leaflet angle (°)	1.48	1.32–1.66	<0.001
Posterior leaflet angle (°)	1.12	1.07–1.17	<0.001
Tenting area (cm^2)	5.06	2.82–9.07	<0.001
Tenting height (mm)	1.57	1.32–1.86	<0.001
Coaptation length (mm)	6.84	0.47–0.99	<0.05
Mitral annulus (cm^2)	1.07	0.92–1.23	NS
Sphericity index diastole	1.09	1.03–1.14	0.002
Sphericity index systole	1.08	1.03–1.13	0.003
Posterior papillary muscle length, 4-chamber view (mm)	1.07	0.99–1.16	NS
Posterior papillary muscle length, 2-chamber view (mm)	1.08	1.00–1.16	NS
Anterior papillary muscle length, 2-chamber view (mm)	1.05	0.97–1.14	NS
Coaptation-to-septum distance (mm)	1.04	0.97–1.12	NS

TABLE 6

Multivariate Cox proportional hazard ratio analysis of predictors of mitral regurgitation (MR) recurrence at mid-term follow-up after mitral annuloplasty

Variable	Hazard Ratio	95% Confidence Interval	*P* Value
Distal mitral anterior leaflet angle (°)	1.48	1.32–1.66	<0.001
Posterior mitral leaflet angle (°)	1.13	1.07–1.19	<0.001

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