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Pulmonary arterial pressure detects functional mitral stenosis after annuloplasty for primary mitral regurgitation: An exercise stress echocardiographic study

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Introduction: The restrictive mitral valve annuloplasty (RMA) is the treatment of choice for degenerative mitral regurgitation (MR), but postoperative functional mitral stenosis remains a matter of debate. In this study, we sought to determine the impact of mitral stenosis on the functional capacity of patients.

Methods: In a cross-sectional study, 32 patients with degenerative MR who underwent RMA using a complete ring were evaluated. All participants performed treadmill exercise test and underwent echocardiographic examinations before and after exercise.

Results: The patients' mean age was 50.1 ± 12.5 years. After a mean follow-up of 14.1 ± 5.9 months (6–32 months), the number of patients with a mitral valve peak gradient >7.5 mm Hg, a mitral valve mean gradient >3 mm Hg, and a pulmonary arterial pressure (PAP) ≥25 mm Hg at rest were 50%, 40.6%, and 62.5%, respectively. 13 patients (40.6%) had incomplete treadmill exercise test. All hemodynamic parameters were higher at peak exercise compared with at rest levels (all $P < .05$). The PAP at rest and at peak exercise as well as peak transmitral gradient at peak exercise were higher in patients with incomplete exercise compared with complete exercise test (all $P < .05$). The PAP at rest (a sensitivity and a specificity of 84.6% and 52.6%, respectively; area under the curve [AUC] = .755) and at peak exercise (a sensitivity and a specificity of 100% and 47.4%, respectively; AUC = .755) discriminated incomplete exercise test.

Conclusion: The RMA for degenerative MR was associated with a functional stenosis and the PAP at rest and at peak exercise discriminated low exercise capacity.

KEYWORDS
exercise echocardiography, functional mitral stenosis, mitral regurgitation, mitral valve annuloplasty, pulmonary arterial pressure

1 | INTRODUCTION

Mitral regurgitation (MR) is a common heart valve disease, which is mainly attributable to the degenerative/myxomatous mitral valve diseases.[1] The restrictive mitral valve annuloplasty (RMA) is the treatment of choice for severe degenerative MR, and it is superior to the mitral valve replacement (MVR).[2] The gold standard of treatment for secondary MR includes RMA or MVR; however, it is a topic of much debate.[3] Based on the latest ACC/AHA guideline,[4] the RMA is the class I recommendation for primary severe MR, while it has been regarded as class IIb for severe secondary MR. The major complication after RMA includes recurrent MR and mitral stenosis. The mechanism and incidence of early or late functional mitral stenosis after the implementation of RMA for patients with MR are poorly elucidated. The development of pannus overgrowth or using undersized ring for the RMA has been reported to be the main etiologies for the development of mitral stenosis after RMA.[5] In previous studies, the functional mitral stenosis has been defined as a mean transmitral pressure gradient of >5 mm Hg or a mitral valve area (MVA) of <1.5 cm^2 in patients with a functional MR secondary to either ischemic or idiopathic cardiomyopathy.[6–14] In addition, a higher mitral valve gradient at rest and at peak exercise as an indicative of functional mitral stenosis has been found to be influenced by the type of annuloplasty in patients with degenerative MR.[15,16]

In this study, we sought to determine the prevalence of functional mitral stenosis in patients undergoing RMA with complete ring for myxomatous MR. In addition, we decided to evaluate the patients' functional capacity and hemodynamic outcomes using the implementation of treadmill exercise test associated with an echocardiographic evaluation of mitral valve hemodynamics during exercise test. We also attempted to determine factors predicting reduced exercise capacity.

2 | MATERIALS AND METHODS

2.1 | Study protocol and population

In a cross-sectional study, patients who had undergone the RMA from January 2012 to December 2015 were recruited into the study. Demographic data as well as surgical and perioperative echocardiographic parameters were retrospectively extracted from the patients' medical records. All patients were older than 18 years, had myxomatous mitral valve prolapse (MVP), and underwent the RMA using a complete ring insertion. Exclusion criteria included severe MR caused by etiologies rather than myxomatous MVP, residual MR immediately after RMA greater than mild in severity, ischemic MR, atrial fibrillation, refuse to participate, and the inability to perform exercise test. Thereafter, all patients were examined using a transthoracic echocardiography (TTE) and an exercise test using Bruce protocol at the same day. This study was approved by the ethics committee of our institution, Rajaie Cardiovascular Medical and Research Center, Tehran, Iran. In addition, consent form was obtained from all participants before evaluation by an exercise test and a TTE test. All echocardiographic parameters were measured at rest and at peak exercise test to evaluate the functional capacity of patients and its effect on valve hemodynamics.

2.2 | RMA operative techniques

During the surgical repair of MVP, all patients underwent mid-sternotomy on-pump cardiac surgery. All procedures were performed by a single surgeon and his assistants. Annuloplasty sizing was similar and determined based on the size of the anterior leaflets; neither oversizing nor undersizing of annuloplasty ring was implemented in this cohort. The repair of anterior leaflet involvement was performed by a PTFE neochordal insertion; the repair of posterior leaflet included either triangular resection or quadrangular resection with or without sliding plasty, and bileaflet involvement was repaired using a combination of the above-mentioned procedures. In addition, the commisurotomy was also used in some cases when required. A target mean mitral gradient <5 mm Hg or a mitral valve area of ≥2.5 cm^2 after repair was considered acceptable along with a minimal MR and a coaptation length of >5 mm.

2.3 | Treadmill exercise test

An ergometry treadmill exercise test using the Bruce protocol was performed, during which all patients exercised to exhaustion. They were asked to stop the use of calcium channel blocker or β-blockers at least 12–24 hours before the exercise test. An exercise capacity in metabolic equivalents of task (METs) was estimated according to the speed and grade achieved (1 MET equivalent to 3.5 mL/kg/min of oxygen consumption). Treadmill exercise test was performed according to the AHA Guideline.[17] The incomplete exercise test or low workload was defined as <7 METs for men and <5 METs for women.

2.4 | Echocardiographic assessment

The TTE examination was performed by a single echocardiographer using a Vivid 3 ultrasound system (GE Medical System, Horton, Norway) and a 1.7/3.4 MHz transducer. A two-dimensional (2D) electrocardiogram was superimposed on the images. All patients underwent echocardiography at 2 steps, at rest and at peak exercise test. Postexercise echocardiographic images were acquired within 1 minute after peak exercise test. All echocardiographic measurements were performed using the protocols and the standards of the latest guidelines for native valve disease.[18]

The left ventricle ejection fraction was evaluated using a modified biplane Simpson method. The TMG were calculated based on the modified Bernoulli equation. The MVA was measured using 2D planimetry in the parasternal short-axis view at valve tips. The pressure half-time (PHT) was calculated as the interval between the maximum mitral gradient in early diastole and the time point where the gradient is half the maximum initial value (ms). The effective orifice area (EOA) was calculated by the continuity equation as the stroke volume measured in the left ventricle outflow tract divided by the integral of the transmitral velocity during diastole. Indexed EOA was also calculated as EOA divided by body surface area. The anterior and posterior leaflet opening angles (ALOAs and PLOAs) were measured in four-chamber view according to the following formulas:

$$\mathrm{ALOA} = \sin^{-1}\left(\frac{\mathrm{BD}}{\mathrm{ALBD}}\right) \quad (1)$$

$$\mathrm{PLOA} = \sin^{-1}\left(\frac{\mathrm{CD}}{\mathrm{PLL}}\right) \quad (2)$$

in which the BD is the bending distance, the ABLD is the anterior leaflet bending distance, the CD is the coaptation length, and the PLL is the posterior leaflet length.

The right ventricle function was evaluated using visual assessment by 2 expert echocardiographists concomitant with the following criteria:

1. S > 10 m/s defined as normal right ventricle function
2. S = 9–10 m/s defined as mild right ventricle dysfunction
3. S = 9–7 m/s defined as moderate right ventricle dysfunction
4. S < 7 m/s defined as severe right ventricle dysfunction,

in which "S" was systolic velocity in the right ventricle measured by tissue Doppler imaging.

2.5 | Statistical analysis

Categorical variables are presented as numbers (percentages). Normally distributed quantitative variables were presented as mean ± standard deviation, and those nonnormally distributed are presented as median (interquartile range). The continuous variables at pre- and postexercise tests were analyzed using a paired *t* test. The changes in categorical variables at time intervals were analyzed using Friedman test. Correlation between variables was evaluated using Pearson correlation coefficient. Receiver operating characteristics curve was constructed. Logistic regression analysis was used to identify the predictors of incomplete exercise test. Two-sided *P*-values were calculated. All analyses were performed using SPSS statistical software, version 21.0 (IBM Corp, Armonk, NY, USA).

3 | RESULTS

3.1 | Patients' characteristics

Of 38 patients who met our inclusion criteria, only 32 cases were entered in final analysis. Six cases were excluded as follows: (1) a 31-year-old female patient (2.6%) who had atrial fibrillation with a rapid ventricular response, (2) a 33-year-old male patient (2.6%) who completed the exercise test, but he was found to have a partial rupture of surgical annuloplasty ring, which created 2 transmitral flows during the TTE examination (he underwent reoperation due to ring dehiscence), and (3) 4 cases (10.5%) with a moderate or severe MR at the time of study.

Finally, 32 cases undergoing the RMA with a complete ring insertion were evaluated. The patients' mean age was 50.1 ± 12.5 years, and most of them was male (23 patients, 71.9%). A semirigid annuloplasty ring was used in 87.5% of patients, and 46.9% of them had concomitant operations. A total of 15 patients (46.9%) underwent concomitant operations, including 5 cases of coronary artery bypass graft surgery, 4 cases of closure of patent foramen ovale, 2 cases of closure of ventricular septal defect, 2 cases of closure of atrial septal defect, and 2 cases of left atrial appendage closure. Most of cases had functional class II or III before operation (46.9% and 25%, respectively). The mitral valve mean gradient, mitral valve peak gradient, the EOA, and the PAP at rest were 3.3 ± 1.8 mm Hg, 7.9 ± 3.7 mm Hg, 1.9 ± 0.6, and 26.1 ± 6.3 mm Hg, respectively. Other characteristics and surgical factors are summarized in Table 1.

All patients were followed up during a mean of 14.1 ± 5.9 months (6–32 months). The majority of patients (59.4%) had functional class I at immediate postoperative time, and 68.8% of patients had functional

TABLE 1 Baseline characteristics, echocardiographic features, and surgery-related factors in patients undergoing mitral annuloplasty

Study variables	Values
Number of patients	32
Age, y	50.1 ± 12.5
Body surface area, kg/m^2	1.8 ± 0.2
Sex (male/female)	23 (71.9%)/9 (28.1%)
NYHA functional class	
Class I	6 (18.8%)
Class II	15 (46.9%)
Class III	8 (25%)
Class IV	3 (9.4%)
Preoperative echocardiographic features	
LVEF, %	52.7 ± 6.2
TAPSE, mm	17.6 ± 2.2
PAP, mm Hg	32.2 ± 11.9
Involved mitral valve leaflets	
Anterior	4 (12.5%)
Posterior	17 (53.1%)
Bileaflet	11 (34.4%)
Right ventricular dysfunction	
No dysfunction	20 (62.5%)
Mild dysfunction	9 (28.1%)
Moderate dysfunction	3 (9.4%)
Surgery-related factors	
CPB time, min	110.3 ± 33
Co-operations	15 (46.9%)
Triangular resection	10 (31.2%)
Quadrangular resection	5 (15.6%)
Neochordae	9 (28.2%)
Other	8 (25%)
Ring size	30.5 ± 2.9
Ring type	
Semirigid	28 (87.5%)
Flexible	3 (9.4%)
Rigid	1 (3.1%)
Ring brand	
3D MEMO	14 (43.8%)
CG future	7 (21.9%)
Physio	1 (3.1%)
Segiun	6 (18.8%)
Tailor	2 (6.2%)
Duran	1 (3.1%)
Carpentier	1 (3.1%)

NYHA = New York Heart Association; LVEF = left ventricular ejection fraction; TAPSE = tricuspid annular plane systolic excursion; PAP = pulmonary arterial pressure; CPB = cardiopulmonary bypass.
Data are presented as mean ± SD or number (percentage).

class I at last follow-up. When we compared changes in functional class from preoperative to last follow-up, there was a significant difference (*P* < .001). When categorized the hemodynamics into high and low levels based on previous studies[15,19] or the median values in our patients, the number of patients with a mitral valve peak gradient of >7.5 mm Hg, a mitral valve mean gradient of >3 mm Hg, and the PAP ≥25 mm Hg at rest were 50%, 40.6%, and 62.5%, respectively.

3.2 | Treadmill exercise stress echocardiography

All patients were examined using a treadmill exercise test. Thirteen patients (40.6%) had an incomplete exercise test. The achieved exercise capacity was 9.02 ± 2.26 METs, and it was 6.6 ± 0.9 METs in patients with an incomplete test. All echocardiography parameters evaluating the mitral valve hemodynamics were assessed before and after exercise test. All hemodynamic parameters were significantly higher at peak exercise test compared with those at rest (Table 2).

Correlation between echocardiographic parameters and hemodynamic parameters and achieved METs was also evaluated. There was a trend toward patients with higher levels of peak gradient at rest and at peak exercise test to have lower amounts of EOA at rest. There was significant inverse correlation between peak gradient at peak exercise and the EOA at peak exercise (*P* = .041). In addition, there was a trend toward patients with higher levels of transmitral peak gradient at peak exercise and a transmitral mean gradient at peak exercise to have lower amounts of EOA at exercise test. There was significant inverse correlation between PAP at rest and at peak exercise test and achieved METs (*P* = .006 and *P* = .032, respectively). Transmitral peak gradient at peak exercise was also inversely correlated with achieved METs ($r = -.351$, *P* = .049). Other correlations are summarized in Table 3.

All patients were also categorized into 2 groups based on the exercise capacity, high workload or complete exercise test group (ie, patients with METs >7) and low workload or incomplete exercise test group (ie, patients with METs <7). The PAP at rest and at peak exercise tests were significantly higher in patients with incomplete exercise compared with complete exercise group (28.9 ± 7.2 vs 23.6 ± 4.7 mm Hg, *P* = .018 and 32.2 ± 7.4 vs 38.9 ± 11.2 mm Hg, *P* = .050, respectively).

TABLE 2 Hemodynamic and echocardiographic parameters before and after exercise echocardiography

	At rest	At peak exercise	*P*
Heart rate	61.7 ± 5	161.5 ± 8.8	<.001
SBP	122.6 ± 6.9	152.6 ± 12.7	<.001
Stroke volume	63.5 ± 18.5	77.1 ± 22	<.001
Ejection fraction	45.6 ± 5.9	54.8 ± 7.2	<.001
PAP	25.8 ± 6.3	35 ± 9.6	<.001
Peak gradient	8 ± 3.7	16.7 ± 7	<.001
Mean gradient	3.4 ± 1.8	9.2 ± 4.4	<.001
EOA	1.9 ± 0.6	2.2 ± 0.8	.003

SBP = systolic blood pressure; PAP = pulmonary artery pressure; EOA = effective orifice area.

In addition, the peak transmitral gradient at peak exercise was also significantly higher in patients with incomplete exercise compared with complete exercise group (20 ± 7.7 vs 14.5 ± 5.5 mm Hg, *P* = .024). Other variables are summarized in Table 4.

3.3 | ROC analysis

ROC curve analysis was used to detect echocardiographic parameters (ie, mitral valve hemodynamic features) in discriminating patients with an incomplete exercise test. The PAP at rest of ≥22.5 mm Hg (sensitivity and a specificity of 84.6% and 52.6%) and the PAP at peak exercise of ≥29 mm Hg (sensitivity and a specificity of 100% and 47.4%) discriminated low workload test. The area under the curve (AUC) for the PAP at rest and at peak exercise was .755 and .717, respectively. The results of other values in ROC curve analyses were summarized in Table S1. We excluded patients with moderate RV dysfunction and recalculated the discriminatory role of PAP in our cohort. The AUC for the PAP at rest and at peak exercise was .798 (cutoff = 27.5; a sensitivity and a specificity of 72% and 73%) and .763 (cutoff = 29; a sensitivity and a specificity of 100% and 50%), respectively.

4 | DISCUSSION

In this study, we showed that patients undergoing RMA using a complete prosthetic ring for the repair of myxomatous MVP might have some degrees of deteriorated mitral valve hemodynamics and increased levels of PAP during follow-up period. These hemodynamic parameters increased more after treadmill exercise test compared with at rest, suggesting the development of functional mitral stenosis and a consequent less exercise capacity. Moreover, the PAP at rest and peak exercise as well as transmitral peak gradient at peak exercise correlated with lower exercise capacity, and the PAP at rest and peak exercise discriminated patients with lower exercise capacity; however, mitral valve hemodynamic parameters did not.

Although RMA is considered the treatment of choice in patients with degenerative MR, it is associated with an impairment of valve hemodynamics. During an RMA procedure, some components of mitral valve are resected, which can lead to an abnormal coaptation, MR, and the remodeling of the mitral annulus.[20] The main sequel of the RMA includes increased transmitral gradient and a subsequent functional mitral stenosis, which is similar to prosthesis-patient mismatch developed after mitral valve replacement with a small prosthetic valve.[15] It may be hypothesized that the consequences of RMA differ between patients with secondary or degenerative MR, as a complete and properly sized prosthetic ring is usually implemented during the repair of degenerative MR, while the prosthetic ring is undersized by 1 or 2 size in ischemic MR.[7,15] The use of undersized ring along with a leaflet resection may reduce the mitral valve area and reduce valve opening, leading to valve obstruction.[7,9–11,14] After RMA using complete ring in degenerative MR, the extensive resection of leaflets and using complete ring may also cause the development of functional mitral stenosis. In addition, the insertion of ring leads to

TABLE 3 Correlation between echocardiographic and hemodynamic parameters and achieved METs

	EOA at rest		EOA at peak exercise		Achieved METs	
	Correlation coefficient	*P*	Correlation coefficient	*P*	Correlation coefficient	*P*
Heart rate at rest	.013	.944	−.001	.997	−.141	.442
Heart rate at peak exercise	−.045	.808	.019	.918	−.184	.312
SBP at rest	−.026	.921	−.192	.461	−.206	.429
SBP at peak exercise	−.072	.783	−.163	.531	−.033	.899
Peak gradient at rest	−.346	.052	−.349	.050	−.149	.414
Peak gradient at peak exercise	−.328	.066	−.363	.041	−.351	.049
Mean gradient at rest	−.247	.172	−.326	.068	.097	.596
Mean gradient at peak exercise	−.229	.207	−.278	.123	.191	.296
PAP at rest	.061	.739	.057	.758	−.478	.006
PAP at peak exercise	.076	.678	.165	.368	−.380	.032
Stroke volume at rest	.339	.057	.362	.042	.207	.255
Stroke volume at peak exercise	.326	.069	.477	.006	.094	.610
LVEF at rest	.244	.179	.198	.278	.170	.352
LVEF at peak exercise	.226	.214	.217	.233	.145	.428
Achieved METs	.244	.179	.153	.403	—	—

EOA = effective orifice area; SBP = systolic blood pressure; PAP = pulmonary artery pressure; LVEF = left ventricular ejection fraction; MET = metabolic equivalents of task.

changes in annular dimension and consequently involves the expansion of valve annulus during cardiac cycle.[21] Given these hypotheses and the use of incomplete ring or band during recent era of RMA operations for degenerative MR,[15] it seems that further studies with more attention on the type of prosthetic ring or band and the amount of leaflet resection as well as using three-dimensional echocardiography might provide valuable data regarding the underlying mechanism of this phenomenon.

Chan et al. reported that following RMA for degenerative MR, it is more likely to observe elevated mitral gradients, worse hemodynamics, a lower exercise capacity, and a higher PAP level, both at rest and at peak exercise test. They concluded that refinement in the RMA techniques might reduce transmitral gradient impairment and consequent functional deterioration.[15] Mesana et al.[16] also studied patients with degenerative MR who underwent the RMA. They found that RMA using a complete ring may be associated with a higher transmitral gradient at rest and at peak exercise, which underscores the careful consideration of annuloplasty type and size at the time operation. Bertrand et al.[7] evaluated the effect of mitral stenosis after RMA in patients with secondary MR, mainly ischemic one. They showed that EOA increases during exercise, and diastolic anterior leaflet tethering played a key role in this dynamic process. In addition, indexed EOA at peak exercise was an independent predictor of exercise capacity and was associated with clinical outcomes. In contrast, in a group of patients with ischemic MR undergoing the RMA, transmitral gradient was not associated with functional capacity and it should be considered as a measurement of patients' hemodynamics.[6] Our findings are in lines with these studies too. We found that approximately half of patients had at least mild functional mitral stenosis at modest follow-up period. Moreover, all these hemodynamic parameters significantly deteriorated after treadmill exercise test.

Alteration in the transmitral gradients after RMA is associated with physiological and functional impacts on patients' outcomes. The increased level of transmitral gradient after the RMA operation is associated with elevated levels of B-type natriuretic peptide.[15] It has been also demonstrated that mitral stenosis can lead to elevated intracardiac pressures, particularly left atrial pressures which can consequently increase PAP.[19] So, the increment of PAP after the RMA represents a substantial physiological response to functional mitral stenosis which may or not influence functional capacity. Several studies reported that PAP may be better indicative of decreased exercise capacity than mitral valve gradients in patients undergoing the RMA. Kainuma et al.[9] demonstrated that RMA for functional MR resulted in functional mitral stenosis, some degrees of mitral obstruction, higher transmitral gradients, and a lesser value of EOA. However, their findings were somewhat more suggesting residual pulmonary hypertension as the most important sequel of RMA, rather than functional mitral stenosis. Magne et al.[11] showed that among patients with ischemic MR undergoing RMA, the functional mitral stenosis was associated with a higher PAP and a worse functional capacity. In the present study, we found that the strongest factors for discriminating exercise capacity included the PAP at rest and at peak exercise. It remains to be determined to what extent the level of these hemodynamic impairments influences clinical outcomes of these patients. The easily measured PAP can be used for the surgical management of patients if we examine this value in patients with different mitral valve pathologies and different surgical

TABLE 4 Comparing demographics and echocardiographic parameters in groups by exercise capacity

	Complete exercise test (n = 19)	Incomplete exercise test (n = 13)	P
Age, y	50.1 ± 11.2	50 ± 14.7	.986
Sex (M/F)	4 (21.1%)/15 (78.9%)	5 (38.5%)/8 (61.5%)	.282
Body surface area, kg/m^2	1.8 ± 0.2	1.8 ± 0.2	.431
Preoperative PAP, mm Hg	31 ± 10	33.6 ± 14.5	.588
Preoperative LVEF, %	54.2 ± 5.8	50.6 ± 6.5	.126
Echocardiographic parameters before and after exercise test			
Heart rate at rest	61.4 ± 5.5	62.2 ± 4.4	.642
Heart rate at peak exercise	160.7 ± 9.7	162.6 ± 7.4	.549
SBP at rest	121.1 ± 7	124.8 ± 6.5	.282
SBP at peak exercise	151.2 ± 12.8	154.6 ± 13.3	.607
Stroke volume at rest	65.7 ± 19.8	60.2 ± 16.8	.416
Stroke volume at peak exercise	78.8 ± 20.5	74.7 ± 24.6	.608
LVEF at rest	46.6 ± 5.5	44.2 ± 6.4	.278
LVEF at peak exercise	55.8 ± 6.9	53.5 ± 7.7	.380
PAP at rest	23.6 ± 4.7	29.6 ± 6.7	.005
PAP at peak exercise	32.2 ± 7.4	39.7 ± 10.5	.025
Peak gradient at rest	7.5 ± 3.7	8.6 ± 3.9	.429
Peak gradient at peak exercise	14.5 ± 5.5	20 ± 7.7	.024
Mean gradient at rest	3.4 ± 1.8	3.2 ± 1.7	.728
Mean gradient at peak exercise	9.4 ± 4.3	9 ± 4.7	.816
EOA at rest	2 ± 0.7	1.7 ± 0.4	.173
EOA at peak exercise	2.2 ± 0.9	2 ± 0.7	.385

PAP = pulmonary artery pressure; LVEF = left ventricular ejection fraction; SBP = systolic blood pressure; EOA = effective orifice area.

approaches. Moreover, the evaluation of PAP before RMA can also provide important index for the risk stratification of patients and probable modifications in the surgical management of such cases. Further large-scaled studies are required to show the applicability of PAP in patients undergoing RMA operation.

4.1 | Study limitations

When interpreting our results, you should consider some shortcomings. First, this is a retrospective evaluation of relatively small group of patients. Second, our findings cannot be applicable to other centers, particularly due to different techniques used for RMA. Third, we only included patients being able to perform exercise test and those may be more mild or moderate grades of functional stenosis such that patients with severe forms had been excluded from our cohort. Fourth, we have included patients with moderate right ventricular dysfunction, which can influence the measurement of PAP; however, when we excluded 3 patients with moderate right ventricular dysfunction, there was a little difference in the accuracy of PAP at rest and at peak exercise in discriminating patients with incomplete exercise test. Finally, our follow-up was relatively short and we did not have clinical outcomes of patients to explore more aspects of patients' functional outcome.

5 | CONCLUSION

The implementation of RMA with complete prosthetic ring in patients with degenerative MR is associated with impaired transmitral gradients, increased PAP, and lower exercise capacity. These hemodynamic parameters more deteriorated after exercise test despite fixed annular ring. Moreover, elevated PAP at rest and at peak exercise and peak transmitral gradient at peak exercise were associated with lower exercise capacity. Our findings emphasize on the modification of RMA operations in degenerative MR to improve outcomes of patients.

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SUPPORTING INFORMATION

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Table S1. ROC curve analyses showing echocardiographic parameters at rest and at peak exercise to discriminate patients with incomplete treadmill exercise test.

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