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Direct Visualization of Regurgitant Orifice by CMR Reveals Differential Asymmetry According to Etiology of Mitral Regurgitation

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OBJECTIVES This study sought to characterize the shape of regurgitant orifice area (ROA) and mitral apparatus in various forms of mitral regurgitation (MR) by cardiac magnetic resonance (CMR).

BACKGROUND ROA is an accepted parameter of MR severity. However, there are little data on the shape of the ROA in various forms of MR.

METHODS Direct assessment of ROA was performed with a 1.5-T CMR scanner using a breath-hold fast imaging with steady-state free precession. The regurgitant orifice shape and the anatomy of the mitral valve apparatus including mitral annulus, mitral leaflet angles, and mitral valve tenting area were assessed.

RESULTS We studied 74 patients. MR severity was mild in 39%, moderate in 27%, and moderate-to-severe or severe in 34%. Mitral valve pathology was degenerative in 26%, prolapse in 22%, flail in 33%, and functional in 19%. For all patients, ROA correlated significantly with regurgitant fraction ($r = 0.80$, $p < 0.001$). The ROA shape index as expressed by the ratio of the larger length to the smaller length was a median of 2.04 (interquartile range [IQR]: 1.49 to 3.08) over all patients. CMR revealed significant asymmetry of the ROA geometry in functional MR 3.91 (IQR: 2.79 to 4.84) compared with prolapse 2.14 (IQR: 1.80 to 3.04), flail 2.20 (IQR: 1.69 to 2.91), and degenerative MR 1.24 (IQR: 1.09 to 1.57), all $p < 0.01$. The assessment of mitral valve geometry demonstrated that patients with functional MR had significantly increased leaflet angles, mitral valve tenting area, and mitral annulus area (all $p < 0.05$). Of note, the orifice shape index correlated with increasing leaflet angles in patients with functional MR ($r = 0.68$, $p = 0.005$).

CONCLUSIONS Direct assessment of ROA by CMR revealed significant asymmetry of ROA in various forms of MR, particularly in patients with functional MR. The slitlike appearance in functional MR correlates with a distended mitral apparatus. (J Am Coll Cardiol Img 2011;4:1088–96) © 2011 by the American College of Cardiology Foundation

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Mitral regurgitation (MR) is a common and important heart valve lesion in clinical practice (1). MR can have various causes, including degenerative MR, mitral valve prolapse, flail leaflet, or mitral annular dilation (2). The regurgitation orifice area (ROA) is a fundamental measure of valvular incompetence and is an accepted parameter of mitral regurgitation severity (3–5). Because direct visualization of the mitral ROA is difficult by echocardiography (6), data are sparse regarding its shape and size in different etiologies in MR (7). Recent studies employing 3-dimensional echocardiography have

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suggested that shape and ROA of the regurgitant jet may vary according to the etiology of MR (7,8). Additionally, the mitral annulus and mitral valve geometry plays an important role in the structural and functional integrity of the mitral valve complex and may also affect the shape of the ROA (9,10).

Cardiac magnetic resonance (CMR) is increasingly used to assess patients with MR based on accurate quantitative assessment of regurgitant volume and fraction (11–13). Further, the use of CMR to visualize cardiac valves in any chosen plane with excellent image quality and to planimetrically determine the valve orifice has already been demonstrated in stenotic valves (14–16). Very recently, it was shown that CMR can also be used to directly visualize the regurgitant orifice in aortic regurgitation and MR (17,18).

Based on these findings, we hypothesized that the shape and size of the regurgitant orifice in MR may differ among the various etiologies and may be associated with distinct alterations of the mitral valve apparatus. Thus, the purpose of the current study was to assess and characterize the size and shape of the regurgitant orifice and mitral valve apparatus by CMR in various forms of MR.

METHODS

Patients. We enrolled 74 patients with varying etiologies and severity of MR. Degenerative MR was defined as degenerative MR without prolapse due to valve thickening and sclerosis or immobility or isolated annular calcification (2,19). Mitral valve prolapse was defined as an abnormal systolic valve movement into the left atrium with leaflet tips remain in the left ventricle (20,21). Mitral valve prolapse with flail was defined when the free edge of a leaflet is completely reversed in the left atrium. Functional MR was defined as MR with structurally normal mitral valve and incomplete mitral leaflet closure due to left ventricular dilation (22,23). Grading of MR by CMR was defined by regurgitant fraction based on the current guidelines of American Heart Association/American College of Cardiology/American Society of Echocardiography (24,25). Specifically, mild MR was defined as regurgitant fraction <30%; moderate MR was defined as regurgitant fraction of 30% to 39%; moderate-to-severe MR was defined as regurgitant fraction of 40% to 49%; and severe MR was defined as regurgitant fraction ≥50%. Informed consent was obtained from all patients. Part of the data (ROA, regurgitant fraction, and volume) from a subsample (n = 35) of the current cohort has been reported previously (18) and was analyzed for MR shape and geometry of the mitral apparatus as described herein.

Cardiac magnetic resonance. CMR studies were performed on a clinical 1.5-T scanner (Siemens Sonata and Siemens Avanto, Siemens Healthcare, Erlangen, Germany) using a phased-array receiver coil during breath-hold and electrocardiographic trigger. CMR images for ventricular function and morphology were acquired in multiple short-axis, long-axis, and 3-chamber views in a standard fashion (true fast imaging with steady-state precession; slice thickness: 8 mm, echo time: 1.53 ms, pixel bandwidth: 1.085 Hz, repetition time: 3.14 ms, matrix: 256 × 202). The number of Fourier lines per heartbeat was adjusted to allow the acquisition of 20 cardiac phases covering systole and diastole within a cardiac cycle. The field of view was 340 mm on average and adapted to the size of the patient. Calculation of left ventricular volumes and ejection fraction was performed in the serial short-axis slices.

ABBREVIATIONS AND ACRONYMS

2D = 2-dimensional
3D = 3-dimensional
CMR = cardiac magnetic resonance
IQR = interquartile range
MR = mitral regurgitation
PISA = proximal isovelocity surface area
ROA = regurgitant orifice area

Additionally, to calculate regurgitant fraction and regurgitant volume, through-plane phase–contrast velocity mapping of the ascending aorta was used in a retrospective gating technique during normal respiration to cover the whole cardiac cycle (flash: 2-dimensional [2D]; slice thickness: 5 mm, echo time: 3.2 ms, pixel bandwidth: 391 Hz, repetition time: 41 ms, matrix: 256 × 192) (26).

For mitral valve regurgitant orifice visualization, fast imaging with steady-state free precession was used (true fast imaging with steady-state precession; slice thickness: 5 mm, slice overlap: 50%, echo time:

1.53 ms, pixel bandwidth: 1.085 Hz, matrix: 256 × 202, repetition time: 3.14 ms, temporal resolution: 20 to 43 ms depending on scanner [Sonata, n = 35 and Avanto, n = 39]). The protocol of planning the visualization of ROA was described in detail previously (18). In brief, the imaging plane of the mitral valve was defined by acquiring 4-chamber, 3-chamber, and long-axis 2-chamber views. The subsequent slices were defined parallel to the valvular plane and additionally, especially in cases of orifices with an eccentric regurgitant jet, perpendicular to the direction of the jet. The planimetry of the regurgitant orifice during systole was then performed in the angulated "short" axis on the slice that was still located on the maximum systolic regurgitant orifice at the tip of the leaflets view (Fig. 1). On the cropped images, the length of the long and short axes of the regurgitant orifice was measured and the ratio of long-axis length to short-axis length was calculated (ROA shape index) (Fig. 1). The inner contour of the regurgitant orifice at the point of the bright pixels was manually outlined. Intraobserver and interobserver variability for ROA measurement has been previously described (18).

Additionally, CMR measurements were performed including mitral valve tenting area in the 3-chamber view (Fig. 2). The degree of leaflet tethering was estimated by measuring the angle between the annular plane and the leaflet (anterior leaflet [A°], posterior leaflet [P°]). The measurements of the mitral angles were performed in early systole when the mitral valve has just closed and the aortic valve is still closed. Further, the mitral annulus area was planimetered on the basal slice of the short-axis stack demonstrating the mitral valve annulus. On the same basal slice, the degree of circularization of the annulus (mitral annulus shape index) was calculated by the ratio of the anteroposterior dimension to the commissure-commissure plane. Examples for regurgitant orifices of various etiologies are presented in Figure 3.

Statistical analysis. All data are expressed as mean ± SD or median values (interquartile range [IQR]). Categorical variables are presented as frequencies and percentages. Normally distribution was tested by means of skewness, kurtosis, histogram, and Q-Q plot. Differences in mean values between 2 groups were compared by Student *t* test and between all groups by analysis of variance. For ROA shape index, which was not normally distributed, Mann-Whitney *U* test and Kruskal-Wallis *H* test were used. Chi-square test was performed to compare frequencies between groups. Pearson correlation was used to calculate linear correlation for

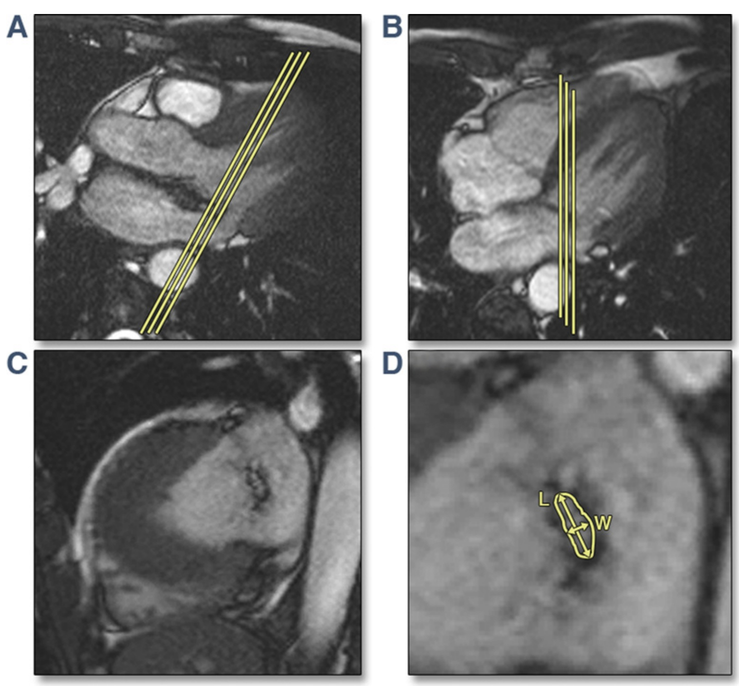

Figure 1. CMR Protocol for Slice Positioning to Perform Visualization of Mitral Valve Regurgitant Orifice

(A) Three- and **(B)** 4-chamber view and **(C)** angulated short-axis view. Manual contouring of the largest systolic orifice area is shown on a cardiac magnetic resonance (CMR) zoom image of the regurgitant orifice **(D),** with measurement of the length (L) and width (W).

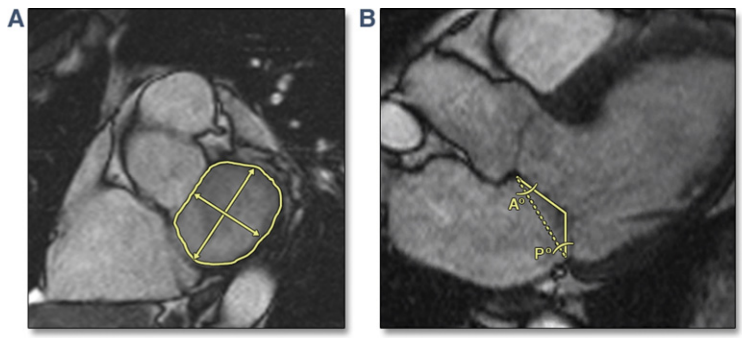

Figure 2. CMR Images of Mitral Valve Apparatus

(A) Cardiac magnetic resonance (CMR) image showing the mitral annulus morphology with measurements of commissure-commissure dimension and anterior-posterior dimension; mitral annulus area is hatched. **(B)** CMR image showing the angle measured between the mitral leaflets and the septal portion of the anterior leaflet (A°) and lateral portion of the posterior leaflet (P°); mitral valve tenting area is hatched.

selected variables if they were distributed normally; otherwise, Spearman rank correlation coefficients were calculated. A multiple regression analysis was used to determine which of the variables of mitral valve apparatus are applicable as predictor variables for MR severity as well as ROA shape. Because this investigation is an exploratory study, no adjustments for multiple testing were made. All reported p values are 2-sided and a p value of 0.05 was considered the threshold of statistical significance. SPSS (version 15.0, IBM SPSS, Armonk, New York) was used for statistical analysis.

RESULTS

Patient characteristics. Characteristics of the 74 patients are depicted according to MR etiology in Table 1. Age ranged from 24 to 79 years (mean 58 ± 14 years). There were 23 women and 51 men. Among them, 52 were in sinus rhythm and 22 were in atrial

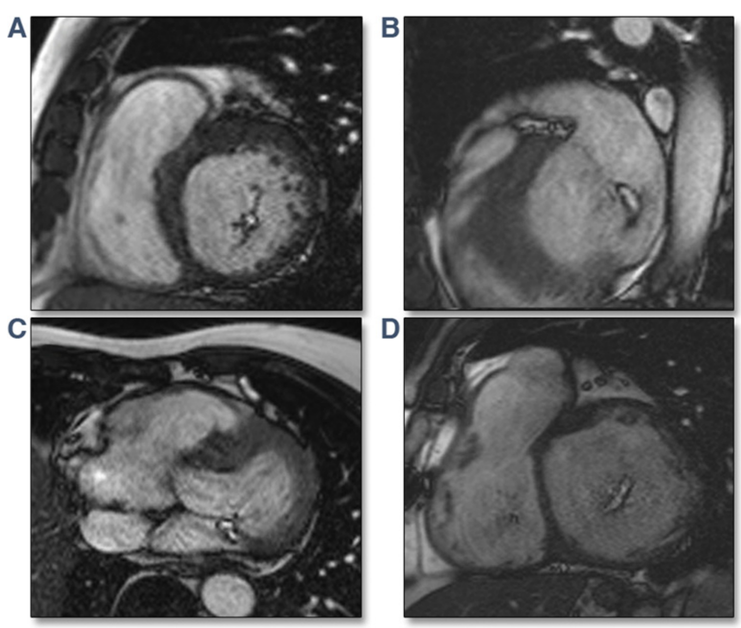

Figure 3. Examples of Asymmetry of Regurgitant Orifice of the Mitral Valve in Various Etiologies

The etiologies shown are**:** **(A)** degenerative mitral regurgitation (orifice shape index: 1.2, ROA: 0.25 cm^2); **(B)** mitral valve prolapse (orifice shape index: 2.5, ROA: 0.50 cm^2); **(C)** mitral flail leaflet (orifice shape index: 2.53, ROA: 0.48 cm^2); and **(D)** functional mitral regurgitation (orifice shape index: 6.23, ROA: 0.80 cm^2). ROA = regurgitant orifice area.

Table 1. Demographic and Clinical Characteristics of the Patients With Different MR Etiology

	Degenerative (n = 19)	Prolapse (n = 15)	Flail (n = 25)	Functional (n = 15)	p Value
Age, yrs	59 ± 17	54 ± 15	60 ± 14	59 ± 11	0.586
Sex (% men)	8 (42)	13 (87)	21 (84)	9 (60)	0.008
Sinus rhythm	9 (47)	13 (87)	20 (80)	10 (67)	0.067
Heart rate	76 ± 13	68 ± 8	79 ± 14	79 ± 15	0.064
Systolic blood pressure	133 ± 23	129 ± 17	130 ± 18	110 ± 13	0.003
NYHA functional class at presentation	2.4	1.9	2.4	2.7	0.117
CMR-EF, %	53 ± 13	55 ± 9	54 ± 11	27 ± 11	<0.001
CMR-ESV, ml	75 ± 56	100 ± 51	96 ± 47	224 ± 112	<0.001

Values are mean ± SD or n (%), unless otherwise indicated. The p value denotes significant differences among the 4 groups (ANOVA or Kruskal-Wallis test).
ANOVA = analysis of variance; CMR = cardiac magnetic resonance; EF = ejection fraction; ESV = end-systolic volume; MR = mitral regurgitation; NYHA = New York Heart Association.

fibrillation. There was no significant difference in heart rate between patients with rate-controlled atrial fibrillation and sinus rhythm (77 ± 5 min^{-1} vs. 75 ± 1 min^{-1}, $p = 0.55$) and the image quality was not reduced. Most patients were symptomatic with dyspnea. Compared with functional MR patients, all other MR subgroups had significantly higher systolic blood pressure. More male patients than female patients presented with MR prolapse and flail. Ejection fraction was significantly lower in patients with functional MR. Larger ventricular dimension volumes were observed in patients with functional MR as compared to patients with degenerative and prolapse/flail MR.

MR characteristics and MR severity. By quantitative grading (regurgitant fraction), 29 patients had mild, 20 moderate, and 25 moderate-to-severe or severe MR. In flail/prolapse MR, 48% of patients had moderate or severe MR. In functional MR, 40% of patients had moderate or severe MR. Mitral valve pathology was degenerative in 26%, prolapse in 22%, flail in 33%, and functional in 19% of patients. Of 25 patients with flail, 20 (80%) had a prolapse as well. The ROA correlated significantly with regurgitant fraction ($r = 0.80$, $p < 0.001$) and regurgitant volume ($r = 0.80$, $p < 0.001$) (Fig. 4). In patients with sinus rhythm, the correlation between ROA and regurgitant fraction was 0.79 and with regurgitant volume was 0.79 ($p < 0.001$, respectively). In patients with atrial fibrillation, the correlation between ROA and regurgitant fraction was 0.82 and with regurgitant volume was 0.82 ($p < 0.001$, respectively). In the multivariate regression analysis, mitral annulus area (beta = 0.51, $p < 0.001$) was the only significant independent predictor for mitral regurgitant severity.

As depicted in Table 2, ROA ranged from 0.25 to 1.0 cm^2 in functional MR and from 0.12 to 1.58 cm^2 in prolapse/flail MR.

Asymmetry of ROA. The shape of ROA by CMR appeared noncircular in the majority of patients, particularly those with functional MR. The median asymmetry shape index of ROA was 2.04 (IQR: 1.49 to 3.08) over all patients, 1.24 (IQR: 1.09 to

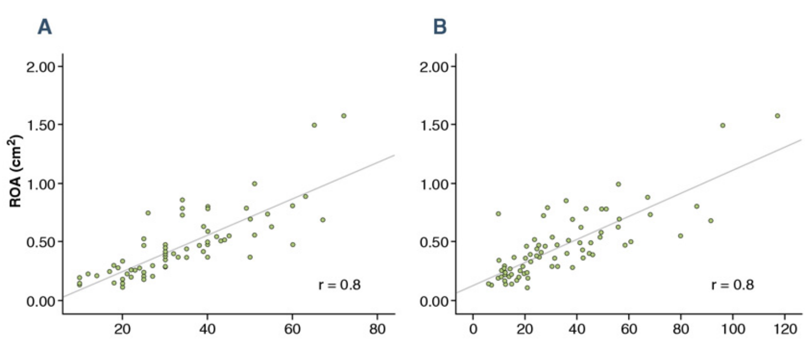

Figure 4. Correlation Plots of ROA and Regurgitant Fraction and Volume

Correlation plots of regurgitant orifice area (ROA) and regurgitant fraction **(A)** and volume **(B).** For all patients, the ROA correlated significantly with regurgitant fraction ($r = 0.80$, $p < 0.001$) and regurgitant volume ($r = 0.80$, $p < 0.001$).

Table 2. Mitral Annular Measurements by Different MR Etiology

	Degenerative	Prolapse	Flail	Functional	p Value
ROA, cm^2	0.25 ± 0.11	0.51 ± 0.20	0.55 ± 0.35	0.56 ± 0.24	0.001
ROA shape index	1.24 (1.09–1.57)	2.14 (1.80–3.04)	2.20 (1.69–2.91)	3.91 (2.79–4.84)	<0.001
Mitral valve tenting area, cm^2	1.72 ± 0.41	2.00 ± 0.57	2.15 ± 0.82	3.55 ± 1.30	<0.001
Anterior mitral leaflet angle, (°)	18 ± 7	13 ± 6	16 ± 6	28 ± 8	<0.001
Posterior mitral leaflet angle, (°)	22 ± 8	14 ± 7	20 ± 9	47 ± 6	<0.001
Mitral annulus area, cm^2	8.31 ± 1.56	13.04 ± 3.81	10.39 ± 3.09	15.26 ± 4.40	<0.001
Mitral annulus shape index	1.31 ± 0.18	1.30 ± 0.18	1.33 ± 0.13	1.18 ± 0.12	0.026
CC diameter, cm	4.27 ± 0.38	4.94 ± 0.53	4.70 ± 0.40	5.11 ± 0.55	<0.001
AP diameter, cm	3.19 ± 0.56	3.74 ± 0.52	3.44 ± 0.45	4.29 ± 0.66	<0.001

Values are mean ± SD or median (interquartile range). The p value denotes significant differences among the 4 groups (ANOVA or Kruskal-Wallis test). AP = anterior-posterior dimension; CC = commissure-commissure dimension; ROA = regurgitant orifice area; other abbreviations as in Table 1.

1.57) in degenerative MR, 2.14 (IQR: 1.80 to 3.04) in prolapse MR, 2.20 (IQR: 1.69 to2.91) in the flail MR, and 3.91(IQR: 2.79 to 4.84) in functional MR (Table 2). Figure 5 depicts the spread of the orifice shape index among MR etiologies. The range of the orifice shape index was smaller in degenerative MR than in prolapse and flail and functional MR.

Relationship between mitral valve apparatus and regurgitant orifice shape index. Mitral annular area, anteroposterior dimension, and commissure-commissure dimension were significantly larger for functional MR than they were for degenerative, prolapse, and flail MR (Table 2). In contrast, mitral annulus shape index was significantly decreased in patients with functional MR as compared to degenerative, prolapse, and flail MR (Table 2). A statistically significant but weak correlation between ROA shape and regurgitant fraction ($r = 0.52$, $p < 0.001$) and with regurgitant volume ($r = 0.46$, $p < 0.001$) was observed.

Mitral valve tenting area, anterior leaflet angle, and posterior leaflet angle were significantly larger in functional MR than for degenerative, prolapse, and flail MR.

Mitral valve tenting area ($r = 0.50$, $p = 0.041$), anterior leaflet angle ($r = 0.64$, $p = 0.01$), and posterior leaflet angle ($r = 0.69$, $p = 0.004$) all correlated significantly with ROA shape index in functional MR but not in degenerative, prolapse, and flail MR (Fig. 6). Posterior leaflet angle was the only significant independent predictor (beta = 0.68, $p < 0.001$) for ROA shape index in functional MR.

DISCUSSION

In this study, the size and shape of the ROA and the mitral valve apparatus were assessed by CMR in patients with MR of different etiologies. It demonstrates significant asymmetry of the ROA in various forms of MR and particularly in patients with functional MR. Further, it shows a correlation between the geometry of the mitral valve apparatus and ROA shape.

MR orifice. MR can have various causes, including mitral valve prolapse, flail, rheumatic heart disease, endocarditis, rupture of papillary muscles or chordae tendinae, congenital abnormalities, or mitral annular dilation due to left ventricular dysfunction (27). All lesions that cause MR do so by reduction or elimination of the normal coaptation between anterior and posterior mitral leaflets, which normally ensures mitral competence.

Mitral regurgitation severity is determined by lesion size (ROA) and the associated volume overload as assessed by regurgitant volume (24). Among

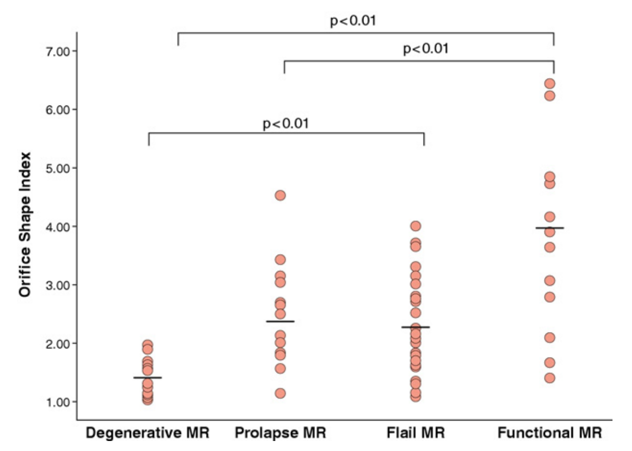

Figure 5. Relationship Between Asymmetry of the Regurgitant Orifice and Etiology of MR

Relationship between asymmetry of the regurgitant orifice and etiology of mitral regurgitation. Orifice shape index as defined by the ratio of long-axis length to short-axis length. The range of the orifice shape index was smaller in degenerative than in prolapse and flail and functional mitral regurgitation (MR).

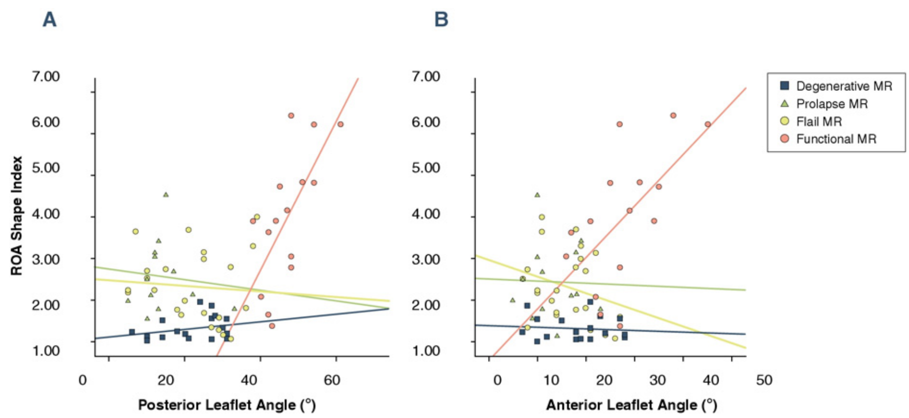

Figure 6. Relationships of ROA Shape Index and Posterior and Anterior Leaflet Angle by Etiology of MR

Relationships of ROA shape index and posterior **(A)** and anterior **(B)** leaflet angle by etiology of MR. No significant correlation was found in the subgroups with degenerative, prolapse, and flail MR. Positive correlation was found only in the subgroup with functional MR **(pink circles)**. Abbreviations as in Figures 3 and 5.

the quantitative measures of MR, regurgitant orifice area is the most important echocardiographic marker of lesion severity (5,28). Direct visualization of the ROA with transthoracic echocardiography or transesophageal echocardiography is difficult (6). Therefore, indirect estimations of the effective regurgitant orifice are derived from calculations according to the proximal isovelocity surface area (PISA) method (24). However, in MR, the orifice shape is often elliptical rather than circular, and this can affect the accuracy of PISA calculations (29,30). Another approach to estimate the ROA would be to directly measure the orifice (anatomic regurgitant orifice) rather than derive it from hemodynamic data. Similarly to 3-dimensional (3D) echocardiography, CMR allows any orientation of planes. Until now, however, CMR has mainly focused on regurgitant volume and regurgitant fraction in addition to quantification of ventricular function and chamber size in patients with mitral regurgitation (11,12). New sequences such as steady-state precession techniques allowed major advances and provide visualization of valvular anatomy (16,17,20,31). However, the concept of regurgitant orifice and shape as known in echocardiography by measurement of the effective regurgitant orifice has not been widely addressed by CMR yet.

Our study results demonstrate that CMR is feasible for directly visualizing and measuring the shape of ROA, enabling a grading of MR severity. Moreover, CMR can provide detailed information about underlying morphologic abnormalities such as annulus dilation, valve prolapse, or flail and can thus indicate the possible cause and mechanism of MR.

Geometry of ROA. ROA is a measure of valvular incompetence and is useful for assessment of MR (5,28). In the current study, direct assessment of ROA revealed significant differences and variations regarding the ROA shape that are characteristic of the underlying mechanism of mitral incompetence.

Regarding degenerative MR, the ROA was most circular, because usually the regurgitant orifice is uniformly fixed, which is caused by leaflet thickening and stiffening (32). Regarding prolapse and flail MR, we observed a wide spectrum of noncircular-shaped ROA, which was determined by the site and extent of leaflet displacement. Regarding functional MR, we found that the mitral apparatus is extended and the regurgitant orifice is elongated and usually located in the left ventricle. This finding corresponds to the movement of the mitral leaflet coaptation line in an apical and posterior direction and an asymmetrical incomplete coaptation pattern caused by leaflet tethering in the majority of functional MR (23,33).

The characterization of regurgitant orifice shape by CMR might also support the understanding of the current approaches for MR severity. Thus, prior studies demonstrated underestimation of effective regurgitant orifice by PISA method in noncircular regurgitant lesions (7,29). With 3D color Doppler echocardiography, it has been shown that this geometric assumption is not always fulfilled (7,8,34). The results of the current study confirm and extend these investigations.

Mitral valve apparatus. In the current study, enlargement of mitral annulus was seen in the functional and prolapse/flail groups compared with the degenerative group. Assessment of annular enlargement with CMR allowed us to assess a sphericity index that revealed asymmetric annular dilation of the anteroposterior and commisure-commisure planes. This is in agreement with the findings of Kwan et al. (35), who also reported circularization of the mitral annulus in the setting of patients with functional MR. This annular remodeling may be secondary to left ventricular remodeling and pathologic enlargement of both the anterior and posterior portions of the mitral annulus. Our results are also in accordance with Grewal et al. (36), who used live 3D transesophageal echocardiography to demonstrate that in patients with severe MR due to leaflet prolapse and with myxomatous mitral annulus, the anterior intertrigonal distance does not dilate and the mitral annulus is not circular.

We could demonstrate that a larger mitral valve tenting area and a greater anterior leaflet and posterior leaflet angle was associated with more slitlike regurgitant orifice shape. In other MR etiologies, these geometric variables of the mitral valve apparatus were not associated with specific regurgitant orifice shapes. These results suggest that the regurgitant orifice shape in functional MR is determined by the configuration of mitral valve angulation, which is supported by an in vitro study showing that leaflet remodeling caused by chordal coapting force component generated a nonuniform regurgitant orifice (10). Additionally, an animal study demonstrated the importance of secondary chordae in generating functional MR (9).

Together, because of the pathogenesis of functional MR, not only regurgitant orifice size but also orifice shape should be determined by geometric changes of the left ventricle and mitral valve apparatus.

Study limitations. It is a technical limitation of current CMR technology as used in our study that the true surface of the mitral regurgitant orifice, which may have a curved, saddlelike or even more complex 3D surface, can only be visualized as a 2D orifice. Even with training and several acquisition steps, as described in the methods section, this technical limitation can currently not be resolved. The true 3D surface may differ from the visualized 2D orifice and hence lead to slightly inaccurate quantitative results. It may possibly also explain the fairly wide spread of regurgitant volumes in patients with ROA above 0.5 cm^2. Hopefully, future technology will allow us to accurately delineate and quantify the true 3D surface of MR orifices.

CONCLUSIONS

Direct assessment of ROA by CMR revealed significant asymmetry of ROA in various forms of MR. The asymmetry of ROA is correlated to distinct changes in the geometry of the mitral apparatus, particularly in patients with functional MR. CMR permits an accurate characterization of ROA in patients with MR of different etiologies and allows important conclusions regarding the pathophysiology of MR.

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REFERENCES

1. Otto CM. Clinical practice. Evaluation and management of chronic mitral regurgitation. N Engl J Med 2001;345:740–6.
2. Enriquez-Sarano M, Frye R. Mitral valve disease. In: Willerson J, Wellens H, Cohn J, Holmes D Jr., editors. Cardiovascular Medicine. 3rd edition. London: Springer, 2007:397–430.
3. Vandervoort PM, Rivera JM, Mele D, et al. Application of color Doppler flow mapping to calculate effective regurgitant orifice area. An in vitro study and initial clinical observations. Circulation 1993;88:1150–6.
4. Enriquez-Sarano M, Miller FA Jr., Hayes SN, Bailey KR, Tajik AJ, Seward JB. Effective mitral regurgitant orifice area: clinical use and pitfalls of the proximal isovelocity surface area method. J Am Coll Cardiol 1995;25:703–9.
5. Enriquez-Sarano M, Avierinos JF, Messika-Zeitoun D, et al. Quantitative determinants of the outcome of asymptomatic mitral regurgitation. N Engl J Med 2005;352:875–83.
6. Hall SA, Brickner ME, Willett DL, Irani WN, Afridi I, Grayburn PA. Assessment of mitral regurgitation severity by Doppler color flow mapping of the vena contracta. Circulation 1997;95:636–42.
7. Kahlert P, Plicht B, Schenk IM, Janosi RA, Erbel R, Buck T. Direct assessment of size and shape of noncircular vena contracta area in functional versus organic mitral regurgitation using real-time three-dimensional echocardiography. J Am Soc Echocardiogr 2008;21:912–21.