JACC: CARDIOVASCULAR IMAGING
VOL. ■, NO. ■, 2019

PUBLISHED BY ELSEVIER

ORIGINAL RESEARCH

The Effect of Systolic Variation of Mitral Regurgitation on Discordance Between Noninvasive Imaging Modalities

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ABSTRACT

OBJECTIVES This study sought to assess the impact of systolic variation of mitral regurgitation (MR) has on discordance between echocardiography and magnetic resonance imaging (MRI).

BACKGROUND Studies have shown discordance between echocardiography and MRI when assessing the severity of MR. Contributing factors to this discordance may include the systolic variation of MR and the use of the color Doppler jet at a single point in time as the basis of many echocardiographic methods.

METHODS This analysis included 117 patients (62 $\pm$ 14 years of age; 58% male) with MR who underwent echocardiographic and MRI evaluation. Discordance was defined as the difference between the grades of MR (mild, moderate, or severe) by MRI and echocardiography. For each patient, 2 echocardiographic methods, the continuous wave time index and the color Doppler time index, and 1 MRI method, the systolic variation score (SVS), were measured to quantify systolic variation of MR.

RESULTS There was absolute agreement between echocardiography and MRI in 47 (40%) patients, a 1-grade difference in 54 (46%) patients, and a 2-grade difference in 16 (14%) patients. Only the SVS significantly differed between patients with and without discordance (0.60 $\pm$ 0.23 vs. 0.47 $\pm$ 0.21; $p = 0.003$). On receiver-operating characteristic analysis SVS had moderate predictive power of discordance (area under the curve: 0.67; $p = 0.003$), with an SVS of 53 having a sensitivity of 61% and a specificity of 65% to predict discordance.

CONCLUSIONS Discordance between MRI and echocardiographic assessment of MR severity is associated with systolic variation of MR as quantified by MRI using the SVS. Continuous wave Doppler and the presence of color Doppler were not correlated with discordance. This study highlights an advantage of MRI. Namely, it does not rely on a single point in time to determine MR severity. Because systolic variation had only moderate sensitivity and specificity for predicting discordance, other factors are also responsible for the discordance between the 2 techniques. (J Am Coll Cardiol Img 2019;■:■–■) © 2019 by the American College of Cardiology Foundation.

Studies have shown substantial discordance between echocardiography and magnetic resonance imaging (MRI) in the assessment of mitral regurgitation (MR) severity (1–5). A contributing factor to this discordance may be the well-known systolic variation of MR that occurs during systole. Some of the commonly used American Society of Echocardiography (ASE) recommended quantitative

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Manuscript received November 19, 2018; revised manuscript received January 17, 2019, accepted February 1, 2019.

ISSN 1936-878X/$36.00
https://doi.org/10.1016/j.jcmg.2019.02.014

ABBREVIATIONS AND ACRONYMS

ASE = American Society of Echocardiography

CDTI = color Doppler time index

CW = continuous wave

CWTI = continuous wave time index

MR = mitral regurgitation

MRI = magnetic resonance imaging

PISA = proximal isovelocity surface area

SVS = systolic variation score

parameters such as proximal isovelocity surface area (PISA) and vena contracta, as well as the size of the color flow jet, rely on measurements at a single point in time (6). These measurements overestimate MR severity when there is systolic variation of the regurgitant jet because the measurements are made when the regurgitant rate is at its highest. MRI quantification of MR does not typically rely on direct evaluation of the regurgitant jet. Instead, MRI quantifies MR indirectly, generally as the difference between the left ventricular stroke volume and forward flow. We have previously described an MRI method that quantifies the severity of MR on a frame-by-frame basis during systole (7). In addition, we evaluated echocardiographic methods for assessing systolic variation on the basis of on continuous wave (CW) Doppler and color Doppler assessment of MR. The purpose of this study was to determine whether the systolic variation of the regurgitant jet is correlated with the observed discordance between echocardiography and MRI.

METHODS

The study cohort included 160 patients with MR who were prospectively enrolled in a multicenter study and who underwent evaluation of their MR with echocardiography and MRI. There were 43 patients with irregular heart rates for which MRI-based regurgitant rates could not be measured or who had incomplete echocardiographic data and were not included in this analysis, thus leaving a final study cohort of 117 patients (62 ± 14 years of age; 58% male). There were no patients with a cardiac shunt or more than 5 ml of aortic insufficiency included in this study. All patients enrolled in this study gave informed consent, and the Institutional Review Board of each participating site approved this study. Baseline clinical characteristics of each patient were obtained by interview at the time of study enrollment.

ECHOCARDIOGRAPHIC IMAGE ACQUISITION AND ASSESSMENT OF MR SEVERITY. The methods for echocardiographic assessment for this study have been previously published (1). Briefly, echocardiograms were performed and viewed using commercially available ultrasound machines (Acuson Sequoia, Siemens, Mountainview, California; iE33 xMATRIX, Philips, Andover, Massachusetts) and software (ProSolv, Fujifilm Indianapolis, Indiana; TomTec Imaging Systems, Chicago, Illinois). Comprehensive echocardiograms were performed to allow an integrated approach to the assessment of MR severity recommended by the ASE (6). Components included in each echocardiographic assessment were mitral valve morphology, mitral regurgitant jet dimensions, regurgitant volume and regurgitant orifice area calculated using the PISA technique, mitral E wave, vena contracta, left atrial volume, Simpson's biplane-based left ventricular volumes, left ventricular end-diastolic dimensions, and pulmonary vein systolic flow characteristics. For each study, MR was categorized as mild, moderate, or severe according to the ASE integrated method by a Level 3-trained, National Board of Echocardiography-certified cardiologist who was blinded to the results of the MRI study.

ECHOCARDIOGRAPHIC SYSTOLIC VARIATION OF MR. Systolic variation of MR was assessed using 2 echocardiographic methods, and examples of these methods are shown in Figures 1A to 1H and 2A to 2I. The first method was based on the CW Doppler signal of MR. Systole was defined as the time between mitral valve closure and mitral valve opening, as previously published (8). The length of time the CW Doppler signal that was visible was measured (there was no compensation for signal intensity). The CW time index (CWTI) represents the percentage of time the CW Doppler signal of MR was visible over systole. The CWTI was calculated as follows:

$$\frac{\textit{time the CW signal is present}}{\textit{mitral valve closure} - \textit{mitral valve opening}}$$

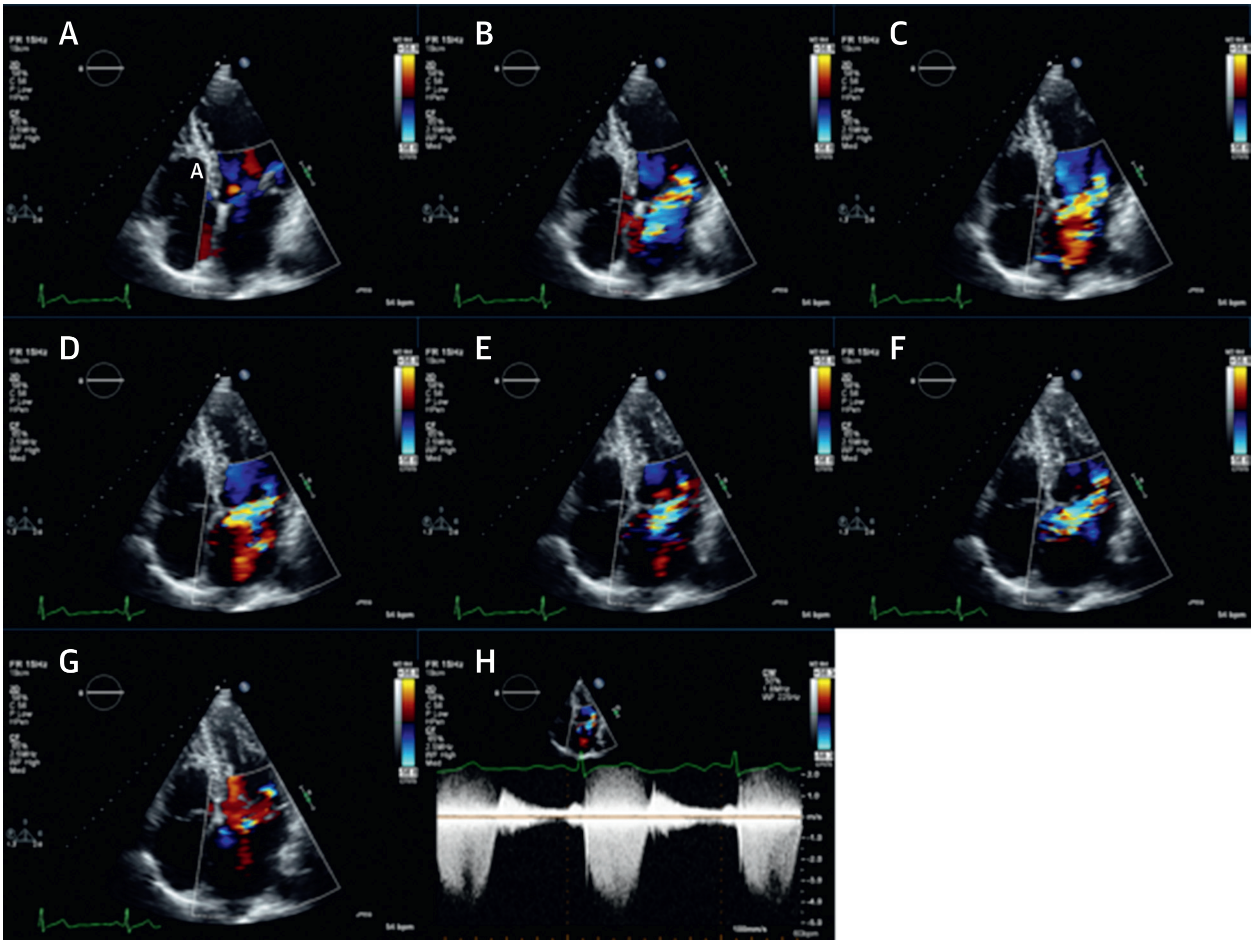
In addition, we categorized the CW Doppler signal dichotomously as holosystolic (CWTI ≥80%) or non-holosystolic (CWTI <80%).

The second method for evaluating systolic variation of MR by echocardiography was based on the color Doppler jet. The apical transthoracic echocardiographic view or the parasternal echocardiographic view in which the color Doppler jet signal was best displayed was chosen. Systole was defined as the number of frames from the start of ventricular contraction until ventricular relaxation as previously published (9). The number of frames during which the color Doppler jet was visible was determined, and the total number of frames during which the ventricle was contracting was determined. The color Doppler time index (CDTI) was calculated as follows:

$$\frac{\textit{number of systolic frames the color Doppler jet is visible}}{\textit{number of systolic frames}}$$

In addition, we categorized the color Doppler jet dichotomously as holosystolic (CDTI ≥80%) or non-holosystolic (CDTI <80%).

FIGURE 1 An Example of CDTI and CWTI in a Patient With Holosystolic MR

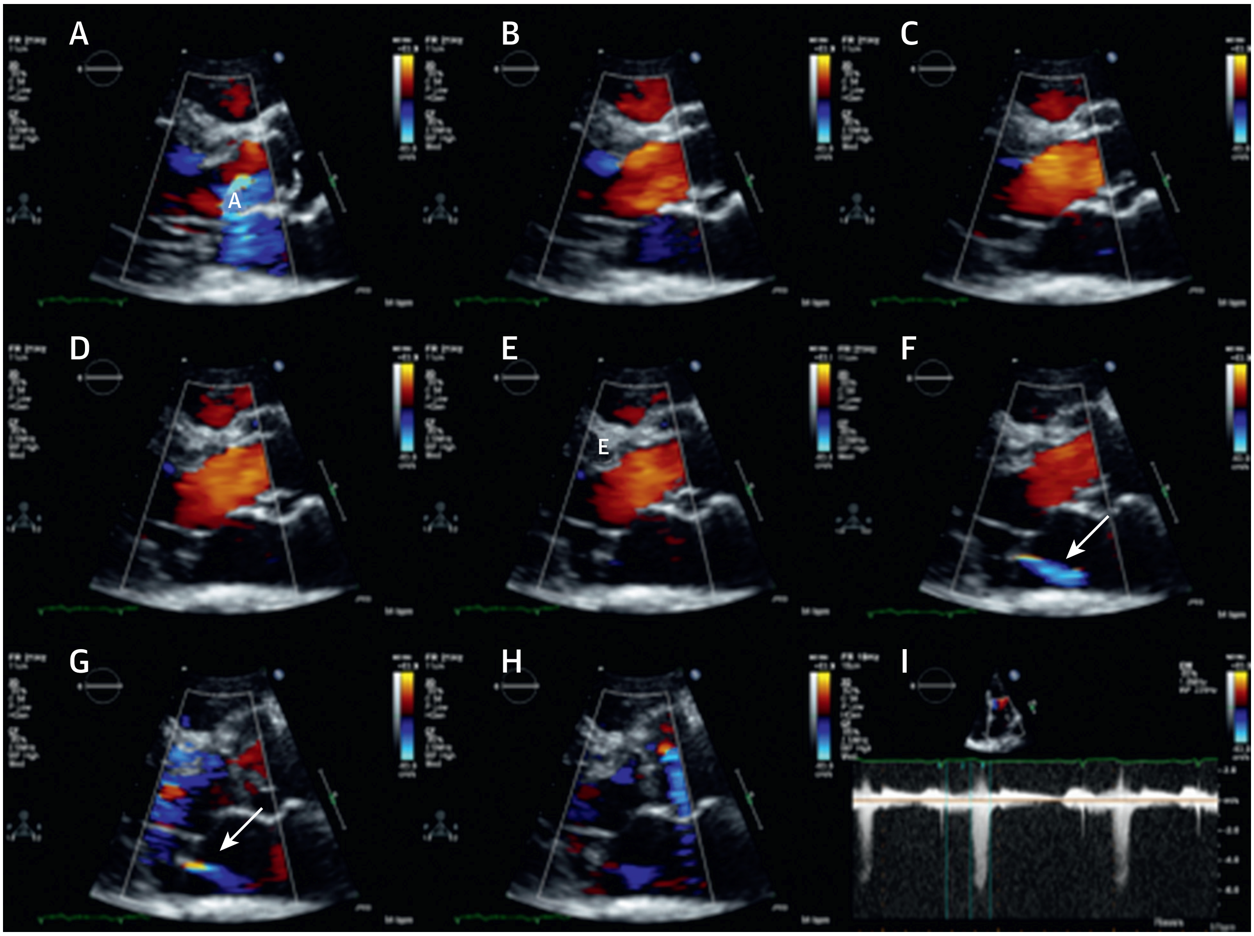


(A to G) Sequential systolic frames of the apical 4-chamber view of the mitral valve with color Doppler. The mitral regurgitant jet is visualized in 6 of 7 (86%) frames of systole. **(H)** A dense holosystolic CW Doppler signal can be seen. CDTI = color Doppler time index; CW = continuous wave; CWTI = continuous wave time index; MR = mitral regurgitation.

MAGNETIC RESONANCE IMAGING. The methods for MRI assessment for this study have been previously published (1). In brief, patients were imaged at 1.5- or 3.0-T. Images were acquired with a local phased-array coil, electrocardiographic gating, and breath holding. Images were analyzed using SuiteHEART (NeoSoft, Pewaukee, Wisconsin). Ventricular volumes were determined by manual segmentation of the short-axis images using a long-axis image to define the position of the left and right ventricular base. Aortic and pulmonary artery flow values were determined using the resident semiautomated algorithm. Correction for baseline flow offsets was performed as described previously (10). Flow measurements from 2 or 3 acquisitions were averaged. MR volume was determined as the difference between the left ventricular stroke volume and forward flow. MR severity was determined on the basis of the regurgitant volume: mild, <30 ml; moderate, 30 to 59 ml; or severe, ≥60 ml.

MRI DETERMINATION OF THE SYSTOLIC VARIATION BY MRI. The technique for quantifying the instantaneous mitral regurgitant rate has previously been described in detail elsewhere (7). In brief, left ventricular volumes were determined using the automated left ventricular segmentation algorithm, which excludes papillary muscles and trabeculations from the left ventricular cavity and uses a long-axis image to define the position of the base of the left ventricle. On the basis of the endocardial borders, the software

FIGURE 2 An Example of CDTI and CWTI in a Patient With Nonholosystolic MR



(A to H) Zoomed parasternal long-axis view with color Doppler. The color Doppler jet is seen **(arrows)** in 2 of 8 systolic frames (25%). **(I)** A nonholosystolic CW signal in the latter third of systole. Abbreviations as in Figure 1.

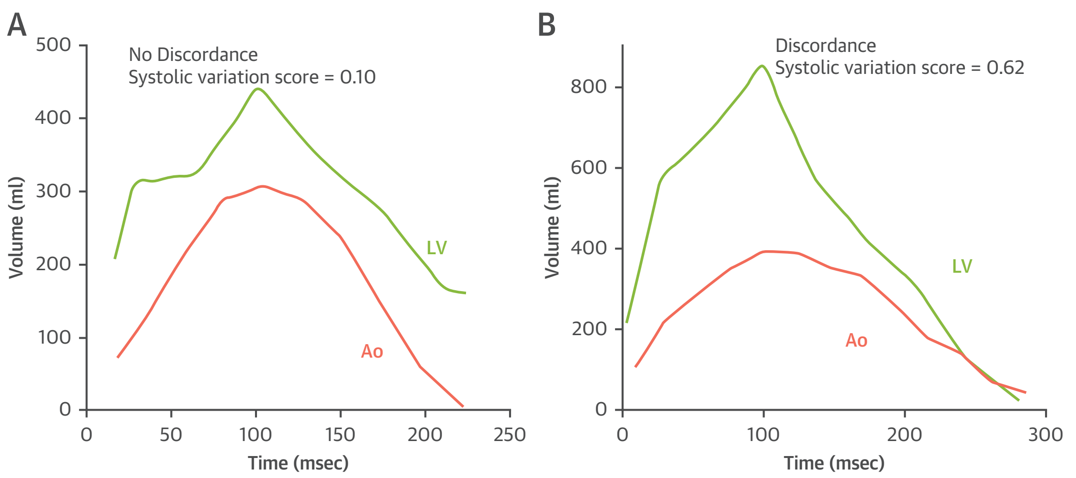
displayed a curve of left ventricular volume versus time. The instantaneous volume of blood exiting the left ventricle was displayed by the software as the slope of the left ventricular volume versus time curve.

An instantaneous volume versus time curve for aortic flow was created by manually integrating the flow curve. Integration was performed on a point-by-point basis using the Newton-Coates trapezoidal rule. In patients without MR, the rate at which blood arrives in the proximal ascending aorta is the same as the rate at which it exits the left ventricle because of the conservation of mass. In patients with MR, the rate of blood exiting the left ventricle exceeds the rate of its appearance in the aorta. The magnitude of this difference for each time point is the instantaneous regurgitant rate. Systole was defined as the time from the start to the end of ventricular contraction. Systole was divided into 3 equal parts—early, mid, and late—and the regurgitant rate was determined for each part of systole. The lowest, middle, and highest regurgitant rates were identified. An MR systolic variation score (SVS) was calculated for each patient as follows:

$$1-\left[\frac{\frac{\text{lowest regurgitant rate}\ +\ \text{middle regurgitant rate}}{2}}{\text{peak regurgitant rate}}\right]$$

so that a higher variation score is associated with a greater amount of systolic variation of MR. If the highest systolic regurgitant rate were 4 times that of the average of the 2 lowest and middle regurgitant

FIGURE 3 **An Example of 2 Patients, 1 Patient With No Discordance Between MRI and Echocardiography and a Low SVS and 1 Patient With 2-Grade Discordance and a High SVS**



(A) The left ventricular stroke volume and aortic flow separate immediately during systole and remain apart during the remainder of systolic, with only a 20% change in regurgitant rate among the thirds of systole. **(B)** In contrast, in a patient with some mitral regurgitation during the first third of systole, almost none the last third of systole, and the majority of mitral regurgitation during the middle section of systole. In this patient the regurgitant rate changes by 99%, consistent with significant systolic variation. MRI = magnetic resonance imaging; SVS = systolic variation score.

rates, the SVS would equal 0.75; if the highest systolic regurgitant rate were greater then the average of the lowest and middle regurgitant rates by 25%, then the SVS would equal 0.20. An example of 2 patients, 1 with no discordance between MRI and echocardiography and a low SVS and 1 with 2-grade discordance and a high SVS, is shown in Figure 3. In Figure 3A, the left ventricular stroke volume and aortic flow curves separate immediately during systole and remain approximately the same distance apart during all of systole, thus indicating a relatively constant regurgitant rate (SVS = 0.10). In contrast, Figure 3B illustrates a patient with substantial variation in MR severity. The separation between the left ventricular stroke volume and aortic flow curves is much more unequal, being most pronounced in midsystole and much less in early and later systole (SVS = 0.62).

DISCORDANCE BETWEEN MRI AND ECHOCARDIOGRAPHY. Discordance between MRI and echocardiography was determined as the difference in the grade of severity of MR. The relationship between discordance and the MRI-based SVS and echocardiographically based CWTI and CWDI was assessed as both continuous and dichotomous variables.

STATISTICAL ANALYSIS. Continuous data are presented as mean ± SD or median (25th, 75th percentile). Categorical data are presented as absolute numbers or percentages. Paired *t*-tests or 2-tailed Student's *t*-test was used to compare continuous variables. One-way analysis of variance with a post hoc least significant difference test was used to compare means of continuous variables among multiple groups. Multivariate analysis was performed to assess factors that predict discordance between MRI and echocardiography in the assessment of MR. Receiver-operating characteristic (ROC) (Youden index) analysis was used to determine the sensitivity and specificity of the SVS to predict discordance. All statistical analyses were performed using SPSS for Windows version 16 (SPSS Inc, Chicago, Illinois). A probability value <0.05 was considered to be statistically significant.

RESULTS

The median time between echocardiography and MRI was 7 (0, 18) days. There was no difference between the systolic blood pressure (129 ± 14 mm Hg vs. 127 ± 16 mm Hg; p = 0.3), diastolic blood pressure (74 ± 11 mm Hg vs. 73 ± 11 mm Hg; p = 0.10), or heart rate (70 ± 13 beats/min vs. 71 ± 15 beats/min; p = 0.90) at the time of MRI and echocardiography. Baseline clinical and imaging demographics are listed in Table 1. On the basis of MRI findings, there were 51 (44%) patients with mild MR, 48 (41%) patients with moderate MR, and 18 (15%) patients with severe MR. On the basis of

TABLE 1 Baseline Patient Characteristics and Parameters of Systolic Variation of MR (N = 117)

Age, yrs	62 ± 14
Male	68 (58)
Hypertension	56 (50)
Diabetes	13 (12)
Hyperlipidemia	38 (34)
Smoking	13 (12)
Coronary artery disease	12 (10)
Dyspnea	40 (36)
Primary MR	104 (80)
Prolapse	43 (37)
Flail	35 (30)
Secondary MR	13 (11)
Echocardiography MR severity	
Mild	13 (11)
Moderate	38 (33)
Severe	66 (56)
MRI MR severity	
Mild	51 (44)
Moderate	48 (41)
Severe	18 (15)
CWTI	0.97 ± 0.10
Holosystolic	109 (93)
Nonholosystolic	8 (7)
CDTI	0.88 ± 0.11
Holosystolic	104 (89)
Nonholosystolic	13 (11)
Systolic variation score	0.55 ± 0.22

Values are mean ± SD or n (%).

CDTI = color Doppler time index; CWTI = continuous wave time index; MR = mitral regurgitation; MRI = magnetic resonance imaging.

echocardiography findings, there were 13 (11%) patients with mild MR, 38 (33%) patients with moderate MR, and 66 (56%) of patients with severe MR.

There were 47 (40%) patients with no discordance between MRI and echocardiography, 54 (46%) patients with 1 grade of discordance, and 16 (14%) patients with 2-grade discordance. The majority of patients had holosystolic MR by both CDTI and CWTI (Table 1). The Doppler CW signal was on average visible during 97% of systole, and the color Doppler jet was visible on 88% of systolic frames. There was on average an approximately 2-fold difference in the regurgitant rate during systole by SVS.

DISCORDANCE AND MEASURES OF SYSTOLIC VARIATION. Of the measures of MR systolic variation, only the SVS was associated with discordance between echocardiography and MRI (concordant: 0.47 ± 0.21 vs. discordant: 0.60 ± 0.23; $p = 0.003$). The mean SVS was higher in patients with discordance compared with patients without discordance (Table 2), and Figure 4 illustrates that patients with 2 degrees of discordance had a significantly higher SVS than patients with 1 degree of discordance ($p < 0.0001$ between groups). On univariate and multivariate analysis, only higher SVS was associated discordance between echocardiography and MRI (Table 3). ROC analysis shows that SVS has a moderate predictive power of discordance (area under the curve: 0.66; $p = 0.003$), with an SVS of 53 having a sensitivity of 61% and a specificity of 65% to predict discordance (Figure 5).

MEASURES OF SYSTOLIC VARIATION AND MR SEVERITY. The SVS had an inverse relationship with the severity of MR, with the greatest amount of systolic variation in patients in mild MR followed by those patients with moderate and severe MR (mild, 0.65 ± 0.20; moderate, 0.51 ± 0.21; severe, 0.36 ± 0.16; $p < 0.0001$). The CDTI increased with increasing severity of MR by echocardiography so that the more severe the MR, the greater the number of systolic frames that contained visible Doppler color signal ($p = 0.01$). The CWTI had no relationship with the severity of MR by echocardiography ($p = 0.50$).

There was no difference in the SVS between patients with and without degenerative MR or functional MR (Figure 6). Patients with eccentric mitral regurgitant jets, flail mitral leaflets, holosystolic CDTI, and holosystolic CWTI had less systolic variation than patients with central mitral regurgitant jets, those without a flail leaflet, those with a nonholosystolic CDTI, and those with nonholosystolic CWTI. However, even among these groups, the mean change between the lowest regurgitant rates and the peak regurgitant rates was 52% for eccentric jets, 44% for flail leaflets, 53% for holodiastolic CDTI, and 53% for holosystolic CWTI.

TABLE 2 Characteristics of Mitral Valve Disease and MR According to the Presence or Absence of Discordance

	No Discordance (n = 48)	Discordance (n = 69)	p Value
Degenerative MR	38 (81)	56 (80)	0.90
Functional MR	5 (11)	8 (11)	0.90
Flail leaflet	16 (34)	19 (28)	0.50
Eccentric color Doppler jet	29 (62)	46 (66)	0.60
Nonholosystolic color Doppler jet	4 (9)	4 (6)	0.60
Nonholosystolic CW Doppler	5 (11)	8 (11)	0.90
CWTI	96 ± 11	97 ± 9	0.70
CDTI	74 ± 14	70 ± 12	0.10
Systolic variation score	0.47 ± 0.21	0.60 ± 0.23	0.003

Values are n (%) or mean ± SD.

CW = continuous wave; other abbreviations as in Table 1.

DISCUSSION

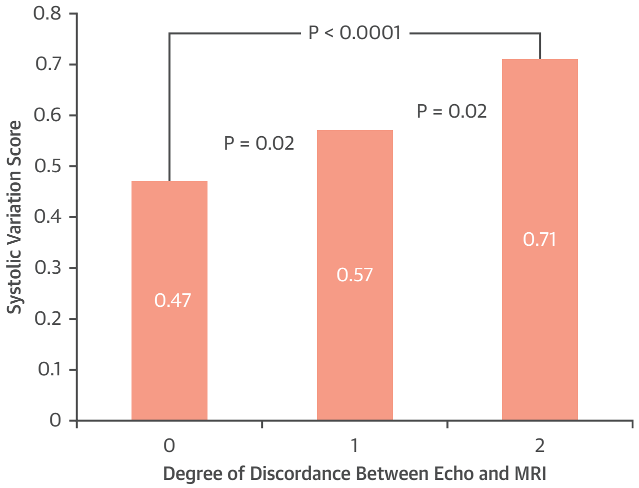
Noninvasive imaging is commonly used to assess the severity of MR. According to the current American

College of Cardiology and American Heart Association guidelines, confirmation of severe MR with noninvasive imaging is a necessary step in deciding which patients are appropriate for surgery (11). Indeed, current guidelines suggest that surgery is a class I or class IIA indication in patients with severe MR and an ejection fraction greater than 35% whether the patient is symptomatic or not. There are no guidelines for isolated mitral surgery for patients with nonsevere MR. Thus, the accurate diagnosis of severe MR is critical for proper patient management.

Several studies have shown substantial discordance between MRI and echocardiography in the assessment of MR severity (1–5,12,13). This is concerning. One study showed that in patients referred for mitral valve surgery, mitral regurgitant volume quantified by MRI predicted the degree of negative remodeling postoperatively, and echocardiography did not (7). In 2 other studies, the regurgitant volume by MRI was predictive of the onset of symptoms in patients with asymptomatic MR, but effective regurgitant orifice area and regurgitant volume by echocardiography was not (12,13). Interobserver variability for quantifying MR has been shown to be low for MRI and substantially higher for echocardiography (1,14–16). The foregoing findings suggest that MRI is more accurate than echocardiography for assessing MR severity.

ASSOCIATION BETWEEN DISCORDANCE AND SYSTOLIC VARIATION. In this study, we explored whether the degree of systolic variation of MR is associated with discordance between echocardiography and MRI. We assessed systolic variation of MR by using 2 echocardiographic methods and a previously published MRI method (7). We found a direct relationship between the degree of discordance between MRI and echocardiography and the systolic variation of regurgitant rate as measured by the SVS. Greater systolic variation of regurgitant rate was associated with greater discordance between the 2 techniques. MRI showed that the degree of systolic variation was generally higher in patients with mild MR and lower in patients with severe MR. Patients with mild MR who have a large amount of systolic variation could have high regurgitant rate for a very short amount of time. This finding is important considering that the most commonly relied on parameters used by echocardiography, such as the size of the color jet, as well as PISA and vena contracta, rely on a single measurement taken during systole, when the regurgitant

FIGURE 4 Association of the Mean SVS and the Discordance Between Echocardiography and MRI



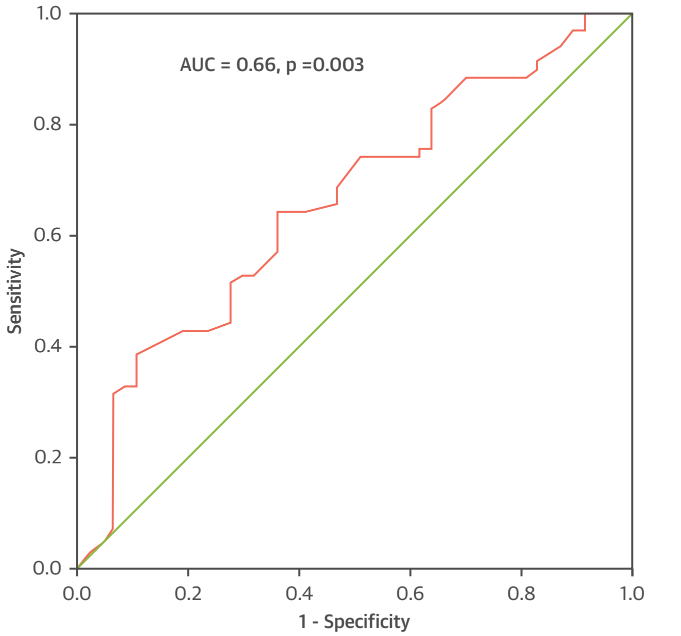
Greater temporal variation of mitral regurgitant severity was associated with greater degree of discordance between echocardiography (Echo) and magnetic resonance imaging (MRI). SVS = systolic variation score.

TABLE 3 Univariate and Multivariate Analysis to Predict the Presence of Discordance Between Echocardiography and MRI

	Univariate Predictors				Multivariate Predictors			
	B	Beta	95% CI	p Value	B	Beta	95% CI	p Value
Atrial fibrillation	−1.062	0.35	0.04–3.20	0.30	–	–	–	–
Eccentric jet	−0.182	0.83	0.39–1.80	0.60	–	–	–	–
LVEDV index	−0.012	0.99	0.97–1.005	0.20	–	–	–	–
LA volume index	0.007	1.007	0.99–1.02	0.50	–	–	–	–
Flail leaflet	0.441	1.554	0.70–3.50	0.30	–	–	–	–
Secondary MR	−0.12	0.89	0.27–2.90	0.80	–	–	–	–
Primary MR	0.006	1.006	0.40–2.60	1.00	–	–	–	–
CDTI	−0.004	0.996	0.97–1.03	0.80	–	–	–	–
CWTI	0.004	1.004	0.97–1.04	0.80	–	–	–	–
SVS	2.87	17.629	2.60–119.00	0.003	2.776	16.049	2.4–108.0	0.004

CI = confidence interval; LA = left atrial; LVEDV = left ventricular end-diastolic volume; SVS = systolic variation score; other abbreviations as in Table 1.

FIGURE 5 **ROC for the Prediction of Discordance Between Echocardiography and MRI Using the SVS**

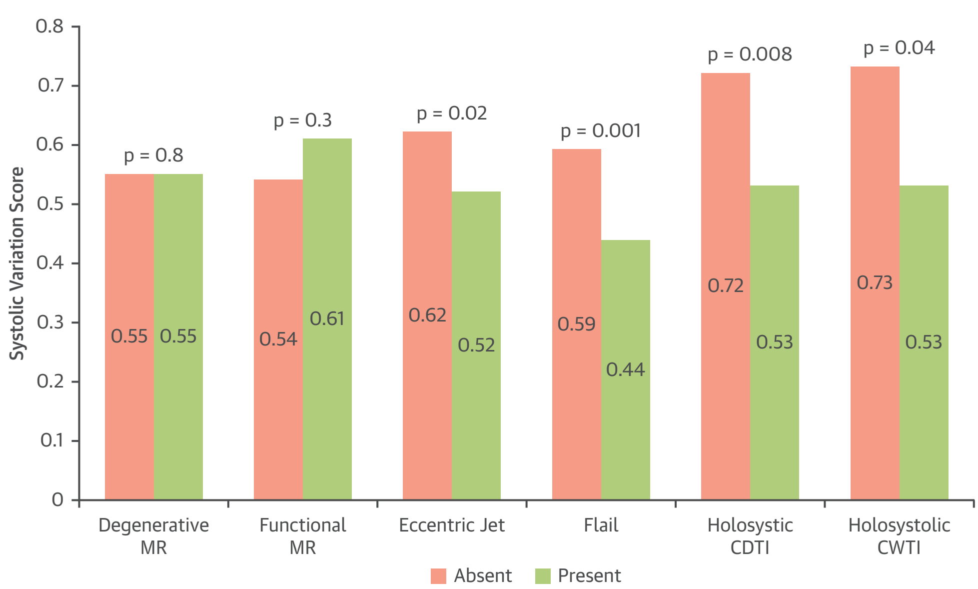


AUC = area under the curve; ROC = receiver-operating characteristics (curve); other abbreviations as in Figures 1 and 3.

rate is greatest. The greatest potential error for overestimation of regurgitant severity is in the patients with mild and moderate MR.

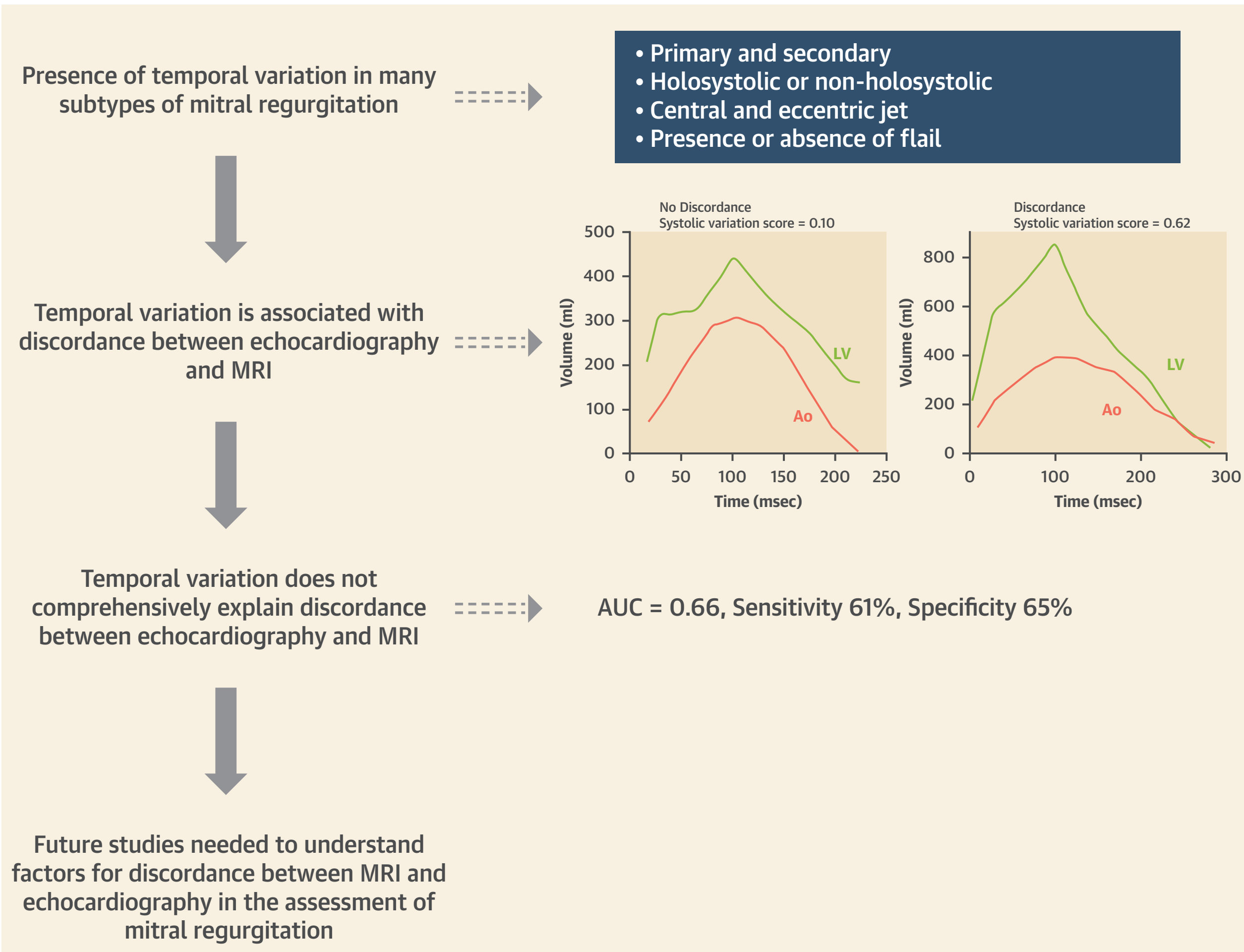
Among echocardiographic parameters of systolic variation, we found that most patients were holosystolic by CW Doppler and color Doppler as quantified by the CWTI and the CDTI. There was no relationship between the systolic variation according to the CWTI and CDTI and discordance between MRI and echocardiography. Thus, echocardiographic assessments of systolic variation were not helpful in determining which patients may have discordant noninvasive imaging results. Arguably, this finding reflects the limitations of the echocardiographic approaches to measuring systolic variation of MR because duration alone rather than a more quantitative assessment of regurgitant flow was derived. We did not measure jet density, as has been proposed (17), or the size of the color jet. However, for the same degree of regurgitation, CW jet density is dependent on technical variables such as gain, angle of insonation, and optimization of the echocardiographic window, whereas color jet dimensions are influenced by these and additional technical variables such as Nyquist limit. With no ready echocardiographic method to provide instantaneous regurgitation flow rates, it is not surprising that echocardiographic indices of systolic variability performed less well.

FIGURE 6 **SVS According to Subtypes of MR and Echocardiographically Based Characteristics of MR**



Temporal variation of mitral regurgitant severity is seen in patients with degenerative and functional mitral regurgitation (MR), central of eccentric jets, presence or absence of a flail leaflet, and holosystolic or nonholosystolic jet. Abbreviations as in Figures 1 and 3.

CENTRAL ILLUSTRATION **Systolic Variation Score: A Magnetic Resonance Imaging Assessment of the Temporal Variation of Mitral Regurgitation**



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The temporal variation of mitral regurgitant severity quantified by the magnetic resonance imaging-derived systolic variation score is seen in all subtypes of mitral regurgitation and is associated with discordance between magnetic resonance imaging and echocardiography. However, the temporal variation of mitral regurgitation does not comprehensively explain all the discordance and future studies are needed.

We further assessed systolic variation of MR in patients with degenerative or functional MR, eccentric or central jets, holosystolic or nonholosystolic MR, and flail or no flail. As previously published (7), we found significant systolic variation of MR even among patients with holosystolic regurgitant jets with an SVS of 53% when considering holosystolic jets by color Doppler and CW Doppler. This finding means that among those patients with holosystolic MR, the regurgitant rate changes on average by a factor of 2 when comparing the 2 lowest regurgitant rates with the peak rate, thus suggesting that when assessing patients with holosystolic MR jets, one cannot assume a constant regurgitant rate and must be cautious even in these patients. Furthermore, patients with degenerative MR are thought to have a greater amount of systolic variation of their MR because of the mechanism of their MR. In this study we found that as a group, patients with degenerative MR had similar systolic variation as those without degenerative MR. However, as would be expected, patients with flail leaflets did have less systolic variation than those without a flail leaflet. In patients with a flail leaflet, the mean change between the average of the lower regurgitant rates and the peak rate was 44%, whereas in patients without a flail leaflet, the regurgitant rate changed by 59%. Overall, these findings suggest that when evaluating MR severity with techniques that rely on measurements of the color Doppler regurgitant jet, one must be cautious and cognizant of the systolic variation of MR in all subtypes of MR, including degenerative MR, functional MR, and holosystolic MR, and in patients with eccentric MR jets.

It is important to highlight that although SVS was associated with discordance, on ROC analysis, SVS had only a moderate sensitivity and specificity to discriminate between those patients with or without discordance. This finding implies that whereas systolic variation of MR may be a contributor to discordance, there are other factors. Although it is important to note systolic variation, the absence of systolic variation does not preclude discordance between echocardiography and MRI. This is particularly true if relying on echocardiography alone because echocardiographic measures of systolic variation of MR were not useful in predicting discordance **(Central Illustration)**.

COMPARISON WITH PRIOR STUDIES. Prior studies have assessed the effect of systolic variation of MR. Early work by Smith et al. (18) quantified the variation in the color Doppler mitral regurgitant jet in 29 patients with primary and secondary MR. These investigators noted that throughout systole the color Doppler jet size varied by a mean of 301%, and the mean difference in jet/LA area was 4.4 cm^2. Additionally Smith et al. (18) reported that the period of systole during which the peak jet was seen also varied considerably. These findings are consistent with the current study, which found systolic variation in both primary and secondary MR. Shiota et al. (19) studied the systolic variation of the regurgitant orifice area in a sheep model. These investigators reported changes in the regurgitant orifice area during systole using electromagnetic flowmeters and Doppler echocardiography (19). Schwammenthal et al. (20) calculated instantaneous mitral regurgitant flow rates using M-mode recordings of the PISA. These investigators described patterns of mitral regurgitant flow, including late peaking, early peaking, and midsystolic peaking, and found a relationship between the instantaneous regurgitant flow and the instantaneous regurgitant orifice area. In agreement with the current study, these investigators reported a significant amount of systolic variation of regurgitant severity in both degenerative and functional MR. In patients with mitral valve prolapse the ratio between peak regurgitant flow and average regurgitant flow was 2.6, whereas in patients with functional MR the ratio was 3.2. Schwammenthal et al. (20) concluded that relying on a single PISA measurement could lead to significant overestimation of regurgitant volume.

Similarly, Enriquez-Sarano et al. (21), using effective regurgitant orifice area, reported a >3-fold change of mitral regurgitant rate in patients with mitral valve prolapse. Topilsky et al. (8) studied patients with mitral valve prolapse and compared patients with holosystolic MR with those with midsystolic or late systolic regurgitation. These investigators reported a significantly shorter duration of MR in patients with mid or late regurgitation, a finding that was reflected in the ~50% less regurgitant volume in that group. Hung et al. (22) studied patients with functional MR by using M-mode PISA and reported significant changes in regurgitant orifice area during systole, which was highly influenced by transmitral pressures and less so by mitral annular area. Thus, prior studies relying on either Doppler jet dimensions or PISA without an outside comparator found significant systolic variations in both degenerative and functional MR, thereby highlighting the pitfalls of relying on a single systolic measurement.

One study, by Buck et al. (9) used regurgitant volume by MRI to assess the effect of systolic variation on the accuracy of PISA-based regurgitant volume by echocardiography. These investigators compared several PISA-based methods to calculate regurgitant volume against mitral regurgitant volume by MRI. The methods included the traditional PISA measurement made at a single point during systole, as well as 2 methods that integrate the change in PISA size over time. These investigators found a moderate correlation between the single PISA measurement and regurgitant volume by MRI with improved correlation when they used the methods that integrate the changes in PISA radius over time. Additionally, Buck et al. (9) described 3 primary patterns of M-mode PISA; flat, concave, and convex, with significant variation of MR rate in 74% of the patients studied.

An advantage of MRI over echocardiography is that MRI does not rely on analysis of the mitral regurgitant jet, which is dynamic in nature. Instead, it relies on the difference between left ventricular stroke volume and forward flow. MRI's indirect approach avoids the pitfalls of analyzing the characteristics of the color Doppler regurgitant jet and making geometric assumptions to calculate transmitral flow. The ASE recommends correcting for systolic variation of MR when calculating regurgitant volume by using the time-velocity integral of the regurgitant jet. However, this method also has pitfalls because it can be uncertain whether an incomplete envelope results from systolic variation of MR or from imperfect alignment of the Doppler beam with the regurgitant jet. One study found that PISA-based regurgitant volume, which used the time-velocity integral method, had only a moderate correlation with MRI-based regurgitant volume (1).

STUDY LIMITATIONS. Although this study was a multicenter prospective study, it included a relatively small number of patients. In addition, the majority of patients in this study had primary MR, and caution should be exercised with regard to extrapolating these findings to patients with secondary MR. In addition, as previously noted, the echocardiographic approaches do not consider the density of the CW spectrum or size of the color Doppler jet, both of which may vary considerably even when a jet is holosystolic. Finally, although not all the MRI and echocardiographic studies were performed on the same day, given similar hemodynamic status at the time of MRI and echocardiographic evaluation, we do not believe that this leads to significant disparity.

CONCLUSIONS

Discordance between MRI and echocardiography assessment of MR severity is associated with systolic variation of MR as quantified by MRI, but not with the CW Doppler- and color Doppler-based echocardiographic measures of systolic variation. The etiology of MR (functional vs. degenerative) and other echocardiographic markers were not different in those patients with and without discordance between noninvasive imaging modalities. This study reinforces the general limitations of relying on quantitative methods that use a single systolic measurement and highlights the advantage of MRI, which does not rely on jet characteristics to assess MR severity. However, systolic variation as measured by MRI had only moderate sensitivity and specificity for predicting discordance, a finding highlighting that other factors cause discordance between MRI and echocardiography.

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PERSPECTIVES

COMPETENCY IN MEDICAL KNOWLEDGE: The temporal variation of the regurgitant rate is common among patients with MR and is associated with discordance between MRI and echocardiography, but it is not the sole reason for discordance. The temporal variation can be quantified by MRI, and this highlights the strength of MRI, which does not rely on single echocardiography-based measures in time, such as PISA and vena contracta.

TRANSLATIONAL OUTLOOK: The impact of the temporal variation of MR on diagnostic accuracy is not well studied. Additional larger studies are required to understand more clearly the relationships among temporal variation, diagnosis, and prognosis in patients with MR.

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KEY WORDS echocardiography, mitral regurgitation, MRI, systolic variation