Quantitation of Functional Mitral Regurgitation During Bicycle Exercise in Patients With Heart Failure

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OBJECTIVES We sought to examine the feasibility and reliability of quantifying mitral regurgitation (MR) during exercise by Doppler echocardiography in patients with heart failure and to assess the relationship between dynamic MR and systolic pulmonary artery pressure changes.

BACKGROUND The severity of MR can be quantified by using several echocardiographic methods. Quantitation of MR during dynamic exercise has not yet been performed.

METHODS Symptom-limited, semi-supine two-dimensional and Doppler echocardiograms during bicycle exercise were obtained in 27 consecutive patients with heart failure and functional MR. Regurgitant volume was measured at rest and during exercise by the proximal isovelocity surface area (PISA) method and by quantitative Doppler echocardiography. Exercise-induced changes in regurgitant volume were compared with changes in the regurgitant jet area to left atrial area ratio, vena contracta width and trans-tricuspid pressure gradient.

RESULTS The regurgitant volume measured by the PISA method increased from 21 ± 12 ml (range 5 to 55) at rest to 39 ± 23 ml (range 8 to 85) during exercise (p < 0.0001). The difference between two observers was low for both rest (2.0 ± 2.7 ml) and exercise measurements (3.5 ± 6.2 ml). The regurgitant volume measured by quantitative Doppler echocardiography increased from 29 ± 13 to 49 ± 24 ml (p = 0.0001). Excellent correlation between the two methods was obtained with exercise (r = 0.92). Exercise-induced changes in regurgitant volume, as measured by the PISA method, correlated well with regurgitant volume changes measured by quantitative Doppler echocardiography (r = 0.88), changes in vena contracta width (r = 0.82) and changes in trans-tricuspid pressure gradient (r = 0.73), but not with changes in regurgitant jet area to left atrial area ratio (r = 0.29). Seventeen patients stopped exercise because of fatigue and 10 because of dyspnea. These 10 patients exhibited greater increases in regurgitant volume (34 ± 6 vs. 11 ± 8 ml), corresponding to a significant elevation of the trans-tricuspid gradient (48 ± 14 vs. 20 ± 14 mm Hg).

CONCLUSIONS Quantitation of functional MR during exercise is feasible in patients with heart failure. There is a good correlation between regurgitant volume measured during exercise by the PISA method and that obtained by quantitative Doppler echocardiography, suggesting that the technique is reliable. An increase in mitral regurgitant volume during dynamic exercise correlates well with elevation of systolic pulmonary artery pressure. (J Am Coll Cardiol 2001; 38:1685–92) © 2001 by the American College of Cardiology.

Functional mitral regurgitation (MR) is frequently present in patients with heart failure (1) and is a marker of adverse outcomes (2). Mitral regurgitation may be dynamic in these patients, resulting in worsening of dyspnea and contributing to progressive left ventricular (LV) dilation and dysfunction (3). Recently, several Doppler methods that allow quantitation of MR have been validated. Two methods have been found reliable and clinically applicable: the first is based on the calculation of aortic and mitral stroke volumes (quantitative Doppler echocardiography) (4), whereas the second is the flow convergence or proximal isovelocity surface area (PISA) method (5,6). The dynamic characteristics of functional MR have been defined at rest (7) and after medical therapy (8,9). The effects of isometric exercise on MR have been studied (8,10). Echocardiography during dynamic exercise has also been performed in patients with MR, either using semi-quantitative grading (with its significant limitations) (11,12) or measuring only LV volumes and ejection fractions (13). Although echocardiography is well suited to the dynamic assessment of exercise-induced changes, quantitative Doppler methods have not yet been characterized during dynamic exercise.

The purposes of this study were to determine: 1) the feasibility and reliability of quantifying MR during exercise by Doppler echocardiography in patients with heart failure and functional MR; and 2) the relationship between dynamic regurgitation and systolic pulmonary artery pressure changes during exercise.

Patient group. The patient group consisted of 27 consecutive patients presenting with heart failure and at least mild functional MR. Heart failure was attributed to ischemic (n = 26) or nonischemic (n = 1) etiologies by coronary angiography and contrast ventriculography. All patients had LV ejection fraction <35% and LV end-diastolic diameter >58 mm and were classified in New York Heart Association (NYHA) functional class I (n = 3), II (n = 14) or III (n = 10). Exclusion criteria were heart failure secondary to valvular heart disease, the presence of aortic regurgitation,
NYHA functional class IV, atrial fibrillation or rest heart rate >100 beats/min. Pharmacologic therapy included an angiotensin-converting enzyme inhibitor in all 27 patients, a diuretic in 24, a beta-blocker in 8, amiodarone in 5, digoxin in 1 and a calcium-channel blocker in 1. The protocol was approved by the Human Ethical Committee of the University Hospital, and all patients gave informed consent.

**Exercise echocardiography.** Patients performed symptom-limited, graded, semi-supine bicycle exercise using an exercise table that could be tilted up to 45° in the left lateral decubitus position and that allowed continuous two-dimensional and Doppler echocardiographic studies. The initial work load was 25 W for 6 min, with 25-W increments in load every 2 min. Continuous electrocardiographic (ECG) monitoring was performed. Blood pressure was measured every 2 min, as which time a 12-lead ECG was also recorded. Beta-blockers were stopped 48 h before the exercise test. All other cardiovascular drugs were maintained.

**Echocardiographic imaging and analysis.** Both baseline and exercise echocardiographic studies were performed in the cycling position on the exercise table, using a phased-array Acuson Sequoia imaging device equipped with a 3.5-MHz transducer. All echocardiographic and Doppler recordings were obtained in digital format and stored on magneto-optical disks for further off-line analysis. For each measurement, a minimum of three cardiac cycles was averaged. Two-dimensional echocardiography was performed in the apical four-chamber view by using tissue harmonic imaging to optimize endocardial definition. The area–length method was used to calculate end-diastolic and end-systolic LV volumes and ejection fraction (14). The frame captured at the R wave of the ECG was selected as the end-diastolic frame, and the frame with the smallest LV cavity was considered as the end-systolic frame. The mitral annular diameter (inner edge) was measured at rest and during exercise, as previously described (4). The diameter of the LV outflow tract (inner edge) was measured only at rest in the parasternal long-axis view. The mitral and aortic stroke volumes were calculated as the pulsed-wave Doppler time–velocity integral × the area of the annuli of the mitral and aortic valves, respectively. The regurgitant volume (quantitative Doppler echocardiography) was calculated as the difference between mitral and aortic stroke volumes.

**Flow-convergence method.** The theoretic basis for the PISA method has been previously described (5,15). Color flow imaging of MR was optimized with a small color angle from the apical window. The image of the mitral valve was expanded by using regional expansion selection. The color flow zero baseline was shifted downward to increase hemispheric PISA. The negative aliasing velocity—usually 20 to 40 cm/s—was adjusted to obtain satisfactory hemispheric PISA. These operations were performed before storage at rest and exercise. At least five cardiac cycles at rest and at least seven during exercise were stored. The radius of the PISA was measured from three frames with optimal PISA. The largest radius, usually in mid-systole, was selected for analysis. The maximal regurgitant velocity and the regurgitant time–velocity integral were obtained with continuous wave Doppler echocardiography. The regurgitant volume and effective regurgitant orifice area were calculated using standard formulae.

**Semi-quantitative assessment.** Vena contracta width was measured from the apical four-chamber view (16). The color flow imaging frame rate was maximized by selecting the narrowest sector angle, and regional expansion selection was used. The largest vena contracta diameter was measured for three cardiac cycles and averaged. Left atrial area and regurgitant jet area were measured by planimetry from the apical four-chamber view, allowing calculation of the ratio of regurgitant jet area to left atrial area. Systolic pulmonary artery pressure was estimated from the systolic tricuspid pressure gradient (in mm Hg) using the modified Bernoulli equation (AP = 4 V², where V = maximal tricuspid insufficiency velocity in m/s). When the tricuspid regurgitant envelope was not pan-systolic at rest, intravenous injections of 5 ml of agitated isotonic saline were given at rest and during exercise (17). To avoid the use of another window (subcostal) during exercise, right atrial pressure was not estimated.

**Sequence of imaging during exercise.** The stepwise sequence used in all patients at the end of the exercise period was as follows: LV outflow tract time–velocity integral, continuous wave Doppler recording of tricuspid regurgitation, mitral annular diameter, mitral inflow time–velocity integral, regurgitant jet area, vena contracta width, PISA recording and continuous wave Doppler recording of MR, followed by a second continuous wave Doppler recording of tricuspid regurgitation.

**Interobserver variability.** To determine the interobserver variability, all measurements—both at rest and during exercise—were repeated by a second independent observer in 10 randomly selected patients. All measurements were obtained from the series of cardiac cycles digitally stored at rest and during exercise. The interobserver variability was measured by the Bland-Altman method (18). It was also expressed as the ratio of the standard deviations of the differences between the two measurements divided by the respective mean values (%). The correlation coefficients between the two measurements were calculated.

**Statistical analysis.** All data management and statistical analyses were performed using GraphPad InStat tm, version 2.04a, on a personal computer. Measurements are expressed
as the mean value ± SD. Differences between variables at rest and at peak exercise were assessed using a two-tailed, paired Student t test. The relationship between the PISA method and quantitative Doppler echocardiography for measuring the regurgitant volume at rest and during exercise was analyzed with linear regression and the Bland-Altman method (18), plotting and regressing the methods’ difference against the methods’ mean value. To estimate the correlations between exercise-induced changes in variables, a simple XY linear correlation and regression analysis was performed. Statistical significance was set at p < 0.05.

RESULTS

Exercise test. The patients exercised for an average of 8.7 ± 2.8 min. Of the 27 study patients, 17 stopped exercise because of fatigue and 10 because of dyspnea. Heart rate increased from 78 ± 12 beats/min at rest to 113 ± 19 beats/min at peak exercise (p = 0.0001). Systolic blood pressure increased from 132 ± 16 to 155 ± 23 mm Hg (p = 0.0002). No patient had chest pain, ischemic ECG changes or significant arrhythmias. Wall motion changes were not specifically assessed, precluding identification of exercise-induced ischemia.

Quantitative two-dimensional echocardiography. Left ventricular end-diastolic volume remained unchanged: 143 ± 38 to 143 ± 36 ml (p = NS). End-systolic volume decreased from 100 ± 40 to 86 ± 30 ml (p = 0.002), whereas ejection fraction increased significantly from 31 ± 9% to 41 ± 11% (p = 0.0001). Mitral annular diameter increased from 31 ± 3.3 mm at rest to 31.8 ± 3.4 mm during exercise (p = 0.0004).

Feasibility of Doppler echocardiography during exercise. Quantitative and semi-quantitative measurements could be obtained in all 27 patients. The mean total time of digital acquisition and storage was 135 ± 34 s (range 75 to 195). An optimal flow-convergence region could be obtained in 22 patients (81%) at rest and in 25 patients (92%) during exercise. Figure 1 shows an example of the PISA obtained at baseline and during exercise. A full envelope of the jet of MR was obtained in 26 patients. A full envelope of the jet of tricuspid regurgitation was obtained at baseline in 24 patients. Contrast enhancement with agitated saline was successful in the remaining patients. Technically adequate Doppler signals were obtained in all patients.

Reproducibility. At baseline, excellent correlations were found between the two observers for regurgitant volume calculated by both the PISA (r = 0.96) and Doppler (r = 0.98) methods, as well as for the trans-tricuspid pressure gradient (r = 0.97). The correlations remained excellent during exercise (r = 0.98, 0.94 and 0.97, respectively). The absolute differences between the two observers for regurgitant volume by the PISA method were 2.0 ± 2.7 ml at rest and 3.5 ± 6.2 ml during exercise. For regurgitant volume by the Doppler method, the differences were 5.0 ± 6.6 ml at rest and 6.2 ± 10.8 ml during exercise (Fig. 2). Interobserver variability was higher for the semi-quantitative methods. When expressed as the standard deviation of the differences between the two measurements divided by the respective mean values, the variability of vena contracta width decreased from 20% at rest to 10% during exercise, whereas the variability of the jet area to left atrial area ratio increased from 20% at rest to 34% during exercise.

Doppler echocardiography. Exercise-induced changes. The regurgitant volume and regurgitant orifice area calculated by the PISA method increased from 21 ± 12 ml at rest (range 5 to 55) to 39 ± 23 ml during exercise (range 8 to 85) and from 15 ± 8 mm² (range 4 to 37) to 27 ± 15 mm² (range 7 to 52), respectively (all p < 0.0001). The regurgitant volume calculated by the quantitative Doppler method, vena contracta width and jet area to left atrial area ratio increased from 29 ± 13 to 49 ± 24 ml, from 4 ± 1 to 6 ± 2 mm and from 23 ± 10% to 37 ± 13%, respectively (all p < 0.0001). The trans-tricuspid pressure gradient increased from 26 ± 9 mm Hg (range 10 to 42) at rest to 55 ± 20 mm Hg (range 22 to 98) at peak exercise (p < 0.0001). Correlations between measurements of MR. Regurgitant volume obtained by the PISA and Doppler methods correlated well at rest (r = 0.78, p < 0.0001) and even better during exercise (r = 0.92, p = 0.0001) (Fig. 3). The absolute values of the differences between the two methods
were 8.8 ± 7.5 ml at rest and 11.7 ± 8.5 ml during exercise. Quality-control plots using the Bland-Altman method showed that there was a trend toward overestimation of regurgitant volume by Doppler echocardiography. Good correlations were found between changes in regurgitant volume by the PISA and Doppler methods \( (r = 0.88, p < 0.0001) \). When the study group was divided in two groups—those above and those below the median increase in regurgitant volume (PISA method: 13 ml)—the correlation was not different for the 14 patients with an increase <13 ml \( (r = 0.82) \) and for the 13 patients with an increase >13 ml \( (r = 0.84) \). The correlation between exercise-

Figure 2. Scatterplots of the differences between the two observers on the y-axis and the mean values obtained by the two observers on the x-axis for regurgitant volume by the PISA (RVP) method and regurgitant volume by the Doppler (RVd) method at rest \( \text{(A and C)} \) and during exercise \( \text{(B and D)} \).

Figure 3. Scatterplots of the differences between the methods (Doppler method minus PISA method) and the mean values of the methods for calculating mitral regurgitant volume at rest \( \text{(left)} \) and during exercise \( \text{(right)} \).
induced changes in regurgitant volume and changes in vena contracta width was $r = 0.82$ ($p < 0.0001$) in the whole study group, but was not statistically significant in the patients in the subgroup with below-median increases in regurgitant volume ($r = 0.34$). No significant correlation was found between the increase in regurgitant volume and the increase in the jet area to left atrial area ratio ($r = 0.29$, $p = \text{NS}$).

**EXERCISE-INDUCED CHANGES IN TRANS-TRICUSPID PRESSURE GRADIENT.** The exercise-induced increase in trans-tricuspid pressure gradient correlated best with the increase in regurgitant volume, as calculated by the PISA method ($r = 0.73$, $p < 0.0001$) (Fig. 4). The correlations with changes in regurgitant volume assessed by Doppler echocardiography, with vena contracta width and with the jet area to left atrial area ratio were $r = 0.69$ ($p = 0.0001$), $r = 0.67$ ($p = 0.0004$) and $r = 0.45$ ($p = 0.02$), respectively.

**EXERCISE-INDUCED SYMPTOMS.** Exercise-induced increases in regurgitant volume (by PISA) and in the trans-tricuspid pressure gradient were higher in the 10 patients who stopped exercise because of dyspnea than in the 17 patients who stopped because of fatigue: $36 \pm 7$ versus $11 \pm 8$ m l ($p = 0.002$) and $48 \pm 14$ versus $20 \pm 14$ mm Hg ($p = 0.03$), respectively. Although there was overlap between the groups in trans-tricuspid pressure gradient changes, the magnitude of increase in regurgitant volume completely distinguished the two groups (Fig. 4).

**DISCUSSION**

This study shows that quantitation of MR is feasible during exercise in patients with ischemic or functional MR. The PISA method appears to be more rapid and practical when the flow-convergence region is optimal. The quantitative Doppler method is applicable in patients with nonoptimal geometry of the flow-convergence region. Increases in vena contracta width may be useful, but are limited to patients with large exercise-induced increases in MR. Regurgitant jet area and the jet area to left atrial area ratio should not be used to assess MR during exercise. Estimated increases in regurgitant volume correlate well with increases in systolic pulmonary pressure, as assessed by the trans-tricuspid pressure gradient, but more effectively determine which patients will stop exercise because of dyspnea as opposed to fatigue.

**Feasibility.** In the present study, the feasibility of measuring regurgitant volume by the PISA method was, surprisingly, better during exercise than at rest. Enriquez-Sarano et al. (15) reported a feasibility of 92% at rest in a large population of patients with MR of various etiologies. Interobserver variability was lower for exercise measurements than for rest measurements (9% vs. 12%). Patients with a dilated LV usually have excellent echogenicity; the regurgitant jet is usually centrovalvular, rather than eccentric. These conditions are favorable for appropriate definition of the flow-convergence region. However, 10 of our patients had a small regurgitant volume at rest, giving rise to a small PISA radius despite a low aliasing velocity. This may explain the better reproducibility during exercise as compared with at rest. Indeed, functional or ischemic MR usually implies a smaller regurgitant volume and orifice area, as compared with organic MR (19). The use of quantitative Doppler echocardiography to measure the volume of regurgitation during exercise may be an alternative in patients with a hemi-elliptic or asymmetric shape of the flow-convergence zone. Interobserver variability was also lower during exercise than at rest for calculation of regurgitant volume by the Doppler method (7% vs. 11%). However, this method is more technically demanding, because it requires the measurement of the mitral annular diameter and of two pulsed-wave Doppler velocity profiles, which obviously cannot be recorded simultaneously. Moreover, small changes in the position of the sample volume may affect time–velocity integrals.

Although semi-quantitative grading of MR would intu-
itively seem to be simpler and easier to obtain during exercise, measurements of jet area and vena contracta width showed higher interobserver variability, as compared with true methods of quantification. Significant interobserver variability in measuring jet area has previously been demonstrated (20). The mean difference in vena contracta measurements between two independent observers was 0.08 ± 0.09 cm at baseline and 0.06 ± 0.05 cm during exercise. The mean difference at baseline is higher than that found by Hall et al. (16), who recorded not only the apical views but also the parasternal long-axis view, which takes advantage of improved axial resolution (21).

**Reliability.** An excellent correlation was found between regurgitant volume during exercise obtained by the PISA and Doppler methods (r = 0.92). This close correlation is exactly the same as that reported by Enriquez-Sarano et al. (15), who compared the two methods under rest conditions.

FLOW-CONVERGENCE METHOD. Accurate quantitation of regurgitant flow rates by the flow-convergence method relies on optimal visualization of the flow-convergence region. The aliasing velocity of color flow mapping is essential for obtaining an appropriate PISA shape (22). There is obviously no information on the most appropriate aliasing velocity to be used during dynamic exercise. We empirically selected the velocity providing the best definition of the proximal flow-convergence zone. The ratio of the aliasing velocity to the peak orifice velocity was 5 ± 2% at rest and 4 ± 2% during exercise. For such a small ratio, no correction is required to avoid underestimation of flow (23). The pitfalls of this method have been established (15). Problems are more common with eccentric jets and severe MR, neither of which were present in our study patients. The most common error is overestimation of regurgitant flow; this may occur when the shape of the flow-convergence area is hemi-elliptical due to inappropriate aliasing velocity selection. Technical expertise is thus mandatory; a learning process is required to be able to select reliable loops within the short imaging time available during exercise.

QUANTITATIVE DOPPLER ECHOCARDIOGRAPHY. Quantitative Doppler echocardiography has proved to be a reliable method. The problem to avoid is overestimation of MR severity (4). This may be due to an overestimated mitral annular area or an overestimated time–velocity integral, or both. We carefully positioned the sample volume at the mitral annulus to avoid recording the higher velocities known to be present at the tip of the leaflets (24). Although the mitral annulus usually becomes more circular in MR, it can be distorted in patients with heart failure. Different methods have been used for the calculation of the mitral annulus area. Some investigators measure the diameter of the mitral annulus at the base of the leaflets at the time of maximal opening in the parasternal long-axis and apical four-chamber views and assume an elliptical orifice (16). Others image the mitral valve orifice in the parasternal short-axis view for planimetry of the maximal orifice area, followed by calculation of the mean mitral valve area as the product of the maximal valve area and the mean-to-maximal opening ratio recorded from guided M-mode echocardiograms in the same view (25). To simplify the measurement during exercise, we only used the apical four-chamber view, because we focused on this view for most MR recordings. Although the variables used for Doppler calculations were recorded during exercise before those used for the PISA method, mean regurgitant volumes calculated by the Doppler method were slightly larger than those obtained with the PISA method.

**VENA CONTRACTA.** Changes in vena contracta width correlated well with changes in regurgitant volume, but this was restricted to the subgroup of patients with increases in regurgitant volume during exercise that were greater than the median value. The correlation could have been higher if we had obtained the vena contracta from multiple views, especially the parasternal long-axis view. Although color flow mapping of the vena contracta of the MR jet is considered to be relatively quick and simple (16), it should be recognized that fine angulation of the transducer and careful adjustment of color Doppler gain with the regional expansion selection mode are required to accurately distinguish the vena contracta from the proximal jet width.

**JET AREA.** Recording of the color Doppler regurgitant jet area would intuitively appear to be the easiest method to use during dynamic exercise. However, the jet area is influenced by the mechanism of regurgitation (26), left atrial size (27), physical jet factors (28) and technical factors, such as gain settings and pulse repetition frequency (20). Furthermore, the color Doppler jet area greatly overestimates the severity of functional MR (29). This study demonstrates moderate reproducibility of measurements, especially during exercise, and reveals a weak correlation between changes in jet area and changes in quantitative measures of MR.

**Relation to pulmonary pressures.** Pulmonary hypertension is associated with a poor prognosis in patients with LV dysfunction (30). The degree of pulmonary hypertension is widely variable and relates to LV diastolic function and the degree of functional MR (31). In this study, all patients exhibited an increase in systolic pulmonary pressure during semi-supine bicycle exercise. This increase showed significant variability, as calculated from trans-tricuspid regurgitant velocity changes. Increases in systolic pulmonary artery pressures were greatest in patients with marked dynamic MR. Exercise-induced increases in the trans-tricuspid pressure gradient correlated well with increases in regurgitant volume, as calculated by the PISA (r = 0.73) and Doppler (r = 0.7) methods, despite the error encountered by neglecting the increase in right atrial pressure with exercise. Other factors also play a role in the dynamic changes in pulmonary pressures during exercise, such as alterations of pulmonary resistance, left atrial dimensions and compliance and the pattern of neurohormonal activation. It should not be assumed that recording regurgitant signals from only the
tricuspid valve would provide sufficient useful information on dynamic MR. Exercise-induced increases in systolic pulmonary artery pressure showed an overlap between patients exhibiting fatigue and those with dyspnea. In contrast, increases in regurgitant volume were higher in all patients who stopped because of dyspnea than in patients who stopped because of fatigue.

**Study limitations.** Several limitations should be acknowledged. The pitfalls of the different methods used for MR assessment could be more important during exercise, mainly because of the short time available for gathering high-quality recordings. We studied a consecutive series of patients who were not selected because of their good echogenicity.

The accuracy of our measurements cannot be established because there is no satisfactory “gold standard” for quantifying regurgitant orifice volume or orifice area in patients, even under rest conditions (32). Although our results appear to be consistent, they need to be confirmed in future studies.

The continuous-wave Doppler technique used for calculating regurgitant volume and orifice area by the PISA method assumes that this orifice area is roughly constant. However, clinical studies have demonstrated a dynamic variation of regurgitant orifice area in functional MR, with early and late systolic peaks and a mid-systolic decrease (25). Phasic changes in transmural pressure play a dominant role by acting to close the mitral leaflets more effectively when pressure reaches its peak in mid-systole (7). Digitized color M-mode imaging of the proximal flow-convergence region have been used for these observations. Limitations of color M-mode imaging for estimating MR flow rates have been noted (33). Furthermore, it is the amount of regurgitant flow, and not orifice size, that determines left atrial pressure and symptoms (34). Even if the mitral regurgitant orifice area decreases in mid-systole, 80% of regurgitant flow occurs in mid-systole because of maximal mid-systolic LV pressure (35).

In this feasibility study, we deliberately decided to focus on the apical four-chamber view to limit transducer displacements. Therefore, we did not record the apical two-chamber view; this would have allowed us to obtain LV volumes by using the bi-apical Simpson’s rule, bi-plane radii of vena contracta and bi-plane regurgitant jet area.

Finally, it should be emphasized that the results of this study cannot be extrapolated to patients with atrial fibrillation or to those with MR of other etiologies, especially mitral valve prolapse.

**Clinical implications.** There has recently been considerable interest in the quantitative evaluation of MR at rest. However, there is currently no information on dynamic exercise-induced quantitation of changes in MR. The present study demonstrated the following:

1. The PISA method can be performed during semi-supine exercise in a high proportion of patients with heart failure and functional MR. If the flow-convergence region is appropriate, it is the most reproducible and probably the most practical method. The regurgitant volume calculated by the PISA method is highly correlated with the regurgitant volume, as assessed by the Doppler method, suggesting that this tool is reliable.

2. Although it is more technically demanding, especially during exercise, the Doppler method can be an alternative in patients with a suboptimal flow-convergence definition.

3. Changes in vena contracta width can be useful, but only in patients with large exercise-induced increases of mitral regurgitant flow.

4. Regurgitant jet area and jet area to left atrial area ratios should not be used to assess functional MR during exercise.

5. Changes in systolic pulmonary artery pressure during exercise correlate well with increases in regurgitant volume. The latter, but not the former, distinguished patients who stopped exercise because of dyspnea from those who stopped because of fatigue.

Further studies are necessary to address the determinants and mechanisms of dynamic MR during exercise and to assess the clinical usefulness and prognostic importance of this method.

**References**


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