Indirect Echocardiographic Markers of Procedural Success in Mitral Transcatheter Interventions: A Case Series

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INTRODUCTION

Mitral transcatheter interventions, such as mitral transcatheter edge-to-edge repair (m-TEER), have emerged over the past decade as a less-invasive option for patients with severely symptomatic primary or secondary mitral regurgitation (MR) who are at high surgical risk and have suitable valvular anatomy.[1-3] Accurately assessing residual MR, a marker of procedural success, with intraprocedural transesophageal echocardiography (TEE) remains challenging. Traditional echocardiographic methods, such as effective regurgitant orifice area (EROA) or vena contracta (VC) width, often become unreliable due to altered valve anatomy.[4,5] This case series highlights indirect echocardiographic parameters that can be used when traditional methods are insufficient for MR quantification after mitral intervention, with a majority of cases focusing on m-TEER. Our aim is to share high-quality images demonstrating the utility of these indicators, highlight the American Society of Echocardiography guidelines describing the strengths and weaknesses of the various MR assessments, and emphasize less commonly reported markers, such as spontaneous echo contrast (SEC) and gradients across the iatrogenic atrial septal defect (ASD).[4,5]

VIDEO HIGHLIGHTS

Video 1: Case 1. Two-dimensional TEE, midesophageal long-axis view with color-flow Doppler preprocedure, demonstrates central severe MR jet that occupies most (>50%) of the left atrium.

Video 2: Case 1. Two-dimensional TEE, midesophageal long-axis view with color-flow Doppler after m-TEER, demonstrates significant reduction in the severity of the MR and no MS.

Video 3: Case 4. Two-dimensional TEE, long-axis (90°) zoom view of the LAA preprocedure, demonstrates no significant SEC despite chronic atrial fibrillation and LAA stasis.

Video 4: Case 4. Two-dimensional TEE, long-axis (60°) zoom view of the LAA after a transcatheter mitral ViV procedure, demonstrates the development of severe SEC in the LAA, suggesting a marked reduction in the severity of the MR.

View the video content online at www.cvcasejournal.com.

CASE PRESENTATION

Case 1

An 80-year-old woman with a history of coronary artery bypass grafting and chronic kidney disease presented with worsening shortness of breath with mild exertion over the past few years. Vital signs were as follows: blood pressure (BP) 134/48, heart rate (HR) 65 beats per minute (BPM) in normal sinus rhythm (NSR), and oxygen saturation (SPO_2) 91% on room air. Physical examination revealed a loud holosystolic murmur, and pulmonary examination was clear to auscultation. On two-dimensional (2D) TEE the patient had severe degenerative MR with prolapse and flail of the middle (P2) scallop of the posterior mitral leaflet. By the proximal isovelocity area (PISA) method, the mitral EROA was 0.40 cm^2. Color-flow Doppler showed a large, central MR jet occupying most of the left atrium suggestive of severe MR (Figure 1A, Video 1, Table 1). The calculated left ventricular outflow tract (LVOT) stroke volume was 31.0 mL (Table 1).

During m-TEER procedure, one device was deployed across the A2/P2 line. Conventional measurements of MR were not pursued given the presence of 2 MR jets after intervention. Color-flow Doppler assessment of the mitral valve (MV) immediately after m-TEER revealed a significant decrease in MR, now displaying as 2 small jets with minimal left atrial (LA) involvement (Figure 1B, Video 2, Table 1). The LVOT stroke volume rose to 53.0 mL (Table 1). Because the residual MR on color-flow Doppler involved less than half of the left atrium and the LVOT stroke volume increased after m-TEER, the procedure was considered successful.

Case 2

A 53-year-old man with left ventricular ejection fraction (LVEF) of 30% due to ischemic cardiomyopathy and known functional MR due to restricted motion of the posterior and anterior leaflets presented with persistent dyspnea despite optimal guideline-directed medical therapy. Vital signs were as follows: BP 110/72, HR 102 BPM in NSR, SPO_2 98% on room air. Physical examination revealed a grade II/VI systolic ejection murmur, regular tachycardia, no pedal edema, and clear lungs to auscultation. Continuous-wave Doppler (CWD) revealed a holosystolic MR jet with a maximum velocity of 3.5 m/sec and a triangular, early peaking spectral Doppler profile (Figure 2A, Table 1). Proximal

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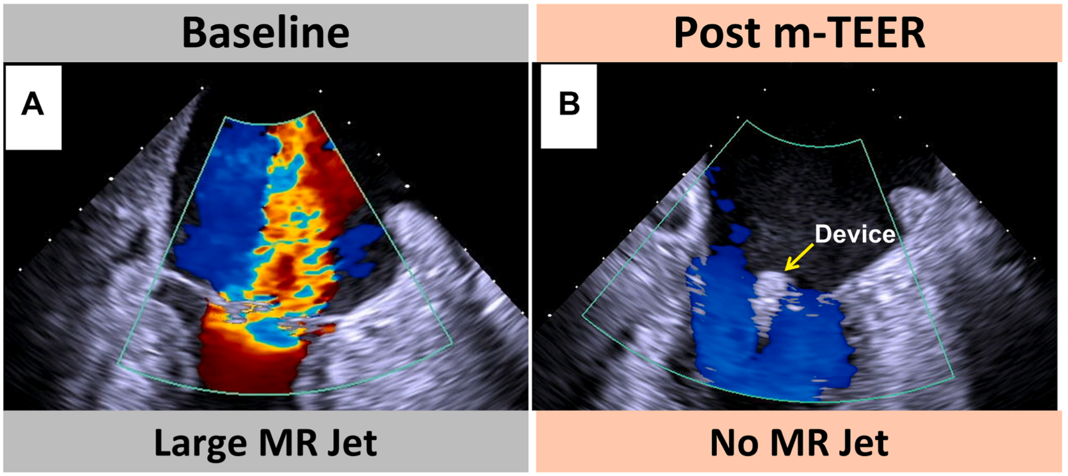

Figure 1 Case 1. Two-dimensional TEE, midesophageal long-axis view with color-flow Doppler in systole at baseline **(A)** and in diastole after repair **(B)**, demonstrates central severe MR jet that occupies most (>50%) of the left atrium and no stenosis post-m-TEER.

Table 1 Echocardiogram findings before and after mitral intervention suggesting resolution of severe MR

Cases	Measurements	Preintervention	Postintervention
Case 1	Color-flow Doppler	Central jet occupying >50% of the left atrium	Two minimal MR jets
	LVOT stroke volume	31 mL	53 mL
Case 2	MR jet spectral Doppler profile	Triangular, early peaking display. Vmax 3.5 m/sec	Parabolic display. Vmax 4.5 m/sec
	Iatrogenic ASD pressure gradients (LA to RA)	Peak-to-mean gradient of 72/28 mm Hg	Peak-to-mean gradient of 16/9 mm Hg
Case 3	Mitral E/A inflow waves	E-wave of 1.2 m/sec with E > A	E < A with slower E-wave deceleration time
	Pulmonary systolic (S) wave velocity	S wave reversed in the RUPV	S wave reversal no longer seen in the RUPV
Case 4	SEC in the LAA	No SEC in the LAA despite chronic AF	Development of SEC in the LAA

AF, Atrial fibrillation; *RUPV*, right upper pulmonary vein; *Vmax*, maximum velocity.

isovelocity area and VC width were not performed due to the elliptical orifice geometry from ventricular functional MR. After transseptal puncture during m-TEER, CWD of the left-to-right shunt through the iatrogenic ASD revealed a peak-to-mean LA to right atrial (RA) pressure gradient of 72/28 mm Hg (Figure 3A, Table 1).

Subsequently, 1 device was deployed at the A2/P2 level during m-TEER. Postprocedurally, there were 2 overlapping residual MR jets. Conventional measurements of MR were not pursued given nonhemispheric flow convergence, 2 MR jets, and elliptical orifices. The residual MR jet on spectral Doppler was holosystolic with a maximum velocity of 4.5 m/sec and a parabolic spectral Doppler profile (Figure 2B, Table 1). Moreover, the peak-to-mean LA to RA pressure gradient through the iatrogenic ASD decreased to 16/9 mm Hg (Figure 3B, Table 1). These hemodynamic improvements suggested procedural success and resolved severe MR.

Case 3

An 82-year-old woman with a history of breast cancer and chest radiation presented with worsening dyspnea and lightheadedness on exertion. Vital signs were as follows: BP 113/68, HR 65 BPM in NSR, SPO_2 94% on room air. Physical examination revealed a systolic ejection murmur with no pedal edema and clear lungs to auscultation. Transesophageal echocardiography revealed severe degenerative MR due to flail middle (P2) scallop of the posterior mitral leaflet and moderate aortic stenosis. Calculated EROA by PISA was 0.61 cm^2. Continuous-wave Doppler of the mitral inflow wave showed an E wave of 1.2 m/sec that was significantly greater than the A wave (Figure 4A, Table 1). The pulmonary vein (PV) systolic (S) wave on CWD was reversed in the right upper PV (Figure 5A, Table 1).

During the m-TEER procedure, 2 devices were deployed at the A2/P2 level. Conventional measurements of MR were limited by 2 irregularly shaped orifices created after m-TEER. Continuous-wave Doppler immediately after the procedure showed the E wave with a slower deceleration time and a velocity significantly less than the A wave (Figure 4B, Table 1). The mean MV gradient measured was 3 mm Hg at an HR of 65 BPM. The pulmonary S-wave reversal was no longer visualized in the right upper PV (Figure 5B, Table 1). The 2 devices were deemed satisfactory in achieving reduction in severe MR and procedural success.

Case 4

A 54-year-old woman with chronic atrial fibrillation and previous surgical mitral and aortic valve replacement for rheumatic heart disease presented with worsening shortness of breath. Vital signs were as follows:

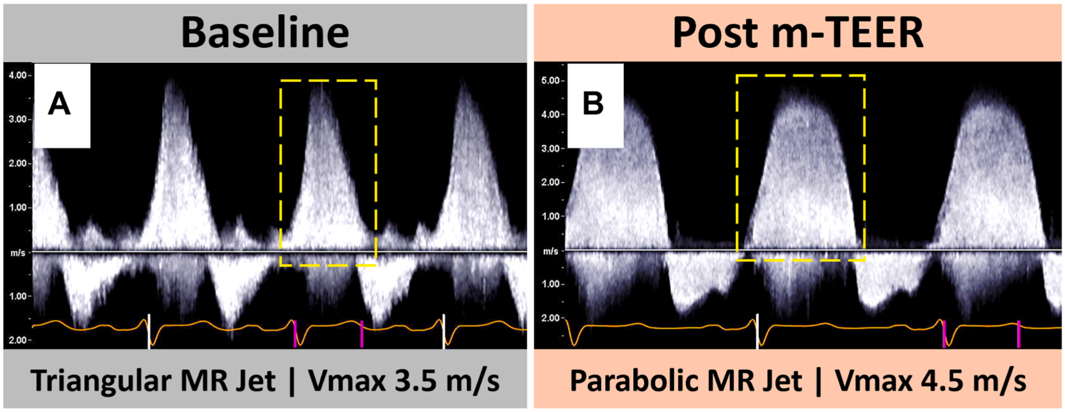

Figure 2 Case 2. Continuous-wave spectral Doppler display demonstrates the baseline MR jet is holosystolic with a triangular, early peaking, low maximum velocity (3.5 m/sec) profile **(A)** that becomes holosystolic with a parabolic, high maximum velocity (4.5 m/sec) profile post-m-TEER **(B)**. *Vmax*, Maximum velocity.

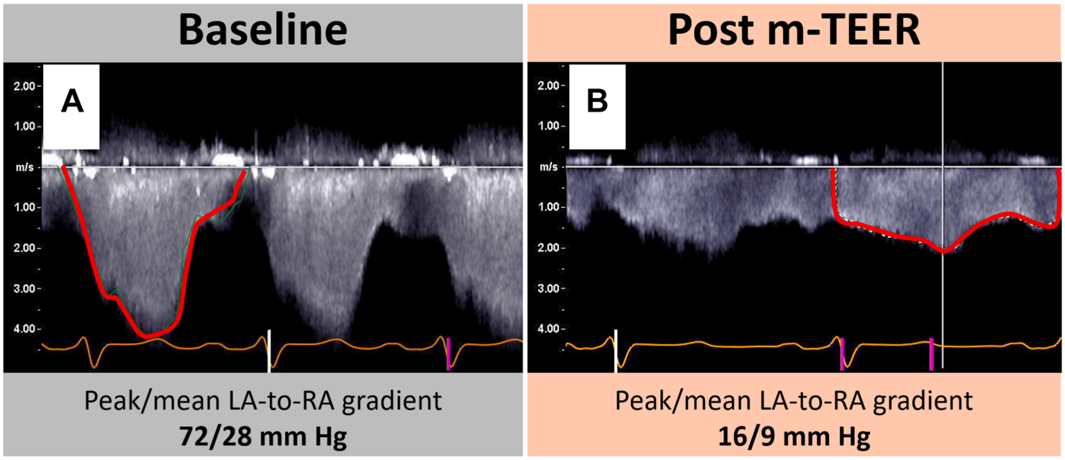

Figure 3 Case 2. Pulsed-wave spectral Doppler display demonstrates the baseline iatrogenic ASD profile **(A)** has a peak/mean LA to RA pressure gradient that is severely elevated at 72/28 mm Hg and that dropped significantly to 16/9 mm Hg post m-TEER **(B)**, consistent with marked improvement in the degree of MR.

BP 115/87, HR 75 BPM in atrial fibrillation, SPO_2 94% on room air. Physical examination revealed a grade IV/VI holosystolic murmur in the apex. On 2D TEE, the patient was found to have severe transvalvular MR due to flail and thickened prosthetic leaflets. Conventional parameters were not feasible given the altered valve anatomy. Two-dimensional TEE of the LA appendage (LAA) showed no "smoke," or SEC despite chronic atrial fibrillation, supporting the presence of a severe MR jet clearing away SEC (Figure 6A, Video 3, Table 1). The MV diastolic gradient was 9 to 13 mm Hg at HR 75 BPM. During transcatheter valve-in-valve (ViV) procedure, a 26 mm bioprosthetic transcatheter valve was deployed inside the existing 29 mm surgical bioprosthetic valve. Repeat 2D TEE of the LAA revealed severe "smoke," or development of SEC (Figure 6B, Video 4, Table 1). The MV diastolic gradient was 4 mm Hg at an HR of 68 BPM post-ViV. The development of SEC, along with other measures of MR, was supportive evidence for successful reduction of severe MR after ViV.

DISCUSSION

In this case series, we highlight several indirect echocardiographic parameters useful for assessing residual MR after mitral interventions when conventional measures cannot be obtained, most of which are described in the American Society of Echocardiography guidelines.[4,5] These include (1) color-flow and spectral Doppler features of the MR jet, (2) mitral inflow E- and A-wave amplitudes and their ratio, (3) PV flow patterns, (4) pressure gradients across the iatrogenic ASD, (5) changes in left ventricular stroke volume and ejection fraction, and (6) the degree of LA SEC. While limited individually, these markers collectively help characterize residual MR severity (Figure 7).

Color-flow Doppler is the primary tool for assessing native MR severity, focusing on regurgitant jet area, VC, and flow convergence. Severe MR on color-flow Doppler typically displays a central jet in the left atrium or an eccentric jet extending into the PVs. After mitral intervention, disappearance of these features may suggest resolution, as demonstrated in the first case. It is important to note that altered valve anatomy frequently produces multiple overlapping jets, which can often overestimate MR and require other parameters for confirmation. The VC width (>0.7 cm indicating severe native MR) on color-flow Doppler is a measure of regurgitant size as it exits the orifice and is unaffected by jet morphology or hemodynamics, but its utility is limited in the presence of multiple jets or noncircular orifices after m-TEER or valve repairs or replacements or in cases of secondary MR.

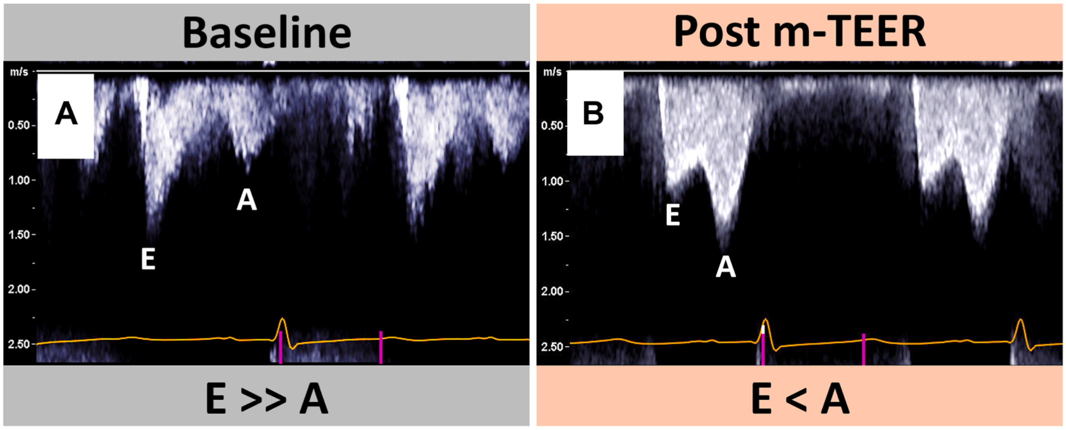

Figure 4 Case 3. Pulsed-wave spectral Doppler display demonstrates the baseline **(A)** mitral inflow profile with an elevated E wave (1.2 m/sec) significantly greater than the A wave (E >> A) that is reversed after m-TEER **(B)** where the profile has an E < A with a slower E-wave deceleration time and mean MV gradient of 3 mm Hg at a HR of 65 BPM.

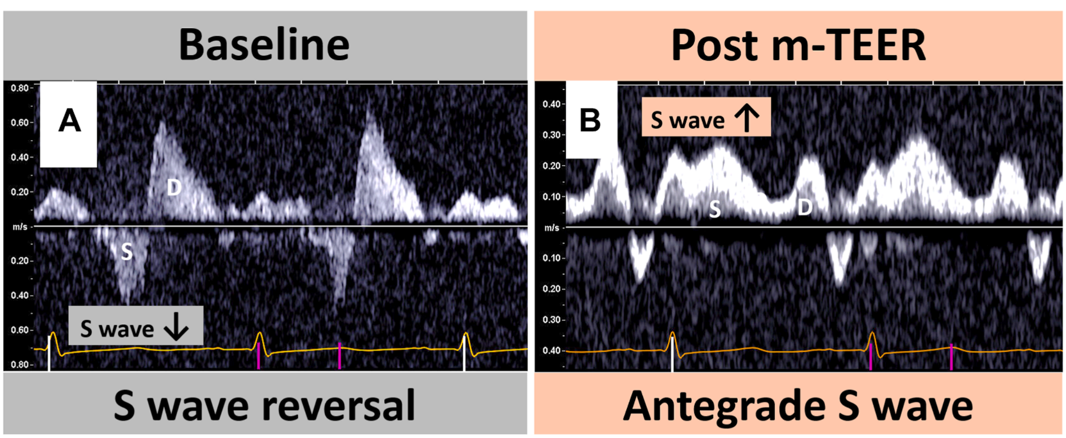

Figure 5 Case 3. Pulsed-wave spectral Doppler display from the right upper PV demonstrates the baseline **(A)** pulmonary systolic (S) wave is reversed (retrograde) indicative of severe MR and is antegrade after m-TEER **(B)**, consistent with reduction in MR.

Three-dimensional VC area (≥0.4 cm^2 for severe MR) improves precision but remains technically challenging and is not yet validated for outcomes. The PISA method, which measures the hemispheric flow convergence proximal to the mitral orifice, estimates the EROA (≥0.4 cm^2 indicating severe MR). However, EROA by PISA assumes a symmetric hemispheric flow convergence geometry and a single regurgitant jet, which is unreliable after mitral intervention due to interference of device components, altered valve anatomy, and the presence of multiple jets.

The MR jet velocity and spectral Doppler profile are qualitative measures of MR severity and LA hemodynamics. Hemodynamically significant MR can present with a triangular, early peaking spectral Doppler profile because of a large regurgitant jet flowing into a noncompliant left atrium leading to a rapid rise and fall of pressures. Compensated MR with a compliant left atrium alternatively has a more parabolic display. Severe native MR can present with either contour, depending on its acuity and hemodynamic impact. As a result, an early-peaking velocity contour is not a sensitive marker for severe native MR. However, observing a change from a triangular to a parabolic spectral Doppler after mitral intervention is convincing evidence of procedural success, as demonstrated in the second case. Jet density, which reflects the concentration of red blood cells within the regurgitant jet, can help qualitatively distinguish moderate or severe from mild MR when a single jet is well aligned with the CWD cursor. After mitral intervention, however, jet density assessment is more challenging if there are multiple or eccentric jets, which can often underestimate MR severity. Regardless, significant residual MR after mitral interventions often has the same density as the mitral inflow wave. Lastly, identifying MR duration during systole is important as a single-frame color-flow Doppler display may overestimate severity in nonholosystolic MR such as MV prolapse.

Mitral inflow velocities on spectral Doppler reflect LA pressure and MR severity. In native valves, a dominant early diastolic (E) wave (≥1.2 m/sec) more than twice the late diastolic (A) wave, with rapid deceleration, indicates elevated LA pressure and severe MR in the absence of significant stenosis, atrial fibrillation, or elevated left ventricular end-diastolic pressure. An A-wave dominant pattern with E < 1.2 m/sec and slow deceleration suggests less severe MR. After mitral intervention, E-wave dominance is less specific due to new valve stenosis and altered filling pressures, but a shift from E-wave dominance to A-wave dominance strongly supports MR resolution, whereas rising E amplitude from baseline may signal worsening MR.

In sinus rhythm, the peak systolic flow velocity in the PVs on spectral Doppler (S wave) is inversely related to LA pressure. S-wave

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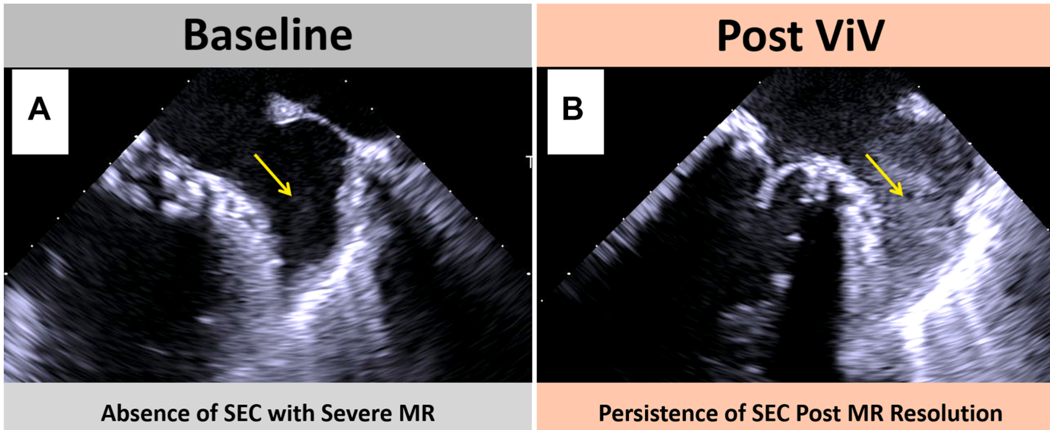

Figure 6 Case 4. Two-dimensional TEE, long-axis zoom view of the LAA at baseline **(A)**, demonstrates no significant SEC despite chronic atrial fibrillation and LAA stasis compared to the development of severe SEC in the LAA after a transcatheter mitral ViV procedure **(B)**, suggesting a marked reduction in the severity of the MR.

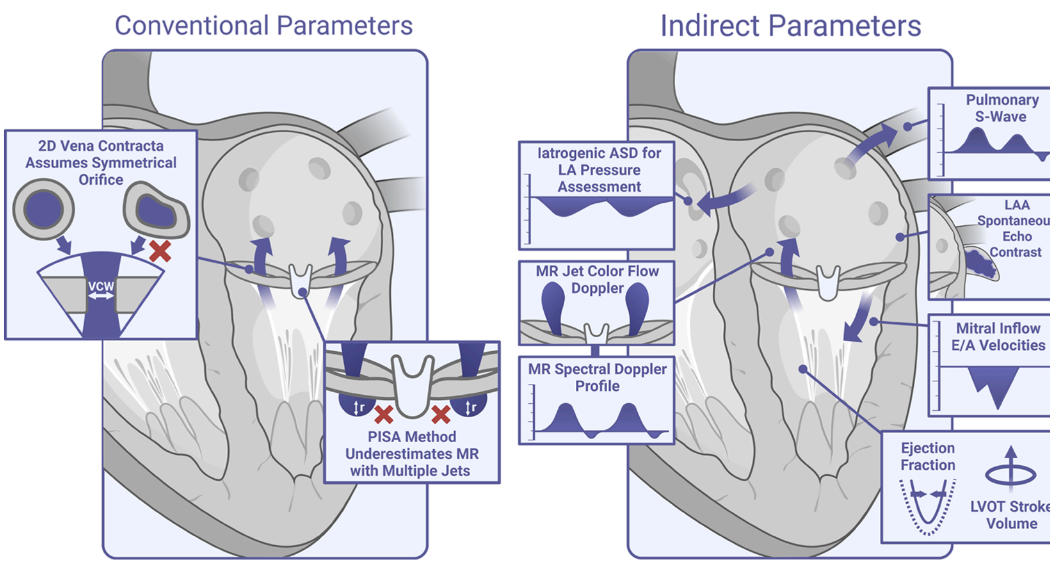

Figure 7 Graphical illustration depicting conventional and indirect echocardiographic measurements often available to assess residual MR after percutaneous mitral intervention. Conventional echo parameters (*left*) may not be available or may not be accurate after mitral intervention. Indirect echo parameters (*right*) are not reliable individually, but rapid changes during serial assessment make these well-suited to percutaneous MV interventions. Created in BioRender. Asachi, P. (2025) https://BioRender.com/t9gf69b.

blunting or reversal is indicative of increased LA pressure, and complete S-wave reversal across multiple PVs is highly specific for severe MR. Notably, atrial fibrillation itself can blunt the S wave regardless of LA pressure, making S-wave blunting alone an unreliable marker of MR severity in this setting. Nevertheless, restoration of a prominent antegrade S wave after intervention in any case is highly suggestive of resolved severe MR and has been linked to improved long-term clinical outcomes.[6]

Regurgitant volume and fraction are typically calculated from LVOT and MV stroke volumes on pulsed-wave Doppler and are not affected by jet morphology or direction. In severe MR, LVOT stroke volume is often reduced because forward flow is diminished by the large regurgitant volume. A postprocedural rise in LVOT stroke volume indicates reduction in regurgitant volume and supports procedural success.

In chronic MR, LVEF may appear normal or even elevated due to volume overload and reduced afterload, which can mask underlying LV dysfunction. A moderate decline in LVEF is expected as afterload normalizes, but a drop exceeding 15% after m-TEER has been associated with worse outcomes in primary MR, likely reflecting unmasked preexisting left ventricular dysfunction. This association has not been observed in secondary MR.[7]

The iatrogenic ASD created by transeptal puncture typically persists for at least several weeks after mitral transcatheter intervention. Its presence provides a mechanism by which to estimate LA pressure. Both mean and peak LA pressure can be approximated, respectively, by adding the mean or peak pressure gradient across the iatrogenic ASD obtained by spectral Doppler to the estimated RA pressure. While LA pressure may be invasively measured soon after transeptal puncture and prior to mitral intervention, these invasive measurements are not available intraprocedurally after catheter removal or during outpatient follow-up. A significant drop in the LA pressure across the iatrogenic ASD is an indicator of successful reduction in significant MR.

Spontaneous echo contrast—colloquially known as "smoke"—in the LA cavity or LAA results from red blood cell rouleaux formation in the setting of stasis such as during atrial fibrillation or with severe LV systolic dysfunction.[8,9] In the presence of severe MR, LA SEC often clears due to the washing effect of an MR jet. Reappearance of LA SEC after mitral intervention in a patient with atrial fibrillation may serve as an indirect marker of successful procedural reduction of MR.

CONCLUSION

Mitral TEER is an increasingly utilized minimally invasive treatment for severe MR. Direct measures of MR severity post–mitral intervention lack validation and are often impractical due to altered valve anatomy. This case series describes a range of indirect echocardiographic parameters that can be used to assess procedural success. They are most likely to provide an accurate assessment of residual MR severity when used in combination, particularly given their individual limitations. Further research is needed to validate these parameters and to explore their association with long-term outcomes after mitral transcatheter interventions.

ETHICS STATEMENT

The authors declare that the work described has been carried out in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki) for experiments involving humans.

CONSENT STATEMENT

The authors declare that since this was a noninterventional, retrospective, observational study utilizing de-identified data, informed consent was not required from the patient under an IRB exemption status.

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DISCLOSURE STATEMENT

The authors reported no actual or potential conflicts of interest relative to this document.

SUPPLEMENTARY DATA

Supplementary data related to this article can be found at https://doi.org/10.1016/j.case.2025.09.002.

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