Color Doppler Splay: A Clue to the Presence of Significant Mitral Regurgitation

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Background: The authors describe a previously unreported Doppler signal associated with mitral regurgitation (MR) as imaged using transthoracic echocardiography. Horizontal "splay" of the color Doppler signal along the atrial surface of the valve may indicate significant regurgitation when the MR jet otherwise appears benign.

Methods: Splay was defined as a nonphysiologic arc of color centered at the point at which the MR jet emerges into the left atrium. The authors present a series of 10 cases of clinically significant MR (moderately severe or severe as defined by transesophageal echocardiography) that were misclassified on transthoracic echocardiography as less than moderate. The splay signal was present on at least one standard transthoracic view in each case. To better characterize the splay signal, two groups were created from existing clinically driven transthoracic echocardiograms: 100 consecutive patients with severe MR and 100 with mild MR.

Results: Splay was present in the majority of severe MR cases (81%) regardless of vendor machine, ejection fraction, or MR etiology. Splay was particularly prevalent among patients with wall-hugging jets (28 of 30 [93%]). In patients with mild MR, splay was present less often (16%), on fewer frames per clip, and had smaller dimensions compared with severe MR. Color scale did not differ between subjects with and those without splay, but color gain was higher when splay was present (P = .04). Machine settings were further explored in a single subject with prominent splay: increasing transducer frequency reduced splay, while increasing color gain increased it.

Conclusions: The authors describe a new transthoracic echocardiographic sign of MR. Horizontal splay may be a clue to the presence of severe MR when the main body of the jet is out of the imaging plane. Splay is likely generated as a side-lobe artifact due to a high-flux regurgitant jet. (J Am Soc Echocardiogr 2020;33:1212-9.)

Keywords: Color Doppler splay, Mitral regurgitation, Valvular disease, Echocardiography, Side-lobe artifact

Mitral regurgitation (MR) is a common valvular abnormality with increasing prevalence in older age groups[1,2] and is an important cause of morbidity and mortality.[3-6] Among symptomatic patients, and even asymptomatic individuals, surgical correction of severe MR reduces mortality.[2,7] In patients with moderately severe or severe MR who are poor surgical candidates, endovascular mitral valve repair improves outcomes, in both primary[8] and secondary[9] MR. Transthoracic echocardiography (TTE) with Doppler imaging is the modality of choice for detection and evaluation of MR.[3-5] It allows quantitative grading, which can predict clinical outcomes[4]: increasing size of the regurgitant orifice is associated with greater risk for death and cardiac events. However, there are limitations to this technology,[1,10-12] and accurate assessment of MR relies on the presence of a discrete, well-visualized jet.[3-5]

We have observed cases of benign-appearing MR (reported as less than moderate) that displayed abnormal color Doppler signal tracking along the atrial surface of the valve in a nonphysiologic fashion that we describe as "splay." On further evaluation with transesophageal echocardiography (TEE), the severity of MR was more significant than originally suspected (Figure 1). We believe that this horizontal splay of the regurgitant jet represents a unique signal that may be a clue to the presence of moderately severe or severe ("actionable") MR.

In this report, we present a series of 10 patients with benign-appearing MR on TTE who demonstrated this splay signal and were later shown to have moderately severe or severe MR on TEE. To better understand the prevalence of this signal and its relationship to severity of MR, we also characterized its presence, dimensions, and duration in a series of patients in whom TTE revealed severe MR and compared them with patients in whom TTE revealed mild MR.

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Abbreviations
MR = Mitral regurgitation
TEE = Transesophageal echocardiography
TTE = Transthoracic echocardiography

METHODS

We first performed a retrospective review of all transesophageal echocardiographic examinations performed at Einstein Medical Center from January 2013 through December 2017. These included inpatients and outpatients. Our aim was to identify patients with regurgitation severe enough to require possible intervention (actionable MR) in whom TTE demonstrated less than moderate MR. We excluded subjects with endocarditis, prosthetic mitral valves, or previous mitral valve repair. There were 182 transesophageal studies reporting moderately severe or severe MR. Of these, 120 patients underwent TTE within 14 days of TEE. After excluding those in whom TTE showed moderate or greater MR, 32 subjects remained. These 32 transthoracic echocardiograms were reviewed in detail to determine the presence or absence of the splay signal.

All transesophageal and transthoracic echocardiographic studies were performed for clinical indications and stored as digital images in the hospital picture archiving and communication system; no study was obtained as part of a research protocol. Studies were performed using Philips (iE33, Sonos 5500, HD15, and Epiq 7; Philips Medical Systems, Andover, MA), GE (Vivid E9, Vivid E95, and Vivid 7; GE Healthcare, Boston, MA), and Siemens (Acuson SC2000; Siemens Medical Solutions USA, Mountain View, CA) echocardiographic machines.

In the second part of the study, consecutive transthoracic echocardiograms were reviewed to obtain 100 patients with reported severe MR and 100 patients with reported mild MR. All echocardiograms were reviewed, and the severity of MR was confirmed by a single reader (G.S.P.). The presence or absence of splay was recorded. When present, the splay signal dimensions (width and depth) were noted, along with the number of frames per cycle in which it was seen. Color scale, color gain, and transducer frequency were also recorded. Initial detection of the splay signal was made on review of digital video images played at normal speed. Frame-by-frame

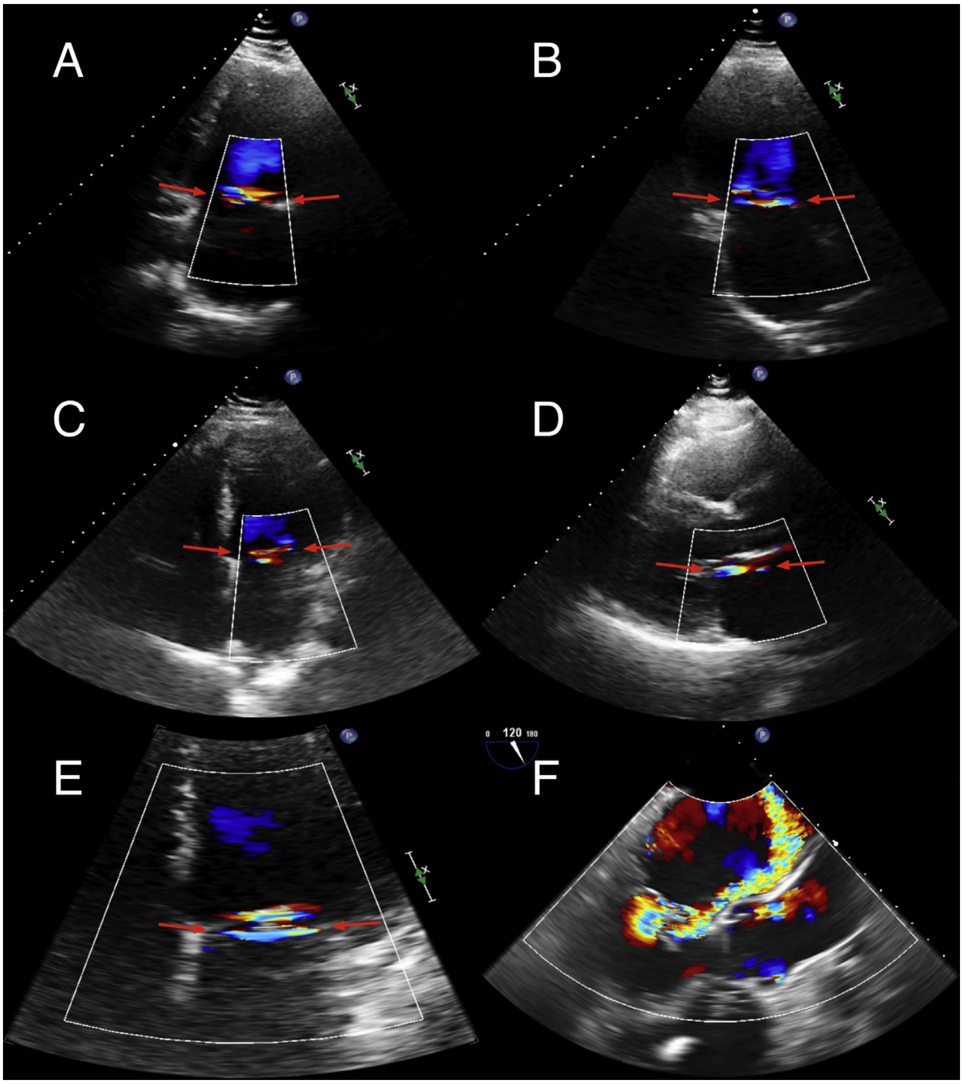

Figure 1 Demonstration of the splay signal in a select patient from the series (subject 2 from Table 1). **(A)** Apical two-chamber view, **(B)** apical three-chamber view, **(C)** apical four-chamber view, **(D)** parasternal long-axis view, **(E)** zoomed-in apical four-chamber view, and **(F)** severe primary MR with an anteriorly directed jet on TEE at 120°. The *red arrows* denote the splay arc.

HIGHLIGHTS

- Splay represents a nonphysiologic color Doppler signal.
- Splay is often seen with significant MR.
- Splay is likely due to side-lobe artifact with high flow through a small orifice.
- Splay is a clue to actionable MR in poorly defined jets.

review was then performed to determine where in systole splay occurred; measurements of the splay signal were made on the frame with the largest splay signal detected.

Finally, we studied different machine settings (using a Philips Epiq 7 echocardiograph) in a single subject who had marked splay in multiple transthoracic views.

Categorical variables are presented as number and percentage and continuous variables as mean ± SD. Comparisons between categorical variables were done using either the χ^2 test or the Fisher exact test, as appropriate. For continuous variables, Student's t test or the Wilcoxon test, when values were not normally distributed, was used. A two-tailed P value <.05 was considered to indicate statistical significance. Statistical analyses were performed using JMP version 14.0 (SAS Institute, Cary, NC).

RESULTS

Thirty-two patients were identified as having moderately severe or severe MR on TEE in whom standard TTE revealed less than moderate MR. Independent review of these cases identified 10 transthoracic studies in which the splay signal was present in at least one standard view (apical four-chamber, three-chamber, two-chamber, or parasternal long- or short-axis). Demographic and echocardiographic data for these patients are displayed in Table 1. Representative echocardiographic images from these cases are presented as a photo montage (Supplemental Figure 1). Age ranged from 51 to 90 years; half of the subjects were men. The mechanism of MR involved in these cases included prolapse or flail, secondary MR due to left ventricular cardiomyopathy, and rheumatic disease. Three subjects had anteriorly directed jets, five had posteriorly directed jets, and two had central jets.

In our review of consecutive transthoracic echocardiograms from 100 patients with severe MR and 100 patients with mild MR, splay was present in the majority (81%) of severe MR cases (Table 2, Figure 2) but less frequently in patients with mild MR (16%; Figure 3). In addition, when present, splay was seen on fewer frames and had smaller dimensions in the mild MR group compared with those with severe MR (Table 2). Splay was particularly prevalent in patients with severe MR who had "wall-hugging" jets (28 of 30 [93%]).

Looking more closely at the 100 patients in whom TTE demonstrated severe MR, we made the following additional observations: (1) splay was present in mid-systole in 72 subjects, in early systole in 50 subjects, and in late systole in 35 subjects, and splay could be seen in a portion of systole or could be holosystolic (16 subjects), and (2) splay could also occur on the ventricular side of the valve (proximal isovelocity surface area splay), noted in 26 subjects (example in Figure 1E).

The splay signal was seen across three vendors' machines, irrespective of left ventricular ejection fraction or etiology of MR. It was most commonly seen in the apical views but was occasionally present in the parasternal long-axis and short-axis views. Examples of splay are demonstrated in each standard transthoracic view along with a corresponding transesophageal view in Supplemental Videos 1 to 10 (available at www.onlinejase.com). Effects of machine settings were

Table 2 Splay prevalence and dimensions

Parameter	Mild MR	Severe MR	P
Splay present	16%	81%	<.0001
Number of frames with splay present	2 ± 1.6	3.6 ± 1.3	<.0001
Width of splay, cm	2.2 ± 0.5	3.2 ± 0.9	<.0001
Depth of splay, cm	0.36 ± 0.11	0.47 ± 0.16	.01

Data (mean ± SD) demonstrate percentage of patients in whom splay was present, number of frames in which splay was present during cycle, width of splay as measured during TTE, and depth of the splay as measured during TTE from the validation cohorts.

Table 1 Demographics and comorbidities

Subject	Rhythm	Age, y	Sex	BMI, kg/m^2	BSA, m^2	HTN	HLD	DM	MI	LVEF, %	Type of MR	Jet direction on TEE	Etiology
1	AF	59	M	39.6	2.6	Yes	Yes	Yes	Yes	20	Secondary	Posterior	DCM, A2 override
2	SR	54	M	37.8	2.5	Yes	Yes	Yes	No	55	Primary	Anterior	P2 flail
3	SR	71	F	32.7	1.9	Yes	Yes	Yes	No	75	Primary	Posterior	P3 flail and P2 cleft-like indentation
4	SR	62	M	39.9	2.4	Yes	Yes	Yes	No	20	Secondary	Posterior	DCM
5	SR	90	F	28.6	2.1	No	No	No	No	55	Primary	Anterior	P2 prolapse and calcified posterior annulus
6	ST	51	F	33.5	1.6	Yes	No	No	No	75	Primary	Posterior	Rheumatic
7	SR	51	M	28.0	1.9	Yes	No	No	No	50	Primary	Posterior	A2 prolapse and posterior calcified annulus
8	AF	85	F	22.7	1.6	Yes	Yes	No	No	50	Primary	Anterior	A3, P3 prolapse
9	SR	67	F	31.6	1.8	Yes	Yes	Yes	No	35	Primary	Central	Rheumatic
10	AF	61	M	35.8	2.5	Yes	Yes	No	No	35	Secondary	Central	DCM

AF, Atrial fibrillation; *BMI*, body mass index; *BSA*, body surface area; *DM*, diabetes mellitus; *DCM*, dilated cardiomyopathy; *HLD*, hyperlipidemia; *HTN*, hypertension; *LVEF*, left ventricular ejection fraction; *MI*, myocardial infarction; *SR*, sinus rhythm; *ST*, sinus tachycardia.

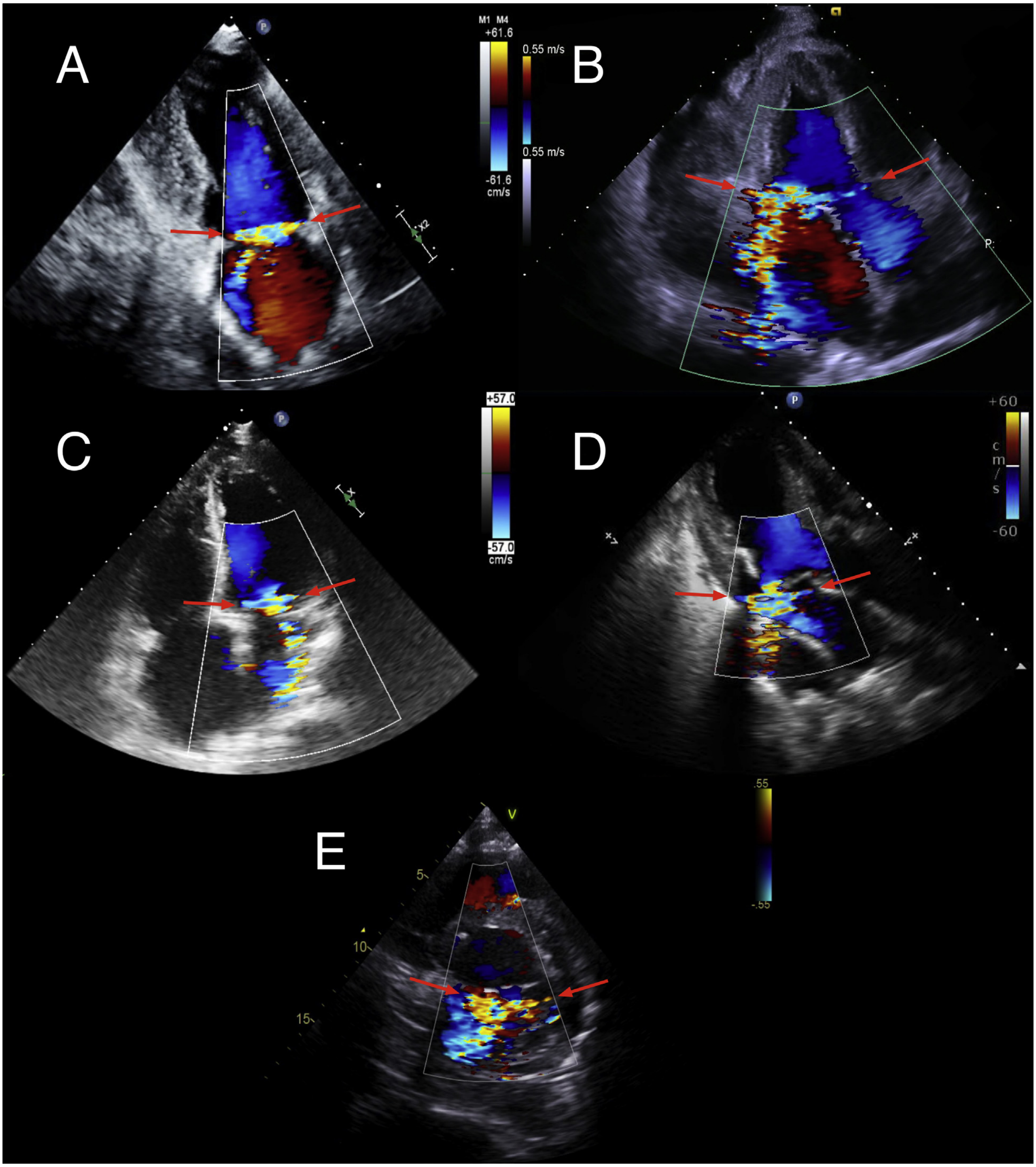

Figure 2 Presence of splay demonstrated in the severe MR validation cohort group. **(A)** Apical two-chamber, **(B)** apical three-chamber, **(C)** apical four-chamber, **(D)** parasternal long-axis, and **(E)** parasternal short-axis views. The *red arrows* denote the splay arc.

explored in subjects studied with Philips equipment (the largest subset). Color scale did not differ according to the presence or absence of splay, but color gain was higher when splay was present (57.5 ± 6.8% vs 55.2 ± 6.1%, $P = .04$). In addition, changing the Nyquist limit could occasionally produce splay when it was not present at baseline (Figure 4).

We further studied various machine settings in a single subject with a prominent splay signal (using a Philips Epiq 7 echocardiograph) and observed the following: (1) reducing transmission frequency from 2.5 to 2.0 MHz increased the splay signal somewhat, while increasing the frequency to 3.3 MHz greatly reduced splay; (2) harmonic imaging had little effect on splay; and (3) increasing

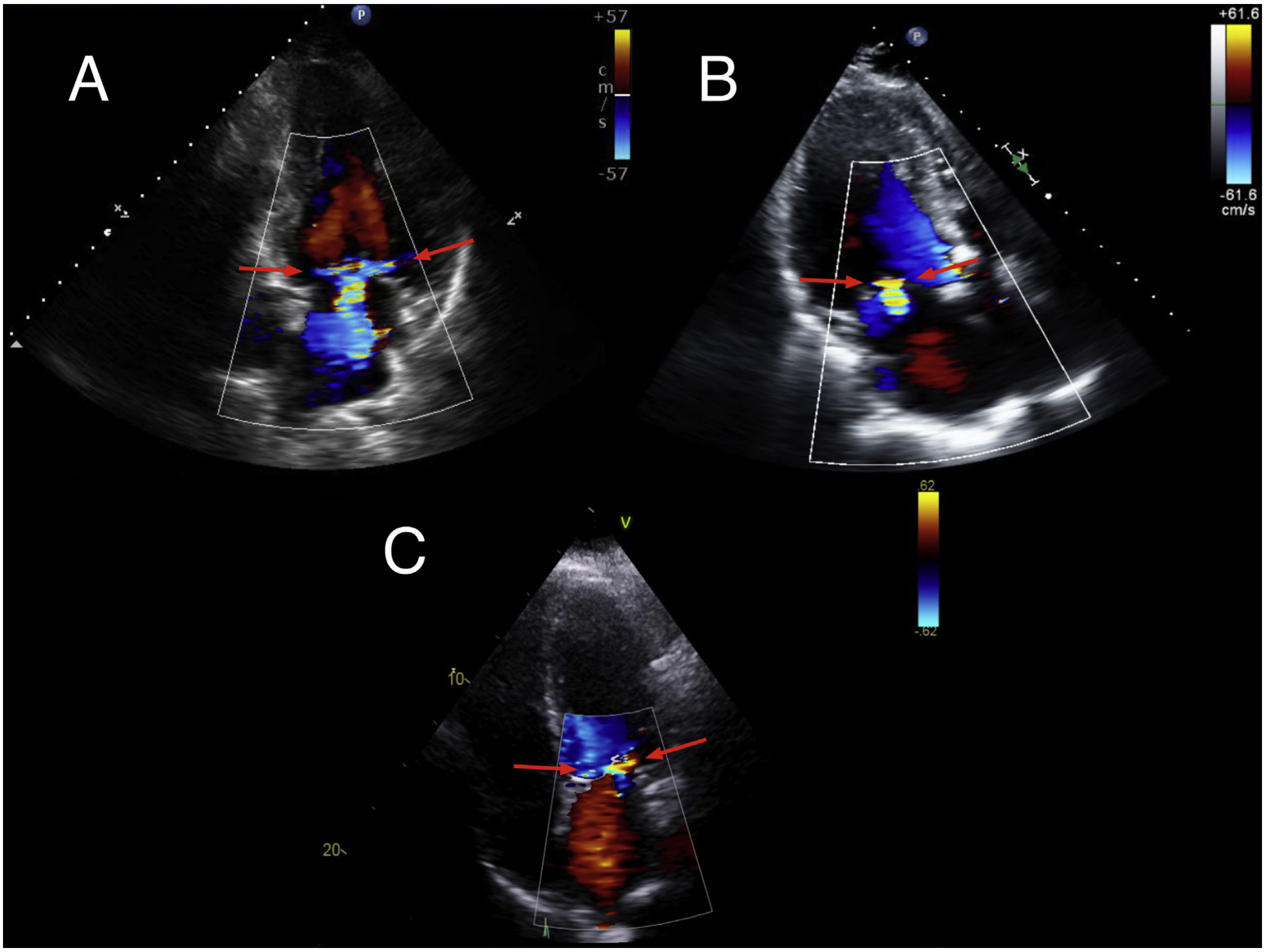

Figure 3 Presence of splay demonstrated in the mild MR validation cohort group. **(A)** Apical two-chamber, **(B)** apical three-chamber, and **(C)** apical four-chamber views. No examples of splay were found in parasternal views. The *red arrows* denote the splay arc.

the color gain increased the splay signal. These findings are illustrated in Supplemental Videos 11 to 13 (available at www.onlinejase.com).

DISCUSSION

MR is a common valvular lesion that carries a significant risk for morbidity and mortality.[2-6] Current recommendations emphasize the importance of MR quantitation,[3,4] particularly if intervention is being considered. However, quantitative measurement of MR can be problematic in the presence of a highly eccentric jet or when the jet is not well visualized.[3,4,13,14] In this study, we describe a horizontal color Doppler signal we have termed "splay," which is frequently associated with severe MR. On occasion, when standard transthoracic views do not adequately image the regurgitant signal, splay may be an important clue to the presence of actionable MR. In a review of patients over a 5-year period, who had moderately severe or severe MR on TEE, we identified 32 cases in which TTE misclassified the regurgitation as less than moderate. Of these 32, splay was present in 10 subjects.

We also examined patients with severe MR, as reported on TTE, and compared them with patients in whom TTE revealed mild MR. The splay signal was more common in patients with severe MR, while those with mild MR had splay less often and of lesser dimensions when it was present. Splay could occur at any point in systole (mid-systole was most common) or could be holosystolic. In addition, it was occasionally seen on the ventricular side of the valve (proximal isovelocity surface area splay). Etiology of MR did not appear to play a role in generation of the splay signal. Nor was splay specific to a particular machine or vendor. It did vary with changes in transducer frequency (more prominent at lower transmission frequencies) and color gain settings (more prominent at higher color gain). Occasionally, shifting the Nyquist limit could bring out splay when it was not present at baseline. Using harmonic imaging had little effect compared with fundamental imaging; this was expected, as harmonic imaging only affects the B-mode image and not color.

We believe that the splay signal occurs as a side-lobe artifact. These artifacts are due to reflected or back-scattered signals that are detected by side lobes that accompany the main beam of the phased-array transducer.[12] Side lobes are generated because of the finite aperture size of the transducer. For rectangular apertures (such as the transducers used in echocardiography) the point-spread function, or focal zone, consists of a main lobe and several side lobes that are mathematically represented as a sinc function during signal processing. Each of the peaks in the sinc function indicates the side lobes of decreasing strength on either side of the main lobe.[15] Typically, the first side lobes

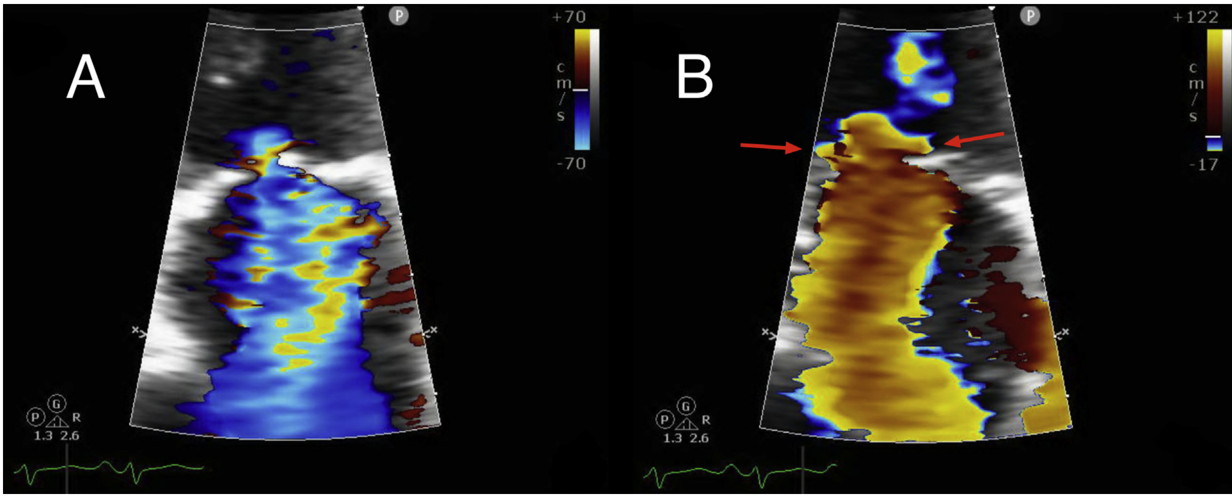

Figure 4 The *left panel* shows a systolic frame displaying a large mitral regurgitant jet but no splay; the *right panel* shows the same view with the Nyquist limit shifted. Note the appearance of splay (*red arrows*).

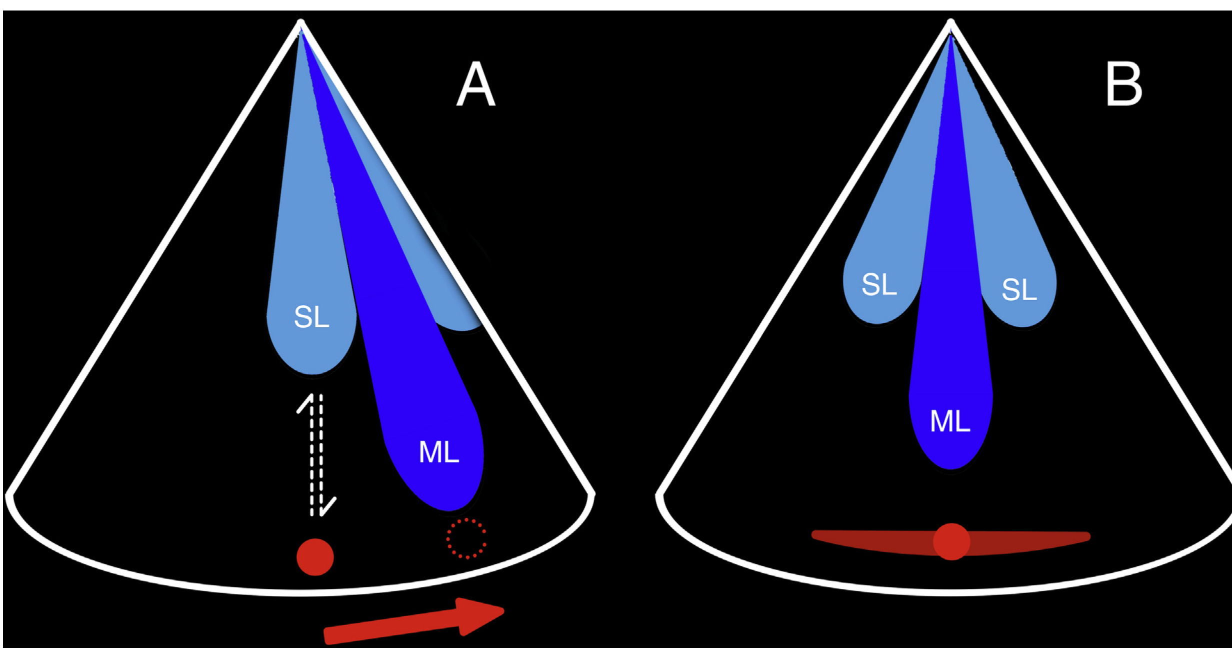

Figure 5 The illustration depicts the formation of a side-lobe artifact. **(A)** Ultrasound waves (*dashed lines*) from the side lobe (SL) of the echo beam reflecting off an "echo-bright" object (*solid red circle*) and returning to the transducer; the machine interprets this signal as coming from the main lobe (ML) and depicts the object in the location of the *dashed circle*. **(B)** What happens as the beam is swept across the "echo-bright" object: the side lobes will each image the object, leading to creation of an arc-like artifact extending to either side of the object.

are of interest because of their higher strength and proximity to the main lobe.

The location of the side lobes is dependent on the aperture size (i.e., the size of the transducer when the full aperture is being used, typically at depths > 4 cm on TTE). It is given by the following equation:

$$\sin(\alpha) = m\lambda D,$$

where α is the angular location of the side lobe with reference to the main lobe location, m is the number of the side lobe, λ is the wavelength, and D is the transducer/aperture footprint (lateral size).

The strength of the first side lobes for rectangular aperture is −13 dB relative to the main lobe.[16]

Side-lobe artifacts present as an arc-like image that follows the curvilinear path of the echo beam (Figure 5).[12] Such artifacts are often seen on two-dimensional TTE when imaging highly echogenic structures such as calcium or prosthetic material; these can be detected by the side lobes of the echo beam as well as the main lobe. Reflected signals returning from the side lobes will be plotted in the location of the main beam at that instant. Thus, as the beam sweeps through the object, dots will be plotted on the screen in the location of the structure and on either side, resulting in an arc-like image whose points are all equidistant from

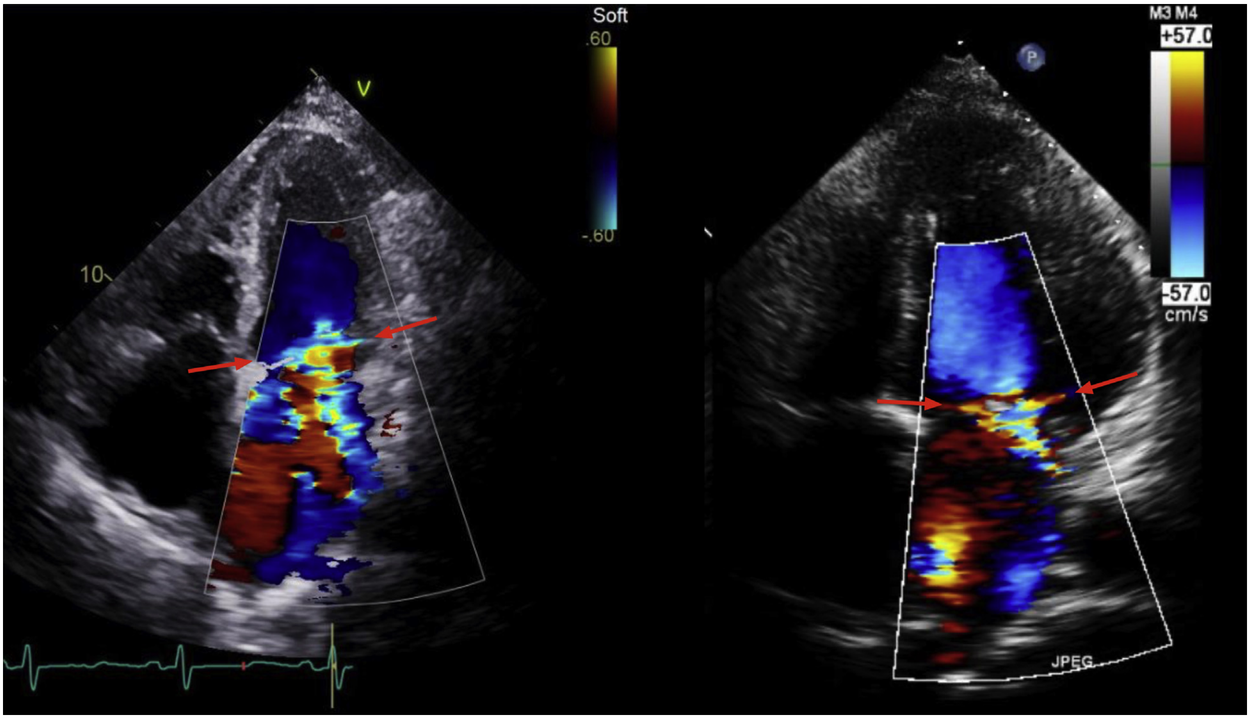

Figure 6 Two examples in which the main-lobe and side-lobe imaging of the emerging regurgitant jet can possibly be distinguished. In both cases, the color of the splay "wings" is different from the center of the splay; the center also tends to be thicker.

the transducer. In the case of color Doppler splay, we believe that the phenomenon is related to volumetric flux (rate of volume flow per unit area), and thus flux of echo scatterers, through a small orifice. In cases of severe MR, a prominent and intense splay signal is often present, whereas in cases of mild MR, there is a less prominent signal or none at all.

Of note, side-lobe artifacts are less frequent on TEE. On the basis of the above equation, they are dependent on the transducer size and wavelength (determined by transducer frequency), both of which are different for TEE compared with TTE.

Although splay can be a tip-off to the presence of clinically significant MR, it should not be the sole criterion in making this determination. All other parameters usually used to assess MR severity should be considered, including jet density on CW Doppler, forward velocities and mean gradient across the mitral valve, vena contracta width, and elevation of pulmonary pressure. Even so, there will be occasional studies in which the regurgitation appears benign but for the presence of splay. Most of these patients will have narrow, highly eccentric MR jets. In such cases, repeat TTE should be considered, with a careful search for eccentric jets, including off-axis views. Alternatively, TEE can be performed.

It is important to differentiate MR splay from an eccentric out-of-plane jet that appears truncated (though in both cases, the MR may be more significant than it would appear on first impression). The key feature of splay is that it occurs in an arc that precisely maintains the distance from the echocardiographic probe; this can be readily appreciated on careful inspection of Supplemental Videos 7 and 9. In addition, splay does not respect anatomic boundaries; in Supplemental Video 9, the color arc crosses the lateral aspect of the anterior leaflet. Finally, the main lobe (the point at which the MR jet emerges into the atrium) is usually a bit rounder and thicker, with the side lobes having a wing-like appearance; on occasion these wings can be a different color than the main lobe (Figure 6). We would also note that both splay and a truncated jet can be present in the same image (Supplemental Video 14 available at www.onlinejase.com).

Quantitative measurement improves the accuracy of MR assessment.[3,4] However, accurate quantitation requires optimal imaging of regurgitant flow. There are many potential reasons such jets may be suboptimally imaged: misalignment of the Doppler cursor, poor visualization of the jet within the left atrium, poor visualization of the area of proximal flow acceleration, and inaccurate measurement of the vena contracta. In such cases, we must rely on other clues to detect the presence of actionable MR. Splay can be helpful in such settings. As observed in our patient series, discrepant readings of MR severity on TTE and TEE are not rare. Finally, we have also noted the splay signal in cases of other high-flux jets, such as aortic stenosis and regurgitation, suggesting that this may be a more generalized phenomenon.

This was a retrospective study, subject to the usual limitations of such studies. We could not define the true prevalence of splay, as we considered only patients who underwent both TTE and TEE within 2 weeks of each other; suspicion that MR was more severe than demonstrated by TTE may have driven ordering of TEE. In addition, splay could not completely distinguish between mild and severe MR, being present in both groups. However, it was more common and of greater dimensions and duration in the severe group. Splay also did not identify all subjects with underestimation of MR severity on standard transthoracic views. But it was able to provide a clue to the presence of actionable MR in 10 of 32 subjects with discrepant findings between TTE and TEE.

CONCLUSION

We describe the presence of a novel echocardiographic sign of significant MR that appears as a splay of color across the mitral valve. Identification of MR splay may be clinically useful in two scenarios: (1) when the regurgitant jet appearance is otherwise benign, the presence of MR splay may be a clue that the regurgitation is greater than it appears, and (2) a prominent and bright splay signal can support the degree of MR as being severe when other indicators are equivocal. The splay signal likely originates as a side-lobe artifact, at the point at which an MR jet emerges into the left atrium.

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SUPPLEMENTARY DATA

Supplementary data related to this article can be found at https://doi.org/10.1016/j.echo.2020.05.002.

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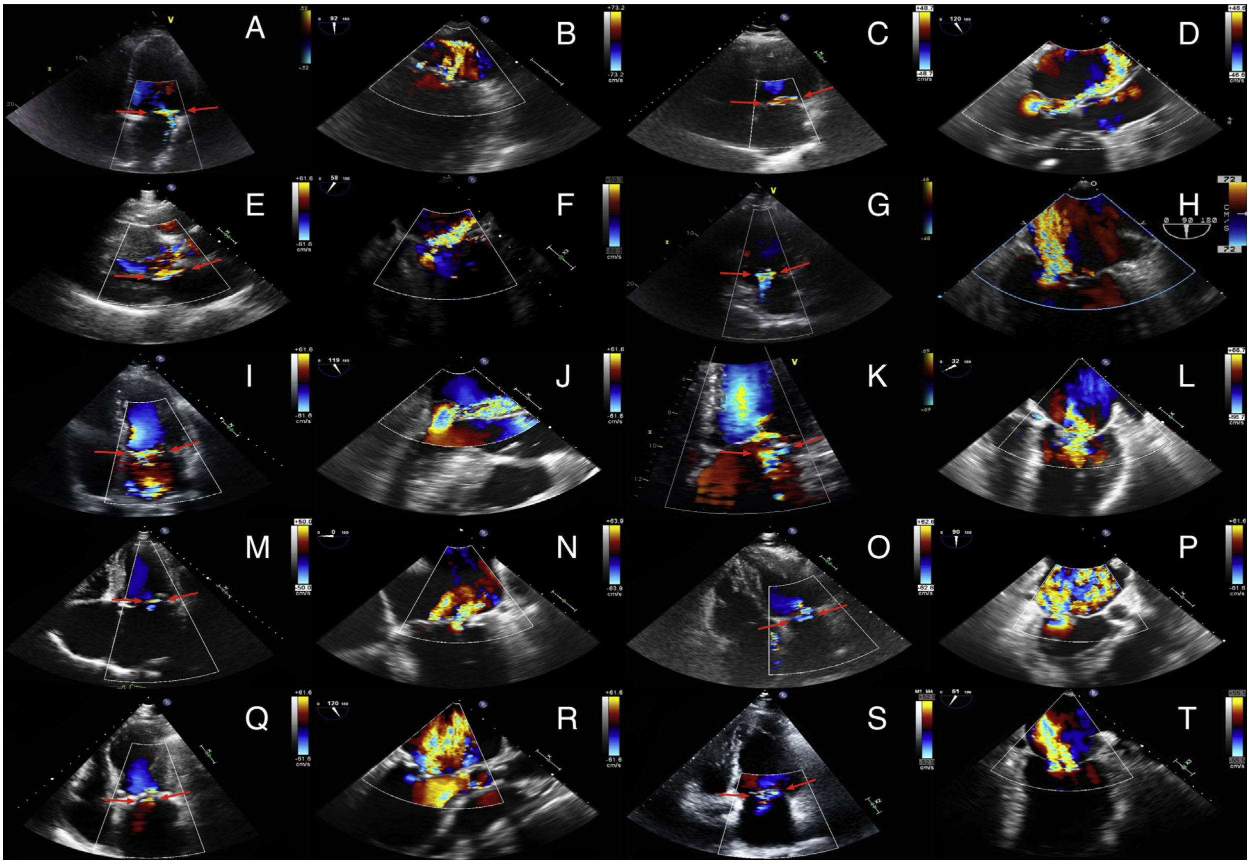

Supplemental Figure 1 Clinical vignettes and representative echocardiographic images (“splay” on TTE designated by *red arrows*). Demographic information is presented in Table 1. Subject 1 was a 59-year-old man presenting with a 1-month history of progressive dyspnea with **(A)** an apical four-chamber view showing mild MR on TTE and **(B)** moderate to severe secondary MR with a posteriorly directed jet on TEE at 92°. Subject 2 was a 54-year-old man presenting with a 2-week history of progressive dyspnea with **(C)** an apical four-chamber view showing mild MR due to a flail P2 scallop on TTE and **(D)** moderate to severe primary MR with an anteriorly directed jet on TEE at 120°. Subject 3 was a 71-year-old woman presenting with syncope with **(E)** a parasternal long-axis view showing mild MR due to flail P3 and P2 cleft on TTE and **(F)** severe primary MR with a posteriorly directed jet on TEE at 58°. Subject 4 was a 62-year-old man admitted for a 1-month history of worsening fatigue and nausea with **(G)** an apical two-chamber view showing mild to moderate on TTE and **(H)** severe secondary MR with a posteriorly directed jet on TEE at 90°. Subject 5 was a 90-year-old man presenting with 6 weeks of dyspnea with **(I)** an apical four-chamber view showing mild to moderate MR on TTE and **(J)** severe primary MR with an anteriorly directed jet due to prolapse of P2 and a calcified posterior annulus on TEE at 119°. Subject 6 was a 51-year-old woman presenting with cough, dyspnea, and chest pain for 3 days with **(K)** an apical four-chamber view showing trace MR on TTE and **(L)** moderate to severe primary MR with rheumatic changes with a posteriorly directed jet on TEE at 32°. Subject 7 was a 51-year-old man referred for outpatient imaging with **(M)** an apical four-chamber view showing mild to moderate MR on TTE and **(N)** moderate to severe primary MR with a posteriorly directed jet due to prolapse of A2 on TEE at 0°. Subject 8 was an 85-year-old woman admitted for chest pain and shortness of breath with **(O)** an apical four-chamber view showing mild to moderate MR on TTE and **(P)** severe eccentric anteriorly directed primary MR due to A3 and P3 prolapse on TEE at 90°. Subject 9 was a 67-year-old woman admitted for shortness of breath for 3 days with **(Q)** an apical four-chamber view showing mild MR on TTE and **(R)** moderate to severe primary MR with a central jet and rheumatic changes on TEE at 120°. Subject 10 was a 61-year-old man admitted with shortness of breath with **(S)** an apical four-chamber view showing mild to moderate MR on TTE and **(T)** moderate to severe secondary MR with a central jet on TEE at 61°.