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Severe Prosthetic Mitral Valve Regurgitation Hidden by Acoustic Shadowing: The Importance of Spectral Doppler in Prosthetic Valve Assessment

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INTRODUCTION

Prosthetic valvular regurgitation is a potentially serious complication after valve replacement. Insonation using multiple transducer positions and off-axis imaging may be required for a complete prosthetic valvular assessment and localization of paravalvular regurgitation (PVR).[1] Acoustic shadowing and reverberations may make detection of significant regurgitation difficult, particularly in the presence of multiple prostheses (e.g., aortic and mitral). Spectral Doppler and quantitative parameters represent important tools for the detection and evaluation of suspected prosthetic regurgitation. This case illustrates the limitations of transthoracic two-dimensional (2D) and color-flow Doppler evaluation in the presence of both mitral and aortic prostheses.

CASE PRESENTATION

A 49-year-old man presented to clinic with progressive dyspnea on exertion and cough. The patient had a complex cardiovascular history, notable for a bicuspid aortic valve (AV) and mitral valve (MV) prolapse with severe mitral regurgitation (MR), for which an MV replacement using a 29 mm bileaflet tilting disk mechanical MV was performed 15 years prior to presentation. In the setting of nonadherance to vitamin K antagonist therapy, multiple retinal, renal, and splenic infarcts were identified and felt to be cardioembolic in etiology. Due to development and progression of an ascending aortic aneurysm and aortic regurgitation (AR), 4 years prior to presentation the patient underwent ascending aortic aneurysm repair and AV replacement with a 27 mm stentless porcine aortic root bioprosthetic valve. At the time of this surgery, nonadherence to vitamin K antagonist therapy with multiple embolic events resulted in a decision to replace the mechanical mitral prosthetic heart valve (PHV) with a 29 mm porcine stented bioprosthetic mitral PHV.

Comorbidities included hypertension, dyslipidemia, and atrial fibrillation, for which prior ablation was performed. Physical examination showed a blood pressure of 125/85 mm Hg, pulse 76 bpm, and no fever. Heart sounds were regular, with a slight right ventricular (RV) lift and a 2/6 holosystolic murmur at the lower left sternal border. There was no jugular venous distention, the carotid upstrokes were normal and without bruits, and the pulmonary examination was normal. Electrocardiography showed normal sinus rhythm with a first-degree AV block. Laboratory evaluation was notable for a blood hemoglobin concentration of 14.3 g/dL and normal thyroid-stimulating hormone level. The patient was referred for echocardiography.

Transthoracic echocardiography (TTE) was completed and compared to the study completed 18 months prior. The patient's height was 178 cm, and weight was 10^2.8 kg, giving a body mass index of 3^2.5 kg/m^2 and a body surface area of 2.2 m^2. The current study showed normal left ventricular (LV) chamber size with mildly increased LV wall thickness and a calculated LV ejection fraction of 65% with no regional wall motion abnormalities. The right ventricle was mildly enlarged with normal systolic function. The AV prosthesis appeared normal by 2D imaging, and no prosthetic or periprosthetic AR was seen. Doppler interrogation of the aortic prosthesis was notable for a peak velocity of 3.0 m/sec, mean gradient of 17 mm Hg, effective orifice area (EOA) of 2.3 cm^2 by the velocity-time integral (VTI), indexed EOA (iEOA) by VTI of 1.05 cm^2/m^2, Doppler velocity index (DVI) of 0.37, VTI ratio of 0.40, and acceleration time of 74 msec.

The mitral prosthesis appeared normal by 2D imaging, and only a small jet of mild periprosthetic MR could be appreciated (Figure 1A, B and D, Videos 1 and 2). The MV peak velocity was 3.1 m/sec (previously 2.2 m/sec; Figure 1C), mean gradient was 15 mm Hg at a heart rate of 76 bpm (previously 8 mm Hg at a heart rate of 72 bpm), EOA by continuity was 1.73 cm^2 (unchanged), iEOA by continuity was 0.79 cm^2/m^2 (unchanged), pressure half-time (PHT) was normal at 107 msec (previously 112 msec), and the mitral prosthesis to LV outflow tract (LVOT) VTI ratio was increased at 3.3 (previously 2.8; Table 1). The tricuspid regurgitant peak systolic velocity was 4.5 m/sec, giving an estimated RV systolic pressure of 83 mm Hg assuming a right atrial pressure of 3 mm Hg. Stroke volume using the 4-chamber method of disks was 112 mL, and Doppler-derived stroke volume through the LVOT was 60 mL, giving a stroke volume index of 27 mL/m^2 and a low cardiac index of 2.0 L/min/m^2.

Given concern for significant prosthetic or periprosthetic MR, a transesophageal echocardiography (TEE) was performed 24 days

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VIDEO HIGHLIGHTS

Video 1: Two-dimensional TTE, parasternal long-axis view with color-flow Doppler, demonstrates mild prosthetic/periprosthetic MR.
Video 2: Two-dimensional TTE, apical 4-chamber view with color-flow Doppler, demonstrates prosthetic and periprosthetic MR masked by acoustic shadowing from the PHV.
Video 3: Two-dimensional TEE, midesophageal 4-chamber (9°) view with color-flow Doppler, demonstrates a jet of prosthetic MR and a larger jet of periprosthetic MR.
Video 4: Two-dimensional TEE, midesophageal 4-chamber (9°) view with color-flow Doppler with a shifted Nyquist limit (39.4 cm/sec), more dramatically demonstrates the periprosthetic MR.
Video 5: Three-dimensional TEE, midesophageal view, volume-rendered display of the MV from the left atrial perspective, demonstrates an area of inferior prosthetic valve dehiscence.

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later, and 3 jets of periprosthetic MR were identified secondary to inferior tissue thinning and partial dehiscence (Figure 2A–D, Videos 2–5), along with systolic pulmonary vein reversals seen in all 4 pulmonary veins. Multiple sets of blood cultures were obtained and showed no growth. The patient underwent coronary angiography, showing normal coronary arteries. Input from colleagues from cardiac surgery and interventional cardiology was obtained, and percutaneous paravalvular leak closure versus surgical correction was considered. Using a shared decision-making approach, we elected to proceed with a surgical approach given the patient's strong desire for definitive correction of the pathology. The patient was taken to the operating room, and intraoperatively, a large area of posterior periprosthetic MR and a small area of anterior periprosthetic MR were again identified. The patient underwent a third MV replacement using a 29 mm stented tissue valve. Postbypass TEE showed an LV ejection fraction of 55% with a normal functioning MV and AV prosthesis and normal RV function without postoperative complications.

DISCUSSION

Transthoracic echocardiography is recommended shortly after valve replacement to obtain a baseline for future comparison.[2] For patients with a bioprosthetic surgical valve, in the absence of changes in clinical

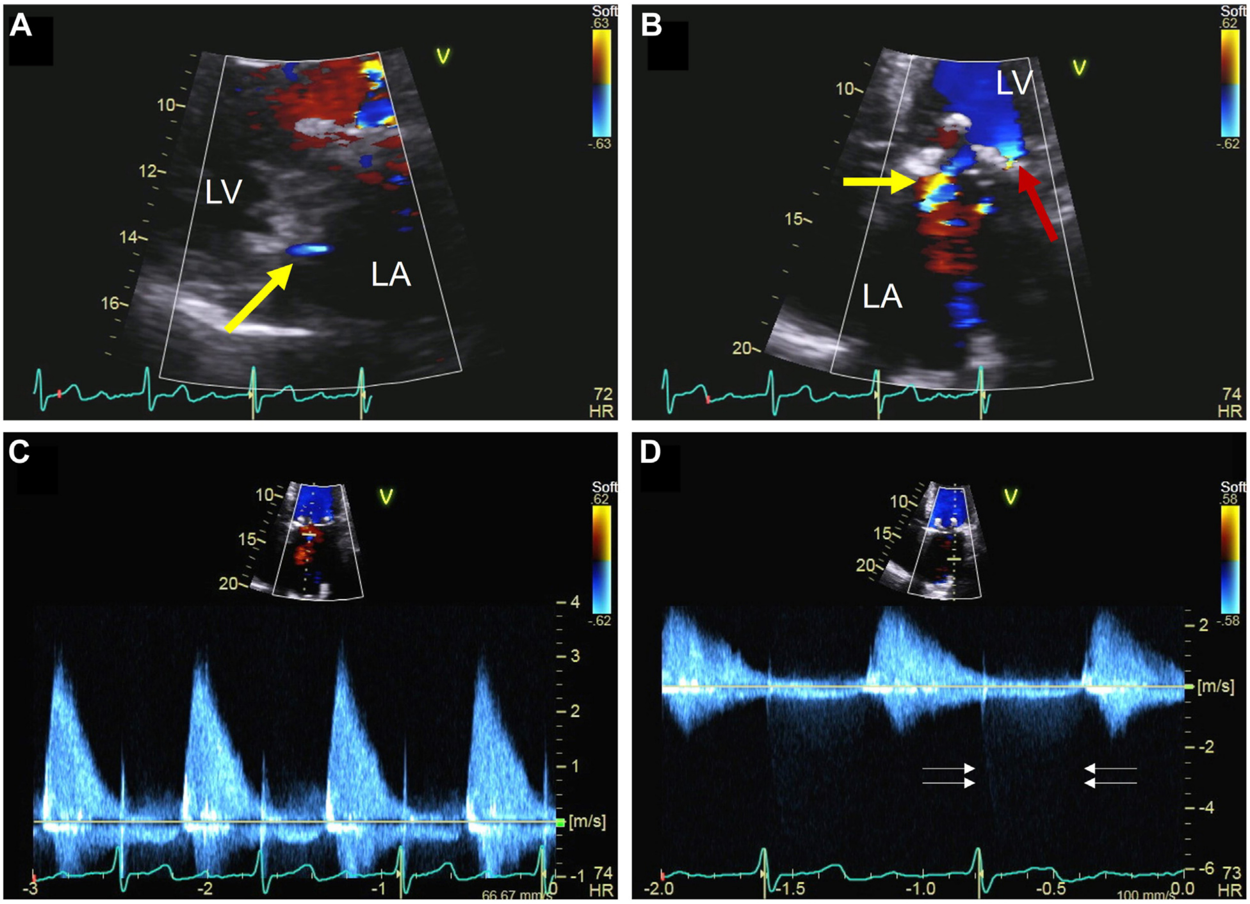

Figure 1 Two-dimensional TTE, zoomed parasternal long axis **(A)** and apical 4-chamber **(B)** systolic views with color-flow Doppler, demonstrate mild prosthetic MR (*yellow arrows*) and mild periprosthetic MR (*red arrow*). Continuous-wave Doppler, spectral display, demonstrates an elevated peak diastolic velocity **(C)** and a weak systolic MR display (*double white arrows*) **(D)**. *LA*, left atrium; *LV*, left ventricle.

Table 1 Doppler echocardiographic parameters of the patient's bioprosthetic mitral PHV at the time of presentation and 18 months prior

Parameter	Previous TTE (18 months prior)	TTE at presentation	Change
MV peak velocity, m/sec	2.2	3.1	+0.9
Mean gradient, mm Hg	8 (HR of 72 bpm)	15 (HR of 76 bpm)	+7
EOA by continuity, cm^2	1.73	1.73	0
iEOA by continuity, cm^2/m^2	0.79	0.79	0
PHT, msec	112	107	–5
Mitral prosthesis to LVOT VTI ratio	2.8	3.3	+0.5

HR, heart rate.

status or signs of valve dysfunction, it is reasonable to perform a TTE 5 and then 10 years after valve implantation and annually thereafter.[2] Bioprosthetic valve dysfunction following a MV replacement can be categorized into 4 broad categories: structural valve dysfunction, nonstructural valve dysfunction (e.g., prosthesis-patient mismatch [PPM] and PVR), endocarditis, and thrombosis.[3,4] The prevalence of PVR for bioprosthetic MVs has been reported to be 7% at 15 years, with a reoperation rate of 50%.[5]

Careful TTE surveillance of a prosthetic MV is typically accomplished primarily through parasternal and apical views, with off-axis imaging often needed for evaluation of eccentric jets of regurgitation.[6] Two-dimensional echocardiographic imaging is useful to evaluate the

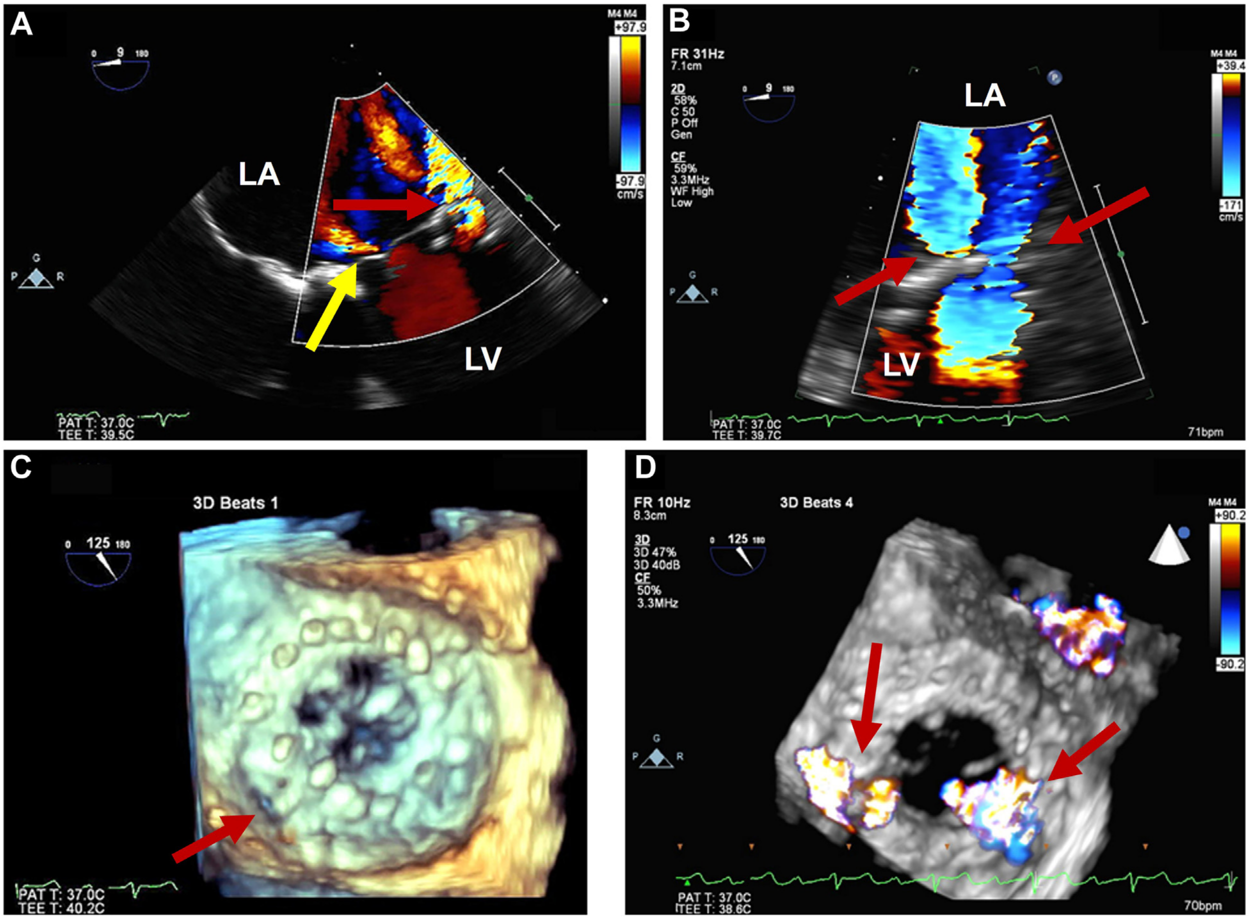

Figure 2 **(A)** Two-dimensional TEE, midesophageal 4-chamber (9°) view with color-flow Doppler display, demonstrates a jet of prosthetic MR (*yellow arrow*) and a larger jet of periprosthetic MR (*red arrow*), and by reducing the Nyquist limit scale **(B)**, the MR jets (*arrows*) and proximal flow acceleration are emphasized. The three-dimensional volume-rendered display of the prosthetic MV from the left atrial perspective in diastole without **(C)** and with **(D)** color-flow Doppler demonstrates the open PHV with stitches and a suggested area of inferior prosthetic dehiscence (*thick red arrow*) and 2 jets of periprosthetic regurgitation (*arrows*). *LA*, left atrium; *LV*, left ventricle.

opening and closing motion of the prosthesis, the presence of leaflet thickening, calcification or abnormal echodensities attached to the valve, and the appearance of the sewing ring.[7] Biventricular size and function, left atrial size, estimation of pulmonary artery and right atrial pressure, and the pulmonary vein flow pattern are also important adjuncts for the overall assessment of prosthetic MV function.[7] The addition of color-flow Doppler is important for the evaluation of blood flow through the valve and for detection and quantification of any regurgitant jet.

However, 2D and Doppler studies can be limited by reverberation and acoustic shadowing both from the prosthesis in question and from prosthetic valves in other positions, particularly mechanical mitral prostheses.[6] Due to shadowing and flow masking in the left atrium, detection of regurgitation with TTE is more difficult for valves in the mitral position and significant prosthetic MR may be missed,[7] particularly in the presence of concomitant AV prostheses. In fact, if the effect of attenuation and masking of a color-flow Doppler regurgitant jet on TTE is higher on prostheses in the mitral position compared with the aortic position,[7] the presence of both of them can cause more limitations in the assessment of the valve due to the reverberation and shadowing of 2 prostheses instead of 1.

For this reason, careful spectral Doppler evaluation of prosthetic valves is important for detection of regurgitation that may not be apparent based on 2D and color-flow Doppler.[6]

Spectral Doppler requires careful orientation of the beam as parallel as possible to the blood flow[6-8] to minimize Doppler error, fundamental for a correct assessment of peak velocity and the mean gradient[8,9] taking heart rate into account. These parameters can be elevated in high cardiac output states (e.g., anemia, pregnancy, or thyrotoxicosis), tachycardia with resultant short diastolic filling time, small valve size, PPM, stenosis, or regurgitation.[7] Additional spectral Doppler parameters that are useful for assessment of prosthetic mitral function include peak E velocity and PHT, although concomitant AR, abnormal compliance of the left atrium and left ventricle, and heart rate may limit this technique.[10] The DVI is expressed as the ratio of the prosthetic MV VTI to the LVOT VTI ($VTI_{Pr}MV/VTI_{LVOT}$ ratio); it is useful both when the cross-sectional area of the LVOT cannot be obtained and in low- or high-flow states.[11] In fact, in cases of significant MR, the VTI increases through the MV and decreases in the LVOT,[11] while in low- or high-output states the ratio will remain unchanged. In our case, we noted the elevated peak E velocity and DVI at 3.3 (Figure 1C), which had increased from the prior echocardiogram.

Determination of EOA is an important Doppler parameter. The EOA of a PHV is generally smaller than the corresponding native valve, leading to higher pressure gradients in a condition referred to as PPM where the prosthesis is relatively small in relation to the patient's body size.[12,13] Together with PVR, PPM represents a cause of bioprosthetic valve dysfunction not related to any morphologic abnormalities of the bioprosthetic and its severity is indeed related to the patient's body mass index and the EOA indexed to the body surface area (iEOA).[4] It has been suggested that the iEOA should be greater than 1.2 cm^2/m^2 to avoid abnormally high gradients in the postoperative period.[12] It is not possible to simply use the labeled size of the PHV[14] or to use the PHT to calculate the EOA as can be done with native MVs.[9,11] On the other hand, the EOA derived from the continuity equation represents a better index of valve function than gradient alone; although the accuracy of this calculation may be better for bioprosthetic valves and single tilting disk mechanical valves, while it may be underestimated in bileaflet valves.[9,11] The $EOA_{pr}MV$ can be calculated as the ratio between the stroke volume and the VTI through the prosthetic MV, using the stroke volume calculated at the aortic annulus in the absence of significant MR or AR.[9] Comparison of the EOA to that calculated immediately after valve implantation ("fingerprint echo") can be invaluable. In our case, the EOA and iEOA were normal, suggesting normal mitral prosthetic opening.

The continuity principle can also be used by comparing the Doppler-derived stroke volume through the LVOT using the VTI to the stroke volume obtained by 2D or three-dimensional estimation of LV end-diastolic and end-systolic volumes. In our case, we noted an estimated LV stroke volume of 112 mL from a 4-chamber method of disks compared to a Doppler-derived forward stroke volume of 60 mL, leaving 52 mL of blood unaccounted for, raising the possibility of unseen prosthetic MR.

Integration of multiple echocardiographic parameters is important in the identification of significant prosthetic MR and includes a dense continuous-wave jet of MR (missing in our case due to acoustic shadowing; Figure 1), elevated peak early velocity ($\geq$1.9 m/sec, particularly for mechanical valves; 3.1 m/sec in our case) and DVI (or $VTI_{Pr}MV/VTI_{LVOT}$ ratio $\geq$2.5; 3.3 in our case), a relatively low systemic stroke volume in relation to total LV stroke volume (Doppler-derived forward stroke volume of 60 mL vs an estimated stroke volume of 112 mL by a 4-chamber method of discs), a large systolic flow convergence zone seen on the LV side of the mitral prosthesis (often not seen due to acoustic shadowing, as in this case), and a significant elevated pulmonary artery pressure (83 mm Hg in our case)[7]; comparison of these parameters to that obtained in prior studies can be helpful.

If prosthetic valvular dysfunction is suspected after clinical and TTE evaluation, additional imaging can be helpful. Cine fluoroscopy can be helpful in showing mechanical valvular motion, and computed tomography imaging can show valve morphology and abnormalities including pannus, fistulas, abscesses, and vegetations. Transesophageal echocardiography is frequently performed to identify the mechanism of obstruction or MR and quantify its severity.[6,7] Given the proximity of the transducer to the posterior cardiac chambers, TEE provides good visualization and assessment of the MV and is highly sensitive in detecting prosthetic MR and assessing the mechanism and severity.[7,15] An additional method that could be used is the administration of an ultrasound-enhancing agent. Indeed, if MR is suspected, an ultrasound-enhancing agent could be useful to improve spectral Doppler accuracy and integrate the evaluation of regurgitation severity, being also of value in the qualitative assessment.[16]

Our case illustrates the ability of TEE to detect multiple jets that were not appreciable on TTE. During TEE it is essential to inspect the valve through multiple planes and identify the origin of the jet and to look for other complications including paravalvular abnormalities such as dehiscence, valve perforation, or abscess as can be seen in infective endocarditis.[7,15] Our patient showed no signs of infective endocarditis and underwent repeated MV replacement for PVR, a form of nonstructural valve dysfunction.[3,4]

CONCLUSION

Acoustic shadowing is a significant limitation in the 2D and color-flow Doppler evaluation of PHVs. Quantitative parameters from spectral Doppler displays represent a valuable tool in diagnosing PHV dysfunction.

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

Complete written informed consent was obtained from the patient (or appropriate parent, guardian, or power of attorney) for the publication of this study and accompanying images.

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DISCLOSURE STATEMENT

The authors report no conflict of interest.

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SUPPLEMENTARY DATA

Supplementary data related to this article can be found at https://doi.org/10.1016/j.case.2024.03.004.

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