Pulmonary Vein Systolic Flow Reversal Seen With Severe Tricuspid Regurgitation

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INTRODUCTION

Abnormalities of pulmonary vein flow (PVF) have been described in the context of several disease states, such as left ventricular (LV) diastolic dysfunction, rhythm abnormalities (atrial fibrillation, atrioventricular dyssynchrony, paced rhythms), and mitral valve disease.[1] The presence of an atrial septal defect (ASD) has also been shown to influence PVF pattern.[2] However, to date, reversal of systolic flow in the pulmonary veins has been described only in the setting of severe mitral regurgitation (MR).[1] We present a case where systolic PVF reversal was seen without MR or ASD—in the context of severe and chronically elevated right atrial (RA) pressures (RAPs) secondary to severe prosthetic tricuspid stenosis (TS) and tricuspid regurgitation (TR).

CASE PRESENTATION

The patient is a 25-year-old woman with a history of ASD repair and an unknown pulmonic valve (PV) procedure in childhood, due to an unknown congenital abnormality, and subsequent bioprosthetic tricuspid valve (TV) and bioprosthetic PV replacements due to endocarditis as an adult. The patient presented with worsening fatigue and dyspnea, and reported abdominal distension and nausea in the past year. Workup revealed large-volume peritoneal ascites with a nodular liver, suggestive of chronic liver disease, on computed tomography. The transthoracic echocardiographic (TTE) examination showed severe prosthetic TS and TR, severe prosthetic pulmonic regurgitation, severely dilated right atrium (RA; RA volume 134 mL by the area-length method), marked bowing of the interatrial septum (IAS) toward the left atrium (LA), a small LA (LA volume 26 mL by the area-length method), and preserved LV systolic and diastolic function (Figure 1, Video 1). The patient was scheduled for redo TV and PV replacement surgery.

Intraoperative preprocedure transesophageal echocardiography (TEE) revealed severe RA dilation (diameter, 5.6 cm); significant prosthetic TS (mean gradient, 12 mm Hg) and moderate-severe TR (continuous-wave Doppler dense jet with early peaking, holosystolic hepatic flow reversal, vena contracta 5 mm; Figure 2, Video 2); severe prosthetic pulmonic regurgitation (pressure half-time 94 ms, wide jet width greater than 50% of pulmonary artery annulus by color flow Doppler, dense jet by continuous-wave Doppler) and significant pulmonic stenosis (peak velocity of 3.2 m/sec, leaflet thickening and immobility; Figure 3, Video 3); mildly reduced right ventricular function by visual assessment; and preserved LV systolic function (calculated LV ejection by biplane method of disks of 56%). Mitral and aortic valves appeared normal by two-dimensional and color flow Doppler interrogation (Figure 4, Video 2). However, on pulsed-wave Doppler interrogation of PVF, prominent reversal of flow was seen during systole in the left upper and right upper pulmonary veins (Figure 5). There was no IAS defect. Right atrial pressure was 26 to 27 mm Hg. Bilateral pleural effusions and ascites were visualized. Portal and hepatic vein flows were interrogated in modified transgastric views showing hepatic systolic flow reversal and portal vein flow reversal, signs of severe systemic venous hypertension (Figure 6).

The patient underwent third time redo sternotomy, bioprosthetic TV replacement, bioprosthetic PV replacement, and right ventricular outflow tract transannular patch augmentation.

Postoperative TEE showed normally functioning newly implanted bioprosthetic TV (Figure 7, Video 4) and PV (Figure 8, Video 5) with mean gradients of 4 mm Hg and 9 mm Hg, respectively, and both without regurgitation. The IAS position appeared normalized, and the RA was now relatively smaller than the LA (Figure 7, Video 4). Also noted was resolution of systolic flow reversal at interrogation of PVF in both the left upper and right upper pulmonary veins (Figure 9). Postprocedure RAP ranged from 7 to 11 mm Hg.

The patient did well initially but developed recurrent respiratory failure from flash pulmonary edema soon after extubation, requiring reintubation and 2 episodes of venovenous extracorporeal membrane oxygenation management. After multidisciplinary discussions, the patient underwent tracheostomy and was successfully weaned off ventilatory support and venovenous extracorporeal membrane oxygenation on postoperative day 12 with home discharge on postoperative day 18.

DISCUSSION

Flow in the pulmonary veins is pulsatile and composed of biphasic or triphasic forward flow in systole and diastole when normal.[3] Abnormalities of PVF have been described in the context of several disease states, such as cardiomyopathies, LV diastolic dysfunction, rhythm abnormalities (atrial fibrillation, atrioventricular dyssynchrony, paced rhythms), and mitral valve disease (stenosis and/or regurgitation).[1] So far, systolic reversal of PVF has been described only in the context of severe MR. Increasing severity of MR may initially result in blunting of the systolic flow, followed by late systolic flow reversal and finally holosystolic flow reversal.[1] Originally, systolic reversal was

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VIDEO HIGHLIGHTS

Video 1: Preoperative TTE. **(A)** Two-dimensional TTE, apical 4-chamber view, demonstrates normal LV systolic function, deviation of the ventricular septum leftward, mildly reduced RV systolic function, degenerative TV prosthesis, and severe dilation of the RA with the IAS bowing toward a small LA. **(B)** Two-dimensional TTE, apical 4-chamber view with color flow Doppler, confirms the absence of significant MR. *LV*, Left ventricle; *RV*, right ventricle.
Video 2: Intraoperative preprocedural TEE of the bioprosthetic TV and native mitral valve (MV). **(A)** Two-dimensional TEE, mid-esophageal (ME) 4-chamber view (0°), demonstrates severe dilation of the RA, mildly reduced right ventricular (RV) systolic function, preserved LV systolic function, and a thickened prosthetic TV. **(B)** Two-dimensional TEE, ME right ventricle–focused 4-chamber view (0°) with color flow Doppler (CFD), demonstrates severe TR and flow acceleration across the prosthetic valve during diastole. **(C)** Two-dimensional TEE, ME RV inflow-outflow view (61°) with CFD, demonstrates the degenerated prosthetic TV. **(D)** Three-dimensional TEE en face view of the bioprosthetic TV seen from the RA demonstrates the degenerated bioprosthetic valve with severely thickened leaflets and severe stenosis. **(E)** Two-dimensional TEE, ME 4-chamber view (0°) with CFD, demonstrates marked deviation of the IAS (*blue arrow*) toward the LA without evidence for a shunt. **(F)** Two-dimensional TEE, ME 4-chamber view (0°) with CFD, demonstrates normal MV without stenosis or regurgitation. **(G)** Two-dimensional TEE, ME 3-chamber view (126°) with CFD, demonstrates normal MV without stenosis or regurgitation.
Video 3: Intraoperative preprocedural TEE of the bioprosthetic PV. **(A)** Two-dimensional TEE, upper esophageal (UE) aortic short-axis (SAX) view (95°) demonstrates thickening and immobility of the bioprosthetic PV. **(B)** Two-dimensional TEE, UE aortic SAX view (95°) with CFD at the level of the PV, demonstrates flow acceleration across the valve during systole and regurgitation during diastole. **(C)** Three-dimensional TEE en face view of the bioprosthetic PV as seen from the pulmonary artery (*left*) and from the right ventricular outflow tract (*right*) demonstrates a degenerated bioprosthetic valve with severely thickened, immobile, and stenotic leaflets.
Video 4: Intraoperative postprocedural TEE after bioprosthetic TV replacement. **(A)** Two-dimensional TEE, ME 4-chamber view (0°), demonstrates a newly implanted bioprosthetic TV and normalized position of the IAS. **(B)** Two-dimensional TEE, ME right ventricle–focused 4-chamber view (0°) of the TV demonstrates normal leaflet mobility and normal leaflet coaptation. **(C)** Two-dimensional TEE, ME right ventricle–focused 4-chamber view (0°) with CFD, demonstrates normal function without stenosis or regurgitation. **(D)** Three-dimensional TEE en face view of the bioprosthetic TV seen from the right ventricle demonstrates normal leaflet motion without stenosis.
Video 5: Intraoperative postprocedural TEE after bioprosthetic PV replacement. **(A)** Two-dimensional TEE, upper esophageal (UE) aortic short-axis (SAX) view (91°), demonstrates a newly implanted bioprosthetic PV with normal leaflet mobility. **(B)** Two-dimensional TEE, UE aortic SAX view (91°) with CFD, at the level of the normally functioning bioprosthetic PV.

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described as yielding excellent sensitivity and specificity values of 93% and 100%, respectively, for diagnosing severe MR.[3] However, subsequent studies have identified that determinants of PVF are complex and are represented not only by the degree of regurgitation but also by LA volume and filling pressures, MR jet characteristics, and diastolic LV filling patterns. Therefore, systolic flow reversal may have a lower sensitivity than previously described.[4]

We present a case of systolic PVF reversal seen in the absence of MR, and rather in the context of severe and chronically elevated RAPs secondary to significant prosthetic TS and severe TR. Theoretically, in the presence of an ASD, severe TR may lead to abnormal PVF pattern by direct right-to-left flow from the RA into the LA. In this patient, systolic flow reversal was observed in the absence of an IAS defect as well. We speculate that the systolic PVF reversal observed was caused by the severe TR jet posteriorly directed during systole toward the IAS in the setting of severe prosthetic TS and highly elevated RAP, leading to further leftward bowing of the IAS during systole. Significant displacement of the IAS into the LA during systole causes LA volume to displace and results in retrograde flow from the LA into the pulmonary veins. This phenomenon of systolic flow reversal is seen prominently in bilateral pulmonary veins. Our theory is supported by postoperative resolution of the systolic reversal once the TR and TS were resolved.

This patient has several echocardiographic indicators of severe venous congestion including severe RA dilation and reversal of flow in the hepatic and portal veins. In this setting, severe RA dilation was impairing LA filling in a rare case of interatrial dependence, resulting in systolic flow reversal in multiple pulmonary veins.

CONCLUSION

Systolic PVF reversal is a specific finding for severe MR. Severe TR could result in abnormalities of PVF in the presence of an ASD and large right-to-left shunt. We observed systolic PVF reversal in the absence of significant MR or ASD. We speculate this was a result of severely elevated RAP due to both severe TS and severe TR jet

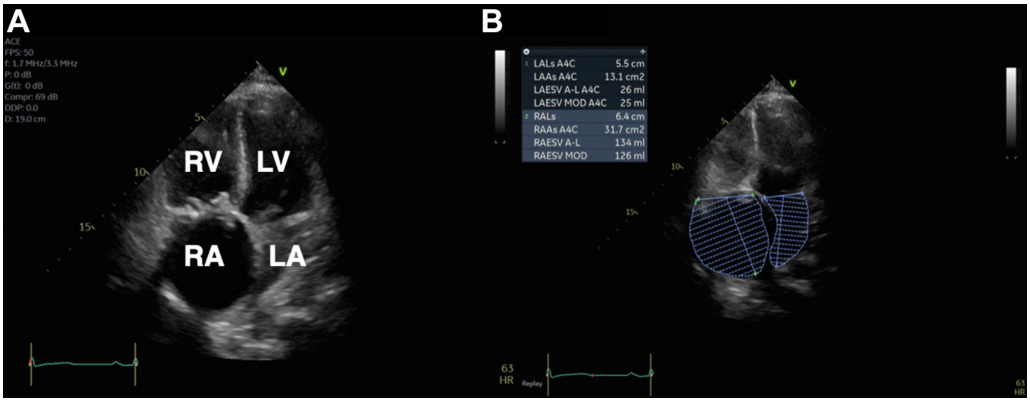

Figure 1 Preoperative two-dimensional TTE. **(A)** Apical 4-chamber view demonstrates a severely dilated RA and marked bowing of the IAS toward a small LA in the setting of a structurally abnormal TV. **(B)** Right atrial volume by the area-length method = 134 mL; LA volume by the area-length method = 26 mL. *LV*, Left ventricle; *RV*, right ventricle.

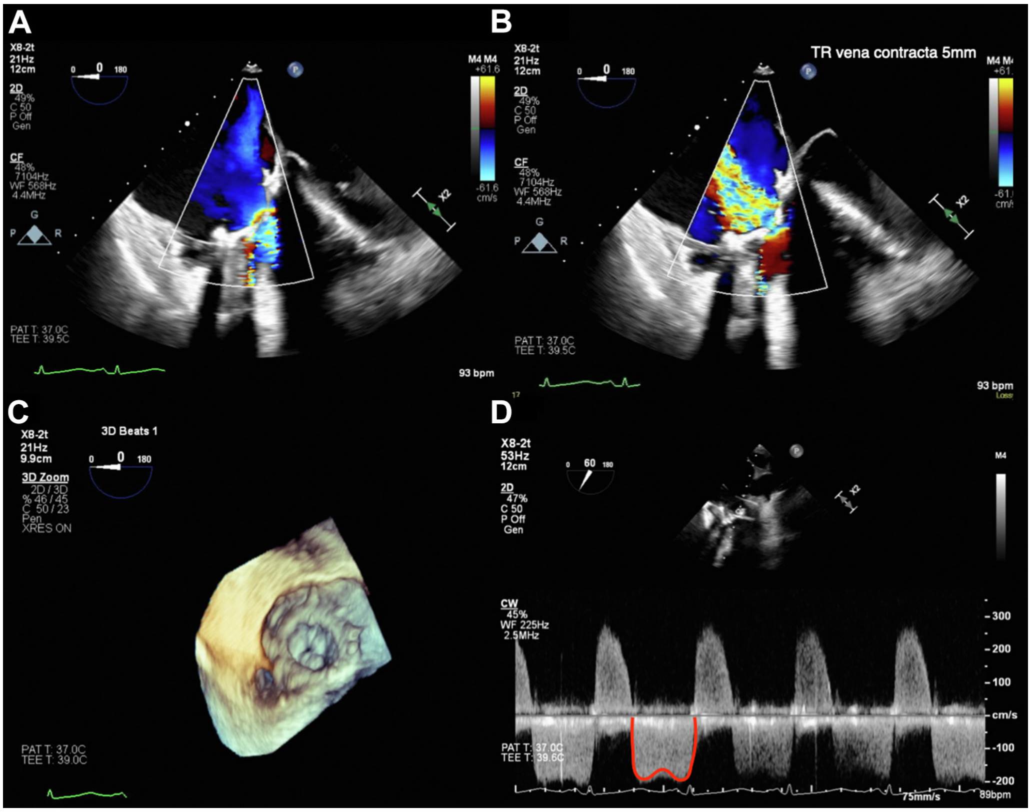

Figure 2 Intraoperative preprocedural TEE. **(A)** Two-dimensional TEE with color flow Doppler, midesophageal (ME) right ventricle–focused view (0°), early diastolic phase, demonstrates severe RA dilation and flow acceleration at the level of the stenotic prosthetic TV, and during midsystolic phase **(B)** it demonstrates severe TR. **(C)** Three-dimensional TEE en face view from the RA perspective during diastole demonstrates the degenerated bioprosthetic valve with severely thickened leaflets and a very small opening. **(D)** Two-dimensional TEE-guided continuous-wave Doppler of the TV from the ME view (60°) demonstrates a mean pressure gradient of 12 mm Hg during diastole and a dense early peaking spectral Doppler envelope of the TR.

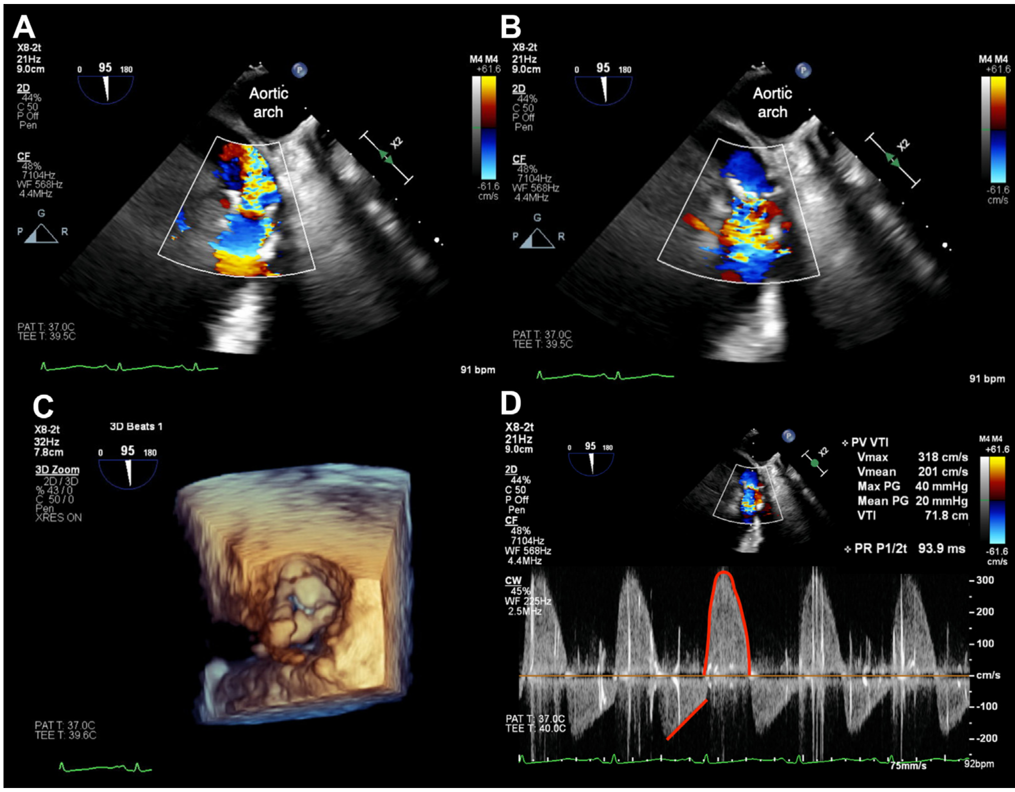

Figure 3 Intraoperative preprocedural two-dimensional TEE with color flow Doppler, upper esophageal (UE) aortic arch short-axis view of the bioprosthetic PV demonstrates flow acceleration at the level of the PV in systole **(A)** and a large regurgitation jet (width >50% of the PV annulus diameter) in diastole **(B)**. **(C)** Three-dimensional TEE, en face view of bioprosthetic PV seen from the pulmonary artery during systole demonstrates thick and degenerated leaflets. **(D)** Two-dimensional TEE-guided continuous-wave Doppler of the bioprosthetic PV from the UE view (95°) demonstrates significant stenosis with a peak systolic velocity 3.2 m/sec and severe regurgitation with a very dense spectral Doppler jet and pressure half-time 94 ms during diastole.

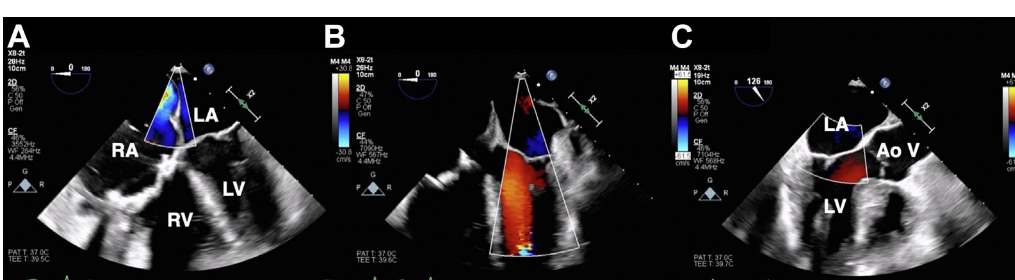

Figure 4 Intraoperative preprocedural TEE. **(A)** Two-dimensional TEE with color flow Doppler, midesophageal (ME) 4-chamber view (0°) during systole, demonstrates marked deviation of the IAS from the RA toward the LA; no evidence for an ASD. **(B)** Two-dimensional TEE with color flow Doppler, ME 4-chamber view (0°) during systole, demonstrates the absence of MR. **(C)** Two-dimensional TEE with color flow Doppler, ME 3-chamber view (126°) during systole, demonstrates the absence of MR and visually normal appearing MV and aortic valve (AoV). *LV*, Left ventricle; *RV*, right ventricle.

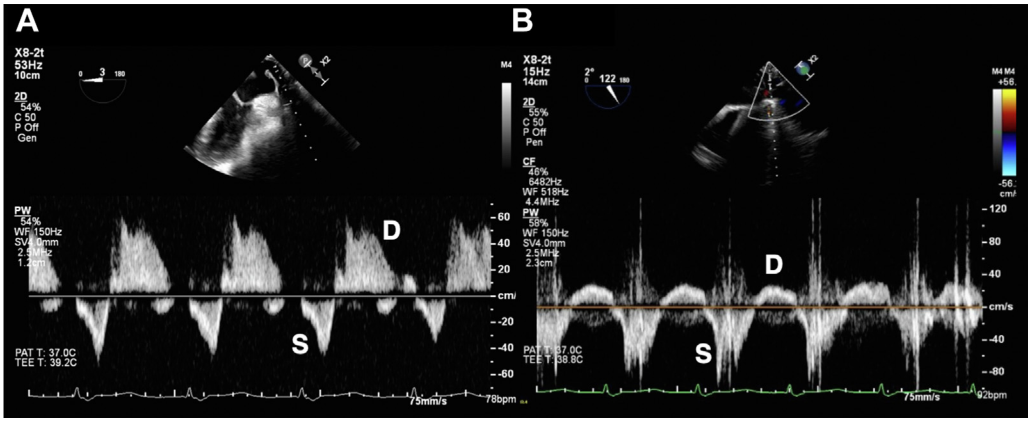

Figure 5 Intraoperative preprocedural two-dimensional TEE-guided pulsed-wave Doppler interrogation **(A)** at the midesophageal left upper pulmonary vein view (3°) and **(B)** the right upper pulmonary vein (122°) demonstrates prominent reversal of systolic flow (S wave). *D*, Diastolic flow.

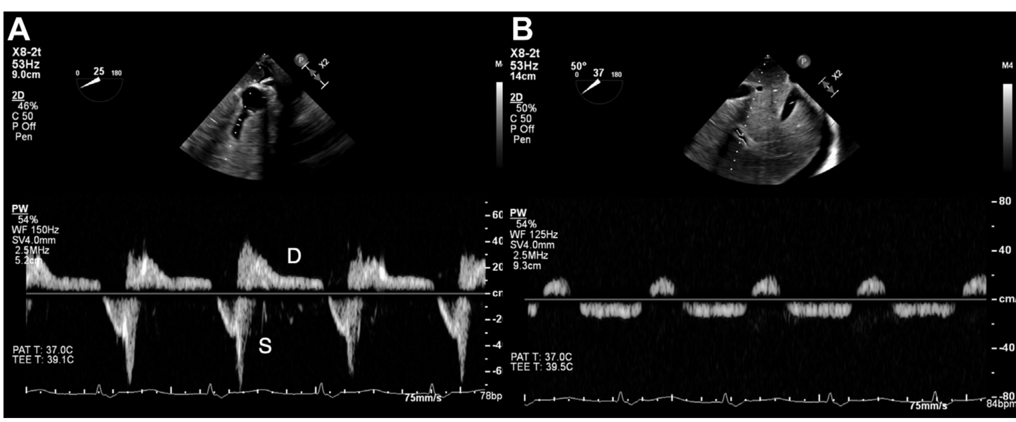

Figure 6 Intraoperative preprocedural two-dimensional TEE-guided pulsed-wave Doppler interrogation at the modified transgastric superior hepatic vein view **(A)** (25°) and **(B)** portal vein view (37°) demonstrates S-wave reversal in the hepatic and portal veins, respectively. *D*, Diastolic flow.

directed toward the IAS causing volume displacement in the LA and consequent PVF abnormalities.

CONSENT STATEMENT

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

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.

FUNDING STATEMENT

The authors declare that this report did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

DISCLOSURE STATEMENT

The authors report no conflict of interest.

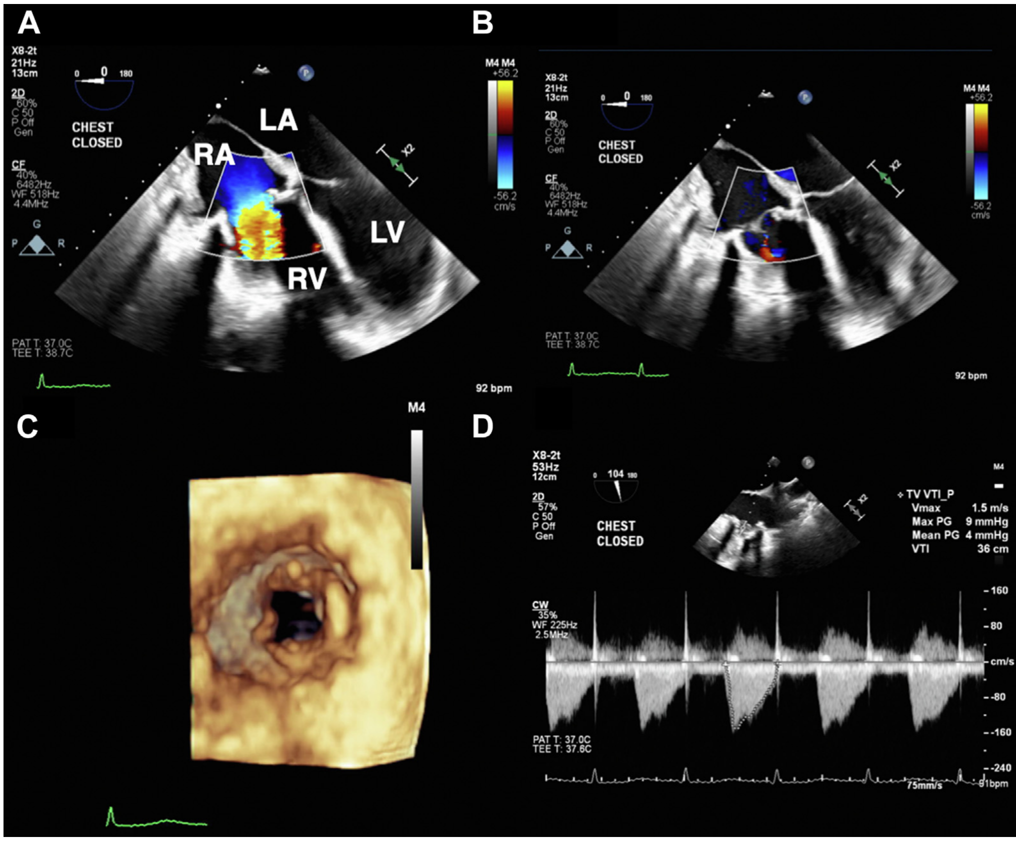

Figure 7 Intraoperative postprocedural TEE after bioprosthetic TV replacement. Two-dimensional TEE with color flow Doppler, midesophageal right ventricle–focused view (0°), early diastolic phase **(A)** and systolic phase **(B)**, demonstrates a newly implanted, normally functioning bioprosthetic TV without stenosis or regurgitation. The IAS is also seen in a midline position. **(C)** Three-dimensional TEE en face view from the right ventricular perspective during diastole demonstrates good TV leaflet opening. **(D)** Two-dimensional TEE-guided continuous-wave Doppler of the TV from the midesophageal modified bicaval view (104°) demonstrates a normal bioprosthetic TV with a mean pressure gradient of 4 mm Hg and no TR. *LV*, Left ventricle; *RV*, right ventricle.

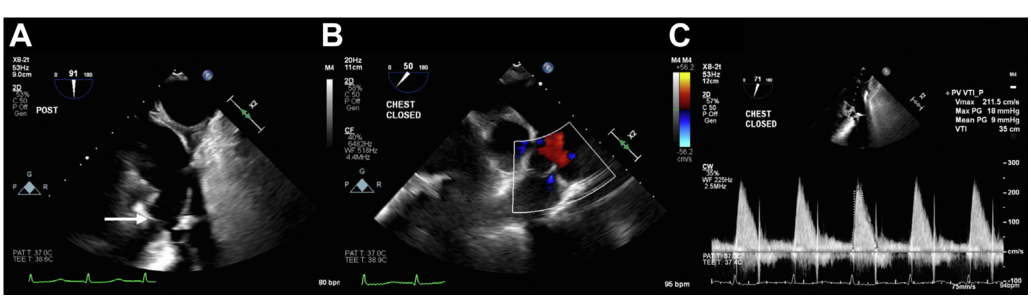

Figure 8 Intraoperative postprocedural TEE. **(A)** Two-dimensional TEE, upper esophageal aortic arch short-axis view of the newly implanted bioprosthetic PV (*white arrow*). **(B)** Two-dimensional TEE with color flow Doppler, midesophageal right ventricle inflow-outflow view (50°) in diastole, shows no pulmonary regurgitation. **(C)** Two-dimensional TEE-guided continuous-wave Doppler of the bioprosthetic PV from the upper esophageal view (71°) demonstrates a mean pressure gradient of 9 mm Hg without regurgitation.

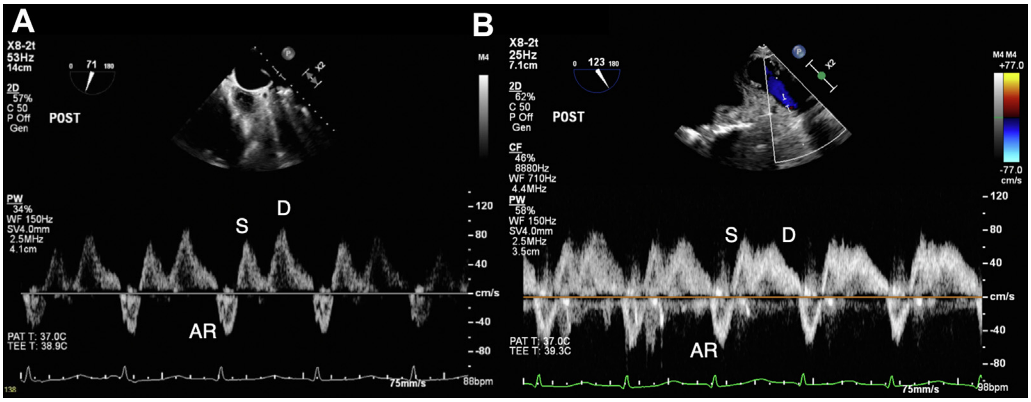

Figure 9 Intraoperative postprocedural two-dimensional TEE-guided pulsed-wave Doppler interrogation **(A)** in a modified midesophageal left upper pulmonary vein view (71°) and **(B)** right upper pulmonary vein view (123°) demonstrates normal antegrade S-wave flow, D-wave flow, and atrial reversal (AR) flow.

SUPPLEMENTARY DATA

Supplementary data to this article can be found online at https://doi.org/10.1016/j.case.2023.03.004.

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