Aortic Stenosis Severity: Rhythm Makes a Difference

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INTRODUCTION

Doppler velocity and pressure gradient–based assessment of aortic valve stenosis (AS) is flow dependent. For a given aortic valve orifice area, both velocity and pressure gradient increase with elevated transaortic flows and decrease with reduction in flow rates. Therefore, assessment of the true severity of AS should be carefully performed during high-flow states, accounting for the factors that can profoundly affect flow across the aortic valve. We describe a challenging case of assessing AS severity in the setting of bradycardia from complete heart block (CHB), normal left ventricle (LV) function, permanent atrial fibrillation (AF), and moderate AS at baseline. Proper evaluation of this patient required that we recognize that gradients were appropriately estimated to be elevated due to increased flow through the aortic valve during each heart beat due to a unique combination of physiological factors mentioned above. Recognition of this phenomenon was critical in accurately classifying AS severity and guiding appropriate clinical decision-making.

CASE PRESENTATION

History of Present Illness

A 74-year-old man was admitted for evaluation of recurrent falls. During the initial evaluation, he was found to be in CHB with a ventricular rate of 35-40 bpm based on telemetry and 12-lead electrocardiogram (ECG). Medical history included AF on carvedilol and apixaban and coronary artery bypass graft surgery that was performed 6 months prior to admission. He also had stage 3 chronic kidney disease, diabetes mellitus, hypertension, and hyperlipidemia. Physical exam was significant for a crescendo-decrescendo systolic murmur at the right upper sternal border, which was also heard throughout the precordium with carotid radiation and no radial pulse delay.

Investigations and Clinical Course

Admission electrocardiogram confirmed the presence of CHB in the setting of permanent AF with a regular ventricular rate of 37 bpm, consistent with the diagnosis of CHB. Initial transthoracic echocardiogram (TTE) performed at this time demonstrated normal left ventricular (LV) systolic function (LV ejection fraction, 65%-70% by visual estimation), dilated left atrium, LV outflow track (LVOT) diameter of 2.2 cm, and a calcified restricted aortic valve (Figures 1 and 2, Videos 1-3). The diagnosis of severe AS was considered based on transaortic valve indices (peak velocity [PV] = 4.8 m/sec, mean pressure gradient = 48 mm Hg; Figure 3A and B). The LVOT velocity-time integral (VTI) was 32 cm, and aortic valve VTI was 116 cm with a stroke volume of 124 mL. The calculated aortic valve area by continuity equation was 1.06 cm^2 with a dimensionless valve index (DVI) of 0.27. Altogether this suggests a diagnosis of severe AS. A permanent pacemaker was placed for treatment of his CHB, and workup for transcatheter aortic valve implantation was recommended. Aortic valve assessment performed during left and right heart catheterization performed after pacemaker placement revealed patent coronary artery grafts and normal filling pressures (right

VIDEO HIGHLIGHTS

Video 1: Parasternal 4-chamber view on TTE prior to pacemaker implantation with corresponding ECG shows normal visually estimated LV ejection fraction of 65% to 70% in the presence of CHB.

Video 2: Transthoracic parasternal long-axis zoomed view prior to pacemaker implantation demonstrating a restricted calcified aortic valve.

Video 3: Transthoracic parasternal long-axis view with Doppler prior to pacemaker implantation demonstrating calcified aortic valve with turbulent flow during midsystole in the setting of CHB.

Video 4: Transthoracic apical 4-chamber view on TTE post–pacemaker implantation with corresponding ECG shows normal visually estimated LV ejection fraction of 55% to 60% in the presence of paced ventricular rhythm.

Video 5: Transthoracic parasternal long-axis zoomed view post–pacemaker implantation demonstrating significant improvement of AS in the setting of a regularly paced ventricular rhythm.

Video 6: Transthoracic parasternal long-axis view with Doppler post–pacemaker implantation demonstrating significant improvement of AS and turbulent flow in the setting of a regularly paced ventricular rhythm.

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

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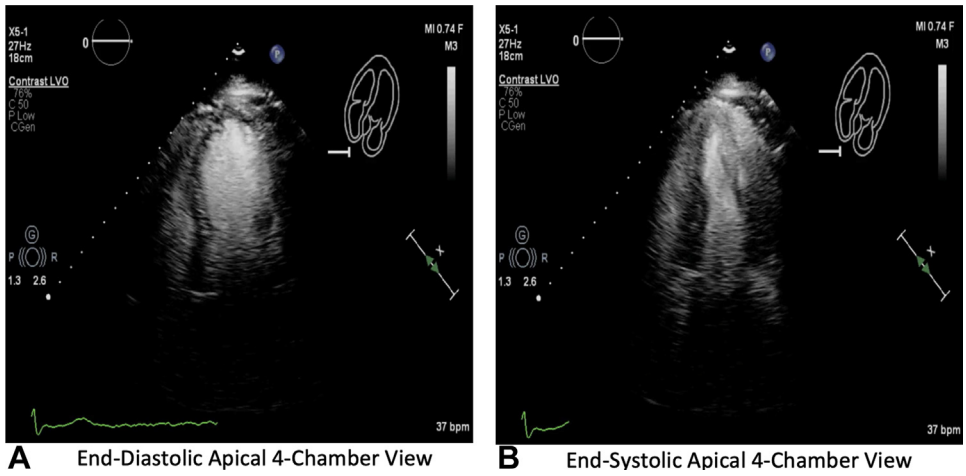

Figure 1 Pre–permanent pacemaker implantation TTE in 4-chamber view with ultrasound-enhancing agent injection demonstrating LV chamber size at end diastole **(A)** and end systole **(B)**.

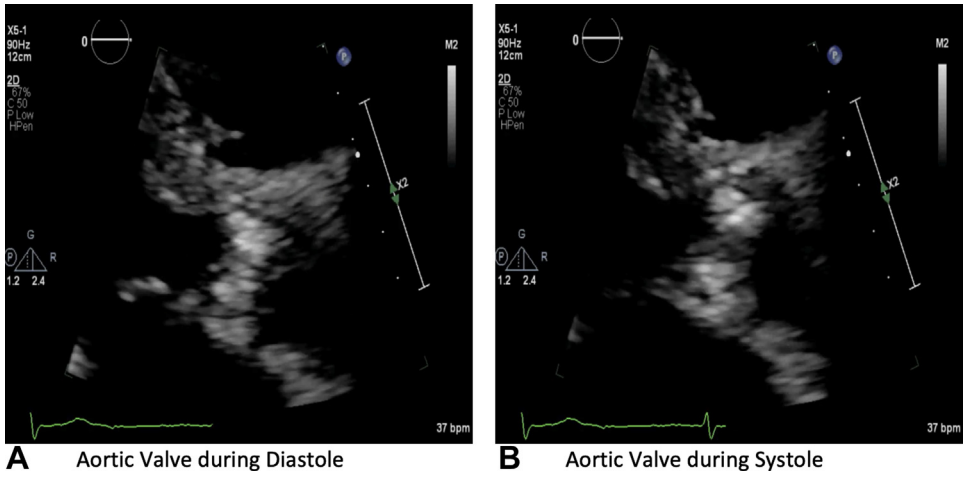

Figure 2 Pre–permanent pacemaker implantation TTE in parasternal long-axis zoomed view demonstrating heavily calcified aortic valve closed during diastole **(A)** and restricted opening during systole **(B)**.

atrial = 4 mm Hg, right ventricle = 30/4 mm Hg, pulmonary artery = 29/10 mm Hg, and pulmonary capillary wedge pressure = 10 mm Hg), and estimated cardiac output was 5.9 L/min at an average heart rate of 79 bpm. The mean aortic valve gradient was 21 mm Hg, and valve area was 1.4 cm^2 on invasive assessment consistent with moderate AS (Figure 4). Left ventricular end-diastolic pressure was 7 mm Hg. Given the discrepancy with the initial echocardiographic assessment of AS, a repeat TTE mirroring imaging windows of the first TTE was performed and eplicated the findings of the invasive aortic valve assessment (PV = 3.4 m/sec, mean pressure gradient = 25 mm Hg) of moderate-grade AS (Figure 3C and D, Videos 4-6). The LVOT VTI, aortic valve VTI, and stroke volume decreased to 18 cms, 64 cms, and 71 mL, respectively. Consequently, the aortic valve area and DVI increased to 1.1 cm^2 and 0.29, respectively, after pacemaker implantation, confirming improvement from severe to moderate AS.

Based on these clinical and echocardiographic results, transcatheter aortic valve implantation was put on hold, and follow-up with watchful monitoring was advised. The patient was able to ambulate without assistance and reported no presyncopal symptoms.

DISCUSSION

Doppler assessment through TTE is the recommended imaging modality of choice for initial evaluation of AS severity.[1] There are many parameters measured during TTE evaluation of AS; however, PV and mean pressure gradient are the most widely used.[1] Peak velocity is the antegrade systolic velocity across the narrowed aortic valve that is measured using a continuous-wave Doppler ultrasound (CWD).[1] This method creates a digital velocity curve with its peak demonstrating PV. Mean pressure gradient is the pressure difference between the LV and aorta in systole and is distinct from the peak gradient calculated from PV.[2,3] It requires averaging the instantaneous gradients over the ejection period. Both measurements are dependent on flow rate across the aortic valve; therefore, in certain unique scenarios these values may be falsely elevated.[2]

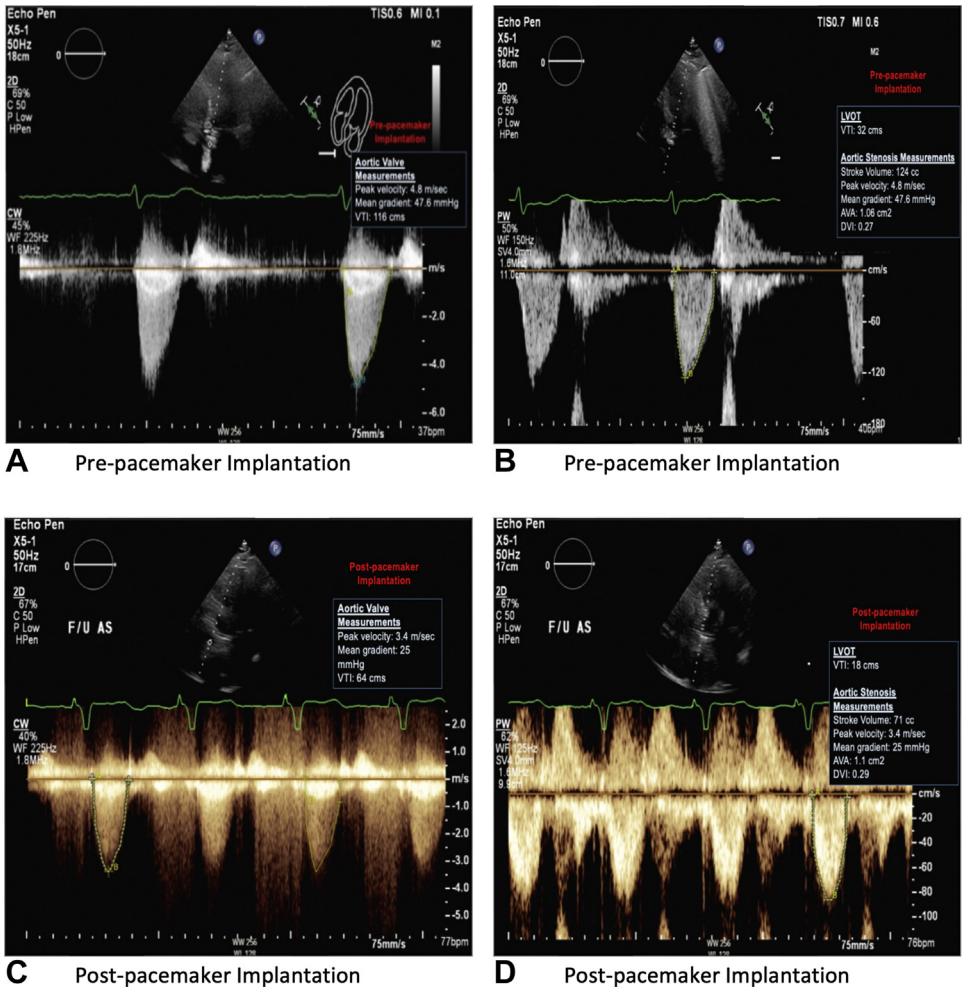

Figure 3 Pre– and post–permanent pacemaker implantation TTE in 5-chamber view. **(A)** Pre–pacemaker implantation CWD assessment of the calcified aortic valve at a heart rate of 37 bpm demonstrating a PV of 4.8 m/sec, an estimated mean pressure gradient of 48 mm Hg, and aortic valve VTI of 116 cm. **(B)** Pre–pacemaker implantation pulse wave Doppler assessment of the calcified aortic valve with the sample volume placed within the LVOT demonstrating LVOT VTI of 32 cm and stroke volume of 124 mL (using LVOT diameter of 2.2 cm). The calculated aortic valve area by continuity equation of 1.06 cm^2 with a DVI of 0.27 pre–pacemaker implantation. **(C)** Post–pacemaker implantation CWD assessment of the calcified aortic valve at a heart rate of 76 bpm demonstrating a PV of 3.4 m/sec, an estimated mean pressure gradient of 25 mm Hg, and aortic valve VTI of 64 cm. **(D)** Post–pacemaker implantation pulse wave Doppler assessment of the calcified aortic valve with the sample volume placed within the LVOT demonstrating a stroke volume of 71 mL and LVOT VTI of 18 cm. The calculated aortic valve area by continuity equation of 1.1 cm^2 with a DVI of 0.29 post–pacemaker implantation.

Our patient presented with CHB causing severe bradycardia with preserved LV systolic function in the setting of permanent AF. This resulted in an increased diastolic filling leading to an elevated stroke volume in an euvolemic state with normal filling LV end-diastolic pressure and pulmonary capillary wedge pressure pressures and an absence of cycle length variability. These hemodynamic changes occurred on the background of existing moderately severe AS and normal LV systolic function.[4] Consequently, increased flow across the aortic valve during each heartbeat contributed to an elevated mean gradient and PV measurements, falsely designating the AS as being severe. Permanent pacemaker implantation led to correction of bradycardia to an average ventricular rate of 70 bpm with consequent normalization of stroke volume from 124 to 71.4 mL. The stroke volume index consequently decreased from 59 to 34 mL/m^2 per heartbeat. This normalized flow across the aortic flow per heartbeat caused a subsequent reduction in PV and mean aortic valve gradient with appropriate reclassification of AS being moderate in severity. Transthoracic echocardiogram and cardiac catheterization both subsequently confirmed findings of moderate AS. This led to a significant change in treatment recommendation despite the presence of a calcified aortic valve. Another unique aspect of this case is that the lack of organized atrial activity from permanent AF in the setting of CHB prevented intermittent cannon activity. This is different from a scenario of paroxysmal AF or sinus rhythm because in those cases the atria may contract against a fully or partially closed mitral valve, resulting in variable LV diastolic filling and stroke volume (and lower consequent mean pressure gradient and PV) on some beats. Due to the nature

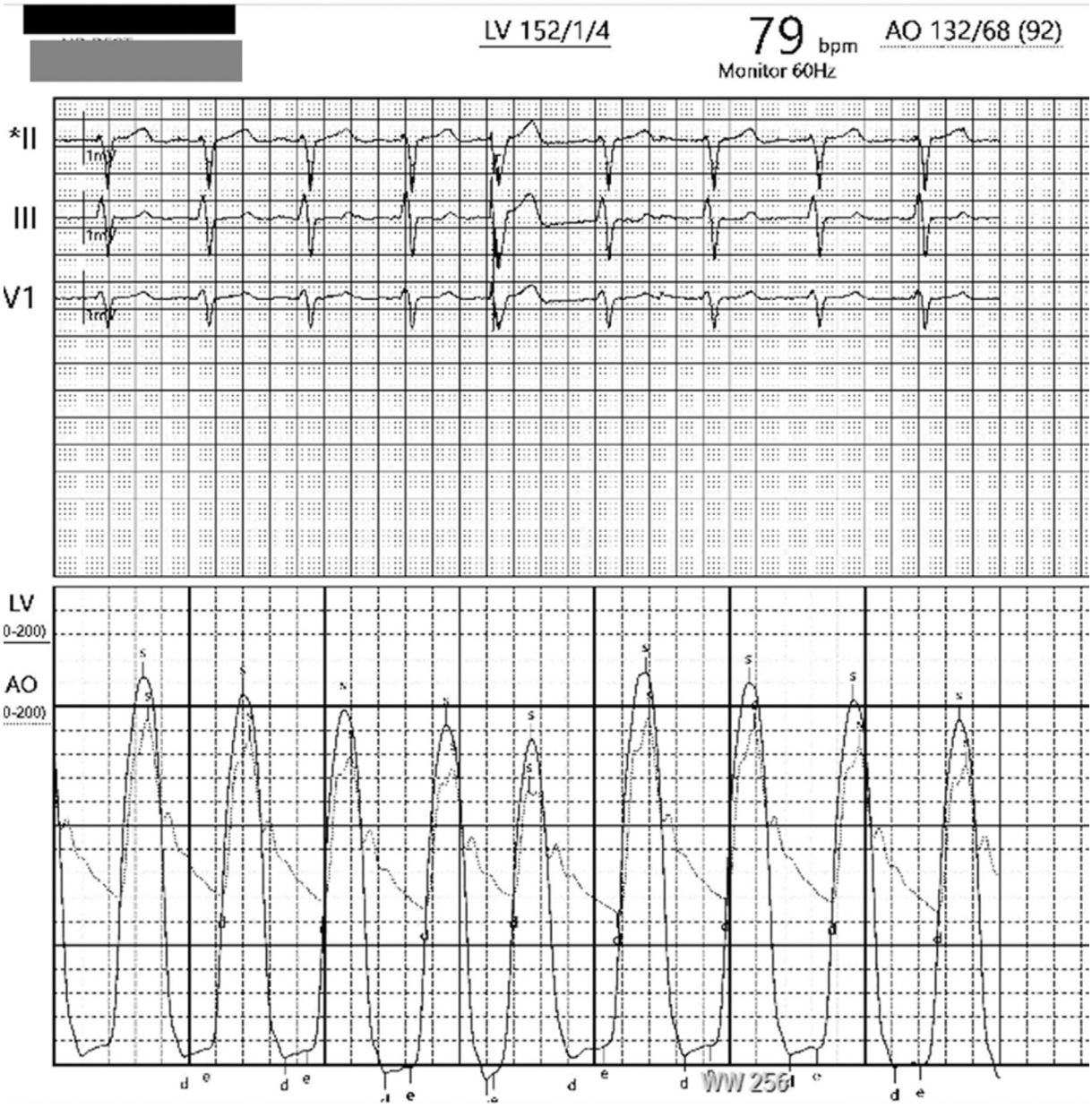

Figure 4 Invasive assessment of the aortic valve severity: illustration of simultaneous LV and ascending aortic (AO) pressures recorded with fluid-filled catheters. Left ventricular end-diastolic pressure is 7 mm Hg. The estimated mean aortic valve gradient is 21 mm Hg, and the valve area is 1.4 cm^2. Heart rate is 79 bpm, and the estimated Fick cardiac output is 5.9 L/min.

of our patient's permanent AF, ventricular diastolic filling was relatively standardized throughout all beats, which allowed us to isolate the cause of increased flow to bradycardia from CHB. This phenomenon has been previously demonstrated in a study by Esquitin *et al,*[5] where it was shown that measurement of the aortic valve after an extrasystolic beat can result in a larger value than a normal sinus beat.[5] Unlike the situations studied in that paper, our case reports minimal variability between systolic cycles given that our patient had a history of permanent AF in the setting of CHB. There are other conditions (Table 1) that are accompanied by a high-flow state and may mimic the problems observed in our case. Current guidelines recommend that proper assessment of AS require identification of potentially reversible high-flow states and its correction when possible.[13]

CONCLUSION

This report illustrates the importance of understanding the role of increased blood flow across the aortic valve that may be seen in CHB and emphasizes how this may impact the assessment of the severity of AS and guidance of appropriate clinical decision-making.

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Table 1 Author-compiled listing of conditions with a high cardiac output that can confound echocardiographic assessment of AS severity due to a high-flow state

Condition	Mechanism	Reference
Hyperthyroidism	Thyroid hormone increases contractility and heart rate.	Siu *et al* (2007)[6]
Myeloproliferative disorders	Increased cellular metabolism and high cell turnover leads to increased metabolic demand and decreased systemic vascular resistance (SVR).	Reddy *et al* (2016)[7]
Sepsis	Hyperdynamic phase with decreased SVR.	Zaky *et al* (2014)[8]
Thiamine deficiency	Buildup of pyruvate and lactate in the blood that leads to vasodilation and decreased SVR.	Ikram *et al* (1981)[9]
Chronic lung disease	Chronic hypoxia and hypercapnia lead to a reduced SVR.	Reddy *et al* (2016)[7]
Arteriovenous fistulas	Shunt bypasses the resistance of the arteriolar and capillary system. This causes an increased flow of blood to the heart, requiring an increase in heart rate and stroke volume, leading to increased cardiac output.	Reddy *et al* (2016)[7]
Cirrhosis	Associated with multiple arteriovenous fistulas and impaired clearance of vasoactive substances leading to decreased SVR.	Chayanupatkul *et al* (2014)[10]
Obesity	Alters myocardial metabolism through insulin resistance and is associated with excessive vasodilation and decreased SVR.	Peterson *et al* (2004)[11]; Gollasch *et al* (2012)[12]
CHB/bradycardia	Increased diastolic filling leads to elevated stroke volumes resulting in increased flow through the aortic valve.	As proposed in this report

SUPPLEMENTARY DATA

Supplementary data related to this article can be found at https://doi.org/10.1016/j.case.2022.04.016.

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