# Three-Dimensional Imaging of the Repaired Aortic Valve

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AORTIC VALVE (AV) REPAIR is a surgical option for patients with type-I (dilation of the aortic root) and type-I (leaflet prolapse, flail, or fenestration) aortic regurgitation (AR).[1-7] Recurrent AR and/or the need for reoperation is as high as 10% at 4 to 5 years after repair.[1-7] Intraoperative echocardiographic imaging can define the etiology of AR, assist in the repair plan, determine the need for immediate re-repair or replacement, and improve outcomes.[1-11] Postrepair predictors of long-term (≥5 years) freedom from recurrent AR (≥ moderate) and the need for reoperation include leaflet coaptation below the annular plane (no residual prolapse), coaptation length >4 mm, and < moderate AR.[2,4,5,10-17]

The assessment of AR severity includes measurements of the regurgitant orifice area (vena contracta area, proximal flow convergence measures)[8-21] and surrogate measurements reflecting the regurgitant orifice (pressure half-time [PHT], vena contracta width [VCW], and proximal jet width [PJW]).[10-13] Although the surrogate measurements are performed more easily, they are most accurate for severe AR, good for mild AR, and variable for moderate AR.[18,19,21] This presents a clinical challenge after AV repair because differentiating between mild and moderate AR may determine the need for re-repair or replacement.[5,8,9] Assessment of AR includes analyzing the following 3 levels of the AR jet: above (supra-aortic), at (valve), and below (subvalve) the AV.[19,22,23] Complicating the evaluation is poor image quality due to postrepair imaging artifacts, para-aortic edema/hematoma, altered AV geometry, and the presence of eccentric and/or complex AR jets.

The authors present 4 cases in which 2- and 3-dimensional (2D, 3D) imaging from transgastric windows improved the assessment of the repaired AV and prevented the need to return to cardiopulmonary bypass for either re-repair or valve replacement for significant AR after repair.

## ECHOCARDIOGRAPHIC IMAGING AND ANALYSIS

A comprehensive echocardiographic examination is performed to evaluate the regurgitant AV before and after valve repair.[19,22,23] The 2D examination includes midesophageal short-axis, long-axis, and transgastric views of the left ventricular outflow tract (LVOT) and AV. After completion of the 2D examination, 3D transesophageal echocardiography (TEE) volumetric datasets are obtained (Philips X7-2t TEE transducer and iE33 xMatrix system; Phillips Medical, Andover, MA) with and without color-flow Doppler (CFD) from the transgastric position. Factory defaults on the echocardiographic system are used for acquisition of images. To acquire a transgastric 3D dataset, 2 orthogonal images of the AV are viewed in x-plane format and the images are optimized for gain, harmonics, penetration, and resolution before acquisition of the 3D data. Volumetric data are obtained using R-wave gated acquisition over 4 beats during a brief period of apnea. Once acquired, the 3D image is cropped to visualize the valve anatomy and/or the regurgitant jet in its entirety: supravalvular (flow convergence), valvular (vena contracta), and subvalvular (proximal jet).

Measurements or assessments performed using 2D imaging include coaptation position and length; VCW, PJW, and LVOT diameter at the level of the jet width measurement; and the vena contracta area (VCA) or the AR jet area in the short-axis view when feasible (Table 1). The VCW is measured as the smallest identifiable neck of flow at the level of the AV in the midesophageal long-axis or transgastric windows in which the AR jet can be seen in its fullest. The PJW is measured within 1 cm sub (below) the AV.

From the transgastric windows, after alignment of the ultrasound beam with blood flow through the LVOT and AV, CFD and continuous-wave Doppler assessments of both systolic and diastolic blood flow are performed to assess valve patency and competence. The continuous-wave Doppler recording of the time-velocity integral permits recording of the changing Aorto-LVOT gradient during the diastolic period and allows measurement of the PHT—the amount of time to 50% reduction in the Ao-LVOT gradient. The PHT is related indirectly to effective regurgitant orifice area (EROA) and AR severity.[24,25]

The severity of AR initially was determined using 2D imaging because this was accomplished quickly. After collection of volumetric data, the 3D images were cropped, viewed, and measured.

Measurements performed using 3D images included the coaptation length and position, VCW, and VCA. These were facilitated with iCROP (Philips), a method that allows cropping of 2 simultaneously displayed orthogonal images to view the AR jet from either side of the valve. The VCA was measured by cropping to the narrowest color Doppler (CD) area in a plane perpendicular to the AV and AR jet. The resulting 3D image was stored digitally and then viewed en face to allow for planimetry of the VCA.

## CASE PRESENTATIONS

### Case 1

A 70-year-old female presented with an ascending aorta aneurysm (Fig 1, A; diameter of 4.8 cm) with effacement of the sinotubular junction and moderate AR (Fig 1, B; vena contracta = 5 mm). After ascending aorta replacement, repair of left coronary cusp fenestration, and plication of a prolapsing left coronary cusp, the intraoperative TEE evaluation showed moderate AR (see Fig 1). Initial midesophageal windows demonstrated moderate AR (VCW = 5 mm, PJ/LVOT ratio = 0.38, and VCA = 30 mm$^2$) and possible leaflet coaptation

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**Table 1. Assessment of Aortic Regurgitation Severity**

| | Mild | Moderate | Severe |
|---|---|---|---|
| Angiographic grade | 1-2+ | 3+ | 4+ |
| Jet density/appearance | Faint/incomplete | — | Dense/complete |
| Pressure half-time | >450 ms | — | <250 ms |
| Proximal jet width | <3 mm | — | >6 mm |
| Proximal jet width/ventricular outflow tract diameter | <0.25 | 0.25-0.64 | ≥0.65 |
| Vena contracta width | <3 mm | 0.3-0 mm | >6 mm |
| Vena contracta area* | <30 mm$^2$ | — | >50 or 60 mm$^2$ |
| Pulse-wave Doppler asc/desc aorta | Faint/brief early diastolic flow reversal | — | Holodiastolic diastolic flow reversal |
| Effective regurgitant orifice area (PISA)† | <10 mm$^2$ | — | <30 mm$^2$ |
| Regurgitant orifice volume (PISA)† | <30 mL | 30-60 mL | >60 mL |
| Regurgitant orifice fraction (PISA)† | <30 mL | 30-60 mL | >60 mL |
| Secondary findings | | LVE, LVSD, LAE, PHTN | |

Abbreviations: PISA, proximal isovelocity surface area; LVE, left ventricular enlargement; LVSD, left ventricular systolic dysfunction; LAE, left atrial enlargement; PHTN, pulmonary hypertension.

*Three-dimensional measure.

†Two-dimensional measure.

below (LVOT side) the annular plane. Additional 2D transgastric images demonstrated coaptation above the annulus, a coaptation length of 8 mm, and a VCW of 3 mm (see Fig 1). 3D images from the transgastric windows (Fig 2) demonstrated the regurgitant jet on all 3 levels and supported an assessment of mild AR (see Fig 2; VCW = 2 mm, VCA = 15 mm$^2$). Transthoracic echocardiography (TTE) examination at 11 months showed stable mild AR and normal left ventricle size.

## Case 2

A 58-year-old male was found to have an aortic root aneurysm (sinus of Valsalva diameter 6.7 cm), dilated AV annulus (3.0 cm), severe AR (calculated regurgitant orifice area [ROA] = 60 mm$^2$, VCW = 12 mm, and proximal jet/LVOT width = 0.75) (Fig 3), and a dilated left ventricle. After aortic root replacement with repair of right coronary cusp fenestration and suspension of left coronary cusp prolapse, intraoperative 2D CD imaging demonstrated moderate AR (jet width = 8 mm and PJW/LVOT = 25%-40%) (Fig 4). The 2D images showed appropriate coaptation above the annular plane and a coaptation length of 10 mm (see Fig 4). Doppler analysis from the transgastric view across the LVOT and AV was consistent with mild AR (PHT = 582 ms) (Fig 5). This was supported by 3D imaging assessment from transgastric windows with a VCA of 16 mm$^2$ (Fig 6). Comparing the regurgitant jet in Fig 4 to that in Fig 6, it is apparent that entrainment or expansion occurs downstream from the AV. Quantification of AR severity from the midesophageal windows is difficult if the vena contracta cannot be identified and assessment is performed further downstream from the valve. Follow-up TTE at 6 weeks showed mild AR.

## Case 3

A 54-year-old male with a noncoronary sinus of Valsalva aneurysm and mild-to-moderate AR underwent an aortic valve-sparing root replacement with repair of multiple AV leaflet fenestrations. After repair, TEE images from the midesophageal windows demonstrated moderate AR (jet width = 6 mm; jet width/LVOT ratio = 50%) (Fig 7). However, imaging of the regurgitant jet at the level of the valve was hampered by artifact and the leaflet coaptation level, coaptation length, and vena contracta could not be identified. 3D images from transgastric windows showed the regurgitant jet at 3 levels (subvalvular, valvular, and supravalvular), demonstrating mild AR (VCA = 19 mm$^2$). Serial TTE studies showed an improvement from mild to trace AR during the initial hospitalization; however, at 17-month follow-up the AR progressed to mild-moderate with normal left ventricle size.

## Case 4

A 20-year-old male with mixed connective tissue disorder and aortic root aneurysm without preoperative AR was scheduled for aortic root replacement. After the aortotomy was performed, it was noted that the aortic leaflets prolapsed and multiple fenestrations were found at the leaflet edges. The patient underwent aortic root replacement with repair of leaflet fenestrations and plication of the non-coronary and right coronary cusps to treat prolapse. Initial postrepair midesophageal TEE images demonstrated moderate AR based on a jet width >3 mm (Fig 8). Transgastric images demonstrated an adequate coaptation length and a narrower PJW (see Fig 8, I; *yellow arrow*). 3D images from transgastric windows displayed the entire AR jet with a narrow VCW (Fig 9, A) and a VCA of 15 mm$^2$ (Fig 9, C), both consistent with only mild AR. Images from the left ventricular outflow perspective highlighted entrainment (*white arrow*) of the AR jet downstream that was consistent with the midesophageal images in Fig 8, F. Follow-up TTE 16 months later showed mild central AR.

## DICUSSION

Intraoperative echocardiographic evaluation of the repaired AV may be limited by imaging artifacts, para-aortic changes, and altered geometry, especially from the midesophageal windows. To overcome these limitations, the valve should be studied using multiple transducer angles and from both transesophageal and transgastric windows.[1,2-10,12,14-16,26] In the cases presented, transgastric imaging facilitated the measurements of coaptation and optimally aligned blood flow with the Doppler beam to assess the transvalvular flow and record the time-