



# Three-Dimensional Morphology of the Left Ventricular Outflow Tract: Impact on Grading Aortic Stenosis Severity

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**Background:** Left ventricular outflow tract (LVOT) measurement is a critical step in the quantification of aortic valve area. The assumption of a circular morphology of the LVOT may induce some errors. The aim of this study was to assess the three-dimensional (3D) morphology of the LVOT and its impact on grading aortic stenosis severity.

**Methods:** Fifty-eight patients with aortic stenosis were studied retrospectively. LVOT dimensions were measured using 3D transesophageal echocardiography at three levels: at the hinge points (HP) of the aortic valve and at 4 and 8 mm proximal to the annular plane. Results were compared with standard two-dimensional echocardiographic measurements.

**Results:** Three-dimensional transesophageal echocardiography showed a funnel shape that was more circular at the HP and more elliptical at 4 and 8 mm proximal to the annular plane (circularity index = 0.92 vs 0.83 vs 0.76,  $P < .001$ ). Cross-sectional area was smaller at the HP and larger at 4 and 8 mm from the annular plane (3.6 vs 3.9 vs 4.1 cm<sup>2</sup>,  $P = .001$ ). The best correlation between two-dimensional and 3D transesophageal echocardiographic dimensions was at the HP (intraclass correlation coefficient = 0.75; 95% CI, 0.59–0.86). When the HP approach was selected, there was a reduction in the percentage of patients with low flow (from 41% to 29%).

**Conclusions:** A large portion of patients with aortic stenosis have funnel-shaped and elliptical LVOTs, a morphology that is more pronounced in the region farther from the annular plane. Two-dimensional LVOT measurement closer to the annular plane has the best correlation with 3D measurements. Measurement of the LVOT closer to the annular plane should be encouraged to reduce measurement errors. (*J Am Soc Echocardiogr* 2017;30:28-35.)

**Keywords:** Left ventricular outflow tract, Aortic stenosis, 3D echocardiography

Echocardiography is the standard imaging modality for the evaluation and management of patients with aortic stenosis (AS).<sup>1-3</sup> Effective aortic valve area (AVA) and transvalvular gradients are the principal measures for grading stenosis severity. Left ventricular outflow tract (LVOT) measurement is a critical step in the quantification of AVA by the continuity equation. Current recommendations on

echocardiography advise measuring the LVOT on the longitudinal long-axis plane, at mid-systole and at 4 to 8 mm proximal to the annular plane.<sup>4</sup> More recently, some other investigators have suggested 2 mm as the recommended point for measuring the LVOT.<sup>5,6</sup> Furthermore, the main limitation pointed out for this method is that the continuity equation assumes a circular morphology of the LVOT, whereas several studies have demonstrated its elliptical shape, and the frequent underestimation of AVA with this assumption compared with planimeted area.<sup>5-9</sup> As a result, there are currently some concerns and controversies regarding the most appropriate method to measure the LVOT.

Three-dimensional (3D) transesophageal echocardiography (TEE) allows real-time volume rendering of images and offline volumetric quantification techniques.<sup>10</sup> This method allows exploration of the morphology of the LVOT and measurement of its dimensions at any distance from the annular plane, without making geometric assumptions. Previous studies using this method confirmed the elliptical shape of the LVOT, but all of them were limited to the analysis of a

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Abbreviations
<b>AS</b> = Aortic stenosis
<b>AVA</b> = Aortic valve area
<b>CSA</b> = Cross-sectional area
<b>HP</b> = Hinge points
<b>ICC</b> = Intraclass correlation coefficient
<b>LVOT</b> = Left ventricular outflow tract
<b>MDCT</b> = Multidetector computed tomography
<b>SVi</b> = Stroke volume index
<b>TEE</b> = Transesophageal echocardiography
<b>3D</b> = Three-dimensional
<b>TTE</b> = Transthoracic echocardiography
<b>VTI</b> = Velocity-time integral

single plane next to the insertion of the aortic valves.<sup>5,6,9,11</sup> Nevertheless, the LVOT is a more complex structure that extends from the annulus of the aortic valve to 8 or 12 mm into the left ventricle. The present study was conducted to assess the morphology and size of the LVOT using 3D TEE along its 8 mm proximal to the annular plane and its impact on AVA estimated by the continuity equation.

## METHODS

A retrospective study was conducted, including 58 patients from a series of 62 consecutive patients referred to our echocardiography laboratory for preoperative evaluation between

January 2010 and May 2012. Transthoracic echocardiography (TTE) and 3D TEE were performed as part of the protocol for patients who were candidates for transcatheter aortic valve implantation. Two-dimensional TTE and 3D TEE were performed with a time interval of <20 days between them. The local clinical research ethics committee approved the protocol, and informed consent was obtained for all patients. In case of poor image quality, patients were excluded from the analysis.

## 2D TTE

Two-dimensional TTE was performed using an iE33 ultrasound system equipped with an S5-1 phased-array transducer (Philips Medical Systems, Andover, MA). A systematic imaging protocol was performed by European Association of Cardiovascular Imaging-accredited cardiologists closely following current guidelines.<sup>1,4,12</sup> The LVOT was measured by two independent observers on a zoomed longitudinal 2D image, in a mid-systolic frame, using the inner edge-to-inner edge technique and at the hinge points (HP) of the aortic valve. Referent LVOT measurement was performed 4 mm and 8 mm proximal to the annulus, in accordance with guideline recommendations.<sup>2,4</sup> Each observer was free to choose any point as long as it was within 4 to 8 mm set in the LVOT. Doppler flow data were acquired from the LVOT, 2 to 4 mm below the annulus, in pulsed-wave mode from the apical five-chamber view. The position of the sample volume was moved distally in the LVOT, toward the aortic valve, until a much steeper rise was obtained, as recommended.<sup>13</sup> Pulsed Doppler spectral strips of LVOT systolic flow were manually traced on the modal curve. Aortic valve flows were obtained from all accessible acoustic positions, including the right parasternal window, to ensure maximal transaortic velocity measurement. The effective AVA was estimated using the continuity equation, averaging measurements from three different cardiac cycles (10 cardiac cycles if the patient was in atrial fibrillation) and assuming a circular shape of the LVOT. Image processing was performed offline using an image management system (Xcelera; Philips Medical Systems).

## 3D TEE

Three-dimensional TEE was performed using the iE33 ultrasound system equipped with a matrix-array X7-2t transducer (Philips Medical Systems). Sedation with intravenous propofol (1 mg/kg followed by 0.5 mg/kg every 3–5 min) was used to minimize distress. Real-time 3D imaging of a pyramidal 60° × 30° data set of the aortic valve and LVOT was obtained. Settings were optimized using narrow-angled acquisition mode to ensure a volume rate up to 25 Hz.<sup>14</sup> QLAB (3DQ module) (Philips Medical Systems) was used for post-processing of images. In a mid-systolic frame (defined as maximal aortic valve opening on 3D transesophageal volume-rendered images), two orthogonal planes with their lines parallel to the longitudinal edge were set through the LVOT. A third plane was traced perpendicular to the previous two planes. This plane was reoriented as needed to ensure the most circular orifice area of the slot. Using the multislice tool of the software, we drew different cuts of the LVOT. First, we selected the minimum number of planes for the software tool, four planes. We adjusted the first plane to coincide with the HP of the aortic sigmoid cusps. Next, we adjusted the distance between the different planes to 4 mm. In this way, we obtained four cuts of the LVOT: at the HP of the aortic leaflets, at 4 mm proximal to the annular plane, and also at 8 mm proximal to the annular plane. The fourth plane, the farthest from the aortic valve, usually passes through the proximal part of the anterior mitral leaflet, so it was not considered for LVOT analysis (Figure 1). A subsequent selection of the appropriate picture allowed us to measure the diameters (anteroposterior and medial-lateral) and cross-sectional area (CSA) by planimetry of the LVOT (Figure 2). LVOT morphology was evaluated by means of the circularity index dividing anteroposterior (short) by medial-lateral (large) diameters. A circularity index of 1 would represent a perfect circle, while a progressively lower value would represent a more ellipsoid geometry. The 3D assessment of AVA was made using the continuity equation and combining the Doppler velocity-time integral (VTI), measured in the LVOT, with the LVOT CSA determined at the three levels.

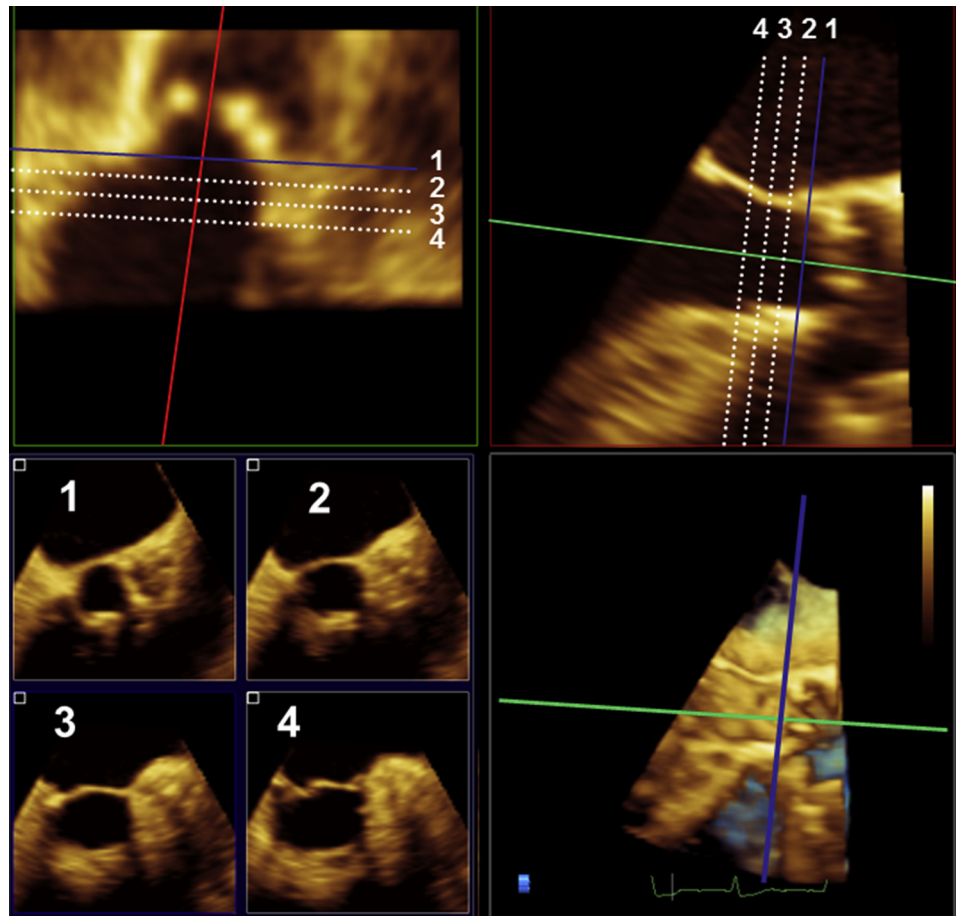
Data were reanalyzed in the whole cohort of patients with the same images and videos, and 2D transthoracic echocardiographic LVOT dimensions were remeasured by the same cardiologist and by a second observer in a blinded fashion, with a time interval of 2 to 7 days. A different observer blinded to the results of 2D TTE performed 3D image processing offline.

## Statistical Analysis

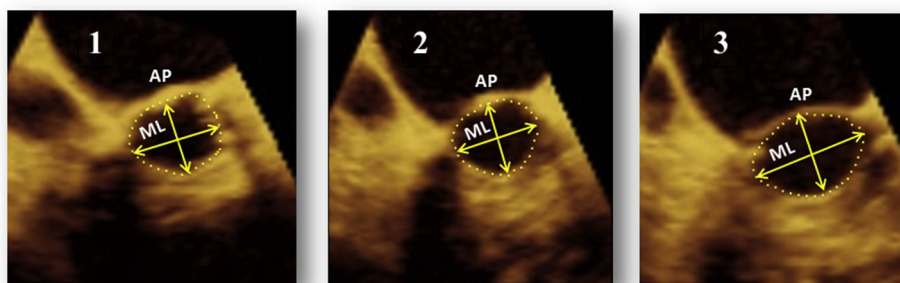
Normal distribution of continuous variables was assessed using the Kolmogorov-Smirnov test (Lilliefors correction). Variable magnitudes are described as proportions, mean ± SD, or median (interquartile range) as appropriate. Differences between variables were assessed using the paired *t* test, analysis of variance, or the Mann-Whitney *U* test as appropriate. Differences between proportions were assessed using the  $\chi^2$  test. Agreement between observers and imaging modalities was assessed using the intraclass correlation coefficient (ICC). Two-tailed *P* values <.05 were considered to indicate statistical significance. Analysis was performed using SPSS version 15.0 (SPSS, Chicago, IL).

## RESULTS

Four patients were excluded from the analysis because of inadequate images. The demographic and echocardiographic characteristics of the 58 patients included are depicted in Table 1. AVA was <1 cm<sup>2</sup>



**Figure 1** LVOT assessed by 3D TEE and multiplanar reconstruction with QLAB and multislice tool. (Top) The two images represent two orthogonal planes with their lines parallel to the longitudinal edge set through the LVOT. (Bottom) The left image corresponds to a third plane traced perpendicular to the previous planes to obtain the CSA of LVOT. Each line (1–4) corresponds to the four planes traced by QLAB multislice tool, with 4 mm between each. For measurements, we selected slice 1 at the HP, slice 2 at 4 mm, and slice 3 at 8 mm into the LVOT.



**Figure 2** LVOT measurements at the HP of the aortic valve (1), at 4 mm (2), and at 8 mm (3) proximal to the aortic annulus. These slices correspond to those in Figure 1 and show how to measure the anteroposterior (AP) diameter, medial-lateral (ML) diameter, and CSA of the LVOT (dotted lines).

in 50 patients and between 1 and 1.3 cm<sup>2</sup> in the remaining eight patients.

### Three-Dimensional Transesophageal Echocardiographic Morphology of the LVOT

LVOT morphology assessed by 3D TEE showed a funnel shape (Figure 1). LVOT CSA was smaller at the level of the HP of the aortic

valve and larger when measured at 4 and 8 mm proximal to the annular plane ( $3.76 \pm 0.9$  vs  $4.05 \pm 1.1$  vs  $4.46 \pm 1.3$  cm<sup>2</sup>,  $P < .001$ ). Only 11 patients (18.9%) had CSAs of the LVOT that were larger at the HP of the aortic valve than measured at 8 mm proximal to the annular plane. These patients had increases of interventricular septal thickness ( $16.2 \pm 4.2$  vs  $14.2 \pm 2.2$  mm,  $P < .001$ ) and interventricular septum/left ventricular posterior wall ratio

**Table 1** Demographic and echocardiographic characteristics of the patients

Variable	Value
Age (y)	74.2 ± 8.4
Women	28 (48%)
Weight (kg)	73.9 ± 15.2
Height (cm)	160.3 ± 8.5
Body surface area (m <sup>2</sup> )	1.77 ± 0.19
Atrial fibrillation	11 (19%)
Interventricular septal thickness (mm)	14.6 ± 2.9
LV posterior wall thickness (mm)	12.9 ± 2.1
LV diastolic diameter (mm)	44.5 ± 8.3
LV systolic diameter (mm)	28.5 ± 9.4
LVEF (%)	58.7 ± 14.8
Left atrial volume index (mL/m <sup>2</sup> )	39.5 ± 18.9
Peak gradient (mm Hg)	69.8 ± 27.1
Mean gradient (mm Hg)	42.1 ± 17.3
SVi (mL/m <sup>2</sup> )	38.1 ± 13.2
AVA, 2D TTE (cm <sup>2</sup> )	0.72 ± 0.24
AVAi, 2D TTE (cm <sup>2</sup> /m <sup>2</sup> )	0.41 ± 0.12

AVAi, Aortic valve effective area index; LV, left ventricle; LVEF, left ventricular ejection fraction.

Data are expressed as mean ± SD or number (percentage).

(1.3 ± 0.4 vs 1.1 ± 0.2,  $P < .01$ ) and higher VTIs at the LVOT (27.2 ± 9.7 vs. 20.2 ± 4.5 cm,  $P < .05$ ). CSA of the LVOT was more circular at the level of the HP of the aortic valve and more elliptical when measured at 8 mm proximal to the annular plane (Figure 3A). In fact, 30% of patients showed circular shapes at the HP, but only 3% did so at 8 mm (Figure 3B). LVOT anteroposterior diameter dimension was similar when measured by 3D TEE at any level. In contrast, LVOT lateral diameter increased from the HP of the aortic valve as measures were made more distal to the annulus (23.1 ± 3.3 vs 24.9 ± 3.3 vs 27.3 ± 3.9 mm,  $P < .001$ ; Table 2).

### Two-Dimensional TTE: Annular Plane versus LVOT

LVOT anteroposterior diameter was larger when measured at the HP than when measured more distal to the annular plane at the reference point (20.8 ± 2.3 vs 19.8 ± 2.3 mm,  $P < .01$ ). Also, the values of the derived calculations were higher when diameter was measured at the HP: stroke volume index (SVi) (41.2 ± 14 vs 38.1 ± 13.2 mL/m<sup>2</sup>,  $P < .01$ ) and AVA (0.79 ± 0.29 vs 0.72 ± 0.24 cm<sup>2</sup>,  $P < .001$ ) (Table 2).

### 2D versus 3D Measurements

The best correlation between 2D TTE and 3D TEE was at the HP level (ICC = 0.75; 95% CI, 0.59 to 0.86;  $P < .001$ ), whereas at the reference LVOT, the correlation with 3D TEE was very poor (ICC = 0.35; 95% CI, -0.21 to 0.57;  $P = NS$ ).

### Reclassification of AS Severity

With TTE, when HP was selected, the number of patients with AVA < 1 cm<sup>2</sup> was reduced from 50 (86%) to 48 (83%) ( $P < .01$ ),

and the number of patients with low flow (SVi < 35 mL/m<sup>2</sup>) decreased from 24 (41%) to 17 (29%) ( $P < .001$ ) (Figure 4)

### Reproducibility of the Measurements

Intra- and interobserver reproducibility of the measurements is depicted in Table 3. The diameter measured by 2D TTE was more reproducible when measured at the HP of the aortic valve. The most reproducible measure was CSA by 3D TEE at the HP level (ICC = 0.96; 95% CI, 0.93–0.97). Intra- and interobserver variability was higher for lateral measurements than for anteroposterior ones.

## DISCUSSION

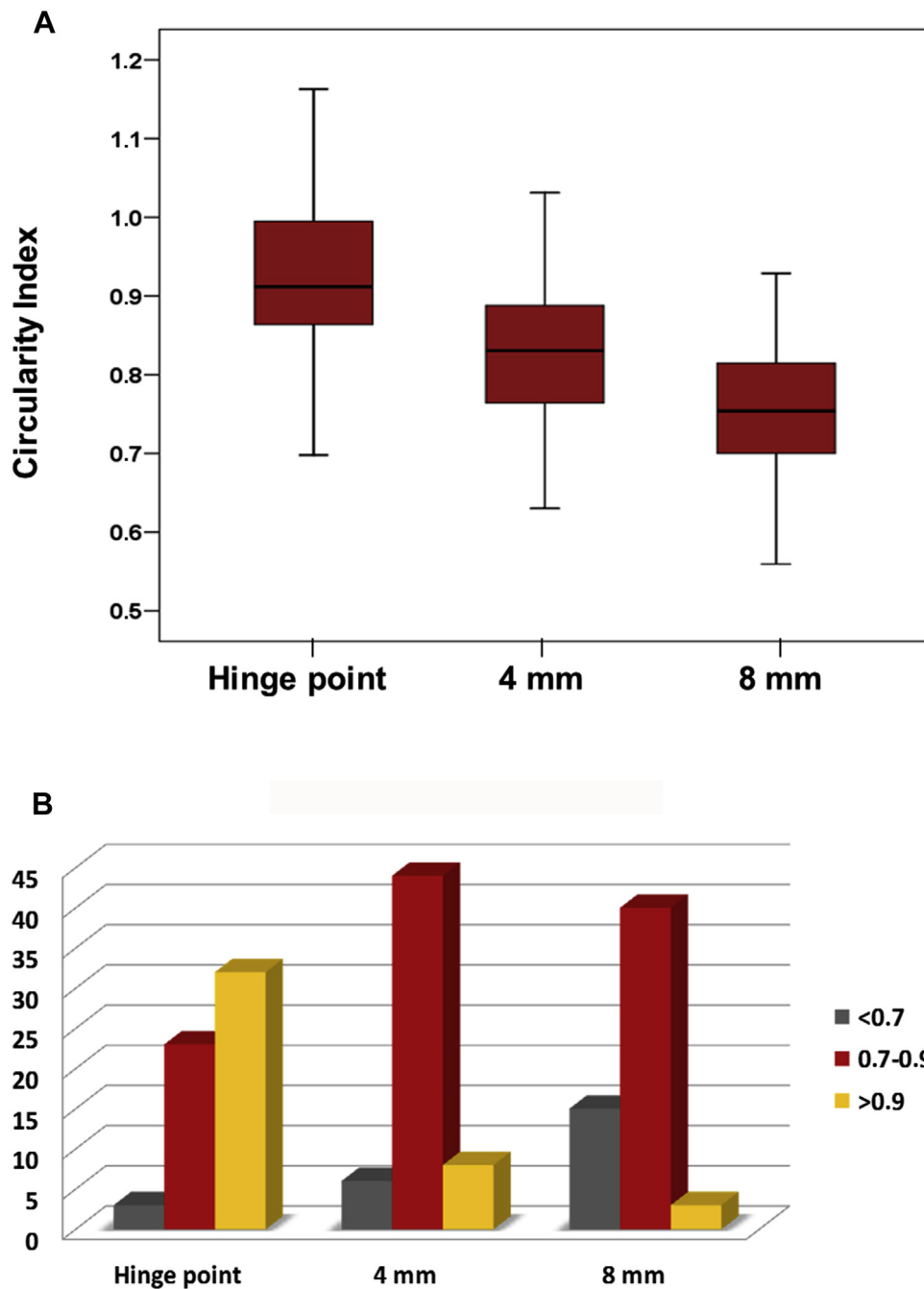
### LVOT Morphology

The most important finding of this study is the demonstration that in patients with degenerative AS, the LVOT is frequently funnel shaped, with an area that is reduced by >15% in just 8 mm. This funnel is more elliptical at the base and tends to be more circular at the valvular plane. Nonetheless, 70% of the patients in the study showed an elliptical morphology at the valvular plane, with a circularity index of <0.9. The reason for the elliptical morphology of the LVOT lies in the predominance of the medial-lateral diameter over the anteroposterior one. Moreover, the farther from the aortic annulus it is measured, the medial-lateral diameter becomes larger, whereas the anteroposterior dimension does not change significantly, which results in a larger CSA (Figure 2). This funnel morphology, to the best of our knowledge, has not been previously described. Previous studies highlighting the elliptical morphology of the LVOT with multidetector computed tomography (MDCT) or 3D TEE<sup>5-8</sup> were restricted to the evaluation of the LVOT at only one plane, relatively closer to the aortic valve. In our study, with 3D TEE, we assessed the LVOT more extensively, performing three measurements in the 8 mm proximal to the aortic valve, and we have been able to demonstrate that this elliptical shape becomes more pronounced as it gets deeper into the left ventricle. The anteroposterior diameter evaluated with 3D TEE remains very similar at the three points of measurement, as opposed to the lateral diameter, which also increases as it gets deeper into the left ventricle (Figure 2). It should be taken into account that patients with severe hypertrophy of the interventricular septum may show a reduced CSA of the LVOT at 4 and 8 mm proximal to the annular plane. In our population, this inverted funnel shape was present in 18% of the patients, and it was associated with a proximal interventricular septal thickness ≥14 mm and an increased LVOT velocity (VTI > 25 cm).

### 2D Transthoracic Echocardiographic Evaluation

The continuity equation for AS evaluation was first proposed by Skjaerpe *et al.*<sup>13</sup> in 1985. In their article, the authors advocated for the measurement of LVOT diameter “just below the aortic valve.” Current echocardiographic recommendations are not clear on which is the most adequate point for measuring the LVOT. Guidelines recommend measuring the LVOT diameter at 4 to 8 mm from the aortic valvular plane.<sup>4</sup> Other authors propose measuring the LVOT at no more than 5 mm from the valvular plane,<sup>15</sup> whereas others support measuring the LVOT just at the HP of the aortic valve.<sup>9</sup>

In our study, LVOT dimensions on 2D TTE differed significantly on the basis of the point of measurement, whether the HP of the aortic valve or at 4 to 8 mm proximal to the valvular plane. Indeed,



**Figure 3 (A)** Circularity index of the LVOT with 3D TEE at the three points of measurement. **(B)** Distribution of patterns of circularity index of the LVOT with 3D TEE at the three points of measurement.

measurement at the HP was significantly higher than measurement at 4 to 8 mm from the valvular plane and was very similar to that obtained with 3D TEE.

Choosing the best point to measure the anteroposterior diameter of the LVOT by 2D TTE is not easy. In our study, intra- and interobserver variability were acceptable and very similar at all points. Nevertheless, the farther from the aortic annulus it was measured, the smaller anteroposterior diameter of the LVOT was obtained by 2D TTE. When compared with 3D TEE, the best correlation was found for the measurement at the HP (Table 2). In this way, there

were no significant differences between the two methods when the measurements were made at the HP. These results seem to support the initial description of the method of Skjaerpe *et al.*<sup>13</sup> Furthermore, LaBounty *et al.*<sup>16</sup> demonstrated in a previous study that effective orifice area calculated with the measurement of the LVOT at the annular diameter rather than the LVOT diameter 0.5 or 1 cm below the annulus resulted in the best agreement with AVA determined by invasive hemodynamics. In contrast, the use of subannular diameters resulted in a significant over- or underestimation of effective orifice area, depending on LVOT morphology (funnel

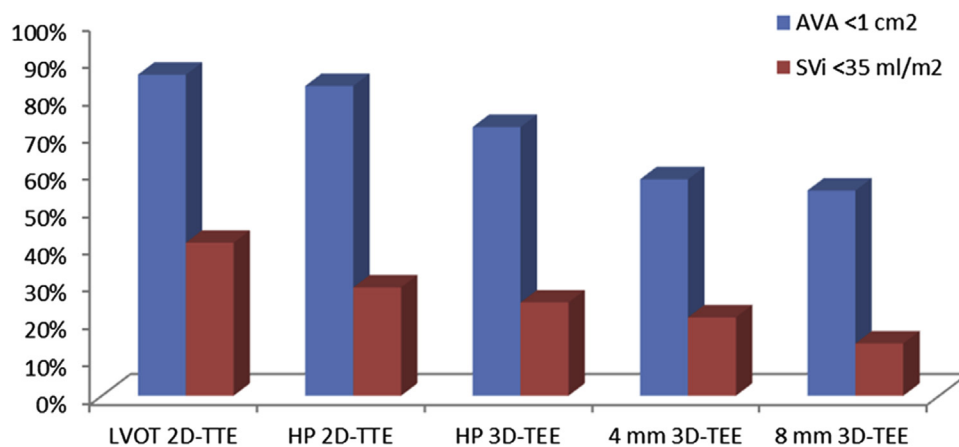
**Table 2** LVOT dimensions and derived calculations assessed by 2D TTE and 3D TEE at the HP of the aortic valve and at 4 to 8 mm of the annular plane

Variable	2D TTE		3D TEE		
	LVOT	HP	HP	4 mm	8 mm
APD (mm)	19.8 ± 2.3*	20.8 ± 2.3 <sup>†</sup>	20.8 ± 2.7	20.1 ± 3.7 <sup>†</sup>	20.4 ± 3.6 <sup>†</sup>
LD (mm)	—	—	23.1 ± 3.3	24.9 ± 3.3*	27.3 ± 3.9*
CIn	—	—	0.91 ± 0.09	0.81 ± 0.1*	0.75 ± 0.09*
CSA (cm <sup>2</sup> )	3.18 ± 0.8*	3.44 ± 0.8*	3.76 ± 0.9	4.05 ± 1.1*	4.46 ± 1.3*
SVi (mL/m <sup>2</sup> )	38.1 ± 13.2*	41.2 ± 14.1*	45.1 ± 17.2	47.8 ± 15.9*	51.9 ± 17.1*
AVA (cm <sup>2</sup> )	0.72 ± 0.24*	0.79 ± 0.29*	0.86 ± 0.32	0.92 ± 0.32*	1.0 ± 0.35*
AVA < 1 cm <sup>2</sup>	50 (86%)*	48 (83%)*	42 (72%)	34 (58%)*	32 (55%)*
SVi < 35 ml/m <sup>2</sup>	24 (41%)*	17 (29%)*	15 (25%)	12 (21%)*	8 (14%)*

APD, Anteroposterior diameter; CIn, circularity index; LD, lateral diameter.

\*P < .01 compared with 3D transesophageal measurement at HP.

<sup>†</sup>No significant difference.



**Figure 4** Proportion of patients with low-flow state (SVi < 35 mL/m<sup>2</sup>) and severe AS (AVA < 1 cm<sup>2</sup>) depending on the point of measurement of LVOT diameter with 2D TTE and 3D TEE.

shaped or hourglass shaped). This may contribute to the discrepancy with invasive measurement of AVA using the Gorlin equation.

### Clinical Implications

The repercussions of the choice of the point of measurement are not negligible. In fact, in our study, when comparing the reference method of measuring the LVOT at 4 to 8 mm of the annular plane, with the measurement at the HP, the number of patients with severe AS (AVA < 1 cm<sup>2</sup>) decreased from 50 to 48. Likewise, the number of patients with low-flow state (SVi < 35 mL/m<sup>2</sup>) decreased from 24 to 17. This could partly explain the high variability in the prevalence of low-flow, low-gradient AS in the different series published.<sup>17-24</sup> Although the reproducibility is similar in both LVOT measurements with 2D TTE, given the better correlation of LVOT diameter at the HP with 3D TEE, measurement of LVOT dimensions at the HP could be advocated as the reference approach.

On the other hand, according to the law of conservation of energy, the velocity of blood flow should increase in the same proportion as the area decreases along the LVOT. Therefore, the LVOT VTI will increase by >15% as one moves distally in the LVOT toward the aortic

valvular plane. This implies that an adequate evaluation of LVOT velocity should involve placing the sample volume as close as possible to the aortic valve plane, while being careful to avoid contamination of the echoes from the valve.<sup>4</sup>

### 3D Transesophageal Echocardiographic Methodology

Three-dimensional TTE is an alternative method to measure the real dimensions of the LVOT. Previous studies using this method<sup>25,26</sup> revealed the elliptical morphology of the LVOT and an underestimation of the calculation of AVA and SVi compared with the LVOT measured by 2D TTE. Tamborini *et al.*<sup>27</sup> showed that 3D TTE is a reliable and valid imaging alternative to MDCT in preoperative transcatheter aortic valve implantation evaluation. Nevertheless, Tsang *et al.*<sup>28</sup> reported that in patients with calcified aortic valves, 3D TTE had the lowest accuracy with the largest variability compared with cardiac magnetic resonance and MDCT. Despite the good correlations, when comparing different imaging modalities, the lowest measurements are obtained with 2D TTE, followed by 3D TEE, and the highest measurements are obtained with MDCT.<sup>27,29-31</sup> However, despite the accuracy of these new cardiac imaging

**Table 3** Intraobserver and interobserver reproducibility

LVOT dimension	Intraobserver ICC (95% CI)	Interobserver ICC (95% CI)
<b>2D TTE</b>		
LVOT (4–8 mm)	0.70 (0.55–0.85)	0.73 (0.59–0.85)
LVOT (HP)	0.75 (0.57–0.86)	0.72 (0.55–0.81)
<b>3D TEE</b>		
APD (HP)	0.91 (0.82–0.94)	0.80 (0.72–0.86)
APD (4 mm)	0.81 (0.74–0.88)	0.80 (0.71–0.89)
APD (8 mm)	0.82 (0.77–0.87)	0.79 (0.66–0.89)
LD (HP)	0.73 (0.55–0.84)	0.61 (0.39–0.79)
LD (4 mm)	0.66 (0.41–0.83)	0.52 (0.23–0.66)
LD (8 mm)	0.68 (0.42–0.82)	0.53 (0.31–0.69)
CSA (HP)	0.96 (0.93–0.97)	0.91 (0.85–0.92)
CSA (4 mm)	0.84 (0.78–0.90)	0.77 (0.62–0.81)
CSA (8 mm)	0.68 (0.41–0.86)	0.55 (0.31–0.69)

APD, Anteroposterior diameter; LD, lateral diameter.

techniques, it is important to acknowledge that the cutoff values to determine low flow and AVA should be reassessed, because the current cutoff values used for AS were only validated against clinical outcomes for standard 2D transthoracic evaluation.

Our methodology with 3D TEE and QLAB evaluation has been previously described by several groups.<sup>5-7,9,11,32,33</sup> We obtained good reproducibility on anteroposterior diameters and CSA at HP and at 4 mm (ICC > 0.9). The medial-lateral diameter and the measurements at 8 mm had lower but acceptable reproducibility<sup>34</sup> (ICC = 0.5–0.7). The reason for these differences lies in the axial and lateral resolution of the technique. Our data on intra- and interobserver variability are consistent with those previously reported.<sup>5-7,9,11</sup> Three-dimensional TEE provides more accurate information than 2D TEE, as it allows a cross-sectional plane at any level of the LVOT.<sup>32</sup> The measurements with this technique have reproducibility comparable with that of MDCT, with reduced intra- and interobserver variability.<sup>33,35</sup> Because of this, the use of 3D TEE in aortic annular sizing for transcatheter aortic valve implantation has been recommended.<sup>33,36</sup>

### Limitations

The main limitation of this study is the lack of a gold-standard imaging technique to establish comparisons. Despite the lack of available multidetector computed tomographic data with which to compare our echocardiographic results, previous studies have shown an excellent concordance in the elliptical shape obtained using both methods, with the magnitude of the dimensions the only variation identified. Indeed, LVOT dimensions were slightly larger when MDCT was used. Therefore, the LVOT morphology described in our study could be valid.

Whether our data, obtained in a rather elderly population, could be extrapolated to younger patients is unknown. Moreover, the sample size could be a limitation to the validity of the results regarding the comparison of LVOT measurements. Finally, the retrospective design of the study could limit somehow the interpretation of the results. This constraint was counteracted, however, by performing TTE and 3D TEE with a time interval of <7 days in the majority of patients and by doing both tests the same day for many of them.

### CONCLUSIONS

Three-dimensional echocardiographic evaluation in patients with degenerative AS showed a funnel-shaped morphology of the LVOT in >80% of patients. This funnel has elliptical bases, being more pronounced in the region of the LVOT farther from the annular plane. Its size and circularity differ significantly on the basis of the point of measurement. The assumption of a circular morphology cannot be accepted, as >70% of patients have ellipse-shaped LVOTs at the HP of the aortic cusps. The best correlation between 2D TTE and 3D TEE is obtained when measured close to the annular plane. Our results support the recommendation of measuring the anteroposterior diameter of the LVOT close to the annular aortic plane to reduce measurement errors and AS misclassifications.

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