LETTER TO THE EDITOR

Accurate Measurement of Left Ventricular Outflow Tract Diameter: Comment on the Updated Recommendations for the Echocardiographic Assessment of Aortic Valve Stenosis

To the Editor:

Accurate echocardiographic calculation of aortic valve area (AVA) is integral to the appropriate management of patients with aortic stenosis.[1] The greatest potential for error in the calculation of AVA by the continuity equation is left ventricular outflow tract (LVOT) diameter, which must be squared to calculate LVOT area.[2-4] In the recent update of the European Association of Cardiovascular Imaging and American Society of Echocardiography recommendations for the assessment of aortic stenosis severity,[5] the discussion and illustrations of LVOT measurement raise questions that deserve attention. These include (1) the location of the measurement for calculation of left ventricular (LV) stroke volume and (2) the imaging plane that yields the correct LVOT diameter in the setting of ectopic calcification.

Regarding the first issue, Baumgartner *et al.*[5] state that it may be necessary to move the sample volume apically by 0.5 to 1.0 cm to obtain a laminar flow curve without spectral dispersion, and thus in this situation, LVOT diameter can be measured at the same distance from the valve as the Doppler sample volume position. Historically, however, LVOT measurement has been made at the annulus.[2-4] There are strong outcomes data using this method for calculating AVA.[6,7] In addition, the LVOT below the annulus is in large part composed of the basal muscular septum and as such is more elliptical and irregular as well as dynamic, particularly in the setting of a septal bulge that is highly prevalent in patients with aortic stenosis.[8] Because the measured aortic annulus is composed primarily of the fibrous interleaflet trigones or triangles,[9] this measurement, on the other hand, varies less with the cardiac cycle and is more accurate and reproducible.[2,10,11] In the legend to Figure 5 of the focused update, the authors state that "in many patients, as in this case, the LV outflow tract is relatively rectangular within 1 cm of the aortic annulus," such that the LVOT diameter is about the same at the annulus as at 1 cm below. In our experience and in view of the literature, this is in fact rarely the case, and most patients with aortic stenosis, especially those with severe stenosis, have a septal bulge and therefore hourglass-shaped LVOT inflow.[11] Mehrotra *et al.*[12] showed that the LVOT is also less distensible in patients with severe aortic

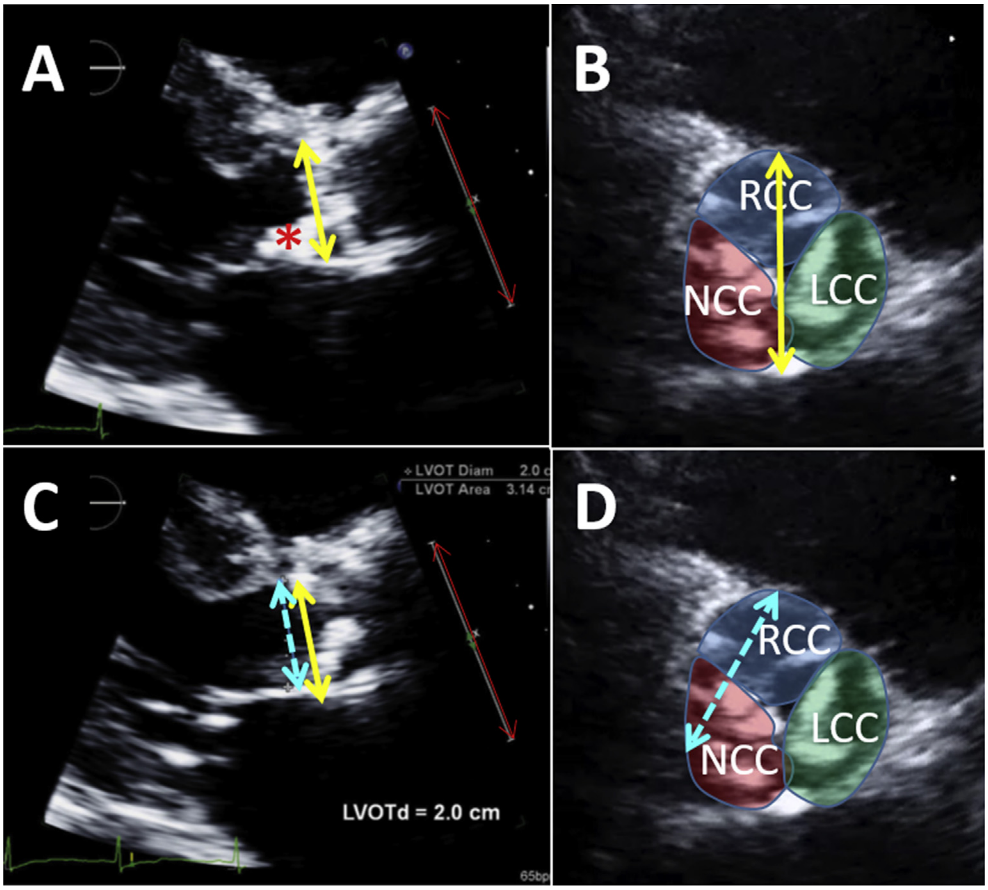

Figure 1 Accurate measurement of the annulus. Figure 7 from the recommendations is reproduced below (panels **A** and **C** represent the original panels **A** and **B**) with the same scale shown (*red arrows* at edge of sector).The original figure legend suggests that measurement in panel **A** would result in an incorrectly small annulus, but the largest diameter of the annulus is obtained from panel **A** (*yellow double arrow*) by excluding the ectopic calcium (*red asterisk*) extending onto the anterior mitral valve leaflet. Panel **B** is a representation of where that measurement would be taken from the short-axis view. The same *yellow arrow* from panel A superimposed onto panel **C** is longer than the suggested measurement (*dashed blue arrow*). Panel **D** is a representation of where that incorrect measurement would be taken from the short-axis view, with the two calcified cusps centered in the aortic root. *LCC*, Left coronary cusp; *LVOTd*, LVOT diameter; *NCC*, noncoronary cusp; *RCC*, right coronary cusp.

Table 1 Checklist for verification of the accuracy of the measurement of LVOT area for the calculation of AVA for the assessment of aortic stenosis severity

Actions	Interpretation and caveats
Use the midsystolic image that bisects the largest dimension of the aortic annulus: i.e., the plane that bisects the right coronary cusp hinge point anteriorly and the interleaflet triangle between the left and noncoronary cusps posteriorly (see Figure 1B)	If two leaflets are well visualized both anteriorly and posteriorly, this may not be the plane providing the largest diameter, and LVOTd may be underestimated from this view (see Figures 1C and 1D).
Measure LVOTd at the aortic annulus: not 0.5 to 1 cm below	Look for the hinge point of the right coronary cusp anteriorly and measure to the mitral-aortic curtain, perpendicular to the long-axis of the aorta (see Figure 1A).
In the presence of LVOT ectopic calcification: use the plane that bisects the largest diameter but excludes the calcification from the LVOTd measurement (see Figure 1A)	
Calculate predicted LVOTd using the formula: $LVOTd = (5.7 \times BSA) + 12.1$	If the LVOTd measured at the annulus is 2 mm smaller or larger than the predicted LVOTd, suspect error in the measurement of LVOTd. Note that the formula may overestimate LVOTd in obese individuals.
Calculate the DVI: $DVI = VTI_{LVOT}/VTI_{AoV}$	If AVA is <1.0 cm^2 and indexed AVA is <0.6 cm^2/m^2 but DVI is >0.25, suspect underestimation of LVOTd.
Corroborate the calculation of LVOT area obtained by 2D TTE with other modalities:	
3D TTE or TEE	Accuracy of 3D TTE determined by the echogenicity of the patient.
MDCT	Planimetered LVOT by MDCT area may be larger than LVOT area calculated using a linear diameter.
Corroborate the measure of LVOT stroke volume by other methods:	
Biplane Simpson	Biplane Simpson may underestimate stroke volume.
3D TTE volumes	Accuracy of 3D TTE determined by the echogenicity of the patient.
Corroborate the measure of AVA by other methods:	
Planimetry of AVA by TTE or TEE	The "anatomic" AVA measured by planimetry is often larger than the "effective" area measured by the continuity equation because of the flow contraction that occurs downstream of the valve orifice.
Hybrid MDCT-Doppler: LVOT area is measured by MDCT and used in the continuity equation to calculate the "hybrid" AVA	The hybrid method systematically measures larger AVAs, and therefore a larger cutoff value (i.e., <1.2 instead of 1.0 cm^2) should be used to define severe aortic stenosis.[6]
In the presence of discordant grading (small AVA with low gradient), calculate indexed AVA: AVA/BSA (cm^2/m^2)	A small AVA in a small patient may correspond to moderate AS. In such patients, the AVA is <1.0 cm^2, suggesting severe AS, but the indexed AVA is >0.6 cm^2/m^2, with a low gradient (<40 mm Hg), suggesting that the stenosis is in fact not severe. The indexed AVA may overestimate the severity of AS in obese patients.

AoV, Aortic valve; *AS*, aortic stenosis; *BSA*, body surface area; *DVI*, Doppler velocity index; *LVOTd*, LVOT diameter; *MDCT*, multidetector computed tomography; *TEE*, transesophageal echocardiography; *3D*, three-dimensional; *TTE*, transthoracic echocardiography.

stenosis with greater peak systolic ellipticity (smaller sagittal plane and larger coronal plane) and greater LVOT cross-sectional area underestimation (relative to normal control subjects) if using a single long-axis (sagittal plane) measurement. The annulus, on the other hand, is more fibrous, exhibiting less dynamic changes and thus a more stable, circular area whether by single-plane measurement or direct planimetry.[13] The ellipticity of the LVOT may also explain recent findings of a larger planimetered LVOT area compared with planimetered annular area.[13] In fact, Caballero *et al.*[13] found that measurements at the level of the annulus resulted in the best correlation between two-dimensional and three-dimensional transesophageal echocardiographic dimensions. Numerous authors have shown that AVA calculation using direct planimetry of the LVOT or annulus results in larger valve areas using the continuity equation.[13-17] A recent head-to-head comparison of multidetector computed tomographic measurement of LVOT area (AVA_{CT}) and