Measuring Aortic Valve Annulus Size for Transcatheter Aortic Valve Implantation – 2D or 3D Imaging Techniques?

Victoria Delgado,[1] See Hooi Ewe,[1,2] David Messika-Zeitoun,[3] Jeroen J Bax[1] and Alec Vahanian[3]

1. Department of Cardiology, Leiden University Medical Center, Leiden; 2. Department of Cardiology, National Heart Centre, Singapore; 3. Service de Cardiologie, Hôpital Bichat, Paris

Abstract

To date, more than 20,000 patients with severe symptomatic aortic valve stenosis and high-risk or contraindication to conventional surgery have been successfully treated with transcatheter aortic valve implantation (TAVI). The results of the multicentre randomised Placement of aortic transcatheter valve trial (PARTNER)[7] have shown the superior long-term survival of patients who received a transcatheter aortic valve compared to patients who were medically treated. In order to optimise the procedural success rate and minimise the number of complications, patient selection and procedural strategy planning are crucial. Selection of prosthesis size is one of the key steps in this pre-procedural evaluation. Accurate measurement of the aortic valve annulus is pivotal to select the most appropriate prosthesis size and avoid complications such as prosthesis migration, paravalvular aortic regurgitation or aortic annulus rupture. Currently, the reference method to measure the aortic valve annulus dimension is still debated. While 2D echocardiography remains as the imaging modality of first choice to measure the aortic valve annulus, 3D imaging techniques have provided important information on the shape, geometry and spatial relationships of this structure. The present review provides an overview of the different imaging techniques to measure the aortic valve annulus and the inherent clinical implications of each technique.

Keywords

Transcatheter aortic valve implantation, echocardiography, multi-detector row computed tomography, aortic valve annulus

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Correspondence: Victoria Delgado, Department of Cardiology, Leiden University Medical Center, Albinusdreef 2, 2300 RC Leiden, The Netherlands. E: v.delgado@lumc.nl

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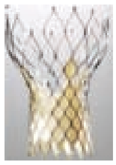
Since the first-in-man experience by Cribier and co-workers,[1] transcatheter aortic valve implantation (TAVI) has rapidly evolved, providing a feasible therapeutic alternative for patients with severe symptomatic aortic stenosis who have high-risk or contraindications to conventional surgery. The promising results of TAVI procedures reported by various registries[2–6] were recently confirmed in the multicentre randomised Placement of aortic transcatheter valves (PARTNER) trial.[7] Patients with severe aortic stenosis who were randomised to TAVI showed lower mortality rates at one-year follow-up as compared to patients who received standard therapy (including medical treatment or balloon valvuloplasty) (30.7 % and 71.6 %, p<0.001).[7] In addition, further technical developments and improvement in the patient selection process and learning curve have led to a progressive reduction in the number of procedural complications such as major vascular complications, aortic regurgitation or stroke. In order to optimise the procedural success rate and minimise the number of complications, accurate patient selection and procedural strategy planning are crucial. Selection of prosthesis size is one of the key steps in this pre-procedural evaluation. Accurate measurement of the aortic valve annulus is pivotal, to select the most appropriate prosthesis size and avoid complications such as prosthesis migration, paravalvular aortic regurgitation,[8] or aortic annulus rupture. Currently, the reference method to measure the aortic valve annulus is still debated.[9] While 2D echocardiography remains the imaging modality of first choice to measure the aortic valve annulus, 3D imaging techniques have provided important information on the shape, geometry and spatial relationships of this structure. This article provides an overview of the different imaging techniques to measure the aortic valve annulus and the inherent clinical implications of each technique.

Transcatheter Aortic Valve Prostheses

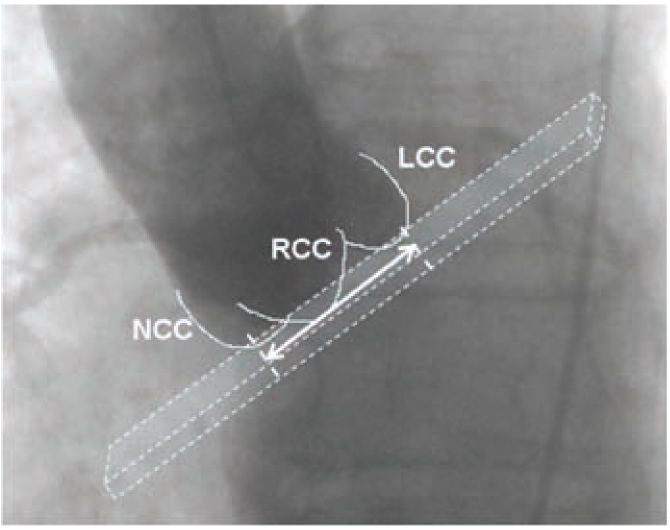
To date, two types of transcatheter aortic valve prostheses have provided the largest evidence in this field: the balloon-expandable Edwards transcatheter heart valve and the self-expandable Medtronic CoreValve®. The unique differences in the designs and sizes between the two prostheses will directly determine the pre-procedural evaluation, the implantation steps and the procedural results. The most recent balloon-expandable Edwards transcatheter heart valve is the SAPIEN XT valve, which consists of three bovine pericardial leaflets mounted on a cobalt chromium frame. This prosthesis is currently available in three different sizes: 23, 26 and 29 mm transcatheter valves for aortic valve annular sizes 18–22 mm, 21–25 mm and 25–27 mm, respectively. In addition, the SAPIEN XT valve can be implanted

Table 1: Anatomic Requirements of the Current Transcatheter Heart Valves

	Edwards SAPIEN XT	Medtronic CoreValve
		
Aortic valve annulus size	18–22 mm → 23 mm THV 21–25 mm → 26 mm THV 25–27 mm → 29 mm THV	20–23 mm → 26 mm THV 24–27 mm → 29 mm THV
Sinus of Valsalva diameter	NA	>27 mm
Sinitubular junction diameter	NA	<43 mm
Height of the coronary ostia	≥10 mm	≥10 mm

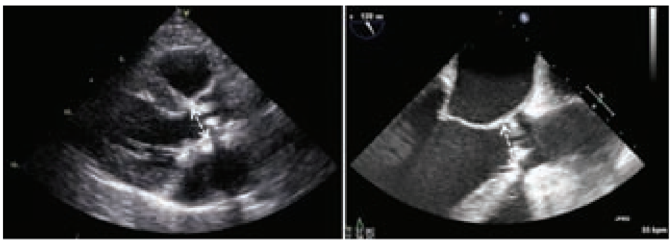
NA = not applicable; THV = transcatheter heart valve.

Figure 1: Measurement of the Aortic Valve Annulus with X-Ray Angiography



The aortic valve annulus is measured at the fluoroscopy projection that permits alignment of the three hinge lines of the valvar leaflets (arrow).

Figure 2: Echocardiographic Assessment of the Aortic Valve Annulus



The aortic valve annulus can be measured with 2D transthoracic (left panel) or transoesophageal (right panel) echocardiography.

retrograde, through a transfemoral approach, or antegrade, through a transapical approach in patients with unfavourable peripheral artery anatomy, or in case of porcelain aorta. The Medtronic CoreValve® is a self-expandable prosthesis that consists of a 53–55 mm nitinol frame with three different functional levels: the upper third level that exerts a low radial force and is placed in the ascending aorta, the constraint middle third level that includes the trifoliate porcine valve and the lower third level that exerts a high radial force and anchors the prosthesis within the left ventricular outflow tract. Moreover, this prosthesis has a 12 mm skirt covering the lowest portion of the valve helping to prevent significant paravalvular regurgitation after deployment. This prosthesis is currently available in two sizes (26 and 29 mm for aortic valve annulus of 20–23 mm and 23–27 mm, respectively) and can be implanted via a transfemoral or transsubclavian approach. Recent technical developments that provide smaller prosthesis profiles and smaller prosthesis sizes, such as the SAPIEN XT 20 mm and the Medtronic CoreValve 23 mm valves, are anticipated. These endeavours will increase the number of patients eligible for TAVI since the procedure will be feasible in a broader range of aortic valve annulus dimensions. Despite the different prosthesis designs, accurate evaluation of the aortic root anatomy and dimensions is paramount when it comes to selecting the most appropriate prosthesis size.

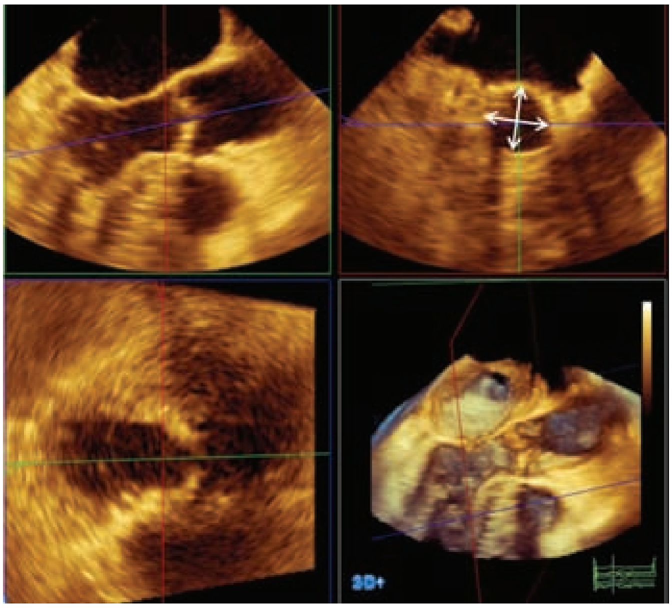
Aortic Root Anatomy – Key Parameters Before Transcatheter Aortic Valve Implantation

The aortic root is the anatomical structure between the left ventricular outlet and the ascending aorta, where it includes the aortic valve annulus, semilunar leaflets, aortic sinuses (of Valsalva) and the sinotubular junction.[10,11] Understanding the exact anatomy and spatial relationships of the aortic root is pivotal in TAVI.The aortic valve annulus corresponds to the anatomic ventriculo–arterial junction. The exact location and delineation of the junction between the myocardium and the aortic wall is not clear. The plane that transects the nadir of the semilunar hinge lines of the valvular leaflets is below this ventriculo–arterial junction and can be used as landmark to size the aortic valve annulus.[12,13] The following components of the aortic root located immediately superior to the aortic valve annular plane are three valvular leaflets and the sinus of Valsalva. Identifying the morphology of the valvular leaflets is crucial before TAVI. Currently, TAVI is indicated in tricuspid aortic valves, although several successful experiences have demonstrated the feasibility and safety of this technique in bicuspid valves.[14] Furthermore, the dimensions of the sinus of Valsalva are important anatomical requirements, particularly in the Medtronic CoreValve implantation. Narrow sinus of Valsalva (<27 mm) may contraindicate the procedure since the constraint (middle third) part of the device may potentially displace the native leaflets towards the coronary ostia and occlude them, with undesirable clinical consequences. Finally, the sinotubular junction is where the sinusal part joins onto the tubular portion of the aortic root. Its dimensions are also important anatomical requirements for the Medtronic CoreValve implantation as a sinotubular junction diameter >43 mm is a formal contraindication for the procedure. *Table 1* summarises the anatomical requirements of the aortic root for SAPIEN XT and Medtronic CoreValve.

Aortic Annulus Measurement – From 2D to 3D Imaging Techniques

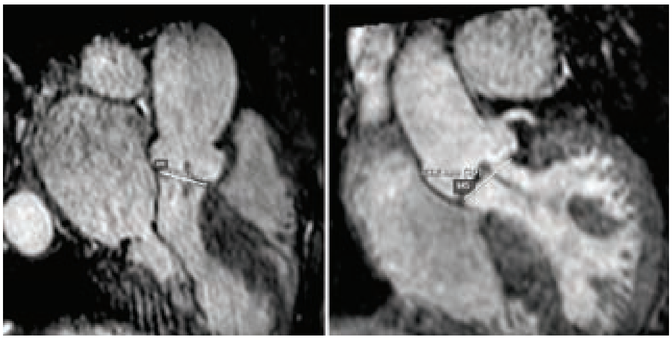
Assessment of the aortic valve annular dimensions for TAVI is highly debated. So far, the imaging modality of reference to measure the aortic annulus has not been established. 2D echocardiography is the most widely used method to size the aortic valve annulus. However, the geometry and location of the aortic root challenge the measurement of this structure with 2D imaging techniques. The aortic valve annulus has an oval shape and is lying on a plane at an angle of 30° from the horizontal axis of the human body.[11,15] With X-ray angiography of the aortic root, the C-arm can be oriented in order to accurately define the aortic valve annular plane, where the nadirs of the hinge lines of the three valvular leaflets sit, and the aortic valve annulus can then be measured (see *Figure 1*). In 40 patients with severe aortic stenosis, Kurra et al. evaluated the accuracy of biplane X-ray angiography for sizing the aortic valve annulus using multi-detector row computed tomography (MDCT) as the reference method.[16] The aortic valve annulus was measured at the left anterior and right anterior oblique projections on X-ray angiography. Similar measurements of the aortic valve annulus were obtained with multiplanar reformations on MDCT. Good agreements between mean aortic annular diameters measured with X-ray angiography and MDCT were observed (2.3 ± 0.4 cm and 2.3 ± 0.3 cm, p=1.0).[16] However, when the aortic valve annulus was measured at the right anterior oblique projection, X-ray angiography provided significantly larger diameters of the aortic valve annulus as compared with MDCT (2.4 ± 0.3 cm and 2.2 ± 0.3 cm, p=0.029), highlighting the oval anatomy of the aortic annulus.[16] Besides being a 2D imaging modality, X-ray angiography of the aortic root may be limited by the need of multiple injections of iodinated contrast media. The use of contrast volume >100 ml has been related to acute renal failure after percutaneous coronary intervention.[17] In addition, renal impairment is a common co-morbidity in patients who are candidates for TAVI and this is of a particular clinical concern as further kidney injury after TAVI has been related to worse clinical outcome at follow-up.[18,19] In contrast, 2D echocardiography is widely available and does not need iodised contrast media. Therefore, 2D echocardiography is the method of first choice to evaluate the aortic root anatomy and geometry and to size the aortic valve annulus. Using transthoracic 2D echocardiography, the aortic valve annulus can be measured at the parasternal long-axis views (see *Figure 2*). As indicated by current recommendations of the American Society of Echocardiography and the European Association of Echocardiography, the aortic valve annulus is measured in mid-systole from inner edge to inner edge.[20] Transoesophageal echocardiography provides superior image quality and may help to better visualise the inner edges of the aortic valve annulus. Using 2D transoesophageal echocardiography, the aortic valve annulus is usually measured at the long-axis view (also called 120° view) (see *Figure 2*). The majority of series have reported good clinical results using 2D transoesophageal echocardiography as the standard methodology to size aortic valve annulus and select the prosthesis size. However, 3D imaging techniques provide exact characterisation of the oval shape of the aortic valve annulus and accurate measurements of the diameters.[13,15] Dedicated post-processing software permits the exact orientation of multiplanar reformation planes on 3D echocardiography and MDCT data and provide the exact cross-sectional area of the aortic valve annulus. In a recent series including 53 candidates for TAVI, Ng et al. demonstrated that the circular areas of the aortic valve annulus calculated with 2D and 3D transoesophageal echocardiography significantly underestimated the planimetered cross-sectional areas obtained with MDCT (16.4 % and 12.9 % underestimation) (see *Figure 3*).[21] In contrast, the (measured) area of the aortic valve annulus, measured with 3D transoesophageal echocardiography, had better agreement with MDCT-measured cross-sectional area and the percentage of underestimation was significantly lower (9.6%). In addition, recent studies have also shown the accuracy of magnetic resonance imaging (MRI) to measure the aortic valve annulus.[22] In these experiences, non-contrast enhanced steady-state free procession MRI sequences of the whole heart are acquired and the 3D data are post-processed with specific 3D tools that permit free navigation and selection of the image plane in order to obtain the most accurate cross-sectional area of the aortic valve annulus (see *Figure 4*). Koos et al. compared MRI and MDCT measurements of the aortic valve annulus in 58 patients evaluated for TAVI.[22] MRI- and MDCT-based measurements of the aortic valve annulus showed a non-significant bias and tight limits of agreement between the two imaging techniques (mean difference: -0.19 mm; 95 % limits of agreement: -2.11–1.73 mm). The high spatial resolution of MDCT has favoured the use of this imaging modality as reference method to measure the aortic valve annulus, to compare the accuracy of other 3D imaging techniques to assess the aortic valve annulus and aortic root dimensions and, to evaluate the spatial relationships of the aortic root with the surrounding structures.[12,13,15] Standardised methodology to assess the aortic valve annular dimensions is crucial in order to establish MDCT as a routine imaging technique to evaluate candidates for TAVI. Recently, in a series of 90 patients with aortic valve disease, the accuracy and reproducibility of a novel automated MDCT imaging post-processing software, 3mensio Valves (version 4.1.sp1), in the assessment of aortic root dimensions was evaluated.[12] On early systolic images of the aortic root reconstructed at 30–35 % of the RR interval, the long-axis of the aortic root and left ventricular outflow tract was defined using two orthogonal multiplanar reformation planes. A third, transverse multiplanar reformation plane was used to display the cross-sectional view of the aortic valve annulus,

Figure 3: Real-time 3D Transoesophageal Echocardiography to Measure the Aortic Valve Annulus



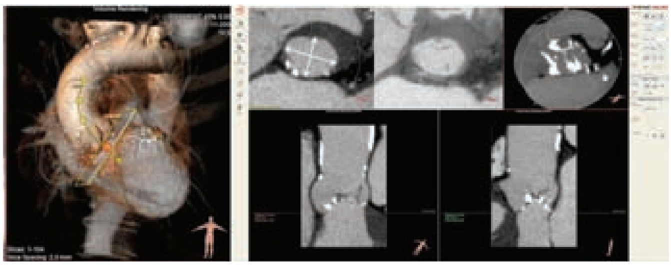
The alignment of the multiplanar reformation planes across the aortic valve annulus provides the cross-sectional plane where the annular diameters can be measured (arrows).

Figure 4: Measurement of the Aortic Valve Annular Diameters with Magnetic Resonance Imaging



The aortic valve annular diameters can be measured from the reconstructed sagittal (left panel) and coronal (right panel) magnetic resonance imaging views. Adapted with permission from the American College of Cardiology Foundation.[19]

Figure 5: Standardised Automated Measurement of the Aortic Valve Annulus with Multi-detector Row Computed Tomography



Definition of the centreline along the aortic root and the transversal plane perpendicular to the centreline provides an accurate cross-sectional visualisation of the aortic annulus and other components of the aortic root (3mensio Valves version 4.1.sp1). The left panel shows the volume rendering of the aortic root with the centreline and the transversal plane across the aortic valve annulus. The right panel shows the cross-sectional view of the aortic valve annulus where the diameters can be measured (arrows).

directly beneath the lowest insertion points of all three aortic cusps (see *Figure 5*). Subsequently, the software displays the stretched views of the aortic root and permits displacement of the transversal plane across the centerline and the height of the sinus of Valsalva, coronary ostia and sinotubular junction relative to the aortic valve annular plane can be measured (see *Figure 5*). This standardised methodology provides highly reproducible measurements of the aortic valve annulus and the other components of the aortic root, with good intra- and inter-observer agreement (intraclass correlation coefficients ranging from 0.97–0.99).[12] In addition, the minimum, maximum and mean aortic valve annulus diameters can be measured. Based on this evidence, 3D imaging techniques may be the preferred modalities to accurately size the aortic valve annulus and select the most appropriate prosthesis size. However, a more important clinical question is whether 3D measurements of the aortic valve annulus will significantly influence the TAVI procedure and outcomes.

Implications of 3D Measurements of the Aortic Valve Annulus on Transcatheter Aortic Valve Implantation Strategy

The methodology used to size the aortic valve annulus has an important impact on the selection of transcatheter valve prosthesis size. Although 2D echocardiography significantly underestimates the aortic valve annular dimensions, as compared to 3D imaging techniques, manufacturers' recommendations are based on 2D measurements. Accordingly, one would expect that the decision to implant a specific prosthesis size might change significantly, depending on the methodology used. In a series of 45 patients undergoing TAVI with Edwards SAPIEN valve, the impact of measuring the aortic valve annulus with 2D transthoracic and transoesophageal echocardiography and MDCT on prosthesis size selection was evaluated.[23] A decision based on MDCT measurements would have modified the TAVI strategy in 38 % of patients compared to transthoracic or transoesophageal echocardiography. In addition, a recent study including aortic stenosis patients who underwent TAVI with a Medtronic CoreValve prosthesis showed that the measurement of the minimum or the maximum diameter of the aortic valve annulus with MDCT would contraindicate the procedure in 26 % and 39 % of patients owing to too small or too large aortic valve annular dimensions, respectively.[13] In contrast, if the prosthesis sizing were based on the mean annular diameter (minimal diameter plus maximal diameter, divided by two), only 11 % of patients would be considered ineligible for TAVI with the Medtronic CoreValve device. Furthermore, the prosthesis sizing based on the mean annular diameter had the best agreement with the operator choice (74 %). In contrast, the agreement with the operator choice was only 44 % or 32 % if only the minimal diameter or maximal diameter was used, respectively.[13] These results underscore the need for a standardised approach to measure the aortic valve annulus, incorporating 3D imaging techniques in order to provide a comprehensive and accurate evaluation of the 3D geometry and dimensions of the aortic valve annulus.

Conclusions

The success of TAVI relies on accurate selection of patients, procedural approach evaluation and procedural guidance. One of the most important steps in the pre-procedural screening process is the sizing of the aortic valve annulus, which is pivotal to select the most appropriate transcatheter prosthesis size. 2D echocardiography is currently the most widely used imaging modality to measure the aortic valve annulus. However, 3D imaging techniques may provide more comprehensive and accurate measurements, and characterisation of this component of the aortic root. Standardisation of aortic valve annular measurements with 3D imaging modalities may be necessary in the workup of candidates for TAVI and future studies are required in order to demonstrate whether the information provided by these imaging techniques will improve the TAVI results. ■

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