

Multimodality Imaging for TAVR

Successful integration of multimodality imaging is essential for ensuring good outcomes as TAVR comes to the forefront of aortic stenosis treatment.

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Aortic stenosis (AS) is the most common valve disease in the aging population, affecting nearly 5% of individuals older than 75 years.¹ Surgical aortic valve replacement (SAVR) has been the main treatment strategy for patients with severe symptomatic AS.² However, many patients with severe symptomatic AS are unable to undergo SAVR due to comorbidities that place them at high risk for surgical morbidity and mortality.³ Transcatheter aortic valve replacement (TAVR) has emerged as a novel and less invasive technique for managing patients with severe symptomatic AS who are believed to be at high risk for conventional SAVR.⁴⁻⁶ In the landmark PARTNER trial, TAVR was associated with a 20% absolute risk reduction in 1-year mortality in inoperable patients with severe symptomatic AS compared to medical therapy.⁴ During TAVR, in contrast to SAVR, the operator does not have direct visual access to the aortic valve. As a result, imaging plays a critical role in preoperative planning and for intraprocedural guidance during TAVR. The role of multidetector computed tomography (MDCT) and other imaging modalities in this context is discussed in this review.

MDCT AND MULTIMODALITY IMAGING BEFORE TAVR

The success and safety of TAVR depends on patient selection based on clinical evaluation and individual anatomic features as assessed by various imaging modalities preoperatively and intraprocedurally. Three-dimensional (3D) imaging of the aortic root, the entire aorta, and the iliofemoral vessels using MDCT has improved significantly in recent years due to improvement in spatial and temporal resolution and the number of detector systems.

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Spatial resolution of current scanners is 0.5 mm, and dual-tube technology makes it possible to achieve a temporal resolution of 75 ms. Aortic root imaging is usually performed with a minimal slice thickness of approximately 0.5 mm, resulting in isotropic datasets that can be obliquely reconstructed without losing spatial resolution. Electrocardiogram (ECG) synchronized image acquisition throughout the cardiac cycle permits reconstruction at any point throughout the RR interval; however, most measurements are typically made in diastolic images. MDCT has some limitations in terms of radiation exposure and iodinated contrast use, with concurrent risk of contrast-induced nephropathy.

Several techniques, such as using dose modulation, prospective triggering, and reduced tube voltage, can significantly reduce the radiation dose delivered.⁷ MDCT without contrast can provide important information regarding the size of the aortic root and calcification; however, precise measurements are limited in the absence of contrast. The dose of contrast can be significantly reduced by intra-arterial injection (discussed later). MDCT plays a key role in addition to echocardiography in preoperative assessment of suitability for TAVR, measuring the size of the aortic annulus, assessing the amount of calcification in the aortic root, determining the

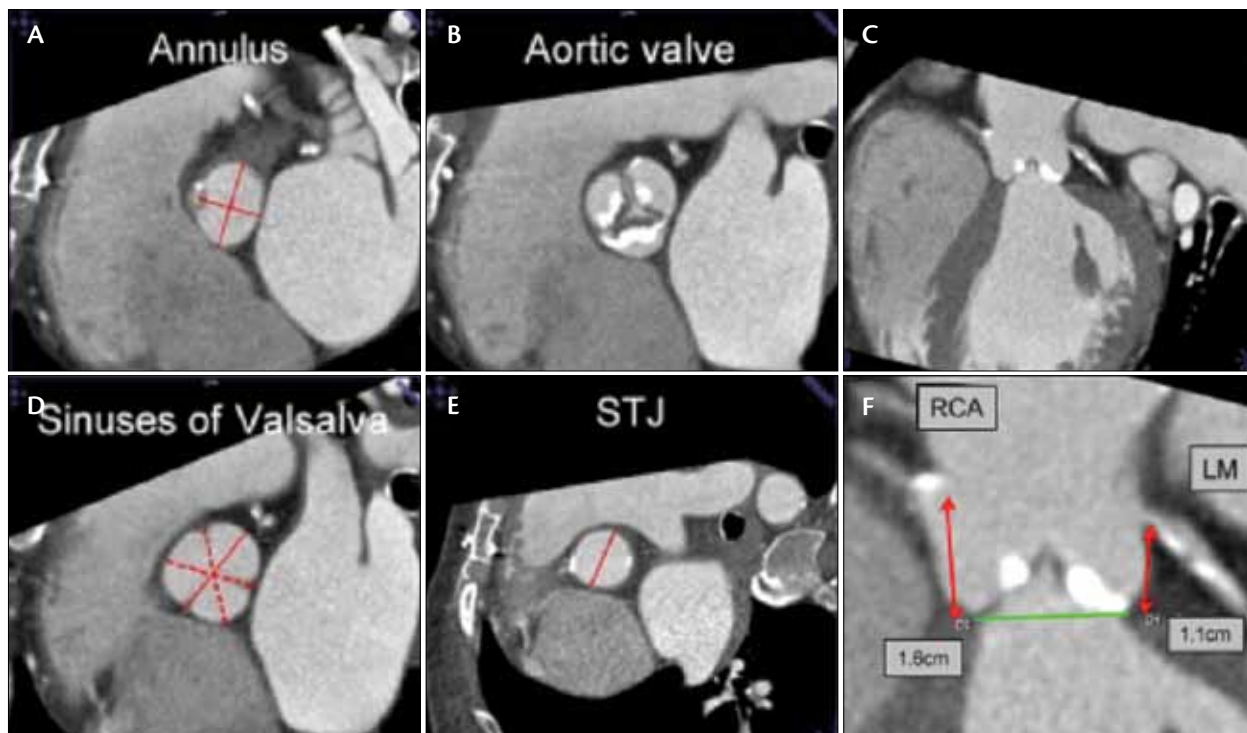


Figure 1. CT imaging of the aortic root. At the annulus, minimum and maximum diameters are reported (A). Planimetry of the aortic valve can be performed at this level (B). At the sinuses of Valsalva, all three diameters (cusp to commissure) are measured, and typically the largest is reported if the root is symmetric (D). Sinotubular junction (E). Distance between the annulus and the ostia of the left main and right coronary artery (C, F). Reprinted from Schoenhagen P, et al. Computed tomography evaluation for transcatheter aortic valve implantation (TAVI): Imaging of the aortic root and iliac arteries. *J Cardiovasc Comput Tomogr*. 2011;5:293-300, with permission from Elsevier.

distance of the coronary ostia from the annulus, predicting the angles of deployment, and evaluating the vascular access sites.

AORTIC ANNULUS

An accurate measurement of the aortic annulus is essential for patient selection, sizing of the valve, and preventing complications with TAVR, particularly aortic regurgitation and valve embolization with an undersized valve and annulus rupture with an oversized valve.⁸ The aortic annulus is a complex structure at the interface of the left ventricular outflow tract (LVOT) and ascending aorta. The aortic root has been described as consisting of three circular rings.⁹ The aortic valve leaflets are attached to the aortic root such that the commissures extend upward into the root in the form of a three-pronged coronet. The aortic annulus is the “inferior virtual basal ring” in the aortic root, as defined by the hinge points at the nadir of each aortic cusp.^{9,10} The middle ring traverses the most prominent part of the sinuses of Valsalva, and the most distal ring from the annulus is defined by the sinotubular (ST) junction. The aortic

annulus is measured on transthoracic or transesophageal echocardiography (TTE or TEE) in the parasternal long axis view using the zoom mode at the insertion of the leaflets in midsystole.^{11,12} On imaging performed with MDCT, contrary to what its name suggests, the aortic annulus has been found to be oval or elliptical in shape rather than circular (Figure 1A).^{11,13} Tops et al found a mean difference of 2.9 ± 1.8 mm between the coronal and sagittal measurements of the aortic annulus using MDCT.¹³ In a study comparing TTE, TEE, and MDCT, Messika-Zeitoun et al found that aortic annulus measurements were similar but not identical with these three different imaging modalities and that the MDCT measurements were larger than echocardiographic measurements.¹¹ It is important to note that the measurements made by TTE, TEE, and MDCT represent different anatomic planes (Figure 2).^{12,14} Some investigators have suggested using a mean of the two measurements obtained by CT.¹⁵ Currently, there is no gold standard for measuring the annulus, but good results of TAVR have been obtained with TEE for sizing of the annulus. However, 3D measurements are critical to account for the oval shape. CT measurements, including perimeter of the LVOT or average diameter, are

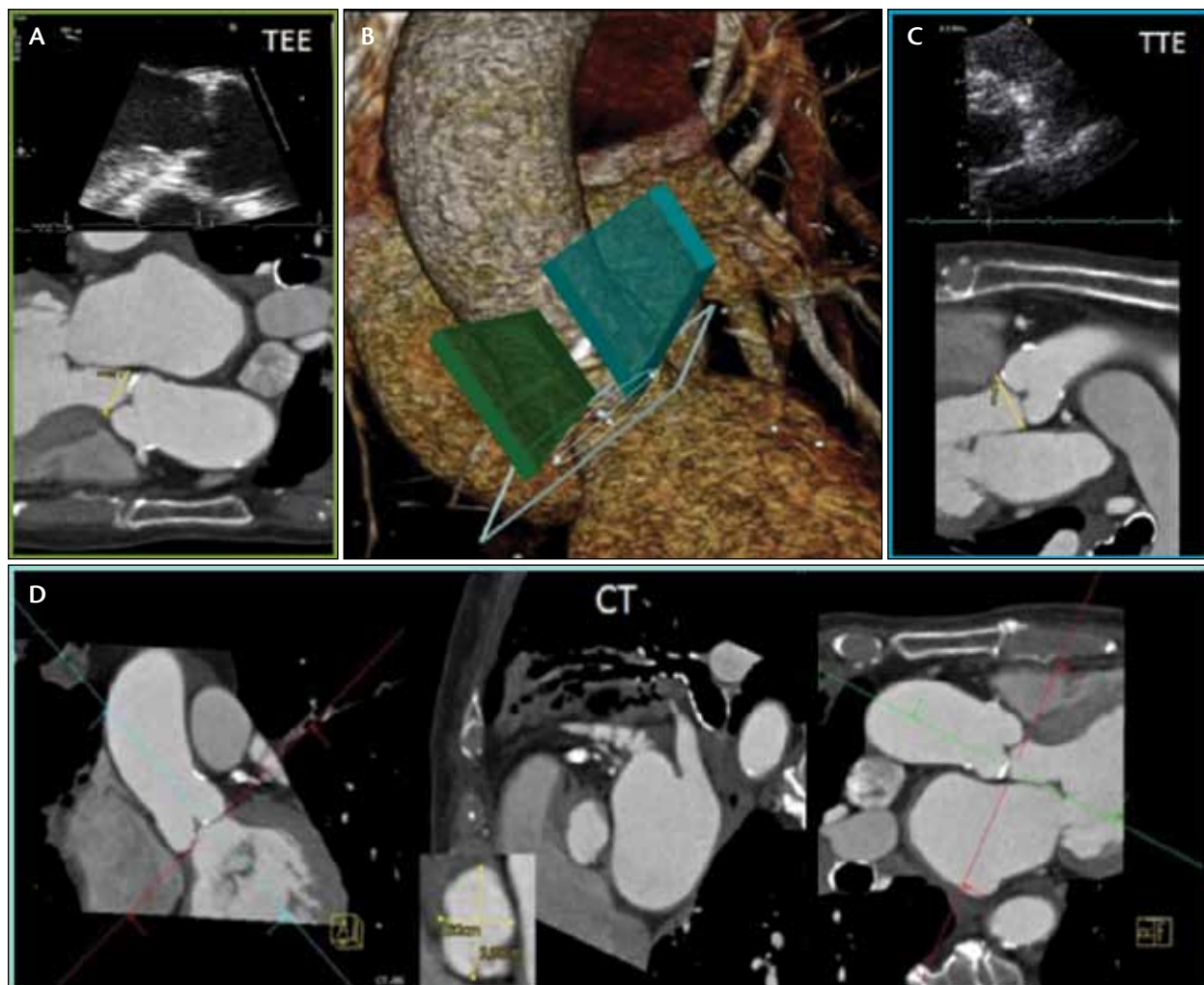


Figure 2. TEE, TTE, and MDCT images of the aortic root in a single patient. In the 3D reconstruction (B), the green, blue, and white planes show the imaging planes of the TTE, TEE, and CT scans. The TEE image and corresponding MDCT reconstruction in the exact same angle with measurement are shown (A). The TTE image and the corresponding MDCT reconstruction are shown (C). The cross-sectional MDCT image of the annulus is shown, demonstrating the elliptical shape (D). The fact that each method measures a different part of the annulus explains the discrepancy between the imaging modalities. Reprinted from Tuzcu, EM, et al. Multimodality Quantitative Imaging of Aortic Root for Transcatheter Aortic Valve Implantation. *JACC*. 2010;55:195-197, with permission from Elsevier.¹⁴

gaining acceptance in determination of valve sizing.

In general, with the currently available devices, an aortic annulus < 18 or > 25 mm is a contraindication for the balloon-expandable Edwards Sapien valve (Edwards Lifesciences, Irvine, CA), and an aortic annulus < 20 or > 27 mm is a contraindication for the self-expandable CoreValve ReValving system (Medtronic, Inc., Minneapolis, MN). Emerging data on the outcomes of TAVR and specific device-anatomy interactions, in addition to the availability of more device sizes, will help determine the best methods for annular sizing, improving success, and preventing complications of TAVR.

AORTIC VALVE LEAFLETS

Direct planimetry for measuring the aortic valve area (AVA) and the LVOT area can be performed using MDCT, and integration of data obtained by MDCT with TTE has been shown to have improved congruence for AS severity.¹⁶ In addition, MDCT allows detailed analysis of the calcification patterns in the leaflets and the device landing zone in the LVOT, which may predict complications such as paravalvular aortic regurgitation, need for permanent pacemaker implantation, and potentially coronary occlusion after TAVR (Figure 1B).^{17,18}



Figure 3. CT showing detailed 3D imaging of peripheral vasculature, including calcification and size of the iliac arteries. Reprinted from Schoenhagen P, et al. Computed tomography evaluation for transcatheter aortic valve implantation (TAVI): Imaging of the aortic root and iliac arteries. *J Cardiovasc Comput Tomogr.* 2011;5:293-300, with permission from Elsevier.

CORONARY OSTIA

Left main coronary artery (LMCA) ostial occlusion during TAVR is a potentially fatal complication. In this regard, the distance between the aortic annulus and the ostium of the LMCA and the length of the left coronary leaflet are critical and can be accurately measured preoperatively on MDCT.^{19,20} This distance can also be measured on TEE and angiography; however, MDCT measurements are most precise (Figure 1C and 1F). Although there are no definite criteria for exclusion of patients based on this distance, a cutoff of 11 to 14 mm has been suggested.⁸ Additionally, the burden of calcification on the aortic valve leaflets, location of the ostium in the left sinus (ie, anteriorly, posteriorly, or in the middle), and the size of the left sinus may be predictors for LMCA ostial occlusion.¹⁴

SINOTUBULAR JUNCTION

The ST junction is the interface between the aortic root and the ascending aorta. Calcification of the ST junction appears to be important for optimal positioning of the

valve (Figure 1E). By restricting balloon expansion at the aortic aspect, significant ST junction calcification can potentially lead to ventricular displacement and motion of the device at the time of TAVR.¹² For the CoreValve ReValving system, the ST junction diameter should be in the range of 27 to 43 mm.

PERIPHERAL VASCULAR ACCESS AND AORTIC ANATOMY

The large sheaths used for transfemoral access for TAVR have been associated with vascular complications.⁸ Early transcatheter delivery systems used 22- to 24-F sheaths, whereas the newer systems are compatible with 18-F sheaths (outer diameter, approximately 7 mm). MDCT allows detailed assessment of peripheral arterial anatomy including vessel size, tortuosity, and calcification (Figure 3). In a study by Kurra et al, almost a third of patients evaluated for TAVR had unsuitable iliofemoral access, with more than 75% of patients having a minimal luminal

diameter of < 8 mm.²¹ The presence of circumferential or horseshoe calcification and small-caliber vessels increases the risk of vascular complications. Similarly, the presence of large mobile atheromas in the aorta, which can embolize during manipulation of catheters, should prompt consideration for alternative transapical or transaxillary approaches for TAVR. In patients with renal dysfunction, intra-arterial contrast injection by means of a pigtail catheter placed in the infrarenal abdominal aorta at the time of preoperative coronary angiography followed by CT angiography can provide information on iliofemoral anatomy with significantly less contrast use and risk of nephropathy.²²

ANGLE OF IMAGING

Assessment of the aortic root orientation is critical for precise positioning of the valve along the centerline of the aorta, perpendicular to the aortic annular plane. This can be performed by obtaining x-ray aortograms in two orthogonal planes with repeated root injections (Figure 4).

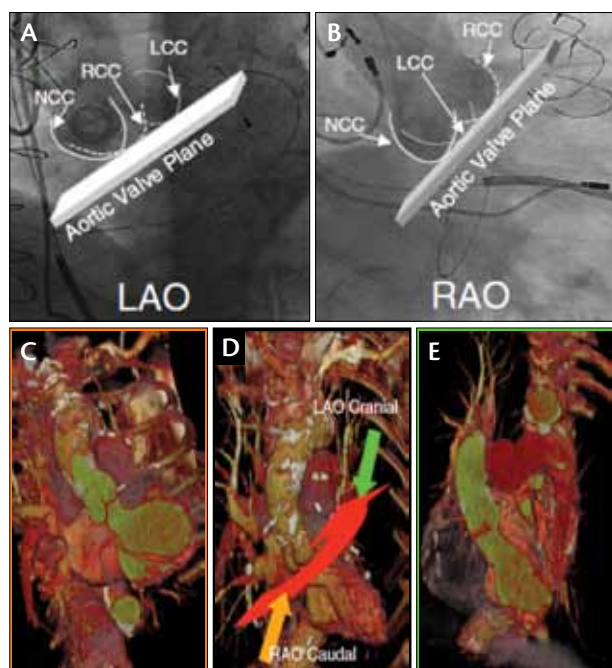


Figure 4. The aortic valve plane as seen in LAO and RAO projection on root angiogram (A, B). CT scan can be useful to predict the aortic valve plane and corresponding best fluoroscopic projection (C-E). This is typically RAO caudal to LAO cranial plane as demonstrated in the center panel (D). The “views” of the arrow planes are shown on the sides, corresponding to the matching color boxes. Reprinted from Kapadia, SR, et al. Imaging for transcatheter valve procedures. *Curr Probl Cardiol.* 2010;35:228-76, with permission from Elsevier.¹²

However, this increases the amount of contrast used and the risk of nephropathy. It has been shown that preprocedural MDCT imaging of the aortic root allows prediction of the optimal angulation of the root angiogram and may decrease the number of aortograms required and hence the contrast use during TAVR.^{23,24} Several commercial systems are now available for predicting fluoroscopic angles appropriate for deployment, including the C-THV (Paieon, New York, NY), the syngo Aortic ValveGuide (Siemens Healthcare, Malvern, PA), or the HeartNavigator systems (Philips Medical Systems, the Netherlands).

IMAGING DURING AND AFTER TAVR

Accurate positioning of the valve during TAVR is usually achieved using fluoroscopy and TEE in a complementary manner. TEE can be performed with judicious use of short-acting sedatives, without endotracheal intubation. TEE is used to assess the aortic annulus and other aortic root measurements in the catheterization laboratory for proper valve sizing. TEE is very useful during balloon aortic valvulo-

plasty to assess positioning and movement of the balloon, flow in the LMCA, and the severity of aortic regurgitation. Serial dilations of the iliac arteries are performed under fluoroscopic guidance for the introduction of large sheaths for the TAVR delivery system. The valve is carefully advanced in the aorta under fluoroscopic guidance. Positioning of the valve is the most important step during TAVR because the current devices are not repositionable. Fluoroscopy is critical during positioning and deployment of the valve. TEE is useful for corroborating the fluoroscopic findings, particularly the relation of the aortic edge of the valve stent to the valve tips, the angle of the valve to the LVOT, central versus eccentric crossing of the valve, and movement of the stent with pacing.

After confirming the position with fluoroscopy and TEE and ensuring absence of inadvertent displacement, the valve is deployed during real-time TEE, with breath-holding and rapid pacing. Immediately after deployment, TEE is used to assess the location and severity of aortic regurgitation. TEE also helps in the detection of complications such as impingement of the coronary ostia (by revealing new regional wall motion abnormalities), dislodgement and migration of the device, pericardial effusion, aortic dissection, and mitral regurgitation.^{25,26} Selective angiography is used if there is any suspicion of coronary compromise after TAVR and to identify iliofemoral access site complications. Newer imaging techniques in the catheterization laboratory, such as 3D rotational angiography and C-arm CT, appear promising for improving the success and safety of TAVR procedures.^{27,28} TTE is currently used at follow-up for assessing the valve gradients, severity of aortic regurgitation, and left ventricular function. The value of MDCT for follow-up imaging remains to be studied.

CONCLUSION

TAVR has become a reality, and its use is rapidly expanding, with good outcomes. Multimodality imaging using fluoroscopy, echocardiography, and MDCT is key in patient and access site selection, device sizing, safe and successful device deployment, early identification of complications, and for follow-up. ■

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