Making the Most of CT in TAVR Planning

From clinical research to standard-of-care procedural planning.

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For procedural planning of transcatheter aortic valve replacement (TAVR), CT has emerged as the standard of care. Unlike routine echocardiography, the acquisition of CT is operator independent and provides a full-body, three-dimensional (3D), and now four-dimensional (4D), assessment that may be analyzed remotely for procedural planning. Recent advances in technology have enabled more rapid acquisitions, higher spatial and temporal resolution, and the need for lower doses of contrast (routinely ≤ 50 mL in our practice) and radiation. The wealth of evidence-based data and superlative image quality that are now available for CT means that it is an indispensable resource that one should strive to make the most of before any TAVR procedure.

PREPROCEDURAL ASSESSMENT

Vascular complications were an important determinant of mortality in the early TAVR era, driven not only by larger device profiles, but also by case selection. To mitigate this, CT has been applied to the determination of access approaches long before its application to annular sizing and other aspects of procedural planning. Early on, CT replaced the previous practice of angiography as the standard of care for iliofemoral assessment in TAVR clinical trials, including the PARTNER trial. Evidence for its superiority over angiography came later with a systematic comparison of cross-sectional, centerline reconstruction versus two-dimensional (2D) angiography. Noncontrast CT was noted to provide no incremental value over angiography in predicting sheath-related complications, but contrast CT was substantially superior. CT was also noted to provide additional value in the assessment of calcification and tortuosity.

Despite a reduction in device profiles and an increase in patients who are anatomically suitable for the transfemoral approach, there remains an important minority who requires “alternative” access approaches, including transapical, transaortic, transaxillary/subclavian, transcarotid, suprasternal transaortic/innominate, and transcaval. For all of these approaches, CT is the standard of care in planning their safety and feasibility.

ANNULAR SIZING

Before the advent of CT, the determination of annular size was based on 2D measurements, either on transthoracic echocardiography or transesophageal echocardiography (TEE). This approach was associated with a high rate of paravalvular regurgitation or leak, which was noted to be an important predictor of post-TAVR mortality.

There was a critical appreciation at the start of this decade that the aortic annulus was noncircular; that 2D measurements were thus unreliable, most often underestimating the true dimension of the aortic annulus (Figure 1); and that 3D measurements with CT offered superior discrimination of post-TAVR paravalvular leak (PVL). There was also the appreciation that 2D measurements could, at times, overestimate the aortic annulus dimension, particularly with circular annuli, and that this was an important factor in determining the risk for aortic root injury or rupture, an often fatal complication. This revolutionized the practice and established contrast CT as the standard of care for pre-TAVR procedural planning.

CT measurement should be performed in systole, as the aortic annulus shows some dynamism and is sometimes significantly larger in systole. On average, there is a 10% difference in measurements by area and approximately 5% by mean or perimeter (personal unpublished data). If measurements in only diastolic phases are available, this needs to be taken into account for device sizing, particularly when measurements are borderline for two sizes of a specific device. The appreciation of the value of contrast CT, with its ability to perform cross-sectional measures, led to the use of 3D TEE as an alternative in patients who are unable to receive contrast. Even in these patients,
noncontrast cardiac CT is valuable in its ability to assess aortic valvar complex (AVC) measurements and calcification that may complement 3D TEE sizing in the decision-making process for device selection and procedural planning.

**AVC CALCIFICATION**

CT offers unrivaled assessment of AVC calcification. Leaflet calcification may increase the risk of PVL; however, a greater concern is calcification below the aortic annulus in the left ventricular outflow tract that may increase the risk of not only PVL, but also aortic root injury and the implantation of a permanent pacemaker (PPM). This has led to the appreciation of calcium in the device landing zone as an important factor in pre-TAVR planning.

Calcium is traditionally quantified on a standardized 2- to 3-mm slice noncontrast CT to generate the Agatston score, which was originally devised for coronary calcium quantification. However, most centers no longer acquire noncontrast scans as part of the pre-TAVR workup. Recently, the Agatston score has been closely correlated to a contrast score based on a threshold of detection above the brightness of contrast (measured in Hounsfield units [HU], and an HU-850 threshold of detection). The relevance of thresholds of calcium is device specific, but this methodology provides an important framework for the further study of AVC calcium.

The quantity and distribution of calcium in the AVC/device landing zone is relevant to the potential outcomes. For instance, leaflet calcium in the left coronary cusp predicts the need for PPM after TAVR, but subannular calcium below the noncoronary cusp is most relevant, likely because the atrioventricular node is below the noncoronary cusp and the leaflet calcium may direct the prosthesis to the opposite side. This is a form of cavoceap injury, whereas direct injury to the atrioventricular node is relevant below the leaflets.

**IMPLANTATION ANGLE AND ROOT ANGULATION**

Device positioning is critical to the optimization of TAVR outcomes, and malpositioning can contribute to complications, including PVL and the need for a PPM. CT offers a 3D orientation of the aortic annular plane, which may be used to optimize the fluoroscopic projection during TAVR device malpositioning. This is especially important in angulated or horizontal aortas that pose an increased risk of PVL after TAVR, particularly with self-expanding designs, and are clearly identified by pre-TAVR CT.

**LEAFLET MORPHOLOGY**

TAVR was developed to treat aortic valve stenosis with tricuspid leaflet morphology, a degenerative condition typically seen in patients older than 80 years. Tricuspid morphology is the predominant leaflet morphology in high-surgical-risk populations (generally elderly); however, with the recent expansion in TAVR, intermediate-risk and even low-surgical risk populations are now treatable in the setting of clinical trials. Correspondingly, the ability to treat younger age groups means a higher frequency of bicuspid aortic valve (BAV) anatomy that increases with younger age and is seen in up to half of patients older than 70 years; this has been seen in TAVR patients in China, who are typically younger. Although outcomes...
Extreme calcification can often generate an artifact on an echocardiogram that may impede appreciation of true leaflet morphology. CT can provide definitive information on leaflet morphology, particularly with the advent of 4D CT, which has provided unprecedented spatial resolution, enabling more precise characterization of BAV morphology (Figure 2).26

**CARDIAC MUSCLE AND CHAMBER ASSESSMENT**

A CT scan can provide important cardiac muscle and chamber information that is complementary to an echocardiogram. A “suicide” ventricle may occur when hyperdynamic function resulting from relief of afterload by TAVR and a small cavity coupled with a severely hypertrophied muscle result in cavity obliteration and profound hypotension. Preemptive awareness can trigger close attention to periprocedural hydration and, if necessary, the use of ß-blockers and pressors to mitigate the hemodynamic influence. Severe septal hypertrophy can clearly be seen on CT and the likely contribution of subaortic obstruction, which may coexist with aortic stenosis, may be evaluated; severe septal hypertrophy may also pose technical challenges to device positioning. Recent advances in 4D CT can provide information on biventricular function and even left-right regurgitation fraction that can evaluate the magnitude of coexisting mitral regurgitation; this is done in a similar way to the chamber method performed on cardiac MRI.

**CORONARY ASSESSMENT**

Pre-TAVR coronary assessment focuses not only on the extent of coexisting coronary disease, but also the risk of coronary obstruction, a rare but serious complication after TAVR, with a very high rate of associated mortality.27 The height of the aortic annulus in relation to the coronary ostia, especially the left main ostium, is an important parameter in pre-TAVR assessment, but the risk of obstruction is perhaps more influenced by sinus (ie, sinus of Valsalva) dimension, which has entered sizing algorithms of many prostheses. A combination of low coronary height and small or borderline sinus dimension should trigger concern. In this setting, coronary protection has been used effectively, where a guide catheter and often a coronary wire and balloon or stent may be placed at the same time as TAVR to immediately address coronary obstruction, should it occur. The threshold for this approach may be lower in the setting of valve-in-valve procedures, where the TAVR “landing zone” may be higher than the native aortic annulus and thus closer to the coronary ostia or may have specific high-risk features, such as a stentless design or “endoskeletal” prosthesis that carries the leaflets on the outside of a stented frame.

Coronary revascularization before TAVR is an important issue of debate, and it is generally accepted that proximal disease should be treated, distal or branch vessel disease should not, and mid-vessel disease is debated, but often treated, and may depend on the vessel. This issue is in the process of being better understood and systematically studied, but pre-TAVR CT can provide a reliable assessment of proximal to mid-vessel disease that can, in the clinic, “clear” coronaries for a TAVR procedure, precluding the need for invasive coronary procedures.

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angioangiography. The challenge in this approach is the extent of coexisting coronary calcification that can often limit optimal luminal assessment, which is confounded by the fact that, prior to TAVR, the physician is limited in pharmacologic optimization of the coronary CT, generally with β-blockade and nitrates.

**ASSESSMENT FOR AUXILLARY TAVR DEVICES AND OTHER CT PARAMETERS**

An increased interest in reducing the risk of neuroembolic stroke has led to the creation of numerous devices, including filters and deflection devices. The Sentinel CPS device (Claret Medical, Inc.) is implanted via the radial approach and requires the placement of one filter in the brachiocephalic and left common carotid, although it may be placed in various aortic arch anatomies such as type I and type II arches (there are limitations, including brachiocephalic artery and left common carotid dimension and other arch anatomies).28 Similarly, the TriGuard device (Keystone Heart), which is a deflection device that covers all the great vessels and is placed via the femoral approach, also requires an evaluation of the orientation of the great vessels and aortic arch and the dimension and angulation of the proximal brachiocephalic artery.29 These are clearly delineated by CT.

CT presents a timeless, comprehensive dataset that may be reconsulted for new information as it emerges. A recent example of a novel CT parameter that is highly relevant to clinical outcomes is membranous septal length, strongly discriminatory for post-TAVR PPM,30 which has been added in retrospect to predictive algorithms.30

**CONCLUSION**

Performing CT before TAVR can provide a wealth of anatomical data that can optimize case selection, procedural safety, and outcomes. Making the most of CT involves committing appropriate time and effort to collect all the information it can offer for pre-TAVR planning with the knowledge that this effort will greatly simplify the procedure itself.

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