Multimodality Imaging in Transcatheter Aortic Valve Replacement

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Transcatheter aortic valve replacement is a major advance that has dramatically changed our approach to elderly patients with severe aortic stenosis. This advance has been made possible by innovative device and delivery improvements, coupled with rapid developments in multimodality imaging. Multimodality imaging draws from multiple imaging fields and is central to patient evaluation and treatment. The primary modalities to date include transthoracic echocardiography and transesophageal echocardiography, computed tomography, and fluoroscopy. Each of these modalities carries a different weight in the various stages of patient selection, procedural guidance, monitoring, and follow-up. Multimodality imaging ensures optimal device selection, delivery, and patient safety, and will continue to advance as the next generation of aortic valve devices further advance cardiovascular care.

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KEY WORDS

Transcatheter aortic valve replacement • Transthoracic echocardiography • Transesophageal echocardiography • Computed tomography • Fluoroscopy • Intravascular ultrasound

Transcatheter aortic valve replacement (TAVR) is a major advance that has dramatically changed our approach to elderly patients with severe aortic stenosis. This advance has been made possible by innovative device and delivery improvements, coupled with rapid developments in multimodality imaging, and an evolving cardiovascular team approach.

Multiple imaging platforms were utilized in patient selection and procedure guidance in the initial landmark trials of high-risk and nonsurgical patients with aortic stenosis.[1-3] Both the SAPIEN (Edwards Lifesciences, Irvine, CA) and CoreValve® (Medtronic, Minneapolis, MN) devices are now US Food and Drug Administration (FDA) approved for use in the United States (Figure 1). Multimodality

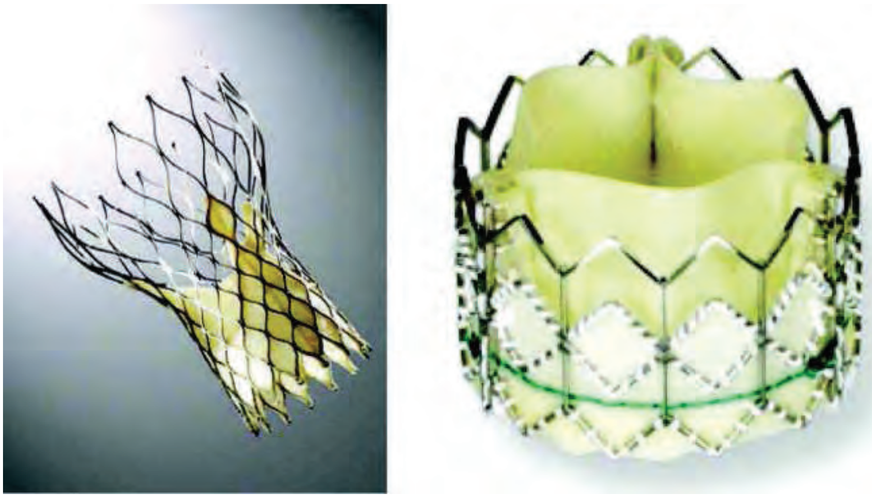


Figure 1. Transcatheter aortic valves. *Left panel*: CoreValve® (Medtronic, Minneapolis, MN). *Right panel*: SAPIEN (Edwards Lifesciences, Irvine, CA). Reprinted with permission from Welt FG et al.[29]

imaging draws from multiple imaging fields and is central to patient evaluation and treatment.[4-7] The primary modalities to date include transthoracic echocardiography (TTE), transesophageal echocardiography (TEE), computed tomography (CT), and fluoroscopy. Each of these modalities carries a different weight in the various stages of patient selection, procedural guidance, monitoring, and follow-up.

The heart team approach utilizes various disciplines to select and manage patients who will benefit from these advanced therapies. Central to transcatheter valve therapies is the collaboration among many different providers. As the preprocedure assessment often requires expertise that spans multiple disciplines, the team will likely involve echocardiographers and radiologists who will not be present during the procedure. Communication between all members of the heart team is essential to maximize procedural success.

Preprocedure Assessment

TTE and cardiac gated CT are the principal techniques utilized in preprocedure assessment.[7] TTE documents severe aortic stenosis and preliminary annulus size, and identifies potential high-risk features. CT accurately assesses annular and aorta size, coronary ostial height from the annulus, and peripheral vascular dimensions that may limit sheath size for a transfemoral valve delivery. Although TEE was utilized to determine the specific valve size for implantation in the Placement of Aortic Transcatheter Valves (PARTNER) trial,[1,3] a large amount of data also supports the use of CT for the selection of valve size.[8-10] In patients with borderline annular dimensions, a preprocedure TEE may be necessary to ensure the patient's annulus is not too small or too large to accommodate the currently available valves.

With TTE, the aortic valve is assessed both with two-dimensional (2D) and Doppler echocardiography. Severely stenotic aortic valves have a maximum velocity > 4 m/s with a mean pressure gradient > 40 mm Hg.[11] The assessment of velocities requires appropriate alignment with the Doppler beam in parallel with the maximal jet. Dedicated continuous-wave Doppler probes and TTE assessment from the right sternal border should be performed on all patients to avoid falsely low velocities from the aortic stenosis ejection jet. In patients with heavily calcified leaflets and eccentric ejection jets, multiple samples from apical, suprasternal, and right parasternal windows with dedicated Doppler and 2D probes will allow the best opportunity to obtain parallel interrogation of the maximal jet.

TTE also assesses the annular diameter. This is assessed in the parasternal long-axis view at the hinge points of the aortic valve (Figures 2 and 3). Given that the

Figure 2. Transesophageal long-axis view of aortic valve hinge points. *Arrows* indicate hinge points of aortic valve. Ao, aorta; Dist, distance between hinge points; LA, left atrium; LV, left ventricle.

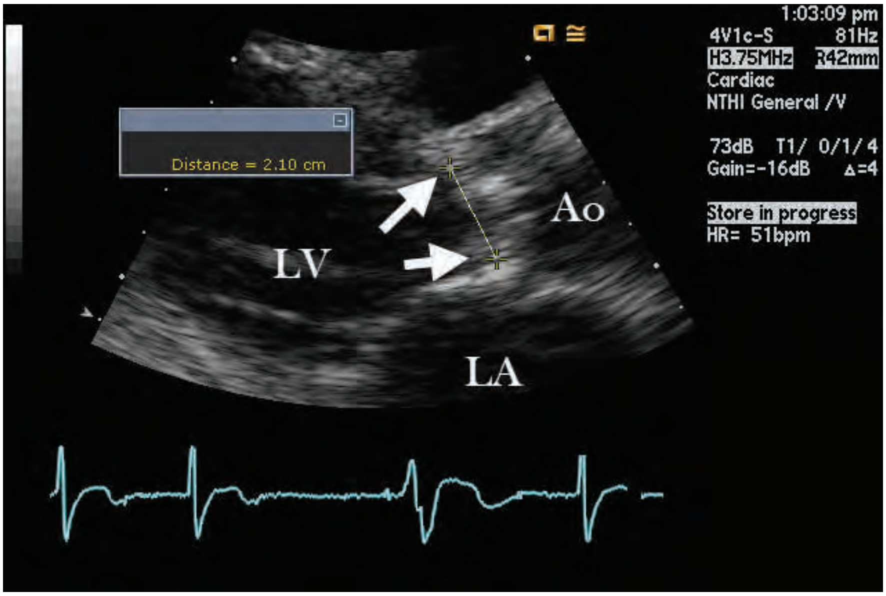


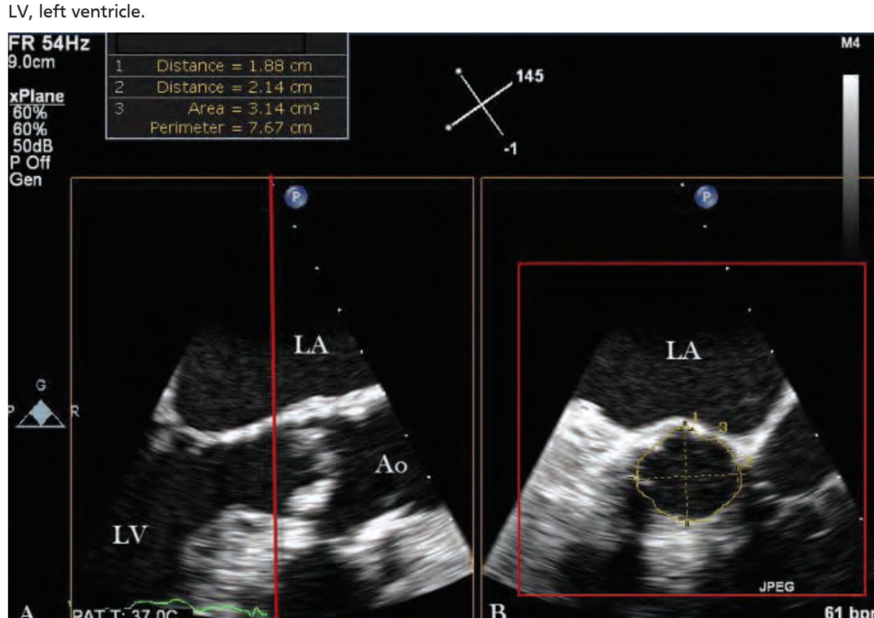
Figure 3. Parasternal long axis transthoracic view measuring the distance between aortic valve hinge points. *Arrows* indicate hinge points of aortic valve. Ao, aorta; Dist, distance between hinge points; LA, left atrium; LV, left ventricle.

shape of the annulus is often not circular but more oval, the anteroposterior diameter may underestimate the mean diameter of the annulus. Studies using three-dimensional (3D) echocardiography have demonstrated that 3D TEE yields a larger annular diameter than 2D TEE and impacts prosthesis size selection.[12] When TEE and CT were compared with direct surgical measurement, a CT-derived effective diameter based on circumference and end-systole TEE values most reliably predicted surgical annulus sizing.[13] Biplane echocardiography with TEE and TTE probes has the potential to quickly provide an orthogonal view of the annulus and better evaluate its circular versus oval shape (Figure 4). Careful attention is necessary to align the region of interest along the basal annulus to avoid overestimating the annular area with biplane echocardiography.

CT with gated cardiac and abdominal angiography plays a key role in the preprocedural evaluation.[9] This study may be done in a single scan with gated chest images and nongated abdominopelvic angiography using the same contrast bolus. In patients with renal failure, a noncontrast gated study can also yield important information about calcification of the aortic and mitral valves, aorta, and peripheral vessels. In patients with impaired renal function, when contrast is not contraindicated, contrast sparing protocols may be utilized. These protocols range from decreasing flow rate and decreasing keV to advanced high-pitch CT scans that rapidly image from the chest to the peripheral vessels. In patients in whom very low contrast is necessary, a CT angiogram of the abdomen and pelvic vessels may be done with 15 mL of contrast (diluted 1:3 to 1:4 with saline) injected through a pigtail catheter placed in the infrarenal abdominal aorta.[14]

Cardiac gated CT requires significant postprocessing with double oblique and 3D imaging. Much of the data gleaned from CT centers around the feasibility and safety of valve deployment. The primary focus is on the aortic valve, the basal annulus, and its immediately adjacent structures. The valve is characterized as uni-, bi-, or tricuspid, with mild, moderate, or severe calcification. Although the calcification is typically more central on the cusps, the annulus and sinuses may also have significant calcification.

Figure 4. Transesophageal image of aortic valve in simultanous long- and short-axis views. (A) Long-axis view. *Red line* represents short-axis plane demonstrated in panel B. 1, distance in anterior/posterior orientation; 2, distance in lateral orientation; 3, area of basal annulus and perimeter of tracing. Ao, aorta; LA, left atrium; LV, left ventricle.



Heavy annular calcification should be described with specific comment. The extent and severity of calcification may increase postdeployment complications such as paravalvular regurgitation.[15]

Basal Annulus

The aortic valve annulus is a complex, 3D structure. There is no single plane in which all cusps meet the aortic wall. At the most inferior aspect of the aortic valve annulus the medial location of each of the cusps do form an imaginary plane as they attach to the aorta, continuous with the left ventricular outflow tract (LVOT).

The basal annulus is often ellipsoid with a minor and major diameter. Valve sizing in the PARTNER trial was based on the diameter in the long-axis TEE view. This TEE valve sizing measurement generally is the minor diameter of the ellipse. Although TEE routinely provides a measurement smaller than multislice CT (MSCT), previous clinical results with TEE as the primary sizing modality have been favorable.[16] A more thorough assessment of the basal annulus is possible with 3D imaging with TEE, TTE, and MSCT. When CT-derived annulus area was utilized prospectively to determine valve size, there was a significant reduction in postprocedure aortic insufficiency when compared with traditional 2D TEE.[10] The specific measurement that determines valve choice will depend on the expertise available at each institution and specific patient factors that influence the image quality for each modality.

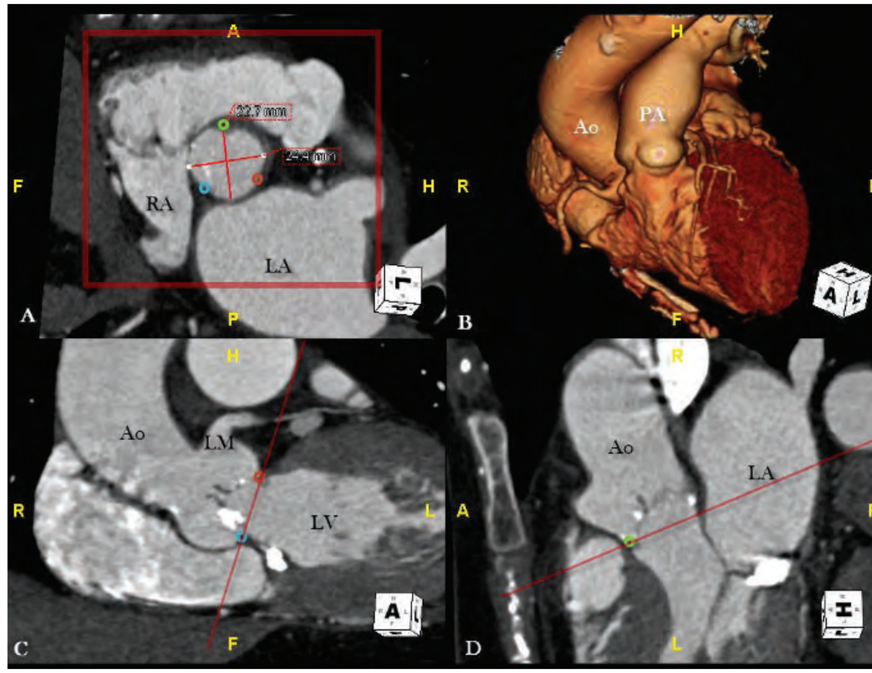


Figure 5. Multidetector computed tomography. Gated cardiac study demonstrating aortic valve basal annulus. **(A)** Short axis of basal annulus. The annulus is oval with minor axis of 22.7 mm and major axis of 24.4 mm. The *circles* demonstrate the most inferior portion of the respective cusps. *Red*, left coronary cusp. *Blue*, noncoronary cusp. *Green*, right coronary cusp. *Red square*, imaging plane demarcated by *red line* in panels C and D. **(B)** Three-dimensional cardiac rendering. **(C)** Long-axis view of aortic valve with most inferior portion of left and noncoronary cusps demonstrated. *Red line* is short-axis imaging plane. **(D)** Long-axis view of aortic valve with most inferior portion of right coronary cusp demonstrated. Ao, aorta; LA, left atrium; LM, left main (coronary artery); LV, left ventricle; PA, pulmonary artery; RA, right atrium;

Annulus Measurement

The annulus measurements obtained with CT require a gated cardiac CT. Multiplanar techniques may be used to identify the basal annulus (Figure 5). Measurements of annulus area and diameter are easily derived and reproducible.[8,17] The following technique provides a guide to obtaining the basal annulus utilizing the majority of 3D CT software programs available commercially: (1) Scroll inferiorly on the axial images and then adjust the coronal plane to approximate the base of the noncoronary and left cusps. (2) Return to the "modified axial" plane, which will be near a short axis of the aortic valve, and line up the cross hairs so that they cut through the middle of both the noncoronary and left cusps, where the most inferior portion of the leaflet is located; the sagittal plane will have the right coronary cusp in view. (3) Adjust the sagittal plane either up or down to run through the base of the right coronary cusp. At this point, all of the inferior hinge points of the cusps will be in the same plane. (4) Move the modified axial plane (now the short axis) to the level immediately below the hinge points: this is the basal aortic annulus.

The fluoroscopic deployment angle is also predicted from the plane that displays the noncoronary cusp on the left of the screen. At this level, multiple measurements may be taken, including minimum, average, and maximum diameters, annulus area, and perimeter (Figures 5 and 6). These measurements may then be matched to the most appropriate transcatheter valve available.

The basal annulus is also readily identified with 3D TEE.[18] With biplane imaging, the probe head must be parallel to the aorta and the biplane must be perpendicular to the hinge points. In systole, with translation of the heart, the annulus will come into view on the short-axis/biplane image (Figure 4). Pitfalls include poor image quality secondary to heavy calcification, failure to bisect both hinge points,

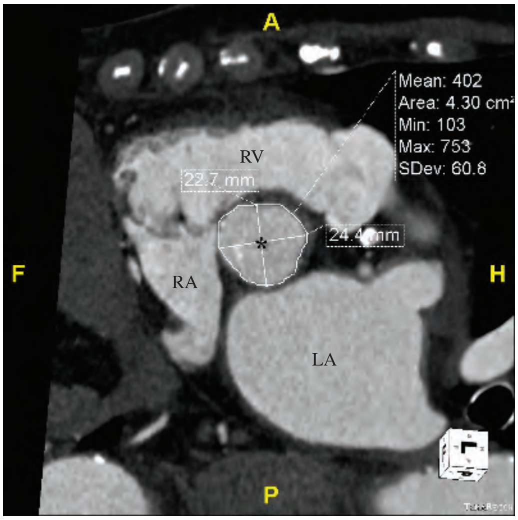


Figure 6. Computed tomography assessment of basal aortic annulus. Area, 4.3 cm^2; diameter 22.7 mm × 24.4 mm. LA, left atrium; RA, right atrium; RV, right ventricle.

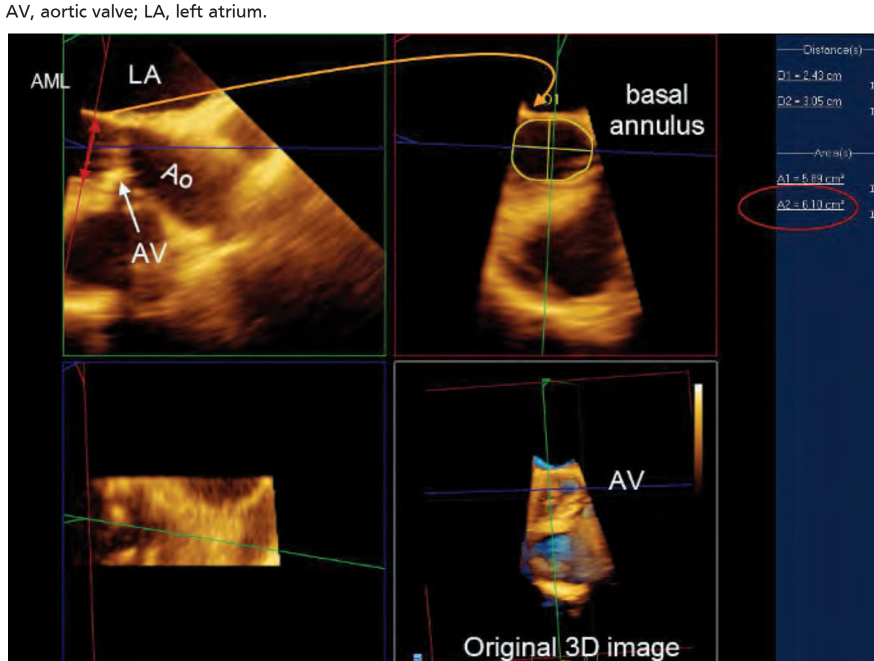
and failure to keep the probe parallel with the aorta. If the probe is not parallel then the annulus will be measured at an angle and size may be overestimated. A 3D volume capture allows additional manipulation when compared with biplane echocardiography (Figure 7). 3D images may be performed with a multiple beat acquisition to obtain a larger field of view and improved resolution. A smaller volume may be obtained with a single beat 3D acquisition. The smaller field of view is generally adequate to visualize the annulus. With the Philips (Andover, MA) platform, a live 3D volume at the midesophageal short-axis view provides excellent assessment of the annulus and valve. This 3D volume can then be manipulated with advanced multiplanar software to determine annulus diameters, area, and perimeter. Advanced imaging software must be present on the echocardiography machine if measurements are done at the time of the procedure. If the TEE is done prior to the procedure, then these images may be manipulated offline (Figure 5). TTE and TEE examinations have excellent agreement in aortic annulus sizing but typically produce smaller values than obtained using MDCT.[16]

Risk of Coronary Occlusion

Coronary artery occlusion has occurred following valve deployment.[19] The etiology of occlusion is often multifactorial and includes bulky calcification on the left or right coronary cusps, low take-off of the coronary ostia, and diminutive sinuses of Valsalva. These findings may be described with either TEE or MDCT.[9,20] Additionally, using fluoroscopy a left main or right coronary artery injection may be performed during aortic balloon valvuloplasty to ensure a bulky leaflet does not occlude the respective coronary ostium. In general, a distance of < 10 mm between the base of the coronaries and the hinge point of the respective cusp poses an increased risk for occlusion. A very bulky left or right coronary cusp and diminutive sinuses also increase the risk. These findings should be considered when assessing risk.

To determine the coronary ostial height with CT, in the same plane that the basal annulus is assessed, rotate the crosshairs to bisect the left main and the left coronary cusp. In the bisected plane, measure from the cusp hinge-point to the base of the left main artery. After assessing the left main artery, the short-axis view may be rotated to measure the right coronary artery. Although the right and left coronary arteries can be viewed in the same plane,

Figure 7. Three-dimensional (3D) assessment of the basal aortic valve annulus. *Upper left panel*, long-axis view. *Upper right panel*, short-axis view allowing measurement of diameter and area or annulus. *Lower left panel*, orthogonal view of aortic valve along blue plane. *Lower right panel*, original 3D image of aortic valve viewed from aorta in the red plane. *Green* and *blue* plane orientations are demarcated. Ao, aorta; AV, aortic valve; LA, left atrium.



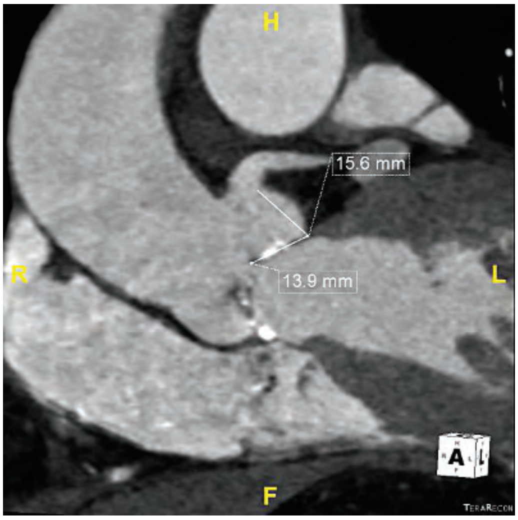


Figure 8. Computed tomography assessment of left main ostial height and left coronary cusp leaflet length.

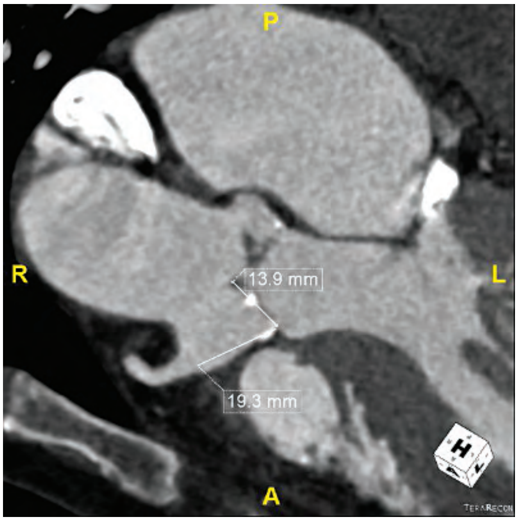


Figure 9. Computed tomography assessment of right coronary artery ostial height and right coronary cusp leaflet length.

careful attention to the hinge-point location is necessary as the cusp length may be underestimated if the bisecting plane does not cross the center of the cusp. Moving the short-axis plane superiorly to the sinuses and sinotubular junction will allow measurement of the respective diameters (Figures 8 and 9).

Deployment Angle

The ideal fluoroscopic view for valve deployment is at the point at which the most basal points of the three aortic cusps are visible along a single plane. In the 2D fluoroscopy view, ideally, all the cusps are visualized with the noncoronary cusp located on the left side of the screen, the right cusp in the center, and the left cusp on the right side of the screen. Multiple techniques to derive this angle exist. Utilizing the aforementioned CT method to determine the annulus will also provide the deployment angle. Most commercial CT workstations with cardiac packages provide a corresponding C-arm angle for each view. Subtle changes may be necessary in the catheterization laboratory if the patient is positioned slightly differently than during the CT. If CT is not used to predict the angle of deployment, then an anteroposterior or a 10° left anterior oblique, 10° caudal view often provides a reasonable starting point, after which further adjustments may be made. For fluoroscopy adjustments, the image intensifier (II) should be moved in the direction of the middle/anterior cusp. If, on the initial image, the anterior cusp is superior and to the left of the annular plane formed by the noncoronary and left cusps, then the II is moved more cranial and left anterior oblique to bring the right cusp down and toward the middle—the II "chases the middle cusp."

An appropriate preprocedure assessment has the ability to reduce the amount of contrast utilized in the hybrid suite to locate the ideal fluoroscopic deployment angle. As with echocardiography, the reproducibility of predicted angles of deployment will improve with constant feedback to the CT reader regarding predicted versus actual angle of deployment. (Figure 10). If the CT data are not reliable in the hybrid suite, 3D reconstructions of C-arm rotational aortic root angiograms can also predict deployment angle.[21] Rotational imaging in the hybrid suite removes the potential error in patient positioning encountered when using data from a previously obtained CT to predict a deployment angle; however, with careful attention to patient positioning during the CT and in the operating room, this additional imaging tool is not a strict requirement.

Peripheral Vessels

Peripheral vessel sizes often limit the use of larger sheaths for transfemoral access.[22] The initial FDA-approved Edwards Lifesciences devices require either a 24F sheath requiring a minimum luminal diameter of 8 mm (26-mm valve) or a 22F sheath requiring a 7-mm minimum luminal diameter (23-mm valve). The next generation of Edwards Lifesciences devices will require an 18F sheath with a luminal diameter of 6 mm (23- and 26-mm valves). The Medtronic

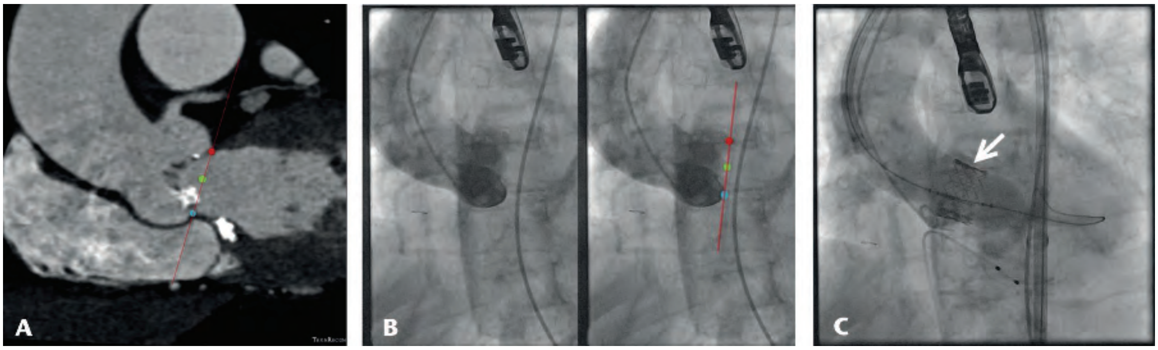


Figure 10. **(A)** Computed tomography long-axis view of aortic valve and basal annulus. This angle corresponds to a fluoroscopy C-arm angle of left anterior oblique (LAO) 20°, caudal (CAU) 10°. The *circles* demonstrate the most inferior portion of the respective cusps. The *red line* is the plane that all of the cusps line up in at this C-arm angle. *Red*, left coronary cusp. *Blue*, noncoronary cusp. *Green*, represents the position of the right coronary cusp (cusp is not in this two-dimensional image, it is located anteriorly). **(B)** Fluoroscopy aortogram at C-arm angle LAO 20°, CAU 10°, demonstrating alignment of all cusps within a single plane. **(C)** Fluoroscopy view of aortic valve deployment (*arrow*) at LAO 20°, CAU 10°, demonstrating excellent alignment of valve cells.

CoreValve utilizes an 18F device across all of the available valves. These smaller sheaths will decrease the number of patients excluded from transfemoral access procedures. If patients are not candidates for transfemoral access, they may be candidates for transapical or transaortic valve delivery.

Aside from determining eligibility for a transfemoral approach, a close assessment of the peripheral vessels also decreases the risks for vascular complications during the procedure and identifies bypass conduit options if necessary. The key components of vascular assessment include tortuosity, calcification, and lumen diameters. All of these factors must be integrated to assess risk. Severe tortuosity is concerning in a heavily calcified vessel although the same tortuosity in a vessel without calcification would likely straighten out with a stiff wire and not pose an increased risk to the patient. Additional subtleties come into play. The outside diameter of these devices is > 1 mm larger than the minimum accepted lumen. As most vessels will tolerate mild stretching, this is often not an issue, unless there is significant calcification that impairs the vessel accommodation. If the peripheral vessels have a large arc of calcium or are circumferentially calcified, then the vessel diameter must be larger than the outside diameter of the delivery system. Excellent communication between the CT reader and the operator is imperative as subtle findings may eliminate a vessel for access or place the patient at increased risk for vascular complications.

If a noncontrast study does not demonstrate significant calcified lesions, then additional imaging such as fluoroscopy, IVUS, or magnetic resonance imaging would be beneficial prior to going forward with a transfemoral procedure.

CT angiography is the key tool in assessment of peripheral vessels. Intravascular ultrasound (IVUS) is also a useful tool in assessing vessel size when contrast is not an option. As just described, reduced contrast protocols should be employed in patients at increased risk for contrast-induced nephropathy. Regardless of the protocol used to obtain the vascular images, center line imaging is necessary to accurately assess vessel dimensions and the presence of significant circumferential calcification (Figure 11).

Noncontrast CT studies are an option for peripheral vessels to determine whether the patient may be excluded from femoral access. However, even though the width of the vessel may be assessed, noncalcified filling defects such as thrombus or dissection will not be apparent. If a noncontrast study demonstrates circumferential calcification in bilateral iliac arteries with a minimal diameter of 6 mm then that patient is not a candidate for peripheral access. Such patients would not require any additional contrast or invasive evaluation in order to be excluded. If a noncontrast study does not demonstrate significant calcified lesions, then additional imaging such as fluoroscopy, IVUS, or magnetic resonance imaging would be beneficial prior to going forward with a transfemoral procedure.

Alternate Access

Transapical and Transaortic

In the United States, both currently available platforms from Edwards Lifesciences and Medtronic allow transfemoral, transaortic, or transapical device delivery. A gated cardiac CT that also includes the aortic root provides the necessary data for direct aortic and transapical planning.

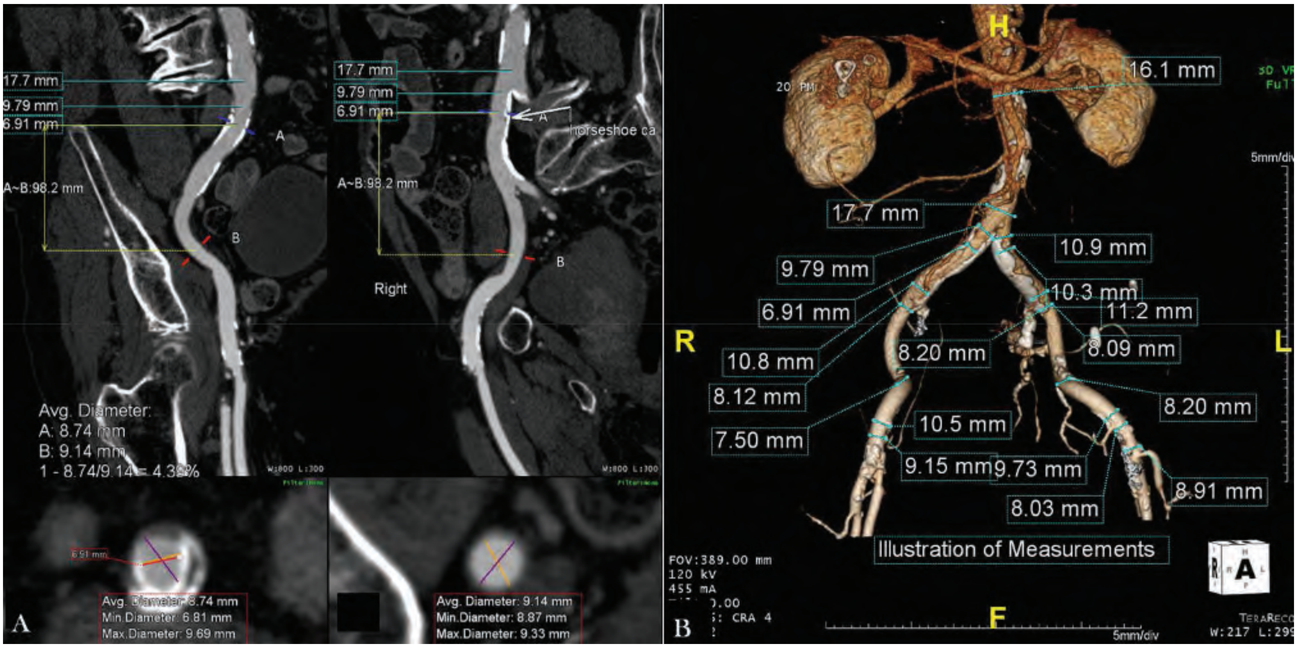
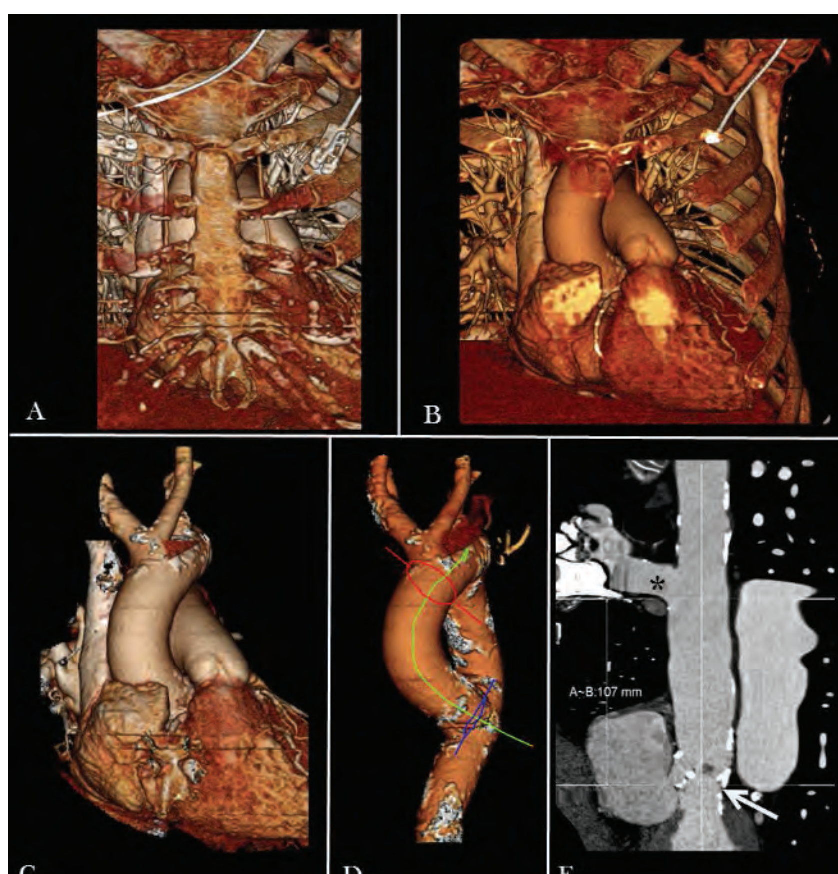


Figure 11. Computed tomography angiography of peripheral vessels. **(A)** Center-line imaging of right ileofemoral system. *Lower left panel* with short axis of severely calcified artery segment. **(B)** Three-dimensional rendering of bilateral ileofemoral system.

When there is consideration of a transapical approach, the apex position relative to the chest wall visualized with CT can help guide the initial surgical site. Additionally, the end-systolic phase of the cardiac CT and the TTE will demonstrate the end-systolic volume. A small end-systolic volume in the transapical approach may accentuate a relative loss in stroke volume when the delivery system is within the left ventricle (LV) as the system displaces some of the blood volume within a very small cavity.

For the direct aortic approach, the surgeon will need to take into account the optimal approach to expose the ascending aorta. Multiple CT views with and without the sternum will assist in identifying whether a sternal approach or a more lateral access is appropriate to access the aorta. Additional views of the aorta with measurements from the annulus to the anticipated aorta entry point will identify impediments, such as severe calcification that would limit the access point (Figure 12).

Figure 12. Three-dimensional computed tomography reconstructions of the ascending aorta during evaluation prior to transaortic approach. **(A)** Sternum and ribs visualized overlying the aorta. **(B)** Partial removal of sternum and ribs demonstrating the relative position of the aorta. **(C)** Complete removal of the bones demonstrating the ascending aorta and cardiac structures. **(D)** Removal of cardiac structures with isolated thoracic aorta. A centerline is drawn in *green* with a *blue line* demarcating the aortic valve annulus and a *red line* demarcating the take-off of the brachiocephalic artery. **(E)** Straight centerline reconstruction of ascending aorta demonstrating a 107-mm distance from the aortic valve annulus to the take-off of the brachiocephalic artery. *brachiocephalic artery; *arrow*, aortic valve annulus.



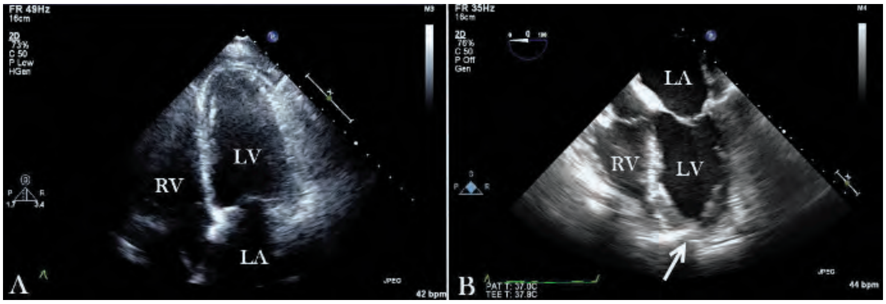


Figure 13. Transapical echocardiographic imaging. (A) Transthoracic image of LV apex obtained immediately prior to skin incision to pinpoint rib space for transapical approach. (B) Intraoperative transesophageal echocardiogram demonstrating indentation from the surgeon's finger on the LV apex to identify optimal location for LV puncture. *Arrow*, indentation on LV apex. LA, left atrium; LV, left ventricle; RV, right ventricle.

Procedure Imaging

Initial imaging during the TAVR procedure is typically TEE. In addition to a standard study, attention is focused on procedure-specific values such as basal annular size, baseline aortic insufficiency, severity of mitral and aortic calcification, baseline pericardial effusion, and presence of LVOT obstruction or a septal knuckle that may increase superior migration of the device during deployment.

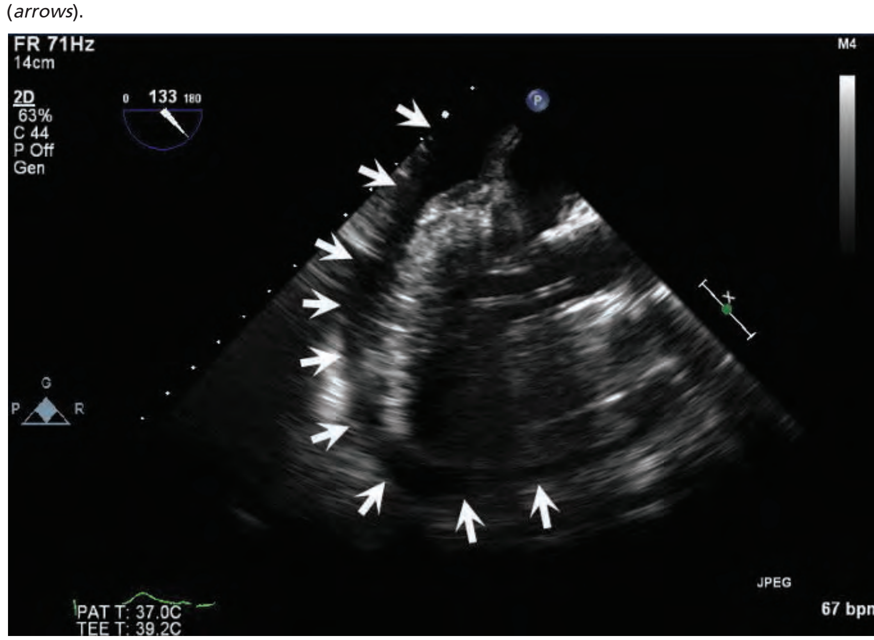
If a transapical approach is planned, then transthoracic apical imaging with the patient in position, immediately prior to the procedure, will locate the apex and finalize the rib space utilized. After the LV is exposed, the TEE can confirm the intended LV entry point by identifying external pressure on the LV by the surgeon's finger in mid-esophageal two- and four-chamber views (Figure 13). Once the wire and sheath are inserted, TEE provides assurance that the mitral apparatus, including the papillary muscles and chordae, are not compromised.

During the procedure, frequent TEE assessment for complications is necessary. These complications include pericardial effusions, aortic dissection, and evidence of acute bleeding such as an underfilled ventricle. After the balloon valvuloplasty and valve deployment, immediate assessment of valve function (mitral and aortic), paravalvular aortic regurgitation (PAR), dissection, annular rupture, hematoma, or LV dysfunction is necessary (Figures 14 and 15).

Paravalvular Aortic Regurgitation

Following aortic valve deployment, PAR is not uncommon. In initial studies, moderate to severe PAR was seen in > 10% of patients.[4] The etiology of PAR is multifactorial with anatomic and procedural causes. From an anatomic perspective, PAR can result from either a significant discrepancy between the dimensions of the ellipsoid basal aortic annulus and the transcatheter heart valve (THV) or the presence of significant asymmetric annular calcification. Patients who have significant PAR have a worse prognosis when compared with those who do not.[23] Mild, moderate, or severe PAR is defined based on Valve Academic Research Consortium definitions.[24] These definitions do not differ for central versus paravalvular regurgitation, although acute interventions will hinge on the type and severity of the regurgitant lesion. Many are promoting an assessment of PAR based on the number of degrees, or the size of the arc, that the aortic insufficiency involves along the periphery of the valve.[25] Immediately after valve delivery, prosthesis dysfunction with leaflet failure may result in one or more of the leaflets remaining open in diastole, producing severe central aortic insufficiency. This typically corrects itself rapidly, although if it fails to correct, then placement of another valve-in-valve may be necessary. Although techniques have been developed to improve valve sizing and reduce the amount of PAR with improved THV to annulus agreement, it is unclear if those patients who had more PAR had anatomic abnormalities that placed them at an overall worse prognosis.

Figure 14. Transesophageal echocardiogram after valve deployment demonstrating large pericardial effusion (*arrows*).



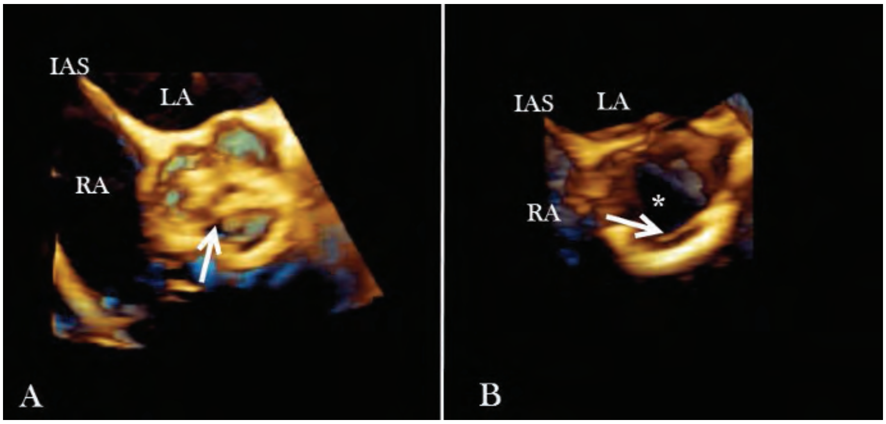


Figure 15. Three-dimensional transesophageal echocardiography of aortic valve in short axis. **(A)** Severe aortic stenosis of a tricuspid aortic valve during systole. **(B)** The same patient following deployment of a SAPIEN (Edwards Lifesciences, Irvine, CA) transcatheter aortic valve. Image obtained during systole. *Aortic valve orifice in systole following transcatheter aortic valve replacement. *Arrow*, native valve leaflet in panel A and bioprosthetic leaflet in panel B. IAS, interatrial septum; LA, left atrium; RA, right atrium.

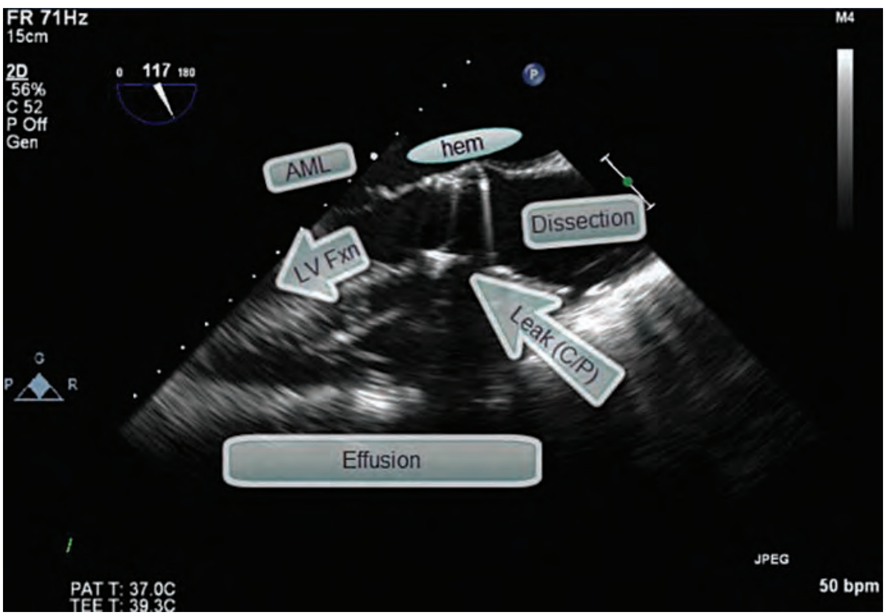


Figure 16. Transesophageal view of aortic valve in long axis after SAPIEN (Edwards Lifesciences, Irvine, CA) valve deployment. *Labels* highlight typical areas to assess for complications after deployment. AML, anterior mitral valve leaflet; C/P, central/paravalvular; hem, hematoma; LV Fxn, left ventricle function.

Thus, the PAR was just a marker for patients with more annular calcification and a stiff or poorly compliant aorta. Retrospective analysis with the CoreValve suggests that those patients, post procedure, who have an elevated left ventricular end-diastolic pressure (LVEDP) paired with low diastolic pressure relative to systolic pressure have a poor prognosis compared with those with higher diastolic aortic pressures and lower LVEDPs.[26]

The etiology and the severity of the PAR should be assessed quickly following valve deployment. With the Edwards Lifesciences platform, if the valve position is too high and there is significant paravalvular regurgitation due to a poor seal at the annulus, then a decision to deploy a lower valve-in-valve may be considered. If the valve is deployed in the appropriate position, and due to poor apposition there are significant areas of regurgitation, a balloon valvuloplasty may be required to decrease the degree of aortic insufficiency.

Significant PAR with the Medtronic platform may arise from technical factors such as a low implantation or undersizing of the annulus. Techniques to treat significant PAR may include post-dilation and, more rarely, valve-in-valve implantation.[27] Additional techniques of snaring or using a balloon to withdraw a CoreValve device implanted too low have also been described.[28]

In addition to assessment of aortic insufficiency, a rapid assessment for annular disruption, mitral valve impairment, pericardial effusion, coronary artery obstruction, aortic dissection, and hematoma should be performed (Figure 16). These can be assessed quickly in the TEE midesophageal view with standard echocardiographic views of the bicommissural (50°-70°) and long axis (110°-130°). Biplane imaging can assess both views simultaneously and allow mitral valve assessment and evaluation of any new wall motion abnormalities that may be seen with coronary obstruction.

After the valve is interrogated, the temporary pacemaker wire and the valve sheath are removed. Careful TEE attention should be given to any evidence of new or enlarging pericardial effusion, as well as changes in right and left ventricular function. A right ventricular puncture secondary to the temporary pacemaker may result in a delayed pericardial effusion that is seen later in the procedure. Additionally, an underfilled right and left ventricle may be a sign of acute hemorrhage secondary to sheath-induced vascular injury. Swift communication of any of the aforementioned findings to the operator and the anesthesiologist is paramount in ensuring the best clinical outcome.

Conclusions

TAVR is changing how cardiologists and surgeons treat aortic valve disease. The improvement in cardiovascular imaging modalities has paralleled the advancements in less invasive interventional tools. Multimodality imaging ensures optimal device selection, delivery, and patient safety. Multimodality imaging will continue to advance as the next generation of aortic valve devices further advance cardiovascular care. ■

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MAIN POINTS

- Transcatheter aortic valve replacement (TAVR), made possible by innovative device and delivery improvements coupled with rapid developments in multimodality imaging, is a major advance that has dramatically changed our approach to elderly patients with severe aortic stenosis.
- Primary imaging modalities to date include transthoracic echocardiography (TTE), transesophageal echocardiography (TEE), computed tomography (CT), and fluoroscopy.
- TTE and cardiac gated CT are the principal techniques utilized in preprocedure assessment. TTE documents severe aortic stenosis and preliminary annulus size, and identifies potential high-risk features. CT accurately assesses annular and aorta size, coronary ostial height from the annulus, and peripheral vascular dimensions that may limit sheath size for a transfemoral valve delivery.
- Initial imaging during the TAVR procedure is typically TEE. In addition to a standard study, attention is focused on procedure-specific values such as basal annular size, baseline aortic insufficiency, severity of mitral and aortic calcification, baseline pericardial effusion, and presence of LVOT obstruction or a septal knuckle that may increase risk of superior migration of a device during deployment.