Chapter 9: Cardiac imaging for TAVR: CTA, TTE, TEE, and valve sizing

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A multidiscipinary heart team approach and high quality cardiac imaging are important to evaluate the aortic valve (AV) prior to transcatheter aortic valve replacement (TAVR). Pre-procedural evaluation confirms the severity of stenosis as well as formulates the best TAVR plan while minimizing possible procedural-related complications.

Essential or Key Steps

- Multiple imaging modalities are often ordered prior to the TAVR procedure to confirm the patient's candidacy for the procedure, evaluate the peripheral vasculature for the best access site and to determine the appropriate THV size.
- MDCT is essential for peripheral vascular access planning and is increasingly being used as a primary preoperative imaging modality for THV sizing and aortic root assessment.
- Intra-procedural 3D-TEE is a supplementary imaging modality that can confirm THV size and guide the proceduralist during THV deployment while continuously evaluating for procedural complications.

Pearls and Pitfalls

- MDCT is able to assess the tortuosity, calcification, and diameter of the peripheral vasculature. 3D reconstruction of the AV annulus provides AV annular dimensions, circumference, area as well as a fluoroscopy deployment angle for the TAVR procedure. MDCT requires intravenous contrast that may be harmful to older patients with possible concomitant kidney disease.
- MDCT is not a "real-time" modality and if images are compromised for any reason (low contrast, gating artifact, or respiratory motion) additional information should be sought prior to deployment (ie. TEE or repeat MDCT exam).
- Intra-procedural 3D-TEE of the virtual AV annulus may be performed to measure the AV annulus dimensions, area, and circumference to confirm THV sizing. Off axis measurements and shadowing from calcification can make measurements challenging.

Pre-TAVR Imaging Modalities

The initial imaging modality ordered to assess the severity of AS is usually a high-quality transthoracic echocardiogram (TTE). Imaging with a transthoracic probe in multiple positions (near-parallel to blood flow) is necessary to assure detection of the highest transvalvular flow velocity using

Doppler. The continuity equation can be applied in most situations to calculate the AV area and AS severity can be determined based on the most recent ACC/AHA guidelines.(1) TTE is also able to assess valvular morphology, AV and aortic root calcification burden, sinus of Valsalva dimensions, left ventricular function and other valvular abnormalities.

The AV complex includes the left ventricular outflow tract (LVOT), the aortic annulus, the AV cusps, the sinuses of Valsalva, and the sinotubular junction. Measurement of the aortic annulus and characterization of the AV complex are important in the selection of the transcatheter heart valve (THV) as well as for anticipating and avoiding complications, such as paravalvular regurgitation (PVL), aortic root rupture, or coronary artery occlusion. The most important measurement currently used for THV sizing is that of the virtual aortic annular plane, commonly referred to as the “aortic annulus”. This plane intersects the lowest attachment site, or hinge point, of each of the three AV cusps. The shape of the aortic annulus is typically elliptical and is dynamic throughout the cardiac cycle. Measurement of the aortic annulus is conventionally made in mid-systole. Historically, THV size was based on a two-dimensional echocardiographic measurement of the aortic annulus made in the long axis (sagittal) plane. While adequate in the majority of cases, this method was difficult to perform accurately and has several limitations.

Three-dimensional imaging has greatly enhanced measurement of the aortic annulus and improved THV selection. Aortic annular dimensions, area, and perimeter measurements made by multi-detector computed tomography (MDCT) has been shown to improve the accuracy of THV sizing and has become the standard imaging modality used to measure the aortic annulus (Figure 1). Most often an ECG-synchronized scan of the heart is combined with a non-ECG gated exam of the aorta and peripheral vasculature to allow for a comprehensive TAVR planning with a single imaging modality. However, this modality does have important limitations. MDCT requires precise ECG gating, multiphase image acquisition, and appropriate timing of contrast. Acquisition techniques vary widely and are based on available local technology and expertise; thus, the appropriate method of ECG synchronization, volume of contrast injection, and range of feasible heart rates varies from site to site. Calcium appears approximately four times larger on MDCT than its actual size (“blooming artifact”) and may make measurement of the annulus more challenging(2). Also, renal impairment can limit the use of intravenous contrast and gating or motion artifacts may occur from irregular heart rhythms or respiratory motion respectively.

Three-dimensional transesophageal echocardiogram (3D-TEE) has also been shown to accurately measure the aortic annular dimensions, area, and perimeter (Figure 2). Advantages of 3D-TEE over MDCT include superior temporal resolution, the avoidance of ionizing radiation and intravenous contrast, and the opportunity to easily acquire three-dimensional images of the AV complex over multiple cardiac cycles and in different acoustic imaging planes. The AV complex can usually be imaged by 3D-TEE within a single three-dimensional volume and therefore avoids gating artifacts. Multiple cardiac cycles can easily be acquired and analyzed allowing for numerous opportunities to select the optimal imaging window and cardiac cycle(s) for analysis. Nonetheless, 3D-TEE does have important limitations including acoustic shadowing from calcium, ultrasound artifacts, and lateral resolution that is inferior to that of axial resolution.

In addition to the aortic annulus, other anatomic feature of the aortic valve complex can influence THV selection and/or be associated with complications during TAVR. Within the LVOT, prominent septal hypertrophy may lead to THV malpositioning. The presence of bulky calcification of the aortic complex has been shown to be associated with paravalvular leak following TAVR. Risk factors for coronary obstruction with TAVR include a distance from the virtual AV annulus to the inferior aspect of the coronary arteries of less than 10 mm, shallow sinus of Valsalva diameters, and bulkly leaflet calcification. Both MDCT and 3D-TEE are highly accurate imaging modalities that can be used to assess anatomic aspects of the aortic valve complex that are critical for TAVR planning; however, each modality has inherent advantages and limitations and requires a high level of expertise and experience.(3)

Rather than exclusively relying upon a single imaging modality, expertise in and integration of information from multiple imaging modalities is likely to yield the best outcomes in decision making regarding TAVR.

Peripheral vascular assessment is required in the pre-TAVR assessment to determine the best access site for the TAVR introducer sheaths. This assessment is mainly performed with MDCT where calcification burden, tortuosity, and artery size are determined. The femoral arteries are the most common access point for TAVR however the subclavian and axillary arteries are also evaluated for alternative access sites (Figure 3). Ideally a comprehensive planning MDCT is performed with a full iodinated contrast dose (usually 85-100 cc injected volume). In patients with renal disease, low-dose contrast MDCT protocols have been developed to assess the femoral arteries for TAVR, which require sacrifices to aortic root image quality.(4) Although low-dose contrast MDCT protocols allow a limited assessment of the aortic root complex, in situations where CT images are compromised for any reason (i.e. low-contrast dose, cardiac or respiratory motion artifacts), the annular dimensions should be confirmed with 3D-TEE prior to THV deployment.

Intra-procedural Imaging Modalities

Intra-procedural 3D-TEE is helpful to confirm AV annular measurements (thereby confirming THV size) and can also guide the interventionalist or surgeon during the TAVR procedure. Baseline assessment of biventricular function, mitral regurgitation and the absence of pericardial effusion (especially after temporary right ventricular pacer placement) are usually made by echocardiography. After the proceduralist crosses the AV with a wire then pigtail catheter, TEE is used to assess for catheter interference with the mitral valve subvalvular apparatus and/or worsening of mitral regurgitation. Balloon aortic valvoplasty (BAV) is often performed to allow increased AV cusp excursion (improving cardiac output during the procedure) and also allows for easier positioning of the THV apparatus (Figure 4). Immediate assessment of aortic regurgitation severity by echocardiography is made after BAV and for those who develop severe aortic insufficiency, the proceduralist may choose to deploy the THV as soon as possible.

THV positioning is primarily performed using fluoroscopy however TEE can be used as an adjunctive imaging modality. Confirmation of the pigtail placement in the noncoronary cusp (for self-expanding valves) or right coronary cusp (for balloon expanding valves) can be performed by intra-procedural TEE. Balloon expandable valves such as the Sapien 3 (Edwards Lifesciences, Irvine, California) can be guided across the AV annulus by TEE. These THV shorten with deployment (mainly from the ventricular side of the valve) whereas the aortic side of the valve remains relatively stable. Positioning of the THV 50-50 across the AV annulus will lead to an ideal final position—roughly three-fourth of the THV on the aortic side of the annulus (Figure 5). Fluoroscopy is the primary imaging modality used for deployment of self-expanding THV such as the Evolut R (Medtronic, Minneapolis, Minnesota). Until the valve is unsheathed, it is difficult to determine the exact starting location of self-expanding THV by TEE. The ideal final position of these valves is approximately 3-5 mm below the AV annulus (Figure 6).

After deployment, the THV position, leaflet mobility, valvular regurgitation, and PVL are assessed by echocardiography (Figure 7). PVL location and severity (if present) are described and peak and mean THV gradients are obtained(5). Grading of PVL is often estimated at the level of the narrowest regurgitate vena contracta and is based on the percent of the circumference the regurgitate jet occupies. Assessment for possible procedure-related complications such as pericardial effusion, aortic injury (aortic dissection, aortic hematoma), or worsening mitral regurgitation should be performed after balloon valvoplasty and THV deployment for each case.

Conscious sedation is being used instead of general anesthesia with increased frequency in Europe and the United States. In this setting, THV positioning and deployment is performed primarily with fluoroscopy guidance. Confirmation of THV positioning and grading of PVL is performed with either aortogram or TTE immediately after deployment. TTE is also used to evaluate for any immediate procedural-related complications. As technology evolves, advanced imaging techniques such as image fusion (echocardiographic or CT) with fluoroscopy may be used to help facilitate THV positioning and placement(6).

Post-TAVR Imaging Modalities

A post-procedure TTE is completed the following day or near the end of the hospitalization when the hemodynamics of the patient has returned to baseline. This TTE can be used to obtain baseline peak and mean THV gradients and also reassess for any procedural related complications or PVL.

Conclusion

Individualized imaging plans are determined by the multidisciplinary team to best assess a patient’s candidacy for the TAVR procedure as well as determine the appropriate THV size. Multiple imaging modalities, occasionally in different specialties, are often required to best assess and treat the patient while reducing procedural-related complications.

FIGURES

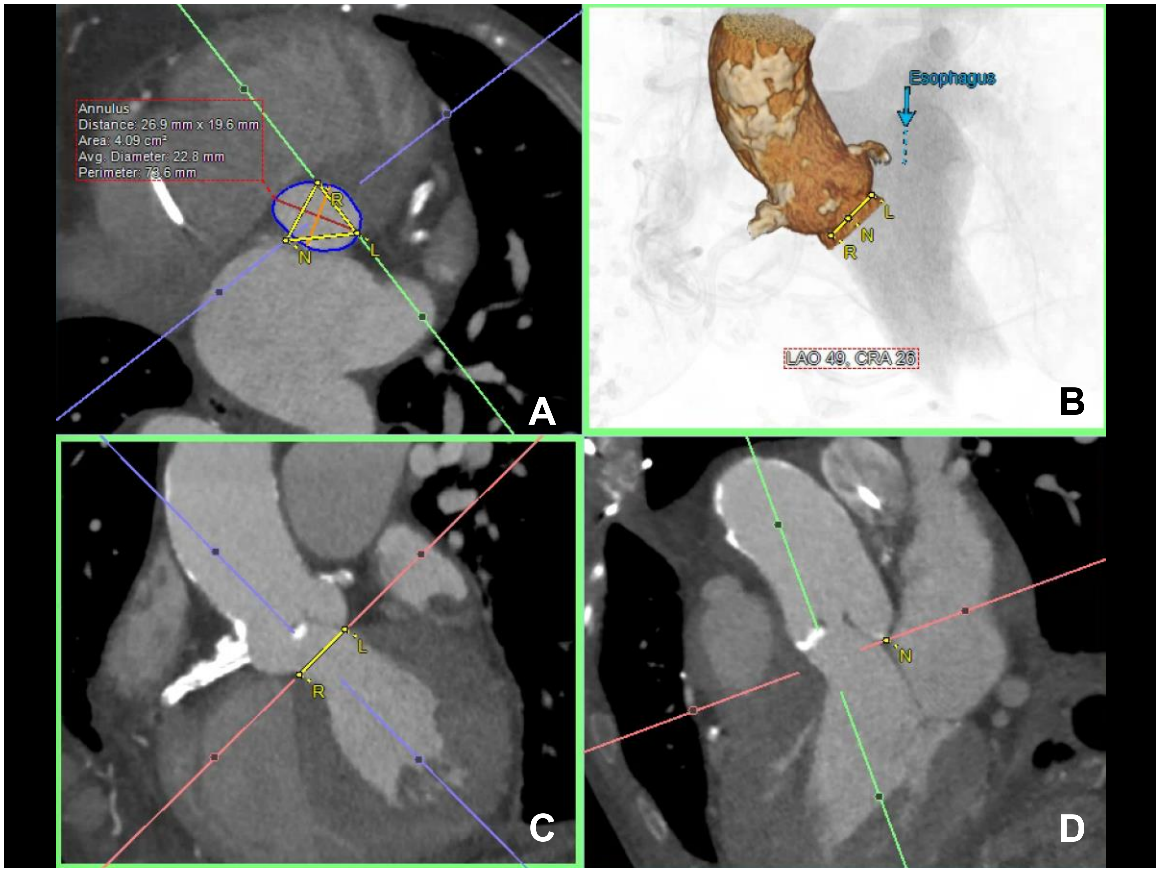
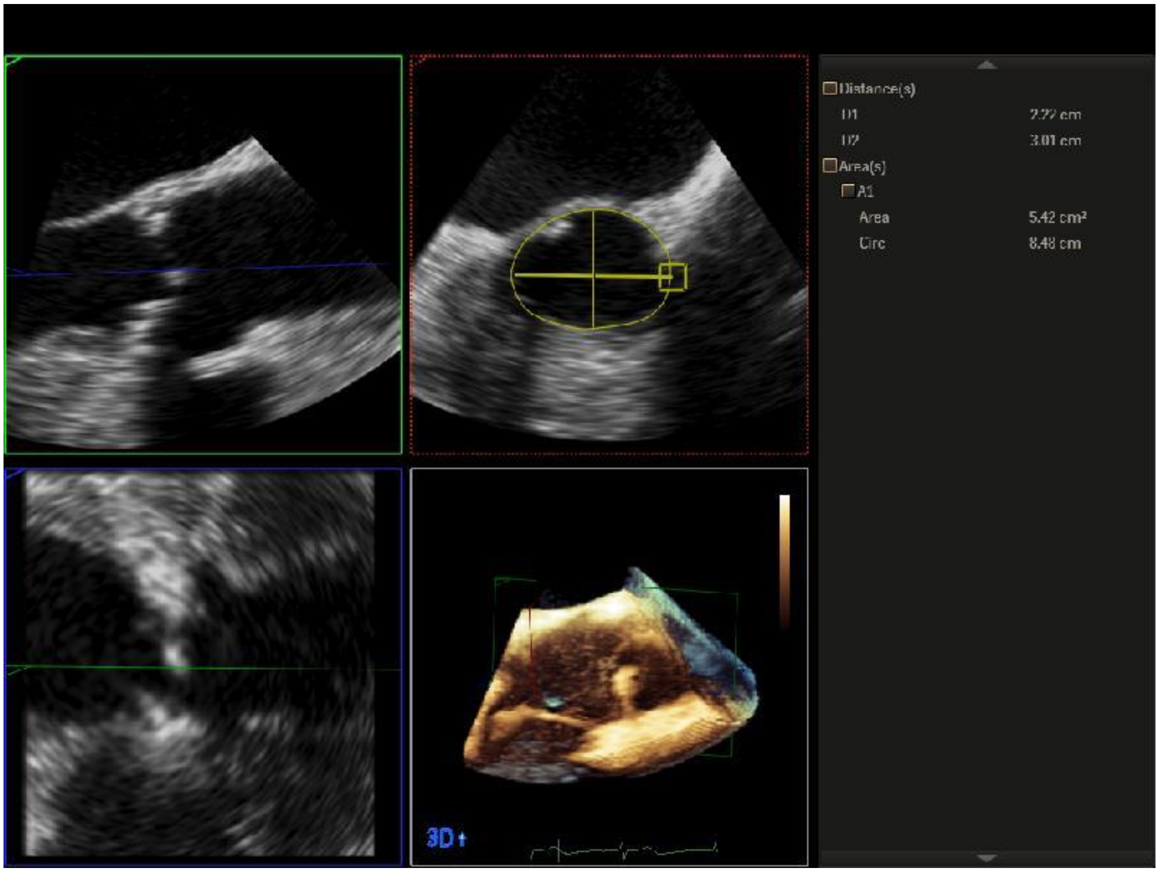


Figure 1: MDCT double-oblique short axis reformatted image (A) of the aortic “annulus”, which is more strictly described as the “virtual basal ring” of the aortic valve. Note the precise localization of each of the “hinge points” of the aortic valve, which are well depicted by offsetting the perpendicular cross-hairs (shown by the pink localizer lines in the corresponding perpendicular oblique panels (C, D). The volume-rendered image (B) depicts the basal ring in profile (yellow line), which can also predict an appropriate C-arm angle for fluoroscopic guidance during the deployment.



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☐Distance(s)
  D1                          2.22 cm
  D2                          3.01 cm
☐Area(s)
  ☐A1
    Area                      5.42 cm²
    Circ                      8.48 cm
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Figure 2: 3D-TEE measurements of the virtual aortic annulus.

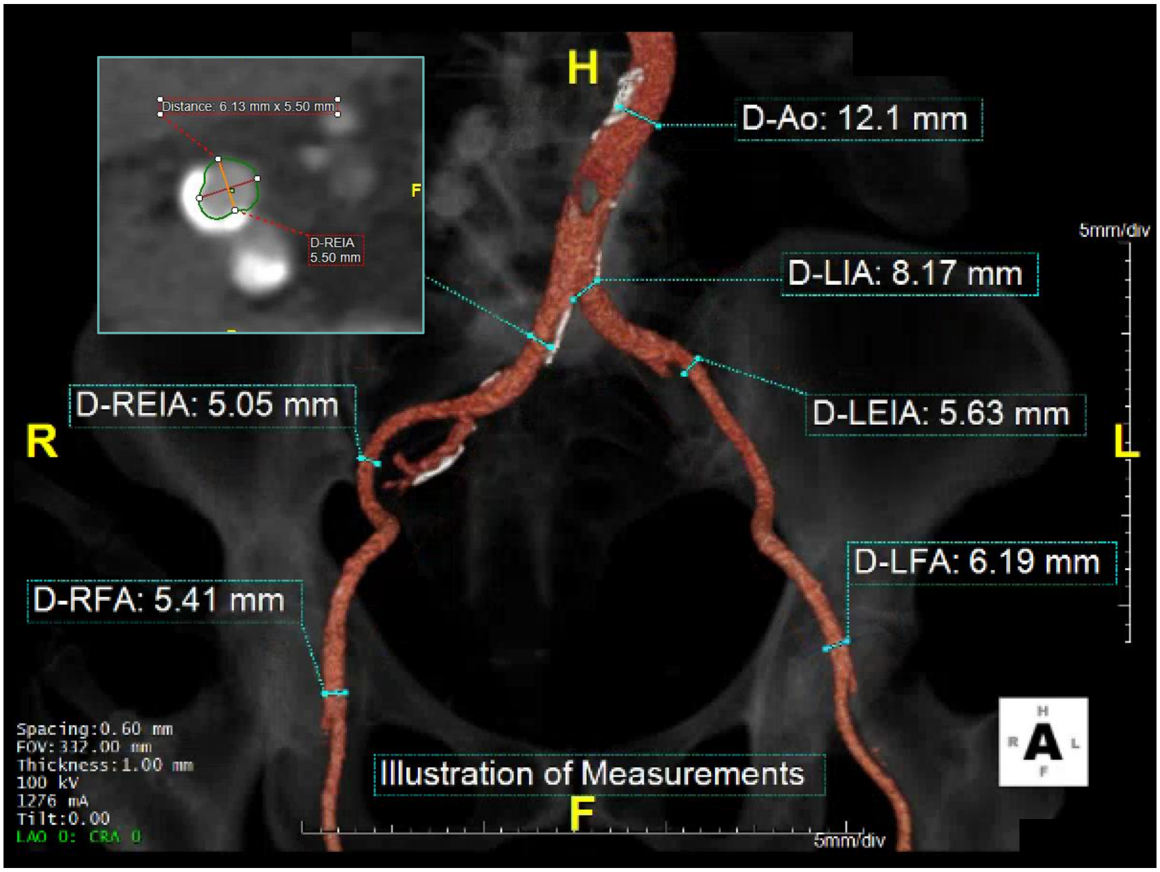

Figure 3: MDCT 3D-volume rendered image of the pelvis (anterior view) with segmentation of the aortoiliac arteries used to assess the aortoiliac vasculature for TAVR access. Minimal luminal diameters are marked on this overview at each vessel segment. Shaded display of the bony pelvis assists in localization of the access site. Each vessel measurement should be performed on double-oblique short axis reformatted images (example inset at the level of the right common iliac artery); axial measurements can be oblique and overestimate vessel diameters.

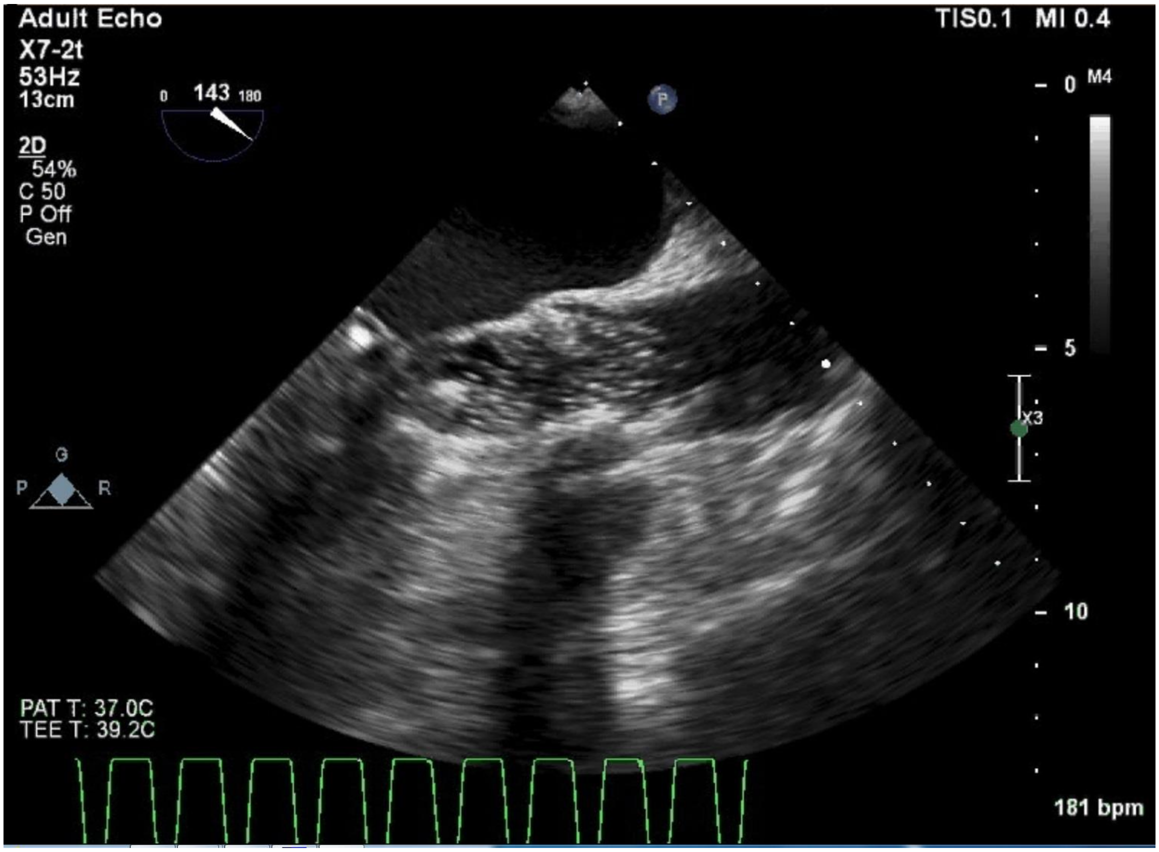

Figure 4: Intra-procedural TEE image showing a balloon aortic valvuloplasty.

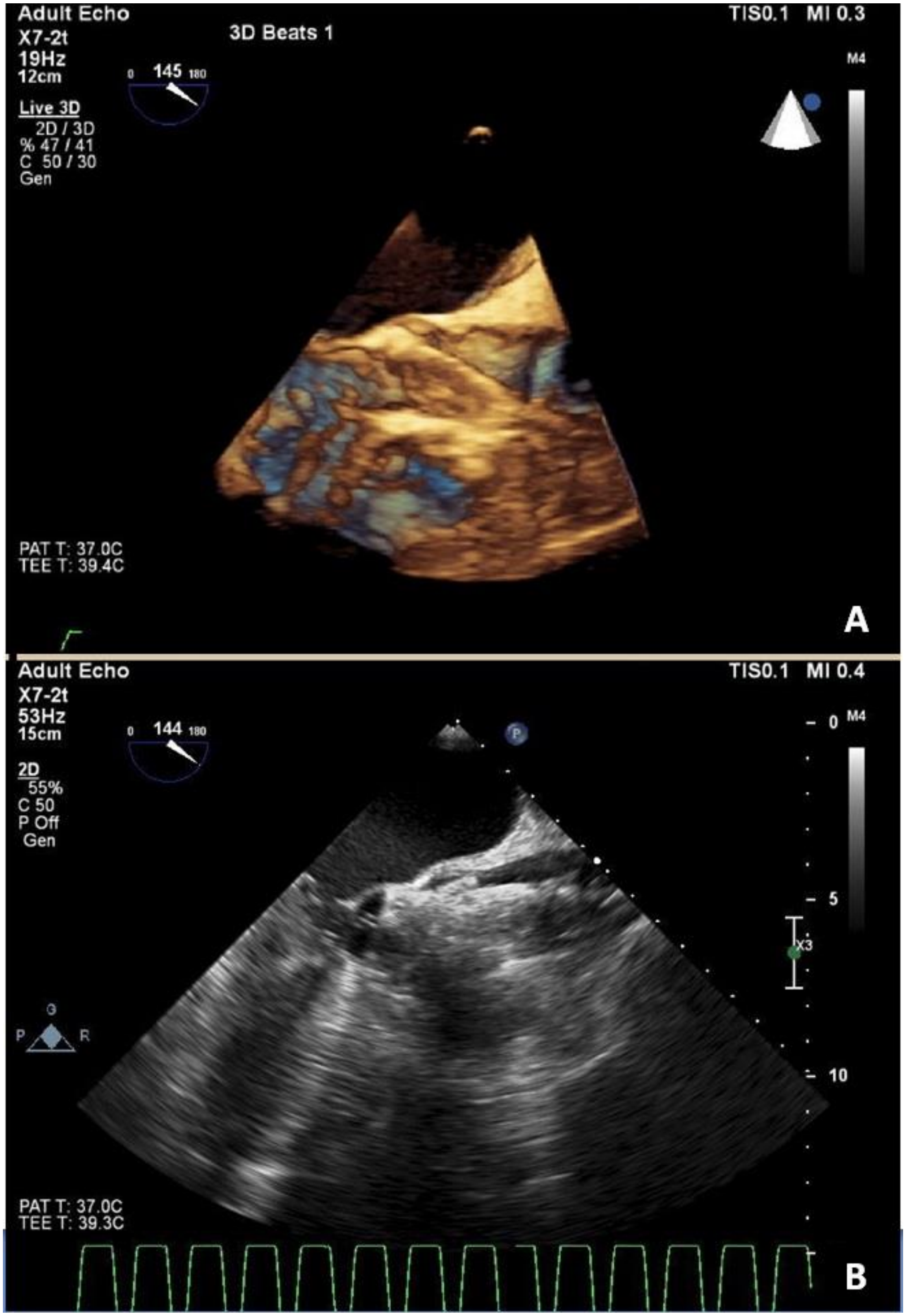

Figure 5: (A): 3D-TEE image showing the "flowering" a self-expanding THV during deployment. (B): 2D intra-procedural TEE image showing deployment of a balloon-expanding THV.

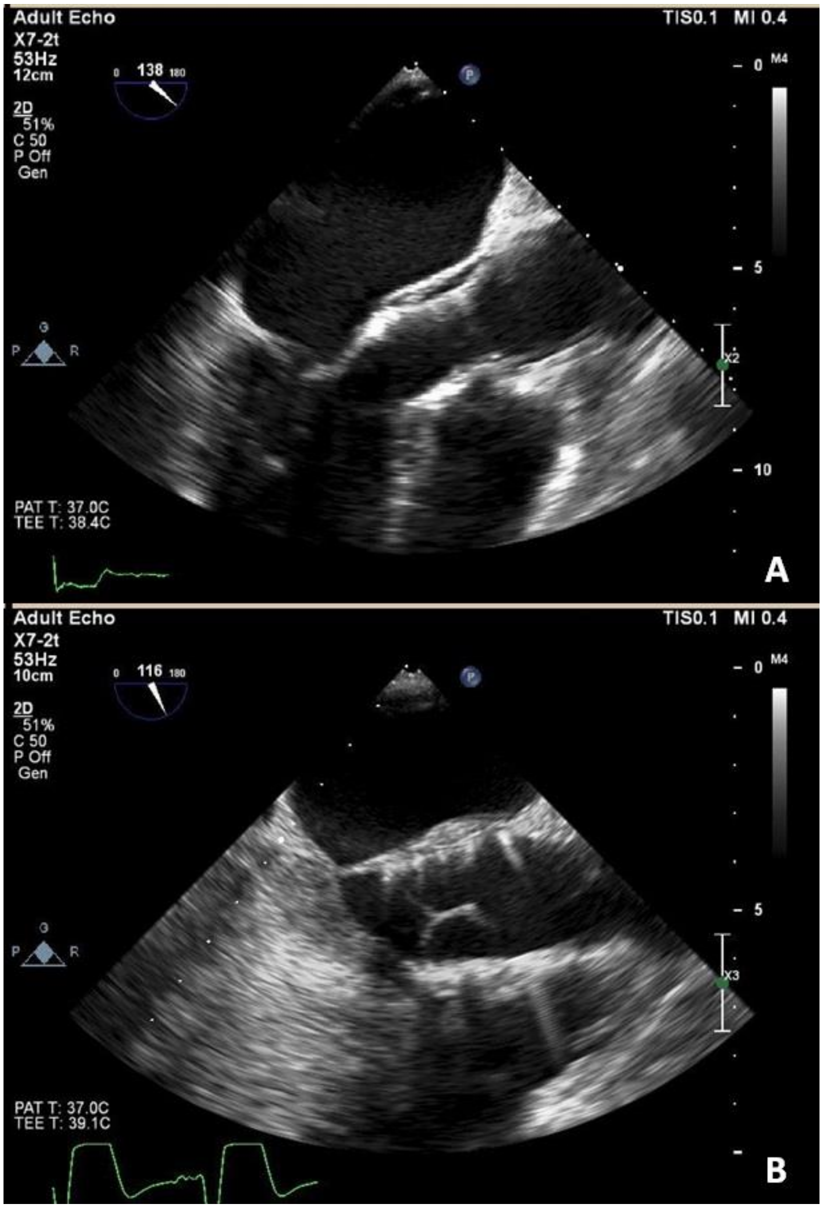

Figure 6: (A): Intra-procedural TEE imaging showing a (A) self-expanding THV (B) balloon-expanding THV in the aortic positions.

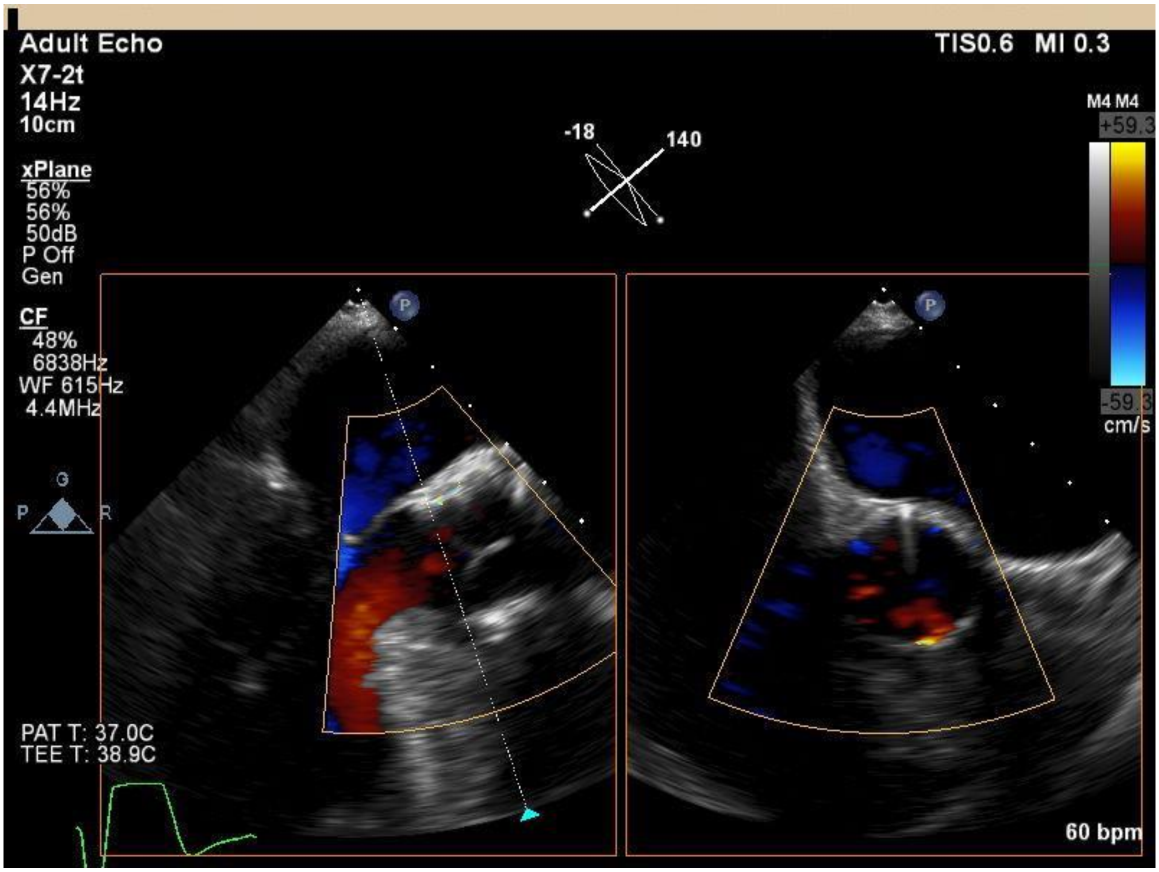

Figure 7: Intra-procedural color Doppler multiplane imaging showing ideal placement of a balloon-expandable THV.

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