



# The transition from transesophageal to transthoracic echocardiography during transcatheter aortic valve replacement: an evolving field

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## Abstract

The advent of transcatheter aortic valve replacement (TAVR) has dramatically transformed the clinical approach to severe aortic stenosis. Over the last decade, several trials have shown the equivalence or even superiority of transcatheter valve replacement over the conventional surgical approach. As a result, TAVR as a treatment for severe, symptomatic aortic stenosis has rapidly extended from inoperable or prohibited-risk patients to intermediate-risk patients. The success of TAVR has led to the wide adaptation of this technique and, subsequently, a significant increase in the number of these procedures performed annually. As the number of these procedures is expected to further increase, especially if its indication will include those with low surgical risk, there is a great demand to improve patient recovery and early discharge without compromising outcomes. In this review, we will discuss the role of echocardiography in the perioperative planning and assessment of transcatheter aortic valve replacement. In addition, we will review the current evidence behind the use of intraprocedural transthoracic echocardiography and the recommended steps for successful transition from transesophageal to transthoracic echocardiography.

**Keywords** Interventional echocardiography · Transcatheter aortic valve replacement · Transesophageal echocardiography · Transthoracic echocardiography · Intraoperative echocardiography · Aortic valve stenosis

## Abbreviations

|      |  |
|------|--|
| AS   | Aortic stenosis                        |
| AV   | Aortic valve                           |
| EOA  | Effective orifice area                 |
| LVOT | Left ventricular outflow tract         |
| MDCT | Multidetector computed tomography      |
| PVR  | Paravalvular regurgitation             |
| TAVR | Transcatheter aortic valve replacement |
| TEE  | Transesophageal echocardiography       |
| THV  | Transcatheter heart valve              |
| TTE  | Transthoracic echocardiography         |
| VTI  | Velocity time Integral                 |
| 2-D  | 2-dimensional                          |
| 3-D  | 3-dimensional                          |

## Introduction

Transcatheter aortic valve replacement (TAVR) has revolutionized the approach to symptomatic severe aortic stenosis (AS). As the clinical trials showed equivalence or even superiority of TAVR in the treatment of severe AS in inoperable/prohibited-risk and high-risk patients over the conventional treatment [1–4], TAVR was granted a Class I recommendation in American Heart Association/American College of Cardiology (AHA/ACC) valvular guidelines for the treatment of this group of patients [5, 6]. In addition, TAVR has a Class IIa recommendation in the AHA/ACC guidelines for the treatment of intermediate-risk patients with severe symptomatic AS [5, 6]. However, this recommendation is expected to advance to Class I as subsequent clinical trials have shown overwhelming evidence of safety and efficacy [7, 8].

During the early years of TAVR, the primary focus was on patient safety and procedural success. All of these early cases were performed using general anesthesia and transesophageal echocardiography (TEE). As the number of TAVR procedure performed annually has steadily increased

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[9, 10], attention has shifted to reducing patient recovery time and hospital length of stay. Such measures are important to address, especially with ongoing trials assessing the efficacy of TAVR among low-risk patients and the anticipation of its utilization among this patient population [11]. In an attempt to reduce the invasiveness, cost, and post-operative hospitalization, a “minimalistic approach” was adopted to perform TAVR utilizing the transfemoral access with monitored anesthesia care (MAC)/conscious sedation and intraprocedural transthoracic echocardiography (TTE). This minimalist approach has shown similar outcomes in comparison to conventional TAVR performed in the hybrid operating room using general anesthesia and transesophageal echocardiography (TEE) guidance [12–14].

Many centers, including ours, have made this transitional change from the use of general anesthesia and intraprocedural TEE to the use of MAC and TTE guidance. This transition was made possible with the advances and improvement in transcatheter heart valve (THV) design and the increased

experience of the TAVR team. For a successful and smooth transition to perform TAVR under MAC and TTE guidance, the TAVR team (including the imagers) must acquire in-depth knowledge about the aortic root complex anatomy, echocardiographic imaging of the aortoannular complex, and the technical features and nuances of the commercially available THV.

## Echocardiography for transcatheter aortic valve replacement

### Pre-procedural assessment

The first step in the preprocedural imaging for TAVR is the assessment of the aortic valve (AV) morphology and the severity of the valve stenosis using TTE (Table 1). Identifying the presence of a bicuspid aortic valve, a traditional exclusion criteria for early TAVR trials, is

**Table 1** Preprocedural echocardiographic assessment of TAVR

|  | Parameter (s)  | Technical consideration (s)   |
|--|--|---|
| <b>AV morphology and severity assessment</b> |  |   |
| AV leaflets                                  | Short-axis view <sup>a</sup>                           | Determine the number of leaflets in systole by visualizing the opening at the raphe   |
| AV/LVOT calcification                        | Short-axis view <sup>a</sup>                           | Quantify the severity and location of the AV and LVOT calcification   |
| LVOT Diameter                                | Long axis view <sup>b</sup>                            | Measure in early to mid systole when the LVOT is more circular using the inner-edge-to-inner-edge convention<br>Preferably measured at the level of the aortic annulus, especially in the setting of basal septal budging, from the point where the right cusp meets the anteroseptal wall to the point where the posterior interleaflet triangle meets the anterior mitral leaflet |
| AV Doppler Imaging                           | CW Doppler   | Multiple windows (including the right parasternal space) are mandatory to ensure the highest gradient   |
| LVOT Doppler imaging                         | PW Doppler   | Place sample volume just proximal to the area of flow acceleration (absence of AV opening and closure clicks).<br>Optimize the gain to ensure a clean modal velocity signal   |
| <b>Aortoannular complex measurements</b>     |  |   |
| Aortic annulus                               | Long axis view <sup>b</sup><br>3D imaging <sup>c</sup> | Measure in systole as described above for the LVOT<br>3D TEE has a higher resolution and it can be an alternative for those with contraindication to MDCT<br>Use MPR to determine the nadir of the aortic valve and to provide measurement of the annulus perimeter, area, and maximum and minimum dimensions   |
| Sinus of valsalva                            | Long axis view <sup>b</sup><br>3D imaging <sup>c</sup> | Measure in diastole using the leading-edge-to-leading-edge convention (from the right sinus to the posterior sinus)<br>Use MPR to measure the maximum dimension between the sinuses   |
| ST junction                                  | Long axis view <sup>b</sup><br>3D imaging <sup>c</sup> | Measure in diastole using the leading-edge-to-leading-edge convention<br>Use MPR to measure the maximum and minimum dimensions  |
| Coronary ostial height                       | 3D imaging <sup>c</sup>                                | RCA height is measured in the sagittal view<br>Left main height is measured in the coronal view   |

AV aortic valve, CW continuous-wave, LVTO left ventricular outflow tract, MPR multiplanar reconstruction, PW pulsed-wave, PLAX parasternal long-axis, PSAX parasternal short-axis, RCA right coronary artery, ST sinotubular junction, TEE transesophageal echo, TTE transthoracic echo

<sup>a</sup>Using PSAX and Mid-esophageal view at ~45° for TTE and TEE, respectively

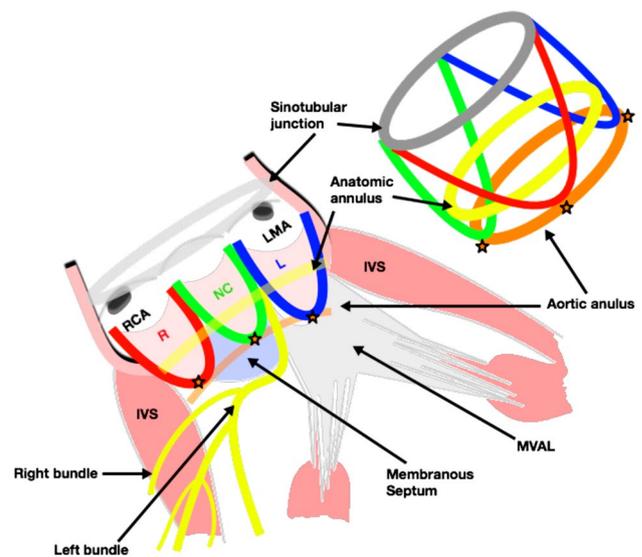
<sup>b</sup>Using PLAX and Mid-esophageal view at ~120° for TTE and TEE, respectively

<sup>c</sup>Using narrow-angle or zoom acquisition usually obtained from short-axis view

essential. The number of leaflets is determined using the AV short-axis view during systole. In addition, it is important to determine the severity of the valvular calcification and its extension into the left ventricular outflow tract (LVOT), a strong predictor of post-TAVR paravalvular regurgitation (PVR) [15, 16]. To assess the AS severity, three parameters must be quantified accurately, namely, AV velocity and velocity time integral ( $VTI_{AV}$ ), left ventricular outflow tract (LVOT) velocity and velocity time integral ( $VTI_{LVOT}$ ), and LVOT diameter. Careful calculation of stroke volume is also important since gradients are dependent on flow. In addition, it is essential to assess the left ventricular systolic and diastolic function and the presence of any concomitant significant valvular lesion(s). Published guidelines elegantly outline how to perform accurate assessment and quantification of AS [17].

The other essential step in the preprocedural imaging is the assessment of the aortoannular complex. Piazza et al. [18] described the aortic root as a complex 3-dimensional (3D) structure that separates the LVOT from the systemic circulation with 3 circular rings (sinotubular junction, anatomic ventriculo-arterial junction, and the aortic annulus) and a crown-like ring (interleaflet trigones) (Fig. 1). The tightest point in the aortic root is the aortic annulus, a virtual ring with its three anchors at nadir of the AV leaflets. Aortic annulus measured in systole is the main parameter used for sizing of TAVR [19, 20]. Accurate sizing of the aortic annulus is essential to avoid undersizing of the THV, which increases the risk of prosthesis embolization and PVR, or oversizing of the THV, which can result in underexpansion of the THV, conduction disturbances, and annulus rupture [19, 20].

Multidetector computed tomography (MDCT) is currently the primary modality used for aortoannular assessment given its high resolution and the 3D nature of the study. MDCT also provides essential information about the coronary height, severity and location of the aortic root calcification, and peripheral vascular assessment for the determination of the appropriate access site for TAVR [19, 20]. Although MDCT has shown to be more accurate in measuring the aortic annulus and reducing PVR after TAVR compared to 2-dimensional (2D) echo [21–23], other studies utilizing 3D echo have demonstrated similar precision in assessing the aortic annulus and equivalent accuracy in predicting PVR. Therefore, 3D echo, especially when TEE is utilized [24–28], is a feasible alternative modality for the assessment of aortic root and coronary heights in preprocedural planning for TAVR when the patient cannot undergo MDCT (Table 1).



**Fig. 1** Schematic presentation of the aortic root. Aortic root consists of 3 circular rings (aortic annulus, anatomic annulus, and sinotubular junction). The anatomic annulus (yellow ring) is at the attachment of the semilunar aortic leaflet to the aortic sinuses. The aortic annulus (orange ring) is a virtual annulus determined by the lowest hinge points of the aortic leaflets. Aortic valve leaflets are depicted in this figure showing the continuity of left coronary cusp (L) with aortomitral curtain and MVAL, the relationship of the right coronary cusp (R) to the muscular septum, and the relationship of the non-coronary cusp (NC) with the membranous septum. There is close proximity of the atrioventricular node and bundle as it passes below the membranous septum on the top of the muscular septum and then it divides into right and left bundle branches. This figure adopted with permission from Hahn et al [20]. *IVS* interventricular septum, *L* left coronary cusp, *LMA* left main artery ostium, *MVAL* mitral valve anterior leaflet, *NC* non-coronary cusp, *R* right coronary cusp, *RCA* right coronary artery ostium

### Intraprocedural assessment

Echocardiography is useful for intraprocedural monitoring of TAVR during the different steps of THV deployment. Either TTE or TEE can be utilized during the procedure, besides fluoroscopy and aortography, for guiding the wire/catheter positioning, assessing post-balloon valvuloplasty results, appropriate positioning of the THV prior to deployment, and evaluating post-deployment results and complication(s) (Table 2). It is critical to be familiar with the THV used in the institution and the landmarks and measurement used to ensure appropriate landing zone of the valve. For example, in the balloon-expandable (Sapien 3, Edward Lifesciences) prosthesis, the valve depth should be 1–2 mm below the aortic annulus but because this valve, once it is deployed, can only be shortened from the ventricular size, it is more critical to assess the aortic aspect of the valve ensuring the valve is below the sinotubular junction and covering the native leaflets [20]. Another example is the self-expanding (Corevalve,

**Table 2** Intraprocedural echocardiographic assessment of TAVR

|                               | Parameter (s)   | Technical consideration (s)   |
|-------------------------------|---|---|
| Catheter and wire positioning | Long axis <sup>a</sup> and short axis views <sup>b</sup>                                    | Pigtail catheter is placed in right sinus of aortic valve when Sapien 3 (Edward Lifesciences) <sup>c</sup> is used<br>Pigtail catheter is placed in the non-coronary sinus of aortic valve when Corevalve Evolut R (Medtronic) <sup>d</sup> is used   |
| Post-valvotomy                | Short axis <sup>a</sup> (above, through, and above the AV) and long axis <sup>b</sup> views | Assessing wall motion to ensure no acute occlusion of the coronary arteries<br>Assessing the extent of aortic regurgitation<br>Assessing the development or worsening of pericardial effusion, to rule out aortic root injury   |
| THV deployment                | AV/LVOT long axis <sup>b</sup> views  | Appropriate positioning of the valve based on the recommended positioning<br>For Sapien 3 valve <sup>c</sup> , the valve should be placed 1–2 mm below the aortic annulus, ensuring the valve is below the sinotubular junction and covering the aortic leaflets<br>For Corevalve Evolut R <sup>d</sup> , the valve should be placed 2–4 mm below the aortic annulus  |
| Post-deployment assessment    | Short axis <sup>a</sup> (above, through, and above the AV) and long axis <sup>b</sup> views | Assess the leaflet movement and absence of valvular regurgitation (central AR)<br>Assess the shape of the prosthesis and the implantation position<br>Identify the mechanism and severity of PVR<br>Rule out other complications such as aortic root rupture, development or worsening of an existing pericardial effusion, new wall motion abnormality due to coronary artery occlusion, and mitral valve disturbances |

A3C apical 3-chamber, A5C apical 5-chamber, AR aortic regurgitation, AV aortic valve, LVOT left ventricular outflow tract, NC non-coronary, PVR paravalvular regurgitation, THV transcatheter heart valve

<sup>a</sup>Using PSAX and Mid-esophageal view at ~45° for TTE and TEE, respectively

<sup>b</sup>Using PLAX, A3C, and A5C views for TTE, and Mid-esophageal view at ~120° and deep gastric view of the LVOT for TEE

<sup>c</sup>Third generation balloon-expandable THV

<sup>d</sup>Second generation self-expandable THV

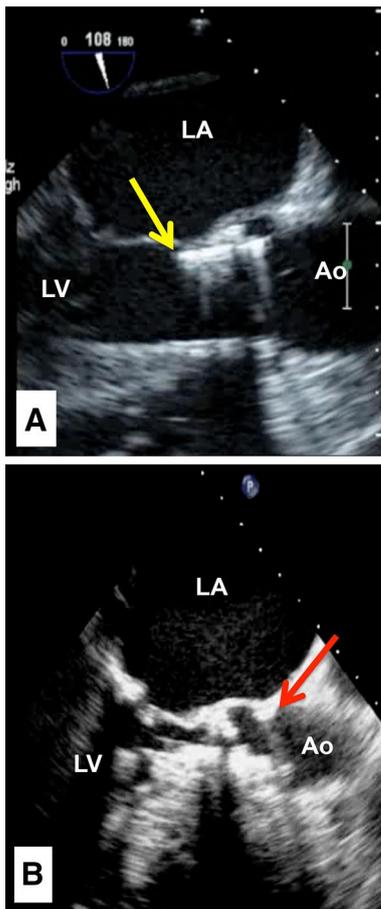
Medtronic), the focus should be on the ventricular side of the valve to ensure that it extends 2–4 mm (not more than 6 mm) below the annulus [20]. Low implantation of the valve can result in conduction abnormalities, interference with mitral valve function, and embolization of the valve to the left ventricle. Too high implantation of the valve increases the risk of valve embolization to the aorta, jeopardizing the coronary flow, and aortic root injury (Fig. 2).

The main difference between TTE and TEE during the intraprocedural monitoring for TAVR is that TEE provides continuous monitoring during the procedure with higher image resolution but these advantages are at the expense of being more invasive (Table 3). Otherwise, both TTE and TEE offer comparable information to ensure appropriate THV placement and to identify periprocedural complication(s). In either modality, multiple views above, through, and below the THV with multiple-beat sweeps are essential to identify periprocedural complications, especially PVR (Fig. 3). As experience with TAVR has grown, there has been a further shift to using fluoroscopy alone to guide THV placement [29] and using TTE immediately after valve deployment to assure proper placement and to assess for valvular and perivalvular regurgitation.

## Postprocedural assessment

A comprehensive TTE is essential after TAVR to establish a baseline evaluation prior to discharge. The post-TAVR echo should have a full evaluation of the cardiac chambers, valvular function and position, including the calculation of the newly implanted THV area and gradients as well as the presence or absence of any procedural complication(s) (Table 4).

For the assessment of the THV function and its effective orifice area (EOA), an accurate measurement of the LVOT is essential. The LVOT should be measured at the ventricular edge of the THV stent, especially when a balloon-expandable valve is used, from the outer-edge to outer-edge while the pulsed-Doppler sample volume placed just proximal to the ventricular edge of the valve stent [20, 30]. Similar to preprocedural assessment, the AV velocity and VTI should be measured using continuous-wave Doppler obtained from multiple views including the right parasternal. A normal THV has a peak velocity of < 3 m/s, a mean pressure gradient of < 20 mmHg, an effective orifice area (EOA) > 1.1 cm<sup>2</sup> and indexed EOA > 0.85 cm<sup>2</sup>/m<sup>2</sup>. The Doppler velocity index (normally > 0.35) is also useful to report especially when the LVOT diameter is difficult to measure [30].



**Fig. 2** Transcatheter heart valve malpositioning. **a** Midesophageal LVOT long-axis view demonstrating a balloon expandable (Sapien 3, Edwards Lifesciences) valve that is implanted too low in the LVOT (yellow arrow). **b** Midesophageal LVOT long-axis view showing a balloon expandable (Sapien 3, Edwards Lifesciences) valve implanted too high in the aorta (red arrow). *Ao* aorta, *LA* left atrium, *LV* left ventricle, *LVOT* left ventricular outflow tract

The determination of the presence or absence of PVR is important to be documented in the baseline echo post-TAVR. This assessment should include describing the location, number, and severity of the PVR. For better identification and quantification of the PVR, multiple imaging planes with color Doppler and multi-beat sweeps are required to ensure complete visualization of the regurgitant jet(s). The main views in TTE for PVR assessment are: parasternal long-axis (with lateral to medial sweeps), parasternal short-axis (with aorta to LVOT sweeps), and Apical 3- and 5-chamber views (with rotational sweeps and off-axis views). Although multiple qualitative, semi-quantitative, and quantitative parameters are suggested by the Valve Academic Research Consortium-consensus document [30] for the determination of PVR severity, frequently these parameters are either difficult to obtain or not accurate in post-TAVR assessment of PVR. The main semi-quantitative parameter proposed for

the assessment of PVR is the circumferential extent of PVR. This parameter is measured in the parasternal short-axis view at the ventricular side of the valve stent and, therefore, it is essential to obtain multiple imaging planes through the valve to ensure the full visualization of the jet(s). However, an imaging plane too far into the LVOT will overestimate the extent of the PVR as the jet widens. Due to the complexity and difficulty in determining the PVR severity, Pibarot et al. [31] have suggested a 5-class grading scale for more accurate assessment of PVR.

### Outcome comparison between intraprocedural TTE versus TEE

With the rapid adoption of TAVR for the treatment of severe aortic stenosis and the increased experience of operators with pre-TAVR planning and device implantation, there has been a gradual transition to improve the quality and cost of care for the TAVR population. In the early experience of TAVR implantation, TEE was used to assist with valve sizing, to monitor for appropriate valve placement across the aortic valve annulus and to identify procedural complications rapidly. However, newer generation device registries suggest that there is a temporal trend towards simplified or “minimalist” TAVR, with the use of local anesthesia and conscious sedation under TTE guidance and the avoidance of invasive hemodynamic monitoring, general anesthesia, and TEE that characterized the early TAVR experience [32, 33].

At the center of the debate for TEE-guided TAVR versus TTE-guided TAVR is the detection of PVR. This is because major complications are usually quickly identified due to hemodynamic instability. Rapid conversion to general anesthesia and placement of a TEE probe can then quickly be performed. Correct device placement has been shown to be effective with angiographic guidance [29] and, thus, has become less reliant on echo. The presence of moderate or greater perivalvular leak, defined using the Valve Academic Research Consortium 2 guidelines, has been identified as a risk factor for post-procedural mortality and impaired left ventricular remodeling [30, 34–38].

The evaluation of PVR by both TTE and TEE can be difficult and thus, skill is required to acquire and interpret the images. The metallic annulus of the deployed valve along with the compacted calcified valve leads to significant acoustic shadowing of the valvular annulus. It is also difficult to follow the true path of the perivalvular leak, as the regurgitant blood likely follows a non-linear pathway around the valvular annulus leading to over- and underestimation of the significance of each regurgitant lesion. Pre-procedural planning using multi-detector computed tomography may assist in the identification of those patients at increased risk of

**Table 3** Comparison between intraprocedural TTE and TEE

| Technical Aspects                                      | TTE   | TEE   |
|--|---|---|
| Image resolution                                       | Lower resolution<br>Suboptimal images due to Patient's position and body habitus  | Higher resolution<br>In general, the image quality is consistently optimal                          |
| Invasiveness   | Non-invasive  | More invasive   |
| Utility in detecting procedure associated complication |   |   |
| PVR assessment   | Better in anterior PVR  | Better in posterior PVR   |
| Pericardial effusion                                   | Faster and easier to detect   | Slower and requires multiple imaging views  |
| Aortic root injury                                     | Less accurate   | More accurate   |
| Coronary artery occlusion                              | Better in evaluating wall motion abnormality  | More difficult in interpreting wall motion abnormality  |
| Mitral valve regurgitation                             | Reasonable accuracy   | Better in assessing mechanism and severity  |
| Complications  | No complication associated directly to TTE  | Oral and teeth injury esophageal injury, stomach injury   |
| Type of anesthesia                                     | MAC or conscious sedation   | Usually GA and intubation, may be used under MAC  |
| Access site  | Utilized mainly in transfemoral access  | Can be utilized in any access site  |
| Monitoring   | Interrupted imaging as the sonographer has to be in the fluoroscopy field and fluoroscopy has to be discontinued during image acquisition | Continuous imaging although rare the TEE has to be withdrawn if it interfere with fluoroscopy field |

GA general anesthesia, MAC monitor anesthesia care, PVR paravalvular regurgitation, TEE transesophageal echo, TTE transthoracic echo

hemodynamically significant PVR, as data suggest that valve calcium score, extremes of implantation depth and valve under-sizing are predictive of greater than moderate perivalvular regurgitation [34, 39]. Abdel-Wahab and colleagues also suggest that pre-procedural use of TEE for determination of valve size is associated with moderate perivalvular regurgitation [40]. Patients with these factors may require extra care in identifying hemodynamically significant PVR. Regardless, post-procedure TTE and intra-procedure TEE have modest agreement in the detection of PVR [14, 41].

The adoption of minimalist TAVR has been extensively studied. The adoption of a minimalist TAVR protocol including local anesthesia combined with conscious sedation, angiographic placement of the TAVR valve, and use of post-procedure TTE has shown to require less procedural adrenergic support [42] and has led to a significantly decreased procedure time [13, 43–45]. Patients undergoing minimalist TAVR also have decreased post-procedural monitoring in the cardiac intensive care unit [13, 43, 46] and decreased hospital length of stay [13, 43, 44, 47]. This decreased length of stay translates into decreased cost of hospitalization [13, 47]. Importantly, there is no significant increase in significant PVR, major complications or mortality with minimalist TAVR [13, 42–45, 47–50]. These profound effects on patient care have led to the development of

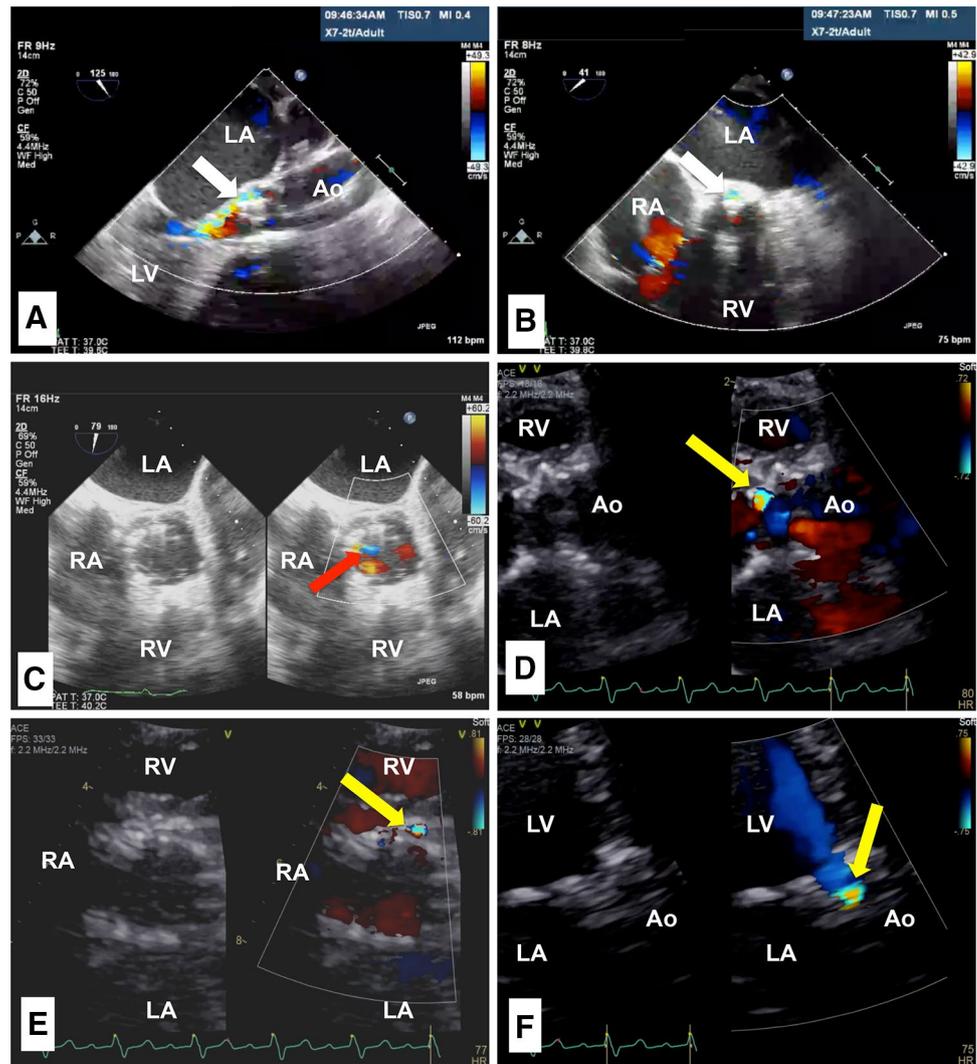
care pathways to improve and expedite safe and high-quality post-procedure TAVR care [51–55].

### Transition from TEE to TTE during the TAVR procedure

As the learning curve and experience of the operator increase with the number of procedures performed, the transition from conventional approach with general anesthesia and TEE to the minimalist approach with MAC and TTE is possible. However, the change should be performed in a stepwise fashion and fulfilling specific requirements. In general, centers with low volume (< 50/year) and, thus, less experience would not be advised to adopt the minimalistic approach [56, 57]. Highly experienced sonographers or physicians with extensive training in TAVR imaging are pivotal for this transition. Moreover, the immediate availability of non-invasive cardiologist or anesthesiologist with expertise in TAVR imaging and the ability to quickly switch from TTE to TEE is mandatory.

The transition from the conventional to the minimalist approach is recommended once a center has achieved sufficient experience with TAVR. There is no specific number to determine the appropriate time for safe transition to the

**Fig. 3** **a** Mid-esophageal LVOT long-axis view is revealing a posteriorly located PVR (white arrow). **b** midesophageal AV short-axis view demonstrated a posteriorly located PVR at 12 o'clock (white arrow). **c** Midesophageal AV short-axis view demonstrating a central, valvular, regurgitation secondary to incomplete expansion of the prosthetic valve (red arrow). **d** Transthoracic PLAX view showing an anteriorly located PVR (yellow arrow). **e** Transthoracic PSAX view showing an anteriorly located PRV at 1 o'clock (yellow arrow). **f** Transthoracic A3C view showing a regurgitation jet that is difficult to determine its mechanism, PVR versus valvular regurgitation, from the same patient in panel D and E (yellow arrow). A3C apical 3-chamber, Ao aorta, LA left atrium, LV left ventricle, LVOT left ventricular outflow tract, PLAX parasternal long-axis, PSAX parasternal short-axis, PVR paravalvular regurgitation, RA right atrium, RV right ventricle



minimalistic approach, but in general, approximately one hundred cases is considered to be an acceptable transitional point. During the pre-transition phase, the selected sonographers or physicians that will be performing the TTE imaging during the TAVR procedure should undergo extensive training for TAVR imaging. The training should include an understanding of the aorto-annular anatomy, AV stenosis assessment, the correct positioning of the different THV utilized in the institution, and the methods of assessing complications including PVR and annulus perforation using multiple continuous sweeps and off-axis views. A clear and well-established protocol for periprocedural TTE assessment of TAVR should be reviewed by the TAVR team and approved by the director of the echo lab to ensure a comprehensive assessment of the AV. Table 5 is the protocol adopted by our echo lab for TAVR imaging.

Finally, it is essential to establish a TAVR team consisting of the interventional cardiologist, cardiothoracic surgeon,

anesthesiologists and non-invasive cardiac imagers. All cases should be discussed ahead of time to determine the risk of the procedure and whether general anesthesia and TEE are needed based on the patient's characteristics and the selected access site. In addition, it is critical to distribute a weekly updated list of the TAVR procedures to the assigned team members performing the procedure.

## Conclusion

TAVR has become the standard of care for the management of those with symptomatic severe AS and high or prohibitive surgical risk and a reasonable option for those at intermediate risk. The indications for TAVR have expanded rapidly over the last decade. As a result, there has been a dramatic increase in the number of TAVR procedure performed worldwide. A minimalistic approach utilizing MAC

**Table 4** Postprocedural echocardiographic assessment of TAVR for assessing AV function

|                      | Echo imaging parameter (s)   | Technical consideration (s)   |
|----------------------|--|---|
| LVOT                 | PLAX view  | For Sapien 3 valve <sup>a</sup> , the LVOT should be measured at the ventricular side of THV stent (outer-edge-to-outer-edge)<br>For Corevalve Evolut R <sup>b</sup> , can be either measured as above or just below the visualized THV leaflets from the inner-edge to the inner-edge of the stent |
| LVOT Doppler imaging | PW Doppler   | For Sapien 3 valve <sup>a</sup> , place sample volume apical to the ventricular edge of the THV stent<br>For Corevalve Evolut R <sup>b</sup> , place sample volume either as above or just below the visualized THV leaflets, according the way the LVOT was measured                               |
| AV Doppler imaging   | CW Doppler   | Use multiple imaging views (including the right parasternal window) and consider utilizing the pedoff probe   |
| PVR assessment       | PSAX (above, through, and above the AV) and long axis <sup>c</sup> views | Use multiple parameters as recommended by the VARC II   |

According to VARC II consensus document [30], normal aortic prosthetic valve has a peak velocity < 3 m/s, pressure gradient < 20 mmHg, Doppler velocity index > 0.35, and EOA > 1.1 cm<sup>2</sup> (> 0.9 cm<sup>2</sup> if BSA is < 1.6 m<sup>2</sup>). Moderate–severe stenosis is expected when the peak velocity > 4 m/s, pressure gradient > 40 mmHg, Doppler velocity index < 0.25 (< 0.2 if the LVOT > 2.5 cm), and EOA < 0.8 cm<sup>2</sup> (< 0.6 cm<sup>2</sup> if BSA is < 1.6 m<sup>2</sup>)

According to VARC II consensus document [30], semi-quantitative (flow reversal in the descending aorta and the circumferential extent of the PVR) and qualitative parameters (regurgitant volume, regurgitant fraction, and EROA) have been suggested. For the calculation of the regurgitant volume the difference in the stroke volume between the LVOT and RVOT. Mild PVR demonstrate no or brief early flow diastolic reversal in the descending aorta, < 10% circumferential extent, regurgitant volume < 30 mL, regurgitant fraction < 30%, and EROA < 0.1 cm<sup>2</sup>. Severe PVR has holo-diastolic flow reversal in the descending aorta, ≥ 30% circumferential extent, regurgitant volume ≥ 60 mL, regurgitant fraction ≥ 50%, and EROA ≥ 0.3 cm<sup>2</sup>

A3C apical 3-chamber, A5C apical 5-chamber, AV aortic valve, BSA body surface area, CW continuous-wave, LVOT left ventricular outflow tract, PLAX parasternal long-axis, PSAX parasternal short-axis, PVR paravalvular regurgitation, PW pulsed-wave, RVOT right ventricular outflow tract, VARC II VALVE Academic Research Consortium-2

<sup>a</sup>Third generation balloon-expandable THV

<sup>b</sup>Second generation self-expandable THV

<sup>c</sup>Using PLAX, A3C, and A5C views

**Table 5** Transthoracic echocardiographic protocol for TAVR deployment

| View  | Imaging  |
|---|--|
| Pre-deployment of TAVR  |  |
| PLAX  | Zoom/Res over aortic valve with and without color<br>Sweep with color on starting at aortic valve level into both RVOT & RVIT to evaluate for PVR    |
| PLAX, PSAX at LV level <sup>a</sup> , A2C, A3C, A4C   | Evaluate for wall motion abnormalities and pericardial effusion  |
| PSAX AV level   | Zoom/Res over aortic valve with and without color<br>Sweep with color on starting at aortic valve level up to the left ventricle to evaluate for PVR |
| A5C   | Zoom/Res over aortic valve with and without color<br>Sweep with color starting at aortic valve level up to the Left ventricle to evaluate for PVR    |
| Surgical team to evaluate the limited echo/fluoroscopy to decide to pull lead wire or to post-dilate the aortic THV if clinically indicated |  |
| If post-dilation was performed, repeat the pre-deployment imaging protocol  |  |
| After lead wire removal   |  |
| Repeat the pre-deployment imaging protocol  |  |
| MV and TV in best window <sup>**</sup>  | Color Doppler to assess for regurgitation  |
| A3C, A5C  | Obtain CW Doppler of AV and PW Doppler at the LVOT   |
| PLAX, PSAX at LV level <sup>a</sup> , A2C, A3C, A4C   | Evaluate for wall motion abnormalities and pericardial effusion  |
| Record standard measurements if image quality allows  |  |

A2C apical 2-chamber, A3C apical 3-chamber, A4C apical 4-chamber, A5C apical 5-chamber, AV aortic valve, CW continuous-wave, LV left ventricle, LVOT left ventricular outflow tract, MV mitral valve, PLAX parasternal long-axis, PSAX parasternal short-axis, PVR paravalvular regurgitation, PW pulsed-wave, RVIT right ventricular inflow tract, RVOT right ventricular outflow tract, TC tricuspid valve

<sup>a</sup>PSAX at the basal, mid, and apical levels of the LV

<sup>b</sup>PLAX, RVIT, PSAX at TC level, PSAX at MV level, A2C, A3C, A4C, subcostal views

and TTE procedural guidance has emerged as a safe and efficient approach in the appropriate patients in institutions with adequate experience with TAVR without compromising the procedural success and clinical outcomes.

### Compliance with ethical standards

**Conflict of interest** Menhel Kinno, Eric P. Cantey and Vera H. Rigolin declare that they have no conflict of interest.

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