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Echocardiography: guidance during valve implantation

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KEYWORDS

Transcatheter aortic valve implantation, aortic valve stenosis, valvuloplasty, aortic prosthesis, three dimensional (3D) transesophageal echocardiography, procedure complications, transfemoral, transapical approach

Abstract

Transcatheter aortic valve implantation (TAVI) by percutaneous or transapical aproach has emerged as an effective and less-invasive treatment for patients with severe symptomatic aortic valve stenosis and high surgical risk. Echocardiography is a fundamental tool in patients' selection for TAVI, for guiding the intervention as well as evaluating the position, deployment and function of the prosthesis. This review describes the role of echocardiography during the intervention, in procedure guidance and in the assessment of complications.

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Introduction

Transcatheter aortic valve implantation (TAVI) has recently emerged as an effective, less-invasive treatment for patients with severe symptomatic aortic valve stenosis and high surgical risk, either in its percutaneous or transapical approach.[1] Rates of success in device implantation of around 95%, and procedure-related mortality rates between 5 and 18% have been reported.[2-4]

Currently, two different systems are available either through transfemoral or transapical approach: the balloon-expandable Edwards SAPIEN® prosthesis (Edwards Lifesciences, Irvine, CA, USA), a trileaflet symmetrical bovine pericardial valve mounted within a stainless steel stent, and the self-expanding CoreValve ReValving® system (Medtronic, Minneapolis, MN, USA). The CoreValve prosthesis consists of a trileaflet bioprosthetic porcine pericardial tissue valve, which is sutured into a self-expanding nitinol frame with an asymmetric shape. For the CoreValve, the sizes of the developed delivery systems have been gradually reduced to 18 Fr, at the third generation, and recently, a new 18 Fr delivery system for the SAPIEN valve has been approved, facilitating the vascular access and deployment of the device. Presently, each system has two different sizes available, compliant with annulus dimensions from 19 to 27 mm. Both systems have been extensively described elsewhere.[5,6]

Echocardiography is a fundamental tool in patient selection for TAVI, for guiding the intervention and to evaluate the position, deployment and function of the prosthesis. The procedure is usually performed under fluoroscopic and transesophageal echocardiographic (TEE) imaging, but a fully echo-guided transapical aortic valve implantation has already been reported.[7,8] This is an important step, considering the risk of acute postoperative renal failure following extensive use of contrast medium, which might reach 28%, according to recent reports.[9]

Transesophageal echocardiographic approach before valvuloplasty and prosthesis implantation

Before starting the procedure, the echocardiographer has to carefully describe the aortic valve anatomy and its anatomical landmarks, distribution of aortic valve calcification, geometry of the left ventricle outflow tract (LVOT) and its spatial relationships, the distance between coronary cusps insertion and coronary arteries ostium and also an eventual ectopic calcification of the basal portion of the anterior mitral leaflet and annulus. The aortic valve annulus diameter is measured, from the insertion of the non-coronary cusp to the insertion of the right coronary cusp in a 135º view (Figure 1). In the 45º view the orthogonal diameter of the aortic root is measured in an upper plane of the coronary arteries arisen. The precise distance of the coronary arteries to the annulus should be measured in order to minimise the risk of complications, namely myocardial ischaemia. It is advisable that at the time of deployment, coronary ostia should be minimally located 14 mm away from the leaflets insertion for the CoreValve and 11 mm for the Edwards SAPIEN prosthesis.

Left and right ventricular systolic function, regional wall motion abnormalities, mitral or tricuspid regurgitation and thoracic aortic arch atheroma should also be evaluated.[10] For the transapical aortic valve implantation approach, the echocardiographer can use transthoracic echocardiography to point the left ventricle apex position.[11]

Although bi-dimensional (2D) echocardiography was the standard technique in TEE, currently three dimensional (3D) TEE is highly available and there is a common perception that it frequently shortens the learning curve of the procedure, which might influence early outcome. Moreover, the 3D transesophageal probe (X7-2t, 7 MHz, Philips Medical Systems, Eindhoven, The Netherlands) has the capability of presenting two orthogonal bi-dimensional simultaneous plane views (e.g., 45º short-axis and 135º) which provides additional information, especially during the intervention (Figure 2). Throughout patient selection, and in the sensitive process of aortic annulus measurement, 3D imaging improves the assessment of valve anatomy and geometry of the LVOT (Figure 3), which was shown to be frequently elliptical instead of circular in form.[12,13] Besides, the sectorial 3D image and amplified or zoom mode 3D acquisition allow the visualisation of the entire guidewires, catheters and prostheses throughout the process. This added value of 3D has become critical in the operating room, so fluoroscopy needs to be in a postero-anterior projection during transapical

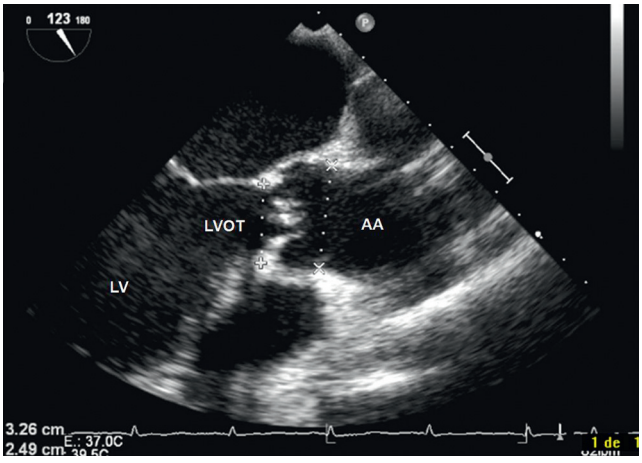

Figure 1. Two-dimensional TEE long axis view (123º) showing measurement of aortic valve annulus and sinotubular junction diameter. LV: left ventricle; AA: ascending aorta; LVOT: left ventricle outflow tract

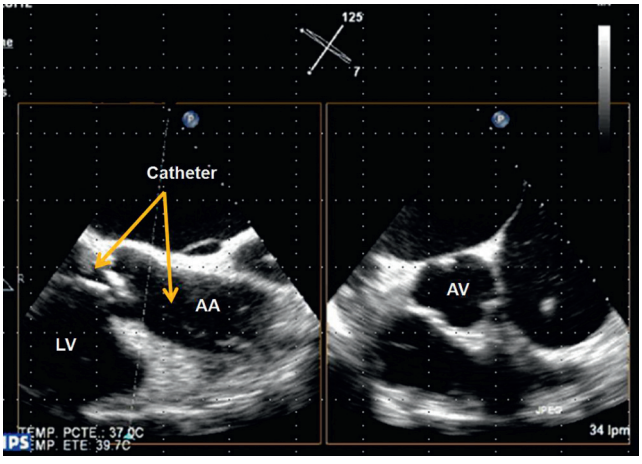

Figure 2. Two-dimensional TEE of two orthogonal simultaneous views (biplane or X-plane). LV: left ventricle; AA: ascending aorta; AV: aortic valve

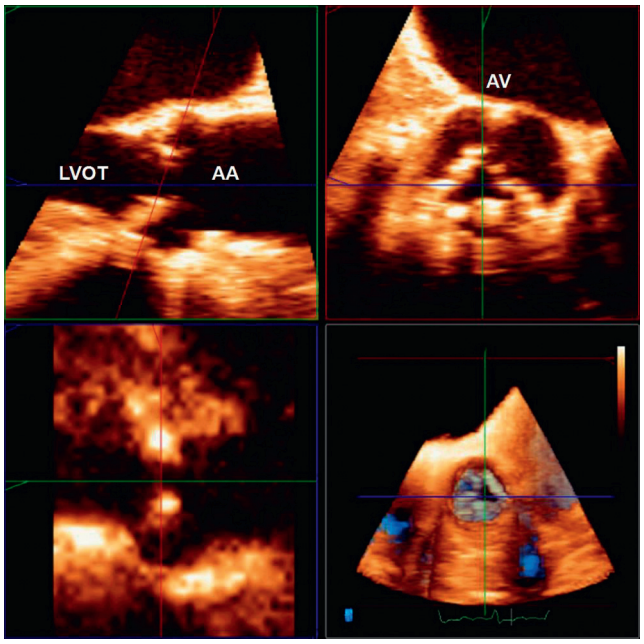

Figure 3. Post-processing of 3D volumetric acquisition using multiplanar reformatting or MPR showing valve anatomy and geometry of the LVOT. LVOT: Oleft ventricle outflow tract; AA: ascending aorta; AV: aortic valve

intervention. As a result, the calcified aortic annulus is positioned over the spine and the echocardiographic support is the only imaging technique which visualises and can guide, as well, the exact placement of the prosthesis.[8] In the process of valve size selection, approximately 10% of oversizing is applied, based on these measurements. Although some oversizing is essential to avoid severe paravalvular leakage, however, in the presence of a rigid aortic root, too much oversizing entails a high risk of serious complications and should be avoided. In addition, it is wise to exclude patients with an annulus larger than the largest available prosthesis, in whom significant paravalvular regurgitation might be expected.[14] In spite of the experience of the operators, the lack of congruence between the annulus and the device is related to significant paravalvular aortic regurgitation, thus the process of precise aortic annulus measurement is essential for better outcomes.[15]

Recent studies have also highlighted the value of multislice computed tomography to evaluate aortic valve annulus morphology and size, however TEE remains the reference technique due to its reliability, safeness and non radiation exposure.[16]

Valvuloplasty and prosthesis implantation

Balloon valvuloplasty is performed with a balloon filled with 1:4 diluted contrast placed in the aortic valve, during rapid ventricular pacing. Echocardiography is used to watch for antegrade or retrograde slippage of the balloon throughout its inflation. Inappropriate motion of the balloon towards the ventricle during inflation may happen due to axial motion of the heart, or to a small sinotubular junction. Conversely, an upward shifting of the balloon towards the aorta may be caused by the presence of a prosthetic mitral valve.[17]

Using the Live 3D mode, the dilatation of the valve with the valvuloplasty balloon and the anatomic results are accurately displayed (Video 1). Following pre-dilation of the native aortic valve, the prosthesis is advanced and deployed within the aortic annulus. This is one of the most critical steps during the intervention, because of the possible misplacement and embolism of the device. After the valve is introduced into the annulus, the pusher is retrieved back into the delivery sheath.

A long-axis view of the aortic root with 2D TEE identifies the end of the delivery catheter through the aortic annulus and, joined with fluoroscopy imaging, allows observation of the initial position, deployment, and final placement of the prosthesis. However, the single plane of the 2D image has several constraints when looking for catheter alignment (Figure 2). Conversely, in spite of the relatively low temporal resolution of the 3D mode as compared to 2D TEE, using the Live 3D mode, the trajectory view is precisely identified (Figure 4). In addition, this discloses with detail the prosthesis deployment in relation to the aortic annulus (Video 2). Therefore, the 3D TEE approach provides relevant information to the interventional cardiologist during this decisive step, with an excellent visual agreement between the fluoroscopic and the 3D TEE images.

In order to accomplish correct position in the deployment process, the prosthesis should be oriented coaxially with the long axis of the ascending aorta and perpendicularly to the aortic annulus, as showed in Figure 5. An oblique position may lead to valve misplacement, particularly in patients with a calcified aortic root and/or narrow sinotubular junction, in whom restriction of balloon inflation may occur with consequent downward displacement of the valve into the ventricle.[17]

One of the issues of confronting TEE during the procedure, is to identify, in one imaging plane, the exact location of the valve stent in relation to the deployment balloon and its ventricular and aortic rims. The stent is recognised as an echogenic rectangular structure seen in bristly profile to the balloon (Figure 5). The image interpretation is easier if the echocardiographer is aware of its length and if 3D TEE is used. As the prosthesis can move up to 2 to 4 mm towards the ascending aorta with balloon inflation, the optimal position is achieved when the ventricular edge of the stent is

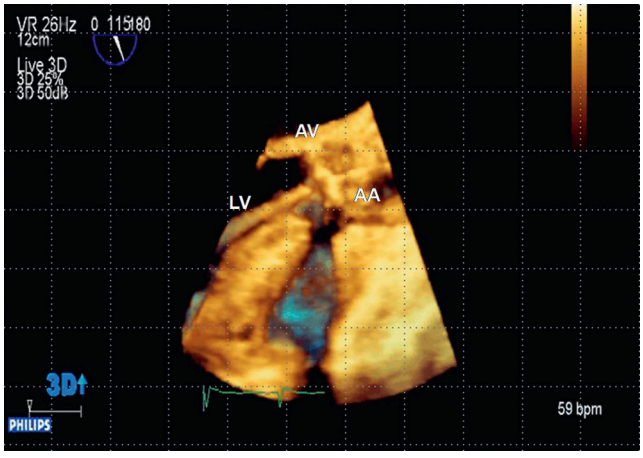

Figure 4. Real-time 3D transesophageal echocardiography showing the relative position of the catheter thought aortic valve and ascending aorta. LV: left ventricle; AA: ascending aorta; AV: aortic valve

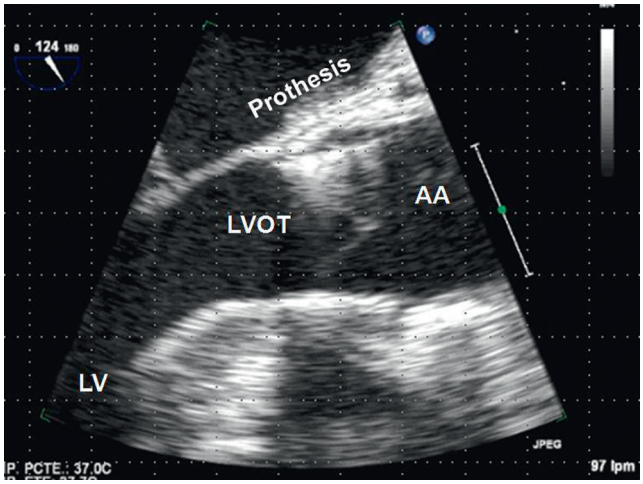

Figure 5. Two-dimensional transesophageal echocardiography long axis view showing the prosthesis, oriented coaxial with the long axis of the ascending aorta and perpendicular to the aortic annulus. LV: left ventricle; AA: ascending aorta; LVOT: left ventricle outflow tract

positioned approximately 2 to 4 mm below the aortic valvular annular plane for the Edwards SAPIEN valve and 5–10 mm for the CoreValve ReValving system. The aortic rim of the stent should cover the upper limit of the native aortic leaflets, and the valve should be deployed when both echocardiographer and interventionist agree that is in the best position.

During deployment, the native aortic leaflets are compressed between the valve stent and the wall of the aortic root. To avoid an upper positioning of the prosthesis in the aorta upon deployment caused by left ventricular ejection flow, pacing is performed until the balloon is completely deflated.

After the permanent aortic prosthesis implantation, the correct positioning is confirmed and aortic regurgitation evaluated immediately after removal of the deployment catheter and guidewire. The aortic end of the valve stent should be below the level of the coronary ostia and the ventricular end of the valve stent should not interfere with anterior mitral leaflet function (Video 3).[10] The prosthesis is expected to present a circular expansion, with native aortic leaflets perfectly contained and prosthesis leaflets moving amply, without significant aortic regurgitation (Videos 4 and 5). Finally, the transgastric window is used for Doppler interrogation of the aortic valve and to record the transaortic pressure gradient reduction and improvements in aortic valve area.

Assessment of results and detection of complications

One of the most common complications is aortic regurgitation, either perivalvular or central. It might be caused by severe asymmetric calcification of the native aortic valve (Figure 6 and Video 6), incomplete expansion of the device, incorrect positioning or inappropriate prosthesis size.[15] An excessively small size might cause paravalvar aortic regurgitation (Figure 7). In contrast, a prosthesis implantation too large for the aortic root can cause suboptimal stent expansion, impaired leaflet mobility and central aortic regurgitation (Figure 8, Videos 7 and 8).

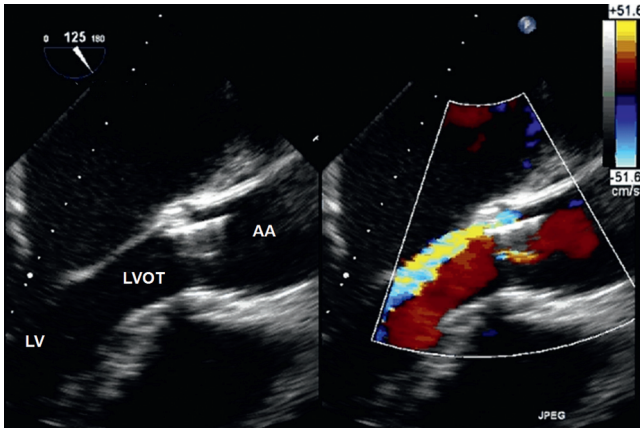

Figure 6. Two-dimensional transesophageal echocardiography long axis view showing moderate perivalvular regurgitation caused by asymmetric calcification. See Video 6 for viewing the entire sequence. LV: left ventricle; AA: ascending aorta; LVOT: left ventricle outflow tract

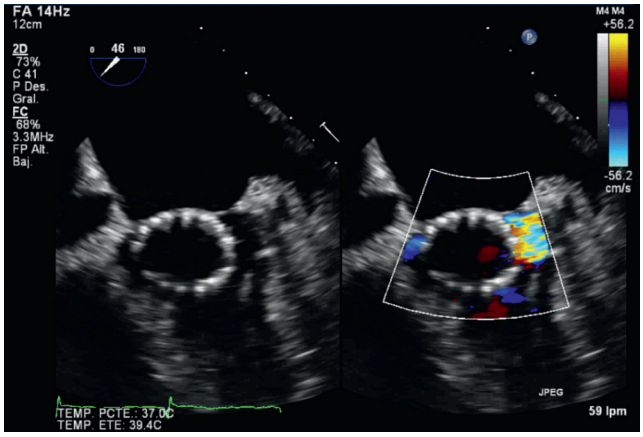

Figure 7. Two-dimensional transesophageal echocardiography short axis view showing perivalvular regurgitation.

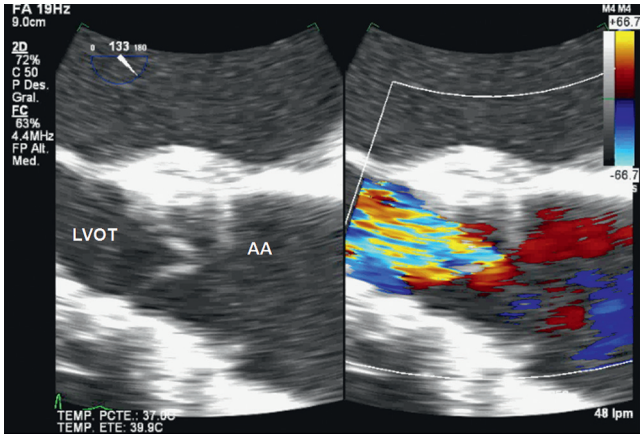

Figure 8. Two-dimensional transesophageal echocardiography long axis view showing central regurgitation. AA: ascending aorta; LVOT: left ventricle outflow tract

Sometimes, mild to moderate aortic paravalvular regurgitations are seen due to minimal defects of sealing involving the posterior commissure, mainly when leaflets highly calcified. As a consequence of the accommodation of the struts to these calcified valves, frequently, after several minutes or several hours, the mild paravalvular regurgitations disappear.

Conventional criteria should be used to assess severity using colour Doppler to view the height and width of the regurgitant jet, but 3D TEE is also useful to evaluate the early functioning of the bioprosthesis, and classify the severity of perivalvular or central regurgitation (Video 7). In case of moderate severity, repeat dilation can be performed. However, primary valve dilatation and risk factors such as the amount of calcification, as a surrogate of risk of aortic rupture, have to be considered before proceeding to repeat dilatation. Furthermore, over dilatation of the stent is not recommended since, it might worsen central aortic insufficiency and potential leakage of the aortic wall. Concerning small paravalvular aortic regurgitation jets, their clinical significance is probably benign and not progressive in the majority of patients.[18]

In the context of acute and severe hypotension, cardiac effusion or cardiac tamponade secondary to wire perforations might be found, as well as left ventricular dysfunction and wall motion abnormalities secondary to an obstructive portion of the valve frame or the sealing cuff being placed directly over a coronary ostium. Conduction abnormalities might also be detected by the echocardiographer, more commonly in prostheses extending farther into the ventricle. Worsening of mitral regurgitation can occur, due to right ventricular pacing or due to the direct mechanical effect of the ventricular edge of the prosthesis on the anterior leaflet of the valve. Using the antegrade apical approach, direct damage or distortion in subvalvular apparatus might occur, leading to acute mitral regurgitation. Therefore, a careful monitoring of the mitral valve during and after implantation is needed. Stroke is also a potential complication of this procedure, with rates ranging from 0% to 10%.[14] Even if potential causes of stroke, such as prolonged hypotension or air embolism from left ventricle apical cannulation cannot be assessed by echocardiography, other causes such as atheroembolism from the ascending aorta and aortic arch or aortic leaflet fragmented material embolisation, should be searched for and highlighted, in order to avoid this potentially lethal complication.[19] Tear or rupture of the aortic root has been reported, with a risk of 0.5%, secondary to excessive balloon dilation or prosthesis oversizing in context of extensive annular calcification (Figure 9).[20] If this complication occurs, the procedure has to be converted to a conventional surgical technique.

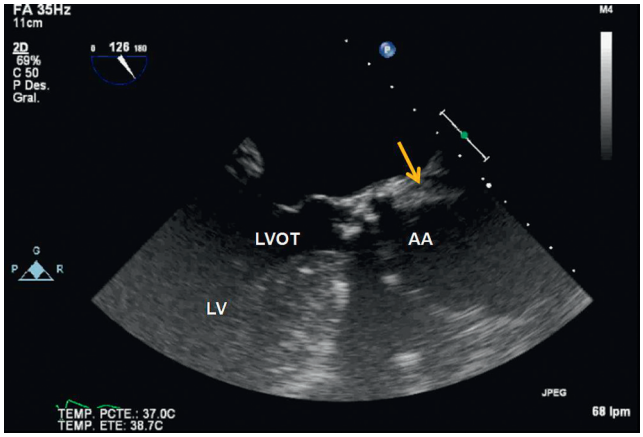

Figure 9. Two-dimensional transesophageal echocardiography long axis view showing aortic root rupture during TAVI. LV: left ventricle; AA: ascending aorta; LVOT: left ventricle outflow tract

Prosthetic embolism is the extreme complication that might occur in consequence of prosthesis mismatch. In case of valve embolisation towards the aorta, it might be resolved through successful transcatheter repositioning. However, if embolisation to the left ventricle occurs, surgical removal is usually the only option.[21,22] Finally, procedural failure can take place. It may be caused by inability to cross the native aortic valve with the guidewire or with the device after valvuloplasty by the inability to pass the device through the aortic arch, upstream migration of the device or extreme malpositioning.[10]

Conclusion - Future directions

The number of patients referred to TAVI is rapidly increasing and innovative advances, such as subclavian access or transapical approach, are being presented today for those with no conventional transfemoral access.[23]

Good communications between the operating team and precise guidance are crucial to procedure success and early detection of potential complications.

In conclusion, 3D TEE monitoring should be used as a standard procedure during TAVI, in combination with 2D TEE. 3D TEE provides more accurate information to the interventional cardiologist during positioning, deployment as well as early functional evaluation of the prosthesis, and consequently makes the procedure safer.

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Online data supplement

Video 1. Real-time 3D transesophageal echocardiography showing aortic balloon valvuloplasty.

Video 2. Real-time 3D transesophageal echocardiography showing aortic prosthesis deployment.

Video 3. Full volume zoom 3D transesophageal echocardiography, showing restricted movement of the anterior leaflet of the mitral valve caused by the ventricular edge of aortic prosthesis.

Videos 4 and 5. Real-time 3D transesophageal echocardiography showing regular aortic prosthesis implantation.

Video 6. Two-dimensional transesophageal echocardiography long axis view showing moderate perivalvular regurgitation caused by asymmetric calcification.

Videos 7 and 8. Full volume 3D transesophageal echocardiography showing central aortic regurgitation jet caused by incomplete expansion of the device, which was too large for the aortic root.