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Review Article

Valvular heart disease and 3-dimensional echocardiography: ready for prime-time?

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Abstract: Significant advances in 3-dimensional echocardiography (3DE) technology have ushered its use into clinical practice. The recent advent of real-time 3DE using matrix array transthoracic and transesophageal transducers has resulted in improved image spatial resolution, and therefore, enhanced visualization of the patho-morphological features of the cardiac valves. Three-dimensional echocardiography provides unique perspectives of valvular structures by presenting "en face" views of valvular structures, allowing for a better understanding of the topographical aspects of pathology, and a refined definition of the spatial relationships of intracardiac structures. Three-dimensional echocardiography makes available indices not described by 2D echocardiography and has been demonstrated to be superior to 2D echocardiography in a variety of valvular disease scenarios. In this review, we discuss the incremental role of 3DE in evaluating valvular anatomic features, volumetric quantification, pre-surgical planning, intra-procedural guidance, and post-procedural assessment of valvular heart disease.

Keywords: Aortic valve, mitral valve, three-dimensional echocardiography, valvular heart disease

Three-dimensional transthoracic echocardiogram

Since the decade of the nineteen-nineties the three-dimensional ultrasound scan has evolved at the same pace as technological development. It is now used as a complement to conventional transthoracic or transesophageal echocardiography [1-3].

The three-dimensional transthoracic echocardiogram (3D-TTE) enables obtaining real time images, with and without Doppler colour, with precise adjustment of the area to be studied or recorded throughout several full-volume heart cycles. The main factor limiting its daily use is the quality of the transthoracic window, which, just like in a 2D-echocardiogram, may be improved by contrast agents.

The real time 3D image enables more precise anatomical assessment of valve structures, the cables of pacemakers and other intracardiac devices, as well as simple measurements on two-dimensional planes. The size of the area to be studied is limited by the temporal resolution. For this reason, the 3D area to be studied must be adjusted over the 2D image.

Full-volume acquisition, with and without Doppler colour, is used for morphological studies as well as for quantifying the volumes and function of different heart chambers and valve disease. Image acquisition requires specific training to minimise the presence of artefacts related to the patient's breathing and to adjust the gain controls. Table 1 provides a schematic description of the acquisition of a 3D-TTE study

Valve disease

In mitral valve disease, 3D-TTE enables planimetric assessment of the mitral valve area and the valve score, as well as a geometric study of the sub-valvular mitral apparatus in dilated cardiomyopathies[4]. In patients with mitral valve

Table 1. 3D-TEE study protocol (2)

Parasternal long axis:
Full volume: sub-valvular mitral apparatus; ejection fraction
Full volume-colour of each valve if mitral-aortic insufficiency
Parasternal short axis:
Plane of the great vessels:
Live 3D: tricuspid-aortic-pulmonary valves
Full volume (± colour) tricuspid valve
Parasternal short axis at mitral valve level:
Full volume (± colour) tricuspid valve
Apical 4 chamber view:
Full volume: LV mass; ejection fraction; asynchrony; area strain; LV outflow tract planimetry, mitral and tricuspid planimetry; volume, ejection fraction and asynchrony of the LA and RA; RV volume and function
Full volume colour of each valvular plane
Live-3D vs. full volume of pathological findings.

RA: right atrium; LA: left atrium; 3D-TOE: three-dimensional transoesophageal echocardiography; RV: right ventricle; LV: left ventricle.

prolapse, it improves anatomical assessment and enables locating the prolapsed segment. There is less experience with the aortic valve. In patients with aortic stenosis, the acquisition of a full volume enables performing reliable and reproducible planimetry of the LVOT, thus optimising calculation of the valve area (Figure 1).

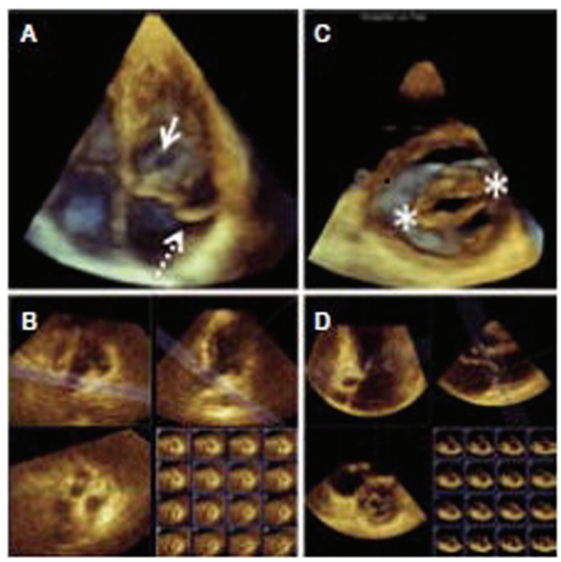

Figure 1. A: Apical plane. The white arrow indicates the outflow tract, and the dotted arrow the P2 prolapse. B: Differents views of planimetry of the left ventricle outflow tract. C: Rheumatic mitral stenosis with commissural fusion (*). D: Different views of rheumatic mitral stenosis with commissural fusion (*) and planimetry of the mitral valve area.

The application of Doppler colour to 3D-TTE improves analysis of regurgitation jets. 3D-TTE also enables locating the origin of the jet and measuring the radius of the proximal flow convergence region (PISA) as well as the area of the contracted vein, especially useful in the case of eccentric jets [5]. The study of the right valves is less protocolised in everyday practice; nevertheless, an anatomical assessment is useful in patients with complex valve disease [6].

Three-dimensional transoesophageal echocardiography

3D ultrasound scans have undoubtedly revolutionised the field of diagnostic imaging using ultrasounds. The possibility of performing studies by transoesophageal route (three-dimensional transoesophageal echocardiography, 3D-TEE) has brought about a tremendous advance in the analysis of heart structures. The working methods for 3D-TEE are similar to those of transthoracic echocardiography and so there is no need to explain them again. However, it is important to emphasise that the temporal resolution of the technique is relatively low (approximately 25-28 Hz in full volume mode) and that obtaining a good quality image mainly depends on adequate control of the gain. Too much gain means the effect of three-dimensional vision is lost whereas if the gain is too low "holes" appear where there are none.

Table 2. 3D-TEE study protocol

Mitral valve:
3D zoom of the mitral valve: between 0 and 90º. Include in the aortic valve sector and confirm that the entire mitral ring is inside.
Full volume in colour of the mitral valve on the same plane
Aortic valve:
Live 3D (with and without colour): short axis of the aortic valve and 135º
Full volume: (± colour): 135º aortic valve and ascending aorta
Tricuspid valve:
Live 3D at 0º
Full volume (with and without colour) at 0º
3D zoom on one modified vena cava axis
Pulmonary valve:
Live 3D at approx. 70º vs. full volume (with and without colour)
Interatrial septum:
3D zoom on one vena cava axis
Left atrial appendage:
3D zoom between 70 and 90º
Left ventricle:
Full volume at 0-90º
Thoracic aortic:
3D zoom

3D-TEE: three-dimensional transoesophageal echocardiography.

Unlike 3D-TTE, 3D zoom is often used to obtain a real time image of a larger area. Unlike 3D-TTE, 3D zoom is often used to obtain a real time image of a larger area. The main uses of this technique are summarised below (Table 2).

Mitral valve

At present, the main indication for 3D-TEE is assessment of the mitral valve (Figure 2). The mitral valve apparatus is anatomically very complex and it is difficult to make a detailed study using 2D-echocardiography.

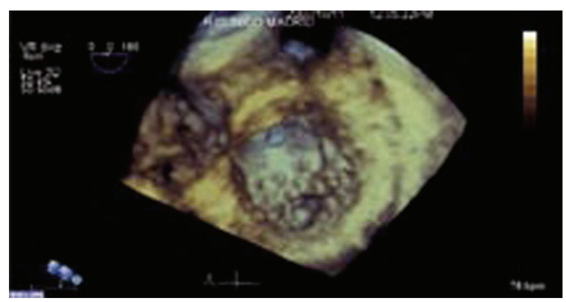

Figure 2. 3D-TEE is assessment of the mitral valve.

3D-TOE improves the definition anatomical of the flaps, commissures, mitral ring and papillary muscles. It enables studying more valves and more closely than 2D-TEE. Compared to traditional methods, 3D-TEE is the non-invasive method that best correlates with the calculations of the mitral valve area derived from the Gorlin formula during cardiac catheterization and the study immediately following percutaneous valvuloplasty. When comparing 3D-TEE and 2D-TEE with surgical findings, there was better correlation between the surgical anatomy and 3D-TEE in the assessment of valve prolapse [7-9], thus increasing the quality of the information provided to the heart surgeon cardiac to repair the mitral valve [10]. 3D-TEE provides information on the dynamic changes of the mitral valve ring during the cardiac cycle and enables studying the position and morphology of the papillary muscles. Displacement of the papillary muscles in patients with dilated cardiomyopathy, together with expansion of the mitral ring, explains the mechanism of mitral insufficiency, progressive bulging of the valve flap, with reduction of the coaptation surface that generates central insufficiency.

Doppler colour images with 3D-TEE enable quantifying mitral insufficiency with more precision than with 2D-TEE [11]. Analysis of the convergence region of proximal flow with 3D-TEE reveals that its morphology is more hemielliptical than hemispherical as previously thought. Assessment of the surface of the contracted vein by 3D-TEE showed significant asymmetry in functional insufficiency rather than organic insufficiency, resulting in a poor estimate of the area of the effective regurgitant orifice when making an isolated measurement of the contracted vein in 2D-TEE.

Aortic valve

Nowadays, aortic valve stenosis is a highly prevalent complaint and adequate determination of its seriousness is essential for correct management. 3D-TOE enables assessing valve and aortic root anatomy, as well as quantifying the valve area using planimetry. The methods normally used for determination of the area of the effective orifice assume a circular morphology of the left ventricle outflow tract (LVOT), however this concept is incorrect. 3D-TEE enables direct quantification of the LVOT area and morphology.

3D-TEE has been shown to be a very useful technique for assessing aortic insufficiency. It improves the anatomical study and enables selecting the ideal plane for analysis of the contracted vein, thus improving diagnostic precision in eccentric or multiple orifice regurgitations. On the other hand, 3D-TEE in conjunction with two-dimensional echocardiography is very useful for establishing the diagnosis and management of multiple aortic disorders [12].

Pulmonary and tricuspid valves

Few studies have been carried out of the right heart valves using 3D-TEE. However, it is possible to evaluate changes secondary to rheumatic and degenerative disease of the tricuspid valve. In relation to the pulmonary valve, its use is mainly focused on the study of congenital heart disease such as pulmonary stenosis and endocarditis.

3D transoesophageal echocardiography in surgery

3D-TOE is successfully used on a daily basis for monitoring different surgical procedures including closure of atrial septal and ventricular septal defects and periprosthetic leakage. It is the technique of choice during percutaneous and transapical aortic prosthesis implant, as well as that of more recently used percutaneous devices to reduce the seriousness of mitral regurgitation [12]. Compared to the 2D technique, it improves real time tracking of guides, catheters and prosthetic devices. It also reduces fluoroscopy time and complications by optimising the choice of closure devices, mainly in complex cases.

Real-time three-dimensional echocardiography (3D-TTE, 3D-TEE) Before Transcatheter Aortic Valve Replacement (TAVR)

Despite recent technological improvements including the development of real-time 3D color Doppler imaging, 3D-TTE is still not used in all centers. It does overcome some of the limitations of 2D TEE. X Plane mode simultaneously displays of two perpendicular 2D view and allows tilting of the secondary plane using the first one as a reference. With this technique one can minimize foreshortening of the AV annulus and underestimating the true AV annular diameter. Off line analysis of 3D Full volume datasets permits alignment of the perpendicular planes (MPRs) to cut through the maximum and minimum AV diameter and offers a short axis view of the LVOT that allows accurate cross section area measurement without relying on geometrical assumptions. Thus, real-time 3D-TEE is capable of determining the maximum annulus diameter, especially in subjects whose annuli are more oval-shaped [13]. Three-dimensional echocardiography is helpful in identifying bicuspid valves. Recently, TEE-based 3D-guided and transthoracic volumetric real-time 3D-echocardiographies have been demonstrated to provide an accurate and reproducible AVA estimate in patients with AS [10]. Both techniques have shown good agreement with TEE and flow-derived methods. Real-time 3D-TEE also facilitates the definition of the virtual and the anatomic aortic annulus as well as the sinotubular junction. Furthermore, in expert hands, 3D-TEE allows measurement of the annulus-to-left main distance and of the left coronary cusp length. However, it cannot currently fully replace MSCT.

Role of 3D-Echo, During and After Transcatheter Aortic Valve Replacement (TAVR)

Most of the described advantages and disadvantages of TEE also apply to the guidance of TAVR by real-time 3D-TEE [14]. Although real-time 3D-TEE can be used as a guiding tool and may improve spatial orientation, it remains limited by the physics of ultrasound and by specific limitations of TEE. However, 3D-TEE may have some advantages over conventional TEE for guiding positioning of the prosthesis immediately prior to deployment. Due to the wide wedge of 3D Live mode, the crimped valve may be more clearly seen as it is moved by native heart beats. The biplane modality that complements two perpendicular two-dimensional planes and allows simultaneous assessment of the valve after deployment on its short and long axis with and without Color Doppler [14]. Off line planimetry of the regurgitant orifice on 3D Color datasets can be considered supplementary to conventional TEE imaging.

The upcoming introduction of 3D-ICE may combine advantages of ICE with those of 3D imaging. Initial studies suggest that 3D-ICE further facilitates intraprocedural guidance, since perpendicular views (short-axis and longitudinal) can be easily obtained from the same volume dataset acquired from the proximal superior vena cava without a need to change the position of the catheter.

Conclusions

The 3D echocardiography should not be interpreted as an isolated tool of 2D echocardiography. The two techniques are complementary and very important to take advantage of both to improve diagnostic accuracy.

3D echocardiography is quite useful for echocardiographers less "experts".

The cardiovascular imaging laboratories that do not have 3D echo machines should not think they can do studies of excellent quality.

3D-Echo is of great value evaluating mitral regurgitation and mitral repair.

3D echocardiography is quite useful evaluating paravalvular leaks and mitral research (mitral remodelling, PISA, etc)

TEE may be of limited value for evaluating the morphology and function of the prosthetic valve from the midesophageal level because of acoustic shadowing anteriorly. The transgastric view and 3D TEE may help improve imaging quality and can possibly provide additional information.

The validity of 3D-TTE and 3D-TEE for assessing regurgitant volume and effective regurgitant orifice area is under investigation.

3D echocardiography is essential in the new procedures of percutaneous mitral valvuloplasty.

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