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IMAGING CARDIOLOGY UPDATE

Advantages of Real-Time Three-Dimensional Echocardiography Over Two-Dimensional Echocardiography

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Abbreviations
2D = two-dimensional
3D = three-dimensional
3DE = three dimensional echocardiography
ASD = atrial septal defect
CT = computed tomography
LV = left ventri-cle(-ular)
MRI = magnetic resonance imaging
PFO = patent foramen ovale
TAVI = transcatheter aortic valve implantation
TEE = transesophageal echocardiography

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INTRODUCTION

Over the last fifty-years conventional two-dimensional (2D) echocardiography has served as a valuable clinical adjunct for the diagnosis and management of cardiovascular disease. However, the echocardiologist was expected to mentally reconstruct the complex structure of myocardium, resulting in geometrical assumptions which in turn could underestimate the validity of clinical findings.

Three-dimensional (3D) echocardiographic (3DE) imaging represents a major innovation in cardiovascular imaging. The usefulness of 3D-echocardiography has been summarized mainly in (a) the evaluation of cardiac chamber volumes and mass, avoiding geometric assumptions; (b) the assessment of regional left ventricular (LV) wall motion; (c) presentation of realistic views of heart valves; (d) volumetric assessment of regurgitant lesions and shunts with 3D color Doppler imaging; and (e) 3D stress imaging. It's worth noting that both beginners and experts benefit from 3DE, since image acquisition has been simplified and accelerated. In addition, concerning inter-observer variability, 3DE offers significant improvement.

Recent technological advancements have rendered this technique feasible both in the echocardiography and the catheterization laboratories for a variety of clinical applications.[1] All these improve the way clinicians perceive cardiac structure and its spatial relationship with other organs. For 3D echocardiography to be efficiently implemented in routine clinical practice, a full understanding of its technical principles and a systematic approach to image acquisition and analysis are required.

EVALUATION OF CARDIAC CHAMBER VOLUMES

The initially explored and most common clinical application of 3DE is the quantitative evaluation of cardiac chamber dimensions and volumes. A firmly established advantage of 3DE imaging over cross-sectional slices of the heart is the improvement in the accuracy of the evaluation of LV volumes and ejection fraction by eliminating the need for geometric modeling, which is inaccurate in the presence of aneurysms, asymmetrical ventricles, or wall motion abnormalities. This novel modality is able to depict the whole extent of the left ventricle, allowing accurate off-line assessment of LV mass and volumes with the implementation of dedicated software. The results have been validated with magnetic resonance imaging (MRI) which is regarded as the standard of reference.[2] Additionally, the complex crescent like morphology of the right ventricle can be assessed and quantified, providing valuable information in various disease sates including congenital heart disease.[3] Theoretically, the intrinsic ability of 3DE imaging to directly measure right ventricular volumes without the need for geometric modeling could be expected to result in improved accuracy and reproducibility compared with traditional 2DE measurements. The left atrium is a structure whose volume alterations have prognostic implications. However, 2D echocardiography systematically underestimates volumes. On the other hand, 3DE offers more accurate measurements as compared to MRI.[4] Recent advances on 3DE have focused on specific software of each particular chamber resulting in more accurate evaluation of shape and function.

ASSESSMENT OF REGIONAL WALL-MOTION ABNORMALIITIES

Real-time three-dimensional echocardiography has the inherent advantage of obtaining information in a full-volume pyramidal dataset within a single acquisition. This translates into clinical practice since the operator can obtain multiple views as deemed necessary which can illustrate regional wall motion abnormalities.[5] That could assist in determining the extent of wall motion abnormality as well as in ruling out artifacts frequently noted in standard imaging planes due to limited endocardial visualization. Moreover, conventional 2D echocardiography requires significant experience in image acquisition, while 3DE can provide information even by an inexperienced user. Recently, myocardial perfusion with 3DE has become possible with the implementation of contrast agents (Figure 1).[6] On the other hand, there are important limitations including low temporal and spatial resolution that limit the diagnostic value of 3DE. These limitations are expected to be overcome with evolution in transducer technology.

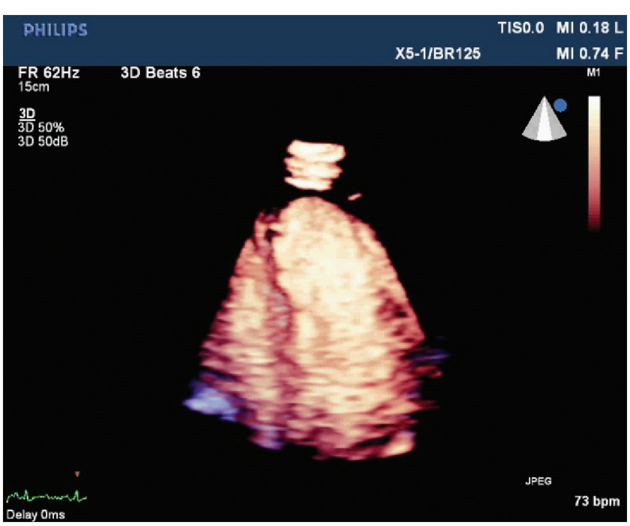

FIGURE 1. 3D echocardiography data set after off-line cropping illustrating apical perfusion defect in 4-chamber view

EVALUATION OF ATHEROSCLEROSIS

Research and clinical interest has recently focused on the 3DE evaluation of atherosclerosis of the carotid artery and aorta.[7] Novel modalities have rendered the volumetric assessment of atheromatous burden a reality, enabling the quantification of atherosclerosis. The evaluation of extension of atherosclerotic disease plays a crucial role in prognosis on various groups of patients with cardiovascular disease. Whether it is really a barometer before the storm remains to be seen.

APPLICATIONS IN INTERVENTIONAL CARDIOLOGY

Real-time three-dimensional echocardiography is now an indispensable resident in the catheterization laboratory, as it is applicable to a wide range of interventions. The interventional echocardiologist must be aware of the different implantation techniques before attempting to guide a procedure. Three-dimensional transesophageal echocardiography (TEE) has been shown to provide additional insight into the anatomical, morphological and hemodynamic assessment of structural heart disease. It has become the imaging modality of choice for many interventionists, and in many cases it serves as the operator's "eyes" to evaluate, guide, and assess the results of procedures in the catheterization laboratory. The unique structural information obtained offers the potential for shorter and safer interventional procedures, with a higher rate of technical success, thus improving patient outcomes.

VALVULAR HEART DISEASE

Using new technology with advanced matrix transducers, transthoracic 3D echocardiography provides more accurate morphological and functional information. It gives detailed data on definitive anatomical characterization (number of cusps or leaflets), and localization, enables planimetry of valve orifice and offers exact information on prosthetic valves with the trade-off of poorer overall imaging quality. Real-time 3DE can guide the interventionist both in patient selection and during the transcatheter valve implantation.

With regards to the trans-catheter aortic valve implantation (TAVI), it is now possible to estimate the exact annulus size, avoiding any geometrical assumptions involving annular shape and geometry. The decision regarding the size of the prosthesis may not always be easy due to the relationship between the complex aortic valve anatomy and the aortic root–LV outflow tract. In 3DE studies, it has been shown that the annulus is often not circular, but rather elliptical.[8,9] Thus, more accurate valve size can be selected for each patient, avoiding complications related to valve under- or over-sizing. Various studies have validated this specific application of 3DE.[10] Moreover, the exact definition of coronary ostia must be performed, especially for the Sapiens Edwards valve. There should be a minimum distance of 10–11 mm between the aortic annulus and the coronary ostium (particularly the left). In clinical practice, this measurement is performed by means of multislice computed tomography (CT) and it can also be determined with full volume 3D echocardiography.[11,12] Furthermore 3DE can aid in the positioning and deployment of the prosthetic valve across the annulus and then assess whether there is any degree of aortic regurgitation.

In addition, 3DE plays an integral role for the transcatheter treatment of mitral valve regurgitation with the MitraClip device. The ability to illustrate the morphology of the complex mitral valve apparatus from the left atrial view (surgical view) has vastly improved our understanding of mitral valve pathology. The clinician can now decide whether the regurgitation is due to degenerative or functional causes which can be corrected with the MitraClip system. Moreover, the eccentricity of the regurgitant jet can be deferred, which is an important step during patient selection stage and evaluate if there is sufficient tissue for mechanical caption of the valve. Intra-procedurally 3DE is very helpful during trans-septal puncture and facilitates catheter orientation towards the mitral valve apparatus.[13]

CLOSURE OF PARAVALVULAR LEAKS AND INTRACARDIAC SHUNTS

Two-dimensional TEE has become an essential and integral tool of the interventional device closure, but it is limited in its ability to detect the position of a catheter or a device relative to its surrounding environment due to only two spatial dimensions. Even in experienced operators, numerous cut planes are necessary in order to mentally reconstruct the anatomical setting. The application of 3DE was shown to be feasible for the accurate determination of atrial septal defect (ASD) size, shape, rims guiding patient and device selection and also demonstrated a decrease in fluoroscopy time. Real-time 3D transesophageal echocardiography provides a novel imaging modality for the guidance of ASD and patent foramen ovale (PFO) closures, giving fast and complete information about the appropriate position of the device in its surrounding environment and assesses post-operatively the firm and complete implantation of the device (Figure 2).[14]

In paravalvular leak closure the main issue is to adequately visualize the leak(s) and assess its spatial relationship with surrounding structures. Real-time 3DE can offer enhanced appreciation of the complex anatomy. More importantly, 3DE can assess the presence of multiple leak sites with irregular shapes, which could affect the result of the intervention. It can also offer guidance during catheter steering and manipulation through the defect without the need for time-intensive offline reconstruction. In addition, 3D echocardiography can be used immediately post- closure (Figure 3) to assess device stability and interaction with surrounding structures.[15]

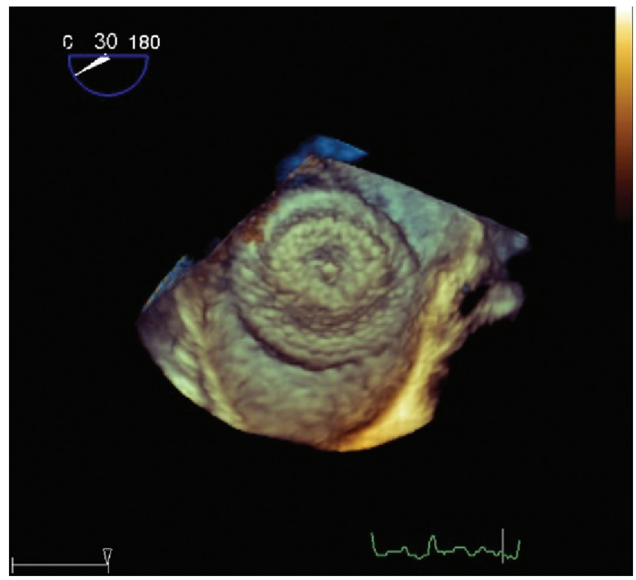

FIGURE 2. "Surgical" view depicting successful implantation of Amplatz ASD closure device. ASD = atrial septal defect.

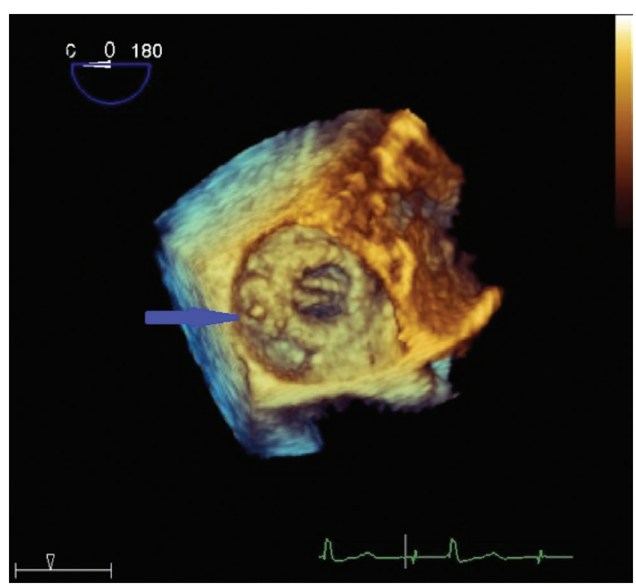

FIGURE 3. Prosthetic mitral valve paravalvular leak closure device (blue arrow) as shown from left atrial view.

CONCLUSION

Real-time three-dimensional echocardiography is a feasible technique offering a more comprehensive insight into structural heart disease. It vastly improves and expands the diagnostic capabilities of cardiac ultrasound in a manner that complements traditional 2D echocardiography. Furthermore, 3DE allows visualization of cardiac anatomy and pathology in a format that is readily appreciated by cardiac surgeons, and is very helpful in guiding and assessing the results of interventional procedures. It is currently applied in various clinical settings and in the future with the improvement in transducer technology it will be the standard of choice procedure.

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