

EDITORIAL

Three-Dimensional Echocardiography

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ABSTRACT

KEY WORDS: *echocardiography;*
three-dimensional echocardiography;
transesophageal echocardiography

ABBREVIATIONS

3DE = three-dimensional
echocardiography
CMR = cardiac magnetic resonance
(imaging)
LV = left ventric-le (-ular)
LVEF = left ventricular ejection fraction
LVESV = left ventricular end-systolic
volume
MV = mitral valve
PMVR = percutaneous mitral valve repair
TAVI = trans-catheter aortic valve
implantation
TEE = transesophageal echocardiography

The strength of echocardiography has always been in its capacity for convenient real-time imaging, its rapid acquisition and analysis capabilities. Echocardiography has been one of the most rapidly expanding fields in modern cardiology and has seen unprecedented advances over the last 20 years. One of the most significant advances in this area is that of three-dimensional echocardiography (3DE). 3DE is not a new idea or indeed a new technique; it has been a research tool in various guises for many years. New transducer technology coupled with advances in computing have transformed this modality from a labour-intensive imaging protocol to a real-time imaging that can be rapidly analysed online. Continued improvements in image acquisition and quantification help integrate this into clinical practice and have brought it to the cusp of widespread clinical acceptance.

Many different 3DE techniques have been developed and validated. By obviating the need for geometric assumptions, transthoracic 3DE allows accurate assessment of left ventricular mass, volumes and function as well as right ventricular and left atrial volumes. Furthermore, the advent of real-time 3D trans-esophageal echo has found a clear role in assessment of valvular disease as well as guidance of percutaneous procedures including trans-septal puncture, atrial and ventricular septal defect closure device deployment, trans-catheter aortic valve implant and percutaneous mitral valve repair. In conclusion, for some time, 3DE has had a host of proven applications within cardiology, which are rapidly becoming a clinical standard.

INTRODUCTION

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One of the most significant advances in this area is that of three-dimensional echocardiography (3DE). 3DE is not a new idea or indeed a new technique; it has been a research tool in various guises for many years. New transducer technology coupled with advances in computing have transformed this modality from a labour-intensive imaging protocol to a real-time imaging that can be rapidly analysed online. Continued improvements in image acquisition and quantification help integrate this into clinical practice and have brought it to the cusp of widespread clinical acceptance.

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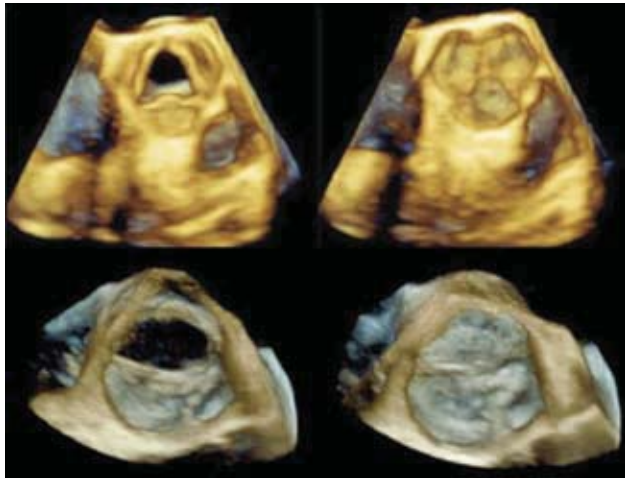


FIGURE 1. 3D imaging offers superior morphological assessment. A tricuspid aortic valve with mildly thickened cusps (top row) and a functionally bicuspid valve (bottom row).

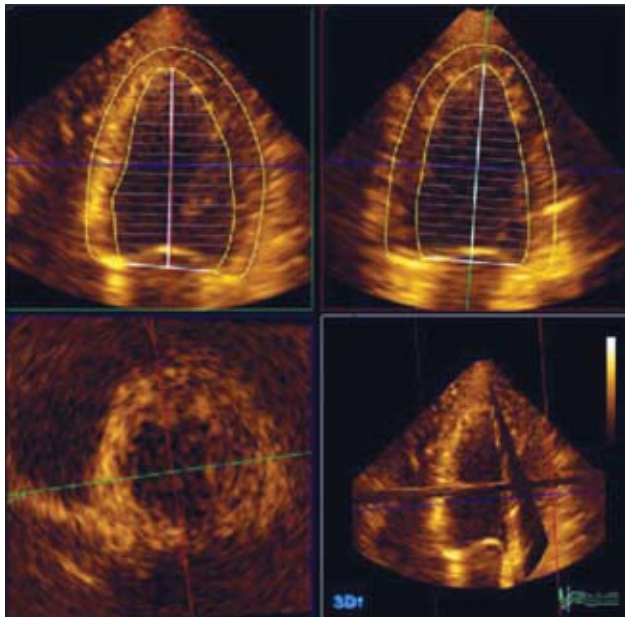


FIGURE 2. 3D quantification of LV mass: 4- and 2-chamber views are extracted from the data set to provide more accurate volume and mass measurements by eliminating long axis errors. LV= left ventricle.

the need for geometric assumptions, transthoracic 3DE allows accurate assessment of left ventricular mass, volumes and function as well as right ventricular and left atrial volumes. Furthermore, the advent of real-time 3D trans-esophageal echo (3D TEE) has found a clear role in assessment of valvular disease as well as guidance of percutaneous procedures includ-

ing trans-septal puncture, atrial and ventricular septal defect closure device deployment, trans-catheter aortic valve implant (TAVI) and percutaneous mitral valve repair (PMVR).

TRANSTHORACIC 3D ECHO

By eliminating the impact of geometric assumptions and off-axis acquisitions, 3DE provides a much more accurate assessment of left ventricular (LV) volumes and mass. The impact of long axis errors that occur with foreshortening in 2D echo was demonstrated by Mor-Avi et al,¹ who compared 2DE, 3DE and cardiac magnetic resonance imaging (CMR) for assessment of LV mass. For this study, an accurate 4-chamber and 2-chamber view were extracted from the 3D dataset and quantification was based on modified biplane Simpson’s method, comparable to standard 2DE techniques. There was excellent correlation between 3DE and CMR ($r = 0.9$ for 3DE, vs. 0.79 for 2DE). A notable finding in this study was that LV length was significantly lower in 2D acquisitions, implying that foreshortening in 2D acquisitions was a significant source of error when compared to 3DE and CMR. Similar observations were made by Pouleur et al in 83 patients with and without wall motion abnormalities.²

Incorporating 3DE for LV quantification may have an impact on clinical decision making. In a study by Hare et al,³ 220 unselected patients were examined and the impact on

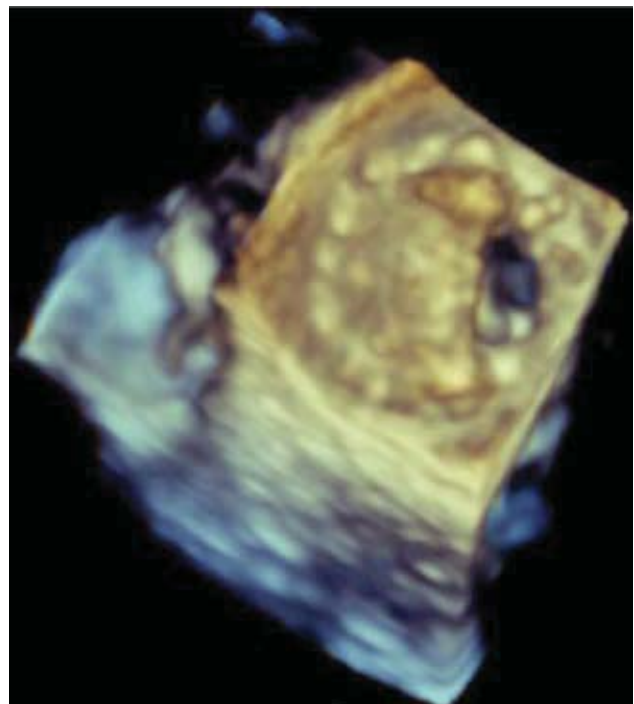


FIGURE 3. Surgeon’s view of an obstructed bileaflet MV prosthesis. Pannus can be seen at the anterior hinge point. MV = mitral valve.

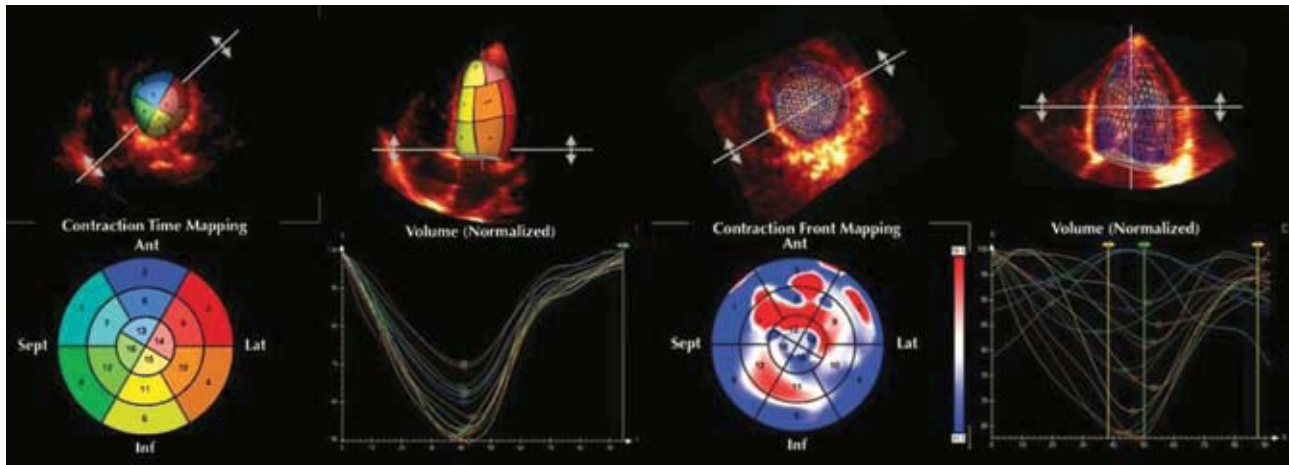


FIGURE 4. 3D regional quantification: Time-volume curves in a normal patient (left) show well synchronized regional contractions as all curves reach their minimum at the same time. A patient with severe LV dysfunction and dyssynchrony (right) displays wide dispersion of times to minimum regional volumes, or peak regional contraction. LV = left ventricle.

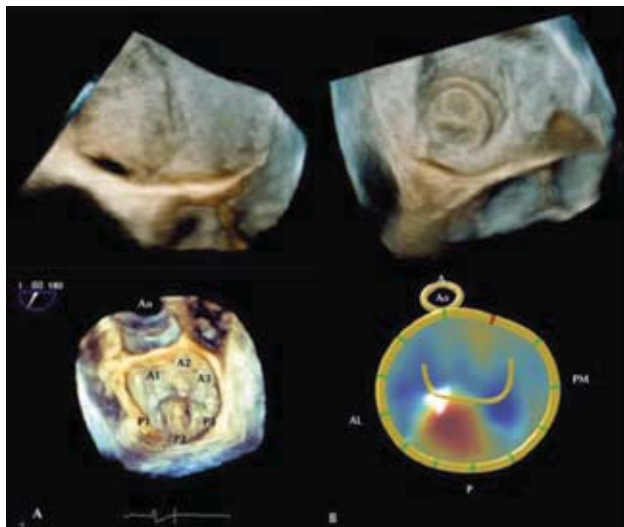


FIGURE 5. Top row: A patent foramen ovale before and after percutaneous occlusion with an Amplatzer device. Lower row: P2 prolapse seen from surgeon's view in real-time 3D (left) and with parametric display (right).

decision making was based on 4 measurement thresholds: 1) LV end-systolic volume (LVESV) $>50 \text{ ml/m}^2$ (indication for surgery in mitral regurgitation), 2) LVESV $>30 \text{ ml/m}^2$ (prognosis post myocardial infarction), 3) LV ejection fraction (LVEF) $<35\%$ (indication for implantable defibrillator therapy) and 4) LVEF $<40\%$ (initiation of heart failure therapy). The investigators found that in this unselected group of patients, 3DE was feasible in 83% and that 3D acquisition and quantification added 5.2 minutes to the routine examination. More importantly, 3DE would have had a significant impact



FIGURE 6. Deployment of Mitraclip device for percutaneous mitral repair, resulting in a double orifice valve.

on decision making, suggesting a different outcome in up to 18% compared to 2DE.

As with traditional echo, 3DE can be used with micro-bubble contrast for left ventricular opacification to optimize endocardial border definition. More recently a low mechanical index contrast imaging has been added to the arsenal of 3D modalities, opening the possibility to assess myocardial perfusion in 3D - this however is still in the domain of research.

3DE may also be used for quantification of LV mechanical dyssynchrony.^{4,6} By dividing the global LV volume into sub-volumes corresponding to the standard myocardial segments, it is possible to derive time-volume curves for each segment and thereby a timing of regional contraction. Several groups have validated the standard deviation of these timings (systolic

dyssynchrony index) in patients with heart failure undergoing cardiac resynchronization therapy. Single center data suggest that this parameter may be more accurate than traditional 2DE and tissue Doppler imaging methods for selecting patients, but multi-center trials are awaited.

TRANSESOPHAGEAL 3D ECHO

One of the most important advances on the 3DE platform was the addition of real-time 3D trans-esophageal echo. The 3DE probe, like its transthoracic equivalent, hosts a matrix array that allows acquisition of high resolution 3D volumes without compromising the 2D imaging quality. This has made 3D TEE indispensable for detailed mitral valve (MV) assessment as well as guidance of percutaneous procedures.⁷⁻¹³

3D TEE easily provides a “surgeon’s view” of the mitral valve so that mental reconstruction of MV geometry is no longer required as the observer can observe all scallops simultaneously. The ability to derive 2D views from any part of the MV means that specific imaging of both commissures and all scallops is simplified and anatomically accurate. In addition, there are a number of software tools that allow accurate quantification of MV annular geometry as well as leaflet characteristics such as tenting and prolapse height and volume.

In a similar manner the LV outflow tract, aortic valve and ascending aorta can be viewed by any angle in real-time which is especially useful in TAVI. However, where 3D TEE is truly indispensable is in deployment of mitral clip for PMVR. With 2D TEE, multiple views are required to guide the trans-septal puncture required for this procedure and to guide deployment of the mitral clip, whereas this is a simple matter in 3D TEE, particularly if more than 1 clip is used.

SUMMARY

For some time, 3DE has had a host of proven applications within cardiology, which are rapidly becoming a clinical standard.⁴⁻¹⁵ As the focus of medical management shifts from treatment to prevention, serial noninvasive measurements and detection of minute changes will become increasingly important. There is already a growing requirement to detect small changes in LV mass, volume, and function in several clinical situations. For this application, we need rapid, accurate, safe, reliable, and reproducible techniques that are convenient for patients and practitioners. 3DE has been proven capable in many of these areas, and it will undoubtedly prove itself in the remainder.

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