Θέματα Απεικόνισης - Κύριες Ενδείξεις
Τρισδιάστατη Υπερηχογραφία

Σταμάτης Κυρζόπουλος,
Ωνάσειο Καρδιοχειρουργικό Κέντρο
• Καμία δήλωση σύγκρουσης συμφερόντων
2D vs 3D

Proven advantages

- Accuracy in evaluation of volumes (no geometric modeling - no errors due to foreshortened views)
- Realistic and comprehensive unique views of cardiac valves and congenital abnormalities
- Intra-operative post-operative setting

Major Drawbacks

- Complex acquisition - lengthy analysis
- Low temporal and spatial resolution
- Image quality dependent on 2D image
Data Acquisition

- Real time or live 3DE imaging (live 3D narrow volume, live 3D zoomed, live 3D wide angle - full volume, live 3D colour)

Overcomes problems of rhythm disturbances or respiratory motion but has poor temporal and spatial resolution.

Multibeat 3DE imaging: better resolution - stitching and moving artifacts.

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**Figure 2.** Different modes of data acquisition using the matrix-array transducer. These include narrow-angled scan (left), zoom mode (middle), and wide-angled scan (right). Reproduced, with permission, from Sugeng et al. (32).

Live 3DE single-beat acquisition of the whole heart (bottom left) and the left ventricle (bottom right) from the transthoracic apical window.
Clinical considerations

Table 1. Cor

<table>
<thead>
<tr>
<th>Studies</th>
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<tbody>
<tr>
<td>Jenkins et al</td>
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<tr>
<td>JACC 2004</td>
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<td>Caiani et al,</td>
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<td>JASE 2005</td>
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<td>Jacobs et al,</td>
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<td>Eur Heart J</td>
<td></td>
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<td>Greupner et</td>
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<tr>
<td>JACC 2012</td>
<td></td>
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<tr>
<td>CMR, cardiac</td>
<td></td>
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<tr>
<td>2DE, two-dim</td>
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</table>

* Mean difference

Figure 5. Volumetric analysis of regional left ventricular (LV) function. Example of LV endocardial surface detected from 2 three-dimensional (3D) data set at 3 different phases of the cardiac cycle, superimposed on a cross-sectional long-axis plane (top left). Schematic representation of the 3D segmentation model: A2C, A3C, and A4C = apical 2-, 3-, and 4-chamber planes, respectively; Ao = central point of the aortic annulus; MV = central point of the mitral valve (top right). Shaded area is an example of an LV endocardial surface segment representing the midepicardial (in-sp) wall. Below are examples of regional volume and wall motion time curves and regional shortening fraction (RSF) in 6 apical segments, obtained in a normal subject (left) and a patient with coronary artery disease (CAD) (right) and hypokinetics in the lateral wall (arrow). Ant = anterior; asp = anteroapical; inf = inferior; lat = lateral; RRR = percent of electrocardiogram RR-interval; pst = posterior; sp = septal.
Clinical considerations
LV volumes-EF

Currently, 3D TTE and TEE assessment of LV volumes and ejection fraction is recommended over the use of 2D echocardiography, as it has been clearly demonstrated to provide more accurate and reproducible measurements.
Clinical considerations
LV volumes - Stress tests

Figure 3.4 Diagram illustrating the differences between conventional 2DE, multiplanar, and full-volume 3D imaging modes in the number of separate views that must be acquired for a complete echocardiographic stress study. As the number of acquisitions decreases, the scanning time required to complete the study becomes shorter. 4CV, Four-chamber view; PLAX, parasternal long-axis; PSAX, parasternal short-axis; 3CV, three-chamber view; 2CV, two-chamber view.

Note the changes in color with pacing reflecting the effects of resynchronization therapy in this parametric display. Ant = anterior; Ant-Sept = antero-septal; EF = ejection fraction; Inf = inferior; Lat = lateral; Post = posterior; Sept = septal.
Clinical considerations
Stress echo tests

Because of its ability to acquire the entire LV volume within one beat, 3D stress transthoracic echocardiography holds promise for incorporation into clinical practice in the future.
Clinical considerations
LV deformation-contrast perfusion imaging

**Figure 9.** Real-time 3-dimensional (3D) visualization of myocardial perfusion. Contrast-enhanced 3D data set obtained in a patient with severe discrete left anterior descending artery stenosis (left). A region in the interventricular septum shows lack of contrast enhancement, indicating a perfusion defect that was supported by abnormal wall motion. This defect was visible in multiple cross-sections (right), allowing easy estimation of its extent.
Clinical considerations
LV mass

Table 2. Comparison of left ventricular mass between 2D/3D echocardiography and cardiac magnetic resonance

<table>
<thead>
<tr>
<th>Studies</th>
<th>Subjects</th>
<th>n</th>
<th>3DE vs. CMR*</th>
<th>2DE vs. CMR*</th>
</tr>
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<tbody>
<tr>
<td>Qin et al., Echocardiogr 2000</td>
<td>Mixed</td>
<td>19</td>
<td>-9</td>
<td>66</td>
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<tr>
<td>Jenkins et al., JACC 2004</td>
<td>Mixed</td>
<td>50</td>
<td>0</td>
<td>76</td>
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<tr>
<td>Mor-Avi et al., Circulation 2004</td>
<td>Mixed</td>
<td>21</td>
<td>-4</td>
<td>34</td>
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<tr>
<td>Oe et al., Am J Cardiol 2005</td>
<td>LV hypertrophy</td>
<td>20</td>
<td>-14.1</td>
<td>58.2</td>
</tr>
<tr>
<td>Caiani et al., Heart 2006</td>
<td>Mixed</td>
<td>46</td>
<td>-2.1</td>
<td>23</td>
</tr>
<tr>
<td>Takeuchi et al., JASE 2008</td>
<td>Mixed</td>
<td>55</td>
<td>-1</td>
<td>6</td>
</tr>
<tr>
<td>Mizukoshi et al., JASE 2016</td>
<td>Mixed</td>
<td>57</td>
<td>-4.8</td>
<td>27.7</td>
</tr>
</tbody>
</table>

LOA, limits of agreement. * Bias and LOA are given in grams. Abbreviations are in Table 1.
Clinical considerations
LA volume

coupled with cardiac disease severity.\textsuperscript{17} Compared to 2DE, 3DE determined LA volumes more closely approximate CMR-derived LA counterparts.\textsuperscript{18} In a recently published study, 3DE determined LA volumes were powerful predictors of future cardiac events, and minimal LA volumes tended to carry a stronger prognostic value over maximal LA volumes.\textsuperscript{19}

Figure 2. Representative case of LA quantification using Philips QLab. From the full-volume datasets, 2 orthogonal long-axis and 1 short-axis views of the LA at end-diastole and end-systole were selected. The software automatically determined the LA wall in 3D space using the deformable shell model and made time domain LA volume curve, from which maximal and minimal LA volumes. Manual adjustment when inadequate tracking of the LA wall was observed. LA, left atrium.
Clinical considerations

RV evaluation

Figure 3. Representative case of RV quantification step-by-step using TomTec 4D RV Analysis software. View adjustment (A), Bevel revision (B), Tracking revision (C), Analysis (D). RV, right ventricular.
Clinical considerations
RV evaluation

EAE/ASE Recommendations for Image Acquisition and Display Using Three-Dimensional Echocardiography

Roberto M. Lang, MD, FASE®, Luigi P. Badano, MD, FESC®, Wendy Tsang, MD®,

Currently, 3DE assessment of RV volumes and ejection fraction shows great promise. However, routine clinical use is limited by the need for excellent quality transthoracic data sets for accurate analysis with software packages.
Clinical considerations - Valvular lesions
MV evaluation

Figure 16 Schematic (left) and 3D TEE image (middle) demonstrating the normal anatomy of the aortic and mitral valves. Three-dimensional TEE image of the mitral valve as viewed from the left atrium demonstrating (1) a posterior mitral leaflet indention (right, top), which is defined as a discontinuation in the leaflet that does not extend to the annulus, and (2) a posterior mitral leaflet cleft (right, bottom), which is defined as a discontinuation in the leaflet that extends to the annulus. Cor., Coronary.
mitral annulus is best appreciated from the 3DE surgical view of the mitral valve with the entire annular circumference captured in one dataset. Moreover, the saddle shape of the mitral valve is best assessed by offline reconstructions, which depict the saddle-shaped contour in three dimensions with high points that are anterior and posterior and low points that are lateral and medial. Commercial software has been developed to precisely quantitate the size, shape, and degree of non-planarity of the mitral valve annulus. This has improved our understanding of mitral valve mechanics. Also, it has assisted surgeons in evaluating the feasibility of mitral valve repair and provided valuable information for annuloplasty ring design.
Clinical considerations - Valvular lesions MR

- 3 dimensional Vena Contracta and PISA improve accuracy of severity estimation

- Better localization of functional anatomy

- Better comprehension and understanding with surgeons or interventional cardiologists
Clinical considerations - Valvular lesions MS

- Superior anatomical MVA

- Post balloon valvuloplasty assessment
Clinical considerations—Valvular lesions
MV evaluation

EAE/ASE Recommendations for Image Acquisition and Display Using Three-Dimensional Echocardiography

Roberto M. Lang, MD, FASE®, Luigi P. Badano, MD, FESC®, Wendy Tsang, MD®,

Three-dimensional TTE and TEE assessments of mitral valve pathology should be incorporated into routine clinical practice as they provide the best physiologic and morphologic information regarding the mitral valve. Three-dimensional transesophageal echocardiography is recommended for guidance of interventional mitral valve procedures.
Clinical considerations - Valvular lesions

AV-root

- Accurate evaluation of LVOT area
- Accurate evaluation SV
- Accurate evaluation of aortic root area
- Better planning of TAVI

Figure 6. Assessment of aortic root by transesophageal 3D echocardiography. As seen in the last row of panel (D), the en face cross-sectional view of aortic annulus is oval rather than circular.
Three-dimensional TTE and TEE assessments of the aortic valve should be incorporated when available into the assessment of aortic stenosis and to elucidate the mechanism of aortic regurgitation. Three-dimensional transesophageal echocardiography is recommended for guidance of transcatheter aortic valve implantation.
Clinical considerations - Valvular lesions TV

EAE/ASE Recommendations for Image Acquisition and Display Using Three-Dimensional Echocardiography

Roberto M. Lang, MD, FASE®, Luigi P. Badano, MD, FESC®, Wendy Tsang, MD®.

There is evidence supporting the routine use of 3D transthoracic echocardiography or transesophageal echocardiography for the evaluation of TV disease.
Clinical considerations—Prosthetic valves

Recommendations for the imaging assessment of prosthetic heart valves: a report from the European Association of Cardiovascular Imaging endorsed by the Chinese Society of Echocardiography, the Inter-American Society of Echocardiography, and the Brazilian Department of Cardiovascular Imaging.

3D echocardiography
Real-time 3D echocardiography, particularly during TOE, is suitable for the evaluation of PHVs and provides incremental advantage over 2D imaging. The 3D ‘en-face’ surgical view of the valve is extremely helpful for determining PHV function and defining the presence, origin, direction, and extension of regurgitant jets. Leaks are defined by 3D echocardiography as echo dropout areas outside the sewing ring confirmed by colour Doppler. 3D echocardiography allows advantageous visualization of PHV components such as the leaflets, rings, and struts (leaflets or disc material support), irrespective of the position. The presence and localization of thrombus formation, pannus, and prosthetic valve dehiscence can be evaluated by 3D echocardiography. This is especially useful for the assessment of mechanical mitral and aortic valves where 2D images are often of poor quality due to acoustic shadowing. With 3D imaging, the ventricular side of mitral prosthetic valves, which is consistently prevented with 2D imaging, can be often visualized.

Figure 2: Mechanical valve in mitral position: normal appearance. 2D and 3D transoesophageal echocardiographic (TOE) appearance of a normally functioning mechanical valve in mitral position. (A) 2D and 3D as well as 2D and 3D colour flow appearance of a bileaflet mechanical valve in the open state from the atrial perspective. Note the two lateral semi-circular orifices and the central slit-like orifice both visible in 2D and 3D TOE. Note the normal antegrade colour flow Doppler and the flow acceleration at the level of the three orifices in 3D TOE. (B) 2D and 3D colour flow appearance of a bileaflet mechanical valve in the closed position from the atrial perspective. Note the normal appearance of the retrograde colour flow Doppler showing physiologic ‘washing jets’ for this type of prosthesis in 2D (F) and 3D colour flow imaging (H). The volumetric reconstructed cardiac computed tomography scan of the bileaflet valve from the atrial (open) and ventricular (close) perspective.
Clinical considerations - Prosthetic valves

Key points

2D TTE is recommended as first-line imaging in PHV. TTE is also the method of choice for Doppler signal recordings. Both TTE and TOE are needed for complete evaluation in a patient with suspected PHV dysfunction. 3D echocardiography, especially with TOE, can provide additional information and is increasingly used. For both TTE and TOE, it is essential to obtain images in multiple views and multiple planes to ensure complete visualization of the valvular and paravalvular region. TTE/TOE has higher sensitivity in mitral than aortic position for examining disc valve motion. For the evaluation of PHV regurgitation, TOE is superior in mitral/tricuspid position while TTE is better in aortic position. TOE, especially when completed by 3D evaluation, remains superior for assessing paravalvular regurgitation.
6.3. Transcatheter Intervention for VHD

**TABLE 7A** Pre-TAVR Evaluation

<table>
<thead>
<tr>
<th>Indication</th>
<th>TTE</th>
<th>TEE (With Possible 3D)</th>
<th>2D TTE</th>
<th>Ex-SE</th>
<th>DSE</th>
<th>Low-Dose DSE</th>
<th>RVG</th>
<th>MPI (SPECT/PET)</th>
<th>CMR</th>
<th>CCT</th>
<th>ANG</th>
<th>Fluoro</th>
</tr>
</thead>
</table>

**TABLE 7B** Intraprocedural Evaluation During TAVR

<table>
<thead>
<tr>
<th>Indication</th>
<th>TTE</th>
<th>TEE (With Possible 3D)</th>
<th>2D TTE</th>
<th>Ex-SE</th>
<th>DSE</th>
<th>Low-Dose DSE</th>
<th>RVG</th>
<th>MPI (SPECT/PET)</th>
<th>CMR</th>
<th>CCT</th>
<th>ANG</th>
<th>Fluoro</th>
</tr>
</thead>
</table>

**TABLE 7C** Postprocedural Assessment After TAVR (Out of Procedure and <30 days)

<table>
<thead>
<tr>
<th>Indication</th>
<th>TTE</th>
<th>TEE (With Possible 3D)</th>
<th>2D TTE</th>
<th>Ex-SE</th>
<th>DSE</th>
<th>Low-Dose DSE</th>
<th>RVG</th>
<th>MPI (SPECT/PET)</th>
<th>CMR</th>
<th>CCT</th>
<th>ANG</th>
<th>Fluoro</th>
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</table>
### APPROPRIATE USE CRITERIA

**ACC/AATS/AHA/ASE/ASNC/HRS/SCAI/SCCT/SCMR/STS 2017 Appropriate Use Criteria for Multimodality Imaging in Valvular Heart Disease**

#### TABLE 8A  Evaluation Prior to Percutaneous Mitral Valve Repair

<table>
<thead>
<tr>
<th>Indication</th>
<th>TTE</th>
<th>TEE (With Possible 3D)</th>
<th>3D TTE</th>
<th>Exercise Testing</th>
<th>CMR</th>
<th>ANG</th>
</tr>
</thead>
<tbody>
<tr>
<td>86. Determine patient eligibility*</td>
<td>A (8)</td>
<td>A (9)</td>
<td>A (7)</td>
<td>A (7)</td>
<td>R (2)</td>
<td>A (7)</td>
</tr>
<tr>
<td>87. Exclude the presence of intracardiac mass, thrombus, or vegetation prior to (within 3 d of the procedure)</td>
<td>M (4)</td>
<td>A (9)</td>
<td>M (5)</td>
<td>R (1)</td>
<td>R (3)</td>
<td>R (1)</td>
</tr>
</tbody>
</table>

* Determined patient eligibility. Currently, MiraClip is the only FDA-approved device available.

3D = 3-dimensional; A = appropriate; ANG = invasive coronary angiography/ventriculography/angiography; CMR = cardiovascular magnetic resonance imaging; FDA = U.S. Food and Drug Administration; M = may be appropriate; R = rarely appropriate; TEE = transesophageal echocardiography; TTE = transthoracic echocardiography.

#### TABLE 8B  Intraprocedural Evaluation During Percutaneous Mitral Valve Repair

<table>
<thead>
<tr>
<th>Indication</th>
<th>TTE</th>
<th>TEE (With Possible 3D)</th>
<th>3D TTE</th>
<th>Angiography/ Fluoro</th>
</tr>
</thead>
<tbody>
<tr>
<td>88. Alignment of the device over the origin of the regurgitant jet and advance to the LV</td>
<td>R (1)</td>
<td>A (9)</td>
<td>M (4)</td>
<td>A (8)</td>
</tr>
<tr>
<td>89. Guidance for grasping the mitral valve leaflets and device closure</td>
<td>R (1)</td>
<td>A (9)</td>
<td>M (5)</td>
<td>A (9)</td>
</tr>
<tr>
<td>90. Assess for adequacy in the reduction of the MR</td>
<td>M (4)</td>
<td>A (9)</td>
<td>M (6)</td>
<td>A (7)</td>
</tr>
<tr>
<td>91. Assess for presence of mitral stenosis</td>
<td>M (5)</td>
<td>A (9)</td>
<td>M (6)</td>
<td>R (1)</td>
</tr>
</tbody>
</table>

3D = 3-dimensional; A = appropriate; Fluoro = fluoroscopy; M = may be appropriate; MR = mitral regurgitation; R = rarely appropriate; TEE = transesophageal echocardiography; TTE = transthoracic echocardiography.
Clinical considerations - LAA
Clinical considerations - Congenital HD
### 3D-TTE Main indications

**Box 7.1 Main indications for a 3D transthoracic echocardiographic study**

1. Patients with distorted LV anatomy (aneurysm, extensive wall motion abnormalities, etc.) in whom accurate measurement of volumes will be clinically relevant
2. Patients with LV dysfunction who may be candidates for device implantation or complex surgical procedures
3. Patients with heart failure, or right heart diseases that may affect right ventricular size and function
4. Mitral valve assessment in patients referred to mitral valve surgery
5. Evaluation of mitral stenosis
6. Patients with tricuspid stenosis and/or more than mild tricuspid regurgitation in whom assessment of tricuspid valve morphology and severity of regurgitation will be clinically relevant (right heart failure, candidates to left heart cardiac surgery, etc.)
7. Congenital heart diseases
8. Patients with unclear anatomy by 2D imaging.
3D-TOE Main indications

**Box 7.2 Main indications for a 3D transoesophageal echocardiographic study**

1. Assessment of mitral valve anatomy in patients in whom the data will be clinically relevant for management: mitral stenosis, functional or degenerative mitral regurgitation, congenital abnormality with unclear anatomy at transthoracic study, endocarditis

2. Left ventricular outflow tract sizing in patients referred for transcatheter aortic valve implantation who cannot undergo cardiac tomography

3. Assessment of aortic valve anatomy in patients with aortic regurgitation, candidates to aortic valve repair (congenital diseases, aortic valve prolapse, etc.)

4. Left atrial appendage orifice sizing in candidates for device closure

5. Assessment of atrial septal defect anatomy and size in candidates for device closure

6. Suspected or known mitral valve prosthesis, structural or non-structural dysfunction, or endocarditis

7. Guiding/monitoring interventional procedures in the catheterization laboratory

8. Pre- and postoperative assessment of mitral valve and congenital heart disease cardiac surgery

9. Monitoring LV function in high-risk non-cardiac surgery (single beat multi-slicing of the LV will allow a comprehensive monitoring of global and regional wall motion)

10. Cases with doubtful 2D anatomy in transthoracic and transoesophageal studies.
Conclusions

• 3D echocardiography is here to stay

• Despite its limitations (mainly low resolution and time consuming data analysis) it is gaining use in every day clinical practice

• Proven superiority in volumes estimation, in valvular lesions assessment (mainly mitral valve), in congenital heart diseases, in understanding the general anatomic relations

• Absolutely essential in planning and performing interventions such as Mitral clip, TMVI, LAA appendage closure