3D-echocardiography to measure left ventricular function in patients with valvular heart disease

Bernard Cosyns, MD, PhD

No Disclosure
Overview

- **Importance of LV function and geometry in VHD**
  - Management
  - Follow-up
  - Diagnosis

- **How to measure LV function and geometry with echo**
  - M-Mode
  - 2D echo
  - 3D echo
  - Additional methods

- **Clinical perspectives**
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• **Clinical perspectives**
LV function and Geometry in VHD
Management of Aortic Regurgitation

- **Significant enlargement of ascending aorta**
  - No
  - Yes
    - AR severe
      - No
      - Yes
        - Symptoms
          - No
          - Yes
            - \( \text{LV EF} \leq 50\% \text{ or } \text{EDD} > 70 \text{ mm} \text{ or } \text{ESD} > 50 \text{ mm} \text{ (or } > 25 \text{ mm/m}^2 \text{ BSA}) \text{ or } \text{ESD} > 50 \text{ mm} \text{ (or } > 25 \text{ mm/m}^2 \text{ BSA}) \)
              - Follow-up
                - No
                - Yes
                  - Surgery *
              - Surgery *

* surgery must also be considered if significant changes occur during follow-up
LV function and Geometry in VHD

Management of Asymptomatic Severe Chronic Organic Mitral Regurgitation

- Severe asymptomatic organic MR
  - LVEF > 60% and LVESD < 45 mm
    - Yes
    - No
      - Atrial fibrillation or sPAP > 50 mmHg at rest
        - No
          - Follow-up*
        - Yes
          - Surgery (repair whenever possible)
  - * valve repair can be considered when there is a high likelihood of durable valve repair at a low risk

* Follow-up*
LV function and Geometry in VHD

Management of Severe Aortic Stenosis

Severe AS (< 1 cm² or < 0.6 cm²/m² BSA)

Symptoms

No

LV EF < 50%

No

Markedly calcified valve and increase in peak jet velocity ≥ 0.3 m/sec within 1 year

No

Patient physically active

Yes

Exercise test

Normal

Abnormal

Surgery

No

Re-evaluate in 6 to 12 months or when symptoms occur
LV function and Geometry in VHD

Management of Symptomatic Severe Chronic Organic Mitral Regurgitation

- **Severe symptomatic organic MR**
  - LVEF > 30%
    - **No**
      - **Refractory to medical therapy**
        - **No**
          - **Medical therapy**
        - **Yes**
          - **Valve repair is likely and low comorbidity**
            - **Yes**
              - **Surgery (repair whenever possible)**
            - **No**
              - **Medical therapy**

*valve replacement can be considered in selected patients*
### LV function and Preop Prognosis

#### Scoring systems for ICU and surgical patients:

**EuroSCORE (European System for Cardiac Operative Risk Evaluation)**

<table>
<thead>
<tr>
<th>Variables (help)</th>
<th>Values</th>
<th>Beta (Logistic EuroSCORE)</th>
<th>Points (EuroSCORE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>65</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female gender</td>
<td></td>
<td>0.304052</td>
<td>1</td>
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<tr>
<td>Emergency</td>
<td></td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Serum creatinine &gt; 200 µmol/L</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L.V.E.F. (&lt; 30 %)</td>
<td></td>
<td>1.044443</td>
<td>3</td>
</tr>
<tr>
<td>C.O.P.D.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surgery on thoracic sorts</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extracardiac arteriopathy</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neurological dysfunction</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Active endocarditis</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Critical preoperative state</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unstable angina</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recent myocardial infarction (&lt; 90 days)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Systolic PAP &gt; 60 mmHg</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Previous cardiac surgery</td>
<td>Yes</td>
<td>1.002625</td>
<td>3</td>
</tr>
<tr>
<td>Postinfect. sepsis rupture</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other than isolated C.A.B.G.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Logistic EuroSCORE:**

Predict Death Rate = 20.53% × [Logit = −4.789894 + Sum (Beta) × Xi where Xi increase by one point per year thereafter, Predicted death rate = exp(Logit)/(1 + exp(Logit))]

**EuroSCORE= Sum (Beta) × Xi**

**Search references**

- Roques F, Michel P, Goldstone AR, Nasrulf SA. The logistic EuroSCORE. Eur Heart J. 2003 May;24(9):582
  [http://www.euroscore.org/logistic.pdf](http://www.euroscore.org/logistic.pdf)
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Pre-op LVEF in organic MR

![Graph showing survival rates for different EF levels.]

- **EF**
- **EF 50–60%**
- **EF <50%**

Survival rates:
- EF: 73%
- EF 50–60%: 53%
- EF <50%: 32%

Significance: p=0.0001
LV size (Long term survival (flail) LVESD)
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- **Clinical perspectives**
Measurements of Aortic stenosis: LVOT

- PS long axis view
- Zoom mode
- Measurement between insertion of leaflets
- From inner edge to inner edge
- Perpendicular to aortic wall
- During early/mid-systole
- Averaging 3-5 beats

LVOT is measured within 0.5 – 1.0 cm of the valve orifice
3D-E for a better evaluation of AS

\[
Aortic \text{ area (cm}^2) = \frac{SV_{3D} \text{ (cm}^3\text{)}}{TVI_{Ao} \text{ (cm)}}
\]

- \(SV_{3D}\): stroke volume by 3D
- \(TVI_{Ao}\): time-velocity integral by Doppler in the aortic valve

- Volume(s):
  - EDV = 137.2 mL
  - ESV = 53.7 mL
- Calculation(s):
  - EF = 60.8%
  - SV = 83.5 mL

Aortic area = \(\frac{SV_{3D}}{TVI_{Ao}}\)

- GP med Ao = 47 mmHg
- ITU V2 Ao = 117 cm
- U2 media Ao = 323 cm/s
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Old ways to measure: M-Mode (> 40 years)

- Still in the most recent guidelines
- Reference marks from parasternal long and short axis
- Oblique measurement: overestimation
- Cursor not perpendicular (anatomical M-mode)
Old ways to measure: M-Mode

- Only 2 points
- Regional dysfunction
- Abnormal septal motion (LBBB)
- 10% error in diameter gives 30% error in volume
Old way to measure: 2D (>30 years)

- Incorrect orientation views
- Trabeculation and papillary muscle
- Regional dysfunction outside the selected views
- Translation of LV
- Geometric assumptions
- Relative inaccuracy and poor reproducibility
Theoretical advantages of 3D echo

- More accurate anatomic information
- Less geometric assumptions
- The heart is a 3D structure
Feasibility of 3D echo

- Less than 5 min
- Issue of true volumes not settled
- Algorithms based on structural hearts
- No large studies on CHD patients
Automatic Boundary Detection
Need for accuracy and reproducibility

Agreement of 2D vs RT3D compared to MRI
Does RT3D improves reproducibility

2D

3D

Jenkins JACC 2004
Less measurement error of RT3D (MRI std)
Reproducibility in serial fup (1y)
3D Methods for LV volumes measurements

Issues:
- Spatial Resolution
- Boundaries Tracings
- Quality of the Images

Mor-Avi et al  JACC 2008 and Circulation 2009
Improvement with contrast

Krenning et al AJC 2007
Contrast in non-selected patients

![Graph showing EDV vs ESV with statistical comparisons]

<table>
<thead>
<tr>
<th>EDV (207 ± 79 mL)</th>
<th>ESV (117 ± 71 mL)</th>
<th>EF (47 ± 13 %)</th>
<th>MRI</th>
</tr>
</thead>
<tbody>
<tr>
<td>-41 ± 21</td>
<td>-22 ± 18</td>
<td>-2 ± 4</td>
<td>NC–2DE</td>
</tr>
<tr>
<td>-18 ± 19</td>
<td>-8 ± 16</td>
<td>-2 ± 4</td>
<td>CE–2DE</td>
</tr>
<tr>
<td>-15 ± 18</td>
<td>-9 ± 12</td>
<td>0 ± 3</td>
<td>NC–3DE</td>
</tr>
<tr>
<td>-6 ± 14</td>
<td>-3 ± 10</td>
<td>0 ± 3</td>
<td>CE–3DE</td>
</tr>
</tbody>
</table>
# LV size and shape

<table>
<thead>
<tr>
<th>Condition</th>
<th>Normal</th>
<th>Concentric Remodeling (Hypertension)</th>
<th>Concentric Hypertrophy (Hypertension/ AS)</th>
<th>Hypertrophic Cardiomyopathy</th>
<th>Eccentric Hypertrophy (AG/MI Regurgitation)</th>
<th>Dilated Cardiomyopathy</th>
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</thead>
<tbody>
<tr>
<td>Mass</td>
<td>N</td>
<td>N</td>
<td>▲</td>
<td>▲</td>
<td>▲</td>
<td>▲</td>
</tr>
<tr>
<td>Volume</td>
<td>N</td>
<td>N- ▼</td>
<td>N</td>
<td>N- ▼</td>
<td>N- ▼</td>
<td>▲</td>
</tr>
<tr>
<td>RWT</td>
<td>N</td>
<td>▲</td>
<td>▲</td>
<td>▲</td>
<td>N- ▼</td>
<td>▼</td>
</tr>
<tr>
<td>V/M</td>
<td>N</td>
<td>▼</td>
<td>▼</td>
<td>▼</td>
<td>N- ▼</td>
<td>▼</td>
</tr>
<tr>
<td>Systolic stress</td>
<td>N</td>
<td>N- ▼</td>
<td>V</td>
<td>▼</td>
<td>▲</td>
<td>▲</td>
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<tr>
<td>Systolic shortening</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Endocardial</td>
<td>N</td>
<td>N</td>
<td>N- ▼</td>
<td>▲</td>
<td>N</td>
<td>▼</td>
</tr>
<tr>
<td>- Midwall</td>
<td>N</td>
<td>N- ▼</td>
<td>▼</td>
<td>-</td>
<td>N</td>
<td>▼</td>
</tr>
</tbody>
</table>
Prognostic value of inappropriate mass in asymptomatic patients with severe AS

LV mass in 3D
LV Mass 2D vs 3D echo

**2D Echo**
- Observer 1
- Observer 2

- $r = 0.79$
- $y = 0.54x + 19$

**RT3D Echo**

- $r = 0.90$
- $y = 0.86x + 14$
LV mass by 3D echo vs MRI

The graph shows a strong correlation between LV mass measured by 3D echo and CMR, with a regression line given by:

\[ y = 0.91x + 12.1 \]

The correlation coefficient, \( r \), is 0.95, and p < 0.001, indicating a high degree of statistical significance.

The difference in LV mass measurements is shown with a mean difference of -1.8 grams. The standard deviation (SD) of the difference is 19.9 grams, with a range of +2SD (38.0 grams) and -2SD (-41.6 grams).
Experts vs Novices: 3DE is robust

Figure 1

Figure 2
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LVEF in patients with MR

LV EDV = 250 ml  LV ESV = 50 ml

LVEF = 80%
Reg. F = 56%

Forward EF = 24%
LV ejection fraction or LV function

EF 71.5%, ESV 47 ml

EF 74.3%, ESV 44 ml

REST

PSv 10.3 cm/s

GLS 22.7 %

EXERCISE

PSv 11.5 cm/s

GLS 23.8 %
Speckle Tracking

- Independent of transducer orientation
- Allows accurate display of tissue velocity, strain rate, strain, and a host of other derived parameters in 2 orthogonal dimensions.
- Recent studies have shown good accuracy
- Usefulness in the clinical setting

Predictors of postop LVEF (MR)

- **LV Lateral Wall**
  - Strain Rate (1/s)
  - EF (%)
  - $R = 0.71$
  - $P < 0.001$

- **Septum**
  - Strain Rate (1/s)
  - EF (%)
  - $R = 0.82$
  - $P < 0.001$

- **Anterior Wall**
  - Strain Rate (1/s)
  - EF (%)
  - $R = 0.62$
  - $P < 0.001$

- **Inferior Wall**
  - Strain Rate (1/s)
  - EF (%)
  - $R = 0.69$
  - $P < 0.001$
2D strain in AS with preserved LVEF

Ng et al Eur Heart J 2011; 32:1542-1550
Real Time 3D strain

Longitudinal Strain

Circumferential Strain

Radial Strain

Area Strain
Rationale For 3D Speckle

Myocardial deformation is 3D

Better geometric description of LV with 3D

Avoid out-of-plane motion artifacts

- Speckle de-correlation (measurement artifacts)
- False motion / deformation

Courtesy of J. Crosby
Challenges for 3D speckle tracking

- Increased FOV at the cost of both spatial and temporal resolution
- Speckle pattern has less details and de-correlation between subsequent volumes is high
- 3D strain normal values depending on the method used (block matching vs elastic registration)
- Same information 2D in less time
Already available – Experimental validation
3D Speckle tracking:
Strain (L, R, C) Volumes, EF, LV mass
Impact of VHD on torsion

MR patients
Controls

Torsional variable | LV indices | Correlation
--- | --- | ---
Peak systolic torsion | LVIDs | −0.40
 | LVEF | 0.38
 | Mitral regurgitant volume | −0.345
 | Systolic sphericity index | −0.40
 | LV mass index | −0.42
Peak untwisting velocity | LVIDs | −0.44
 | Mitral regurgitant volume | −0.38
Time to onset of untwisting | LVDD | 0.358
 | Mitral regurgitant volume | 0.43
Time to peak untwisting velocity | Mitral regurgitant volume | 0.511

2D-slice acquisitions:

• Distance between image planes?
• All planes parallel?

Real time 3D:

• Distance accurately measured
• Parallel planes easily defined
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Clinical perspectives

- 3D echo is certainly the gold standard for LV function evaluation in patients with VHD:
  - More accurate and reproducible than other echo modes
  - One stop shop
  - More validation required
  - Technical limitations to be overcome
  - Reference values

- 3D echo should be the standard for new prospective studies in patients with VHD

- Competing techniques
Other non-invasive 3D imaging techniques

Portable MRI

Bedside MRI
Ionizing Techniques