When Does 3D Echo Make a Difference?

Anthony DeMaria
University of California, San Diego
No Disclosures
Why do 3D imaging?
Real-time, Touch-button 3DE

- Matrix Array Transducer
- Fully sampled
- Supercomputing
- Instantaneous volume rendering
- Intelligent Navigator
Echo vs Cine: Ejection Fraction

3D Echo EF vs Cine EF:
- Correlation coefficient ($r$) = 0.94
- Standard Error of the Estimate (SEE) = 0.054
- Linear regression equation: $y = 0.95x + 0.06$

2D Echo EF vs Cine EF:
- Correlation coefficient ($r$) = 0.76
- Standard Error of the Estimate (SEE) = 0.105
- Linear regression equation: $y = 0.72x + 0.22$
### Table 1. Differences between left ventricular volumes and function assessed by three-dimensional echocardiography and conventional two-dimensional echocardiography in comparison with cardiac magnetic resonance

<table>
<thead>
<tr>
<th>Author</th>
<th>End-diastolic volume (mL)</th>
<th>End-systolic volume (mL)</th>
<th>Ejection fraction (%)</th>
<th>End-diastolic volume (mL)</th>
<th>End-systolic volume (mL)</th>
<th>Ejection fraction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jenkins et al. 4)</td>
<td>-4 ± 9</td>
<td>-3 ± 18</td>
<td>0 ± 7</td>
<td>-54 ± 33</td>
<td>-28 ± 28</td>
<td>-1 ± 13</td>
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<tr>
<td>Kühl et al. 5)</td>
<td>-13.6 ± 18.9</td>
<td>-12.8 ± 20.5</td>
<td>0.9 ± 4.4</td>
<td>-23 ± 86</td>
<td>-19 ± 60</td>
<td>3.7 ± 16</td>
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<tr>
<td>Caiani et al. 6)</td>
<td>-4.1 ± 29</td>
<td>-3.5 ± 33</td>
<td>-8 ± 14</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Shiota et al. 7)</td>
<td>-43 ± 65</td>
<td>-37 ± 67</td>
<td>1 ± 4</td>
<td>-</td>
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<tr>
<td>Zeidan et al. 8)</td>
<td>-6 ± 11</td>
<td>-4 ± 9</td>
<td>2 ± 5</td>
<td>-</td>
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<tr>
<td>Chan et al. 9)</td>
<td>-10.4 ± 26.4</td>
<td>-0.9 ± 18.8</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Corsi et al. 10)</td>
<td>2.9 ± 12</td>
<td>2.8 ± 7</td>
<td>-1 ± 5</td>
<td>-</td>
<td>-</td>
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<td>Sugeng et al. 11)</td>
<td>-4</td>
<td>-1</td>
<td>2</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Nikitin et al. 12)</td>
<td>7 ± 28</td>
<td>3 ± 22</td>
<td>-1 ± 10</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Jacobs et al. 13)</td>
<td>-14 ± 17</td>
<td>-6.5 ± 16</td>
<td>-1 ± 6</td>
<td>-23 ± 29</td>
<td>-15 ± 24</td>
<td>1 ± 9</td>
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<td>Gutiérrez-Chico et al. 14)</td>
<td>-3 ± 1</td>
<td>2 ± 7</td>
<td>0 ± 6</td>
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<tr>
<td>van den Bosch et al. 15)</td>
<td>-3 ± 12</td>
<td>-12 ± 31</td>
<td>-1 ± 7</td>
<td>-</td>
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<tr>
<td>Pouleur et al. 16)</td>
<td>-20 ± 31</td>
<td>-12 ± 31</td>
<td>1 ± 11</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Qi et al. 17)</td>
<td>-22 ± 23</td>
<td>-15 ± 20</td>
<td>5 ± 10</td>
<td>-</td>
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<tr>
<td>Bicudo et al. 18)</td>
<td>-4</td>
<td>0.3</td>
<td>-2</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Shimada et al. 19)</td>
<td>-9.9</td>
<td>-4.7</td>
<td>-0.13</td>
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</tr>
</tbody>
</table>

Mean difference ± SD from cardiac magnetic resonance
Performance of 3-Dimensional Echocardiography in Measuring Left Ventricular Volumes and Ejection Fraction

A Systematic Review and Meta-Analysis

Jennifer L. Dorosz, MD,* Dennis C. Lezotte, PhD,† David A. Weitzenkamp, PhD,† Larry A. Allen, MD, MHS,* Ernesto E. Salcedo, MD*

Aurora, Colorado

Figure 3  Three-Dimensional Echocardiography Versus Cardiac Magnetic Resonance

The absolute Bland-Altman difference between 3DE and CMR, expressed as bias ± 2 SDs for each sub-study. The overall pooled results are shown at the bottom. End-diastolic volume (EDV), end-systolic volume (ESV), and ejection fraction (EF) are shown in A, B, and C, respectively. Abbreviations as in Figures 1 and 2.
Determining accurate left ventricular (LV) function is clinically important. Three-dimensional echocardiography (3DE) achieves better estimation than 2-dimensional echocardiography. However, underestimation of LV volumes has often been reported without a systematic attempt to synthesize these data. This meta-analysis aimed to assess the bias of 3DE in evaluating LV volumes and ejection fraction (EF) and to investigate factors affecting that bias. Studies that compared LV volumes and/or EF between 3DE and magnetic resonance imaging were eligible. Meta-analysis of 95 studies including 3,055 subjects revealed significant underestimation of LV end-systolic volume (−4.7 ml, p <0.0001) and end-diastolic volume (−9.9 ml, p <0.0001), whereas measurement for EF revealed excellent accuracy (−0.13%, p = 0.41). Meta-regression analysis for factors of systematic bias in volumetry revealed that female gender and existence of cardiac disease were associated with more underestimation, whereas use of semiautomatic tracking and matrix-array transducers counteracted the underestimation. In conclusion, by meta-analysis synthesizing many small studies, we found underestimation of LV volumes and factors affecting the systematic bias by 3DE. These data provide a more detailed basis for analyzing and improving the accuracy of 3DE, an indispensable step toward further clinical application in LV assessment. © 2011 Elsevier Inc. All rights reserved. (Am J Cardiol 2011;107:126–138)
3D Makes a Difference

• LV volumes and EF
  – Choosing pharmacologic therapy
  – Using resynchronization
  – Implanting defibrillators
  – Cardio-oncology

• RV structure and function

• Mitral Valve Disease
  – Prolapse
  – Stenosis

• Tricuspid Valve Disease
Published Trials in Which EF was Part of the Entry Criteria (Partial List)

- SOLVD Treatment Trial
- SOLVD Prevention Trial
- SAVE
- US Cravedilol Trials
- MERIT-HF
- CIBIS 1 & 2
- COPERNICUS
- CAPRICORN
- RALES
- ELITE 1 & 2
- Val-HEFT
- PRAISE 1 & 2
- OVERTURE
- CHARM
- PARADIGM
2012 ACCF/AHA/HRS Focused Update Incorporated Into the ACCF/AHA/HRS 2008 Guidelines for Device-Based Therapy of Cardiac Rhythm Abnormalities

A Report of the American College of Cardiology Foundation/American Heart Association Task Force on Practice Guidelines and the Heart Rhythm Society

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William G. Stevenson, MD, FACC, FAHA, FHRS***; Paul D. Varosy, MD, FACC, FHRS†
RECOMMENDATIONS FOR CARDIAC RESYNCHRONIZATION THERAPY IN PATIENTS WITH SYSTOLIC HEART FAILURE

Class I Recommendations

CRT is indicated for patients who have*

- LVEF ≤ 35%
- Left Bundle Branch Block (LBBB)
- NYHA class II, III, or ambulatory Class IV symptoms
- Sinus rhythm
- QRS duration ≥ 150 ms
- Guideline-Directed Medical Therapy

(Level of Evidence: A for NYHA class III/IV; Level of Evidence: B for NYHA class II)

Guidelines for Cardiac Resynchronization

<table>
<thead>
<tr>
<th>Class Ila Recommendations</th>
</tr>
</thead>
<tbody>
<tr>
<td>CRT can be useful for patients who have:</td>
</tr>
<tr>
<td>• LVEF ≤ 35%</td>
</tr>
<tr>
<td>• Sinus rhythm</td>
</tr>
<tr>
<td>• LBBB</td>
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<tr>
<td>• QRS duration 120 to 149 ms</td>
</tr>
<tr>
<td>• NYHA class II, III, or ambulatory Class IV symptoms</td>
</tr>
<tr>
<td>• Guideline-Directed Medical Therapy</td>
</tr>
<tr>
<td>(Level of Evidence: B)</td>
</tr>
<tr>
<td>CRT can be useful for patients who have:</td>
</tr>
<tr>
<td>• Atrial fibrillation</td>
</tr>
<tr>
<td>• LVEF ≤ 35%</td>
</tr>
<tr>
<td>• Guideline-Directed Medical Therapy</td>
</tr>
<tr>
<td>If a) the patient requires ventricular pacing or otherwise meets CRT criteria and b) AV nodal ablation or pharmacologic rate control will allow near 100% ventricular pacing with CRT.</td>
</tr>
<tr>
<td>(Level of Evidence: B)</td>
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<tr>
<td>CRT can be useful for patients who have:</td>
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<tr>
<td>• LVEF ≤ 35%</td>
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<tr>
<td>• Guideline-Directed Medical Therapy</td>
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<tr>
<td>• Non-LBBB pattern</td>
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<tr>
<td>• QRS duration ≥ 150 ms</td>
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<tr>
<td>• NYHA class III, or ambulatory Class IV symptoms</td>
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<tr>
<td>• Guideline-Directed Medical Therapy</td>
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<tr>
<td>(Level of Evidence: A)</td>
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<tr>
<td>CRT can be useful for patients who have:</td>
</tr>
<tr>
<td>• LVEF ≤ 35%</td>
</tr>
<tr>
<td>• Guideline-Directed Medical Therapy</td>
</tr>
<tr>
<td>• Anticipated requirement for significant (&gt; 40%) ventricular pacing</td>
</tr>
<tr>
<td>(Level of Evidence: C)</td>
</tr>
</tbody>
</table>
RECOMMENDATIONS FOR IMPLANTABLE CARDIOVERTER DEFIBRILLATORS

Class I Recommendations

ICD therapy is indicated in patients*:

*Level of Evidence: A*

- With LVEF ≤ 35% due to prior MI who are at least 40 days post-MI and are in NYHA Functional Class II or III
- With LV dysfunction due to prior MI who are at least 40 days post-MI, have an LVEF ≤ 30%, and are in NYHA Functional Class I
- Who are survivors of cardiac arrest due to VF or hemodynamically unstable sustained VT after evaluation to define the cause of the event and to exclude any completely reversible causes

*Level of Evidence: B*

- With nonischemic DCM who have an LVEF ≤ 35% and who are in NYHA Functional Class II or III
- With nonsustained VT due to prior MI, LVEF < 40%, and inducible VF or sustained VT at electrophysiological study
- With structural heart disease and spontaneous sustained VT, whether hemodynamically stable or unstable
- With syncope of undetermined origin with clinically relevant, hemodynamically significant sustained VT or VF induced at electrophysiological study
Estimated Number of Cancer Survivors in the US

Year


Millions

0 2 4 6 8 10 12 14 16 18 20

Projections

DeSantis C, Chunchieh L, Mariotto AB, et al. (2014). Cancer Treatment and Survivorship Statistics,
LEADING CAUSES OF DEATH AFTER BREAST CANCER DIAGNOSIS
CARDIOVASCULAR COMPLICATIONS OF CANCER THERAPY

<table>
<thead>
<tr>
<th>Condition</th>
<th>Survivors (N = 10,397)</th>
<th>Siblings (N = 3034)</th>
<th>Relative Risk (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Major joint replacement*</td>
<td>1.61</td>
<td>0.03</td>
<td>54.0 (7.6–386.3)</td>
</tr>
<tr>
<td>Congestive heart failure</td>
<td>1.24</td>
<td>0.10</td>
<td>15.1 (4.8–47.9)</td>
</tr>
<tr>
<td>Second malignant neoplasm†</td>
<td>2.38</td>
<td>0.33</td>
<td>14.8 (7.2–30.4)</td>
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<tr>
<td>Cognitive dysfunction, severe</td>
<td>0.65</td>
<td>0.10</td>
<td>10.5 (2.6–43.0)</td>
</tr>
<tr>
<td>Coronary artery disease</td>
<td>1.11</td>
<td>0.20</td>
<td>10.4 (4.1–25.9)</td>
</tr>
<tr>
<td>Cerebrovascular accident</td>
<td>1.56</td>
<td>0.20</td>
<td>9.3 (4.1–21.2)</td>
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<tr>
<td>Renal failure or dialysis</td>
<td>0.52</td>
<td>0.07</td>
<td>8.9 (2.2–36.6)</td>
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<tr>
<td>Hearing loss not corrected by aid</td>
<td>1.96</td>
<td>0.36</td>
<td>6.3 (3.3–11.8)</td>
</tr>
<tr>
<td>Legally blind or loss of an eye</td>
<td>2.92</td>
<td>0.69</td>
<td>5.8 (3.5–9.5)</td>
</tr>
<tr>
<td>Ovarian failure‡</td>
<td>2.79</td>
<td>0.99</td>
<td>3.5 (2.7–5.2)</td>
</tr>
<tr>
<td>Chemotherapy Agents</td>
<td>Incidence (%)</td>
<td>Frequency of Use</td>
<td></td>
</tr>
<tr>
<td>----------------------------------------------------------</td>
<td>---------------</td>
<td>------------------</td>
<td></td>
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<tr>
<td>Anthracyclines</td>
<td></td>
<td></td>
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<tr>
<td>Doxorubicin (Adriamycin) (6,7)</td>
<td>3–26*</td>
<td>+++</td>
<td></td>
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<tr>
<td>Epirubicin (Ellence) (10)</td>
<td>0.9–3.3</td>
<td>++</td>
<td></td>
</tr>
<tr>
<td>Idarubicin (Idamycin PFS) (8)</td>
<td>5–18</td>
<td>+</td>
<td></td>
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<tr>
<td>Alkylating agents</td>
<td></td>
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<td></td>
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<tr>
<td>Cyclophosphamide (Cytoxan) (8,11–13)</td>
<td>7–28</td>
<td>+++</td>
<td></td>
</tr>
<tr>
<td>Ifosfamide (Ifex) (8,14)</td>
<td>17</td>
<td>+++</td>
<td></td>
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<tr>
<td>Antimetabolites</td>
<td></td>
<td></td>
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<tr>
<td>Clofarabine (Clofar) (10)</td>
<td>27</td>
<td>+</td>
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<tr>
<td>Antimicrotubule agents</td>
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<tr>
<td>Docetaxel (Taxotere) (10,15,16)</td>
<td>2.3–8</td>
<td>++</td>
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<tr>
<td>Monoclonal antibody-based tyrosine kinase inhibitors</td>
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<tr>
<td>Bevacizumab (Avastin) (10,18,19)</td>
<td>1.7–3</td>
<td>++</td>
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<tr>
<td>Trastuzumab (Herceptin) (20–28)</td>
<td>2–28</td>
<td>++</td>
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<tr>
<td>Proteasome inhibitor</td>
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<tr>
<td>Bortezomib (Velcade) (10,17)</td>
<td>2–5</td>
<td>++</td>
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<tr>
<td>Small molecule tyrosine kinase inhibitors</td>
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<tr>
<td>Dasatinib (Sprycel) (10)</td>
<td>2–4</td>
<td>++</td>
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<tr>
<td>Imatinib mesylate (Gleevec) (34,35)</td>
<td>0.5–1.7</td>
<td>+</td>
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<tr>
<td>Lapatinib (Tykerb) (32)</td>
<td>1.5–2.2</td>
<td>+</td>
<td></td>
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<tr>
<td>Sunitinib (Sutent) (36,37)</td>
<td>2.7–11</td>
<td>+++</td>
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</tbody>
</table>
Expert Consensus for Multimodality Imaging Evaluation of Adult Patients during and after Cancer Therapy: A Report from the American Society of Echocardiography and the European Association of Cardiovascular Imaging

Juan Carlos Plana, MD, FASE, Chair, Maurizio Galderisi, MD, FESC, Co-Chair, Ana Barac, MD, PhD, Michael S. Ewer, MD, JD, Bonnie Ky, MD, FASE, Marielle Scherrer-Crosbie, MD, PhD, FASE, Javier Ganame, MD, PhD, FASE, Igal A. Sebag, MD, FASE, Deborah A. Agler, RCT, RDSC, FASE, Luigi P. Badano, MD, PhD, FESC, Jose Banchs, MD, FASE, Daniela Cardinale, MD, PhD, FESC, Joseph Carver, MD, Manuel Cerqueira, MD, Jeanne M. DeCara, MD, FASE, Thor Edvardsen, MD, PhD, FESC, Scott D. Flamm, MD, MBA, Thomas Force, MD, Brian P. Griffin, MD, Guy Jerusalem, MD, PhD, Jennifer E. Liu, MD, FASE, Andreia Magalhães, MD, Thomas Marwick, MBBS, PhD, MPH, Liza Y. Sanchez, RCS, FASE, Rosa Sicari, MD, PhD, FESC, Hector R. Villarraga, MD, FASE, and Patrizio Lancellotti, MD, PhD, FESC, Cleveland, Ohio; Naples, Padua, Milan, and Pisa, Italy; Washington, District of Columbia; Houston, Texas; Philadelphia, Pennsylvania; Boston, Massachusetts; Hamilton, Ontario and Montreal, Quebec, Canada; Chicago, Illinois; Oslo, Norway; Liege, Belgium; New York, New York; Lisbon, Portugal; Hobart, Australia; Rochester, Minnesota
• **Anthracycline-based regimen:**
  
  echo at baseline, upon completion of therapy and 6 months after

• **HER-2 inhibitors (Herceptin/trastuzumab):**
  
  echo at baseline, and every 3 months during therapy, and once after completion of therapy
MINIMAL DETECTABLE CHANGE BETWEEN SERIAL EXAMS FOR EF MEASUREMENT WITH SIMPSON’S BIPLANE METHOD IS 12%

Reproducibility of Echocardiographic Techniques for Sequential Assessment of Left Ventricular Ejection Fraction and Volumes

Application to Patients Undergoing Cancer Chemotherapy

Paaladinesh Thavendiranathan, MD, MSc, Andrew D. Grant, MD, Tomoko Negishi, MD, Juan Carlos Plana, MD, Zoran B. Popović, MD, PhD, Thomas H. Marwick, MD, PhD, MPH

Cleveland, Ohio

Thavendiranathan, 2013
MINIMAL DETECTABLE CHANGE FOR EF MEASUREMENT

N=56
TEMPORAL VARIABILITY OF EF

N=56
1 year follow-up

<table>
<thead>
<tr>
<th>Method</th>
<th>EF SEM</th>
<th>95% CI</th>
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<tbody>
<tr>
<td>Bi</td>
<td>0.049</td>
<td>(0.045–0.054)</td>
</tr>
<tr>
<td>Bi + CO</td>
<td>0.058</td>
<td>(0.053–0.065)*</td>
</tr>
<tr>
<td>Tri</td>
<td>0.059</td>
<td>(0.054–0.065)</td>
</tr>
<tr>
<td>Tri + CO</td>
<td>0.065</td>
<td>(0.058–0.072)</td>
</tr>
<tr>
<td>3D</td>
<td>0.028</td>
<td>(0.025–0.031)*</td>
</tr>
<tr>
<td>3D + CO</td>
<td>0.051</td>
<td>(0.046–0.057)*</td>
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TEMPORAL VARIABILITY IN EDV AND ESV

N=56

<table>
<thead>
<tr>
<th></th>
<th>EDV SEM (ml)</th>
<th>95% CI</th>
<th>ESV SEM (ml)</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bi</td>
<td>19.0</td>
<td>(17.4–20.9)</td>
<td>8.0</td>
<td>(7.3–8.8)</td>
</tr>
<tr>
<td>Bi + CO</td>
<td>16.1</td>
<td>(14.6–17.9)*</td>
<td>8.3</td>
<td>(7.5–9.2)</td>
</tr>
<tr>
<td>Tri</td>
<td>21.1</td>
<td>(19.3–23.2)</td>
<td>9.8</td>
<td>(8.9–0.7)</td>
</tr>
<tr>
<td>Tri + CO</td>
<td>20.0</td>
<td>(18.0–22.2)</td>
<td>9.5</td>
<td>(8.6–10.6)</td>
</tr>
<tr>
<td>3D</td>
<td>10.5</td>
<td>(9.6–11.6)</td>
<td>5.0</td>
<td>(4.6–5.5)</td>
</tr>
<tr>
<td>3D + CO</td>
<td>18.1</td>
<td>(16.4–20.2)*</td>
<td>8.8</td>
<td>(8.0–9.8)*</td>
</tr>
</tbody>
</table>
INTEROBSERVER AND INTRAOBSERVER VARIABILITY FOR EF MEASUREMENT

N=56

- Intraobserver
- Interobserver
- Interobserver test-retest

%  
0  1  2  3  4  5  6  7  8  

Biplane  Biplane+Co  Triplane  Triplane+Co  3D  3D+Co
Initiation of regimen potentially associated with Type I toxicity

Baseline evaluation of LVEF
- 3DE (preferred) / 2DE (consider contrast)
- GLS, Troponin I

LVEF < 53%*
- GLS < LLN**
- + Troponins
  - Cardiology consultation

LVEF > 53%*
- GLS > LLN**
- - Troponins
  - F/U at completion of therapy, and 6 months later***

* Where feasible, baseline LVEF should be obtained before chemotherapy
** In the absence of baseline LVEF, GLS can be used to assess baseline LV function
*** F/U is to assess for progression of cardiomyopathy or resolution of cardiotoxicity
Dynamic Assessment of Right Ventricular Volumes and Function by Real-Time Three-Dimensional Echocardiography: A Comparison Study With Magnetic Resonance Imaging in 100 Adult Patients

Gregor Leibundgut, MD, Andreas Rohner, MD, Leticia Grize, Alain Bernheim, MD, Arnheid Kessel-Schaefer, MD, Jens Bremerich, MD, Michael Zellweger, MD, Peter Buser, Prof, and Michael Handke, Prof, Basel, Switzerland

Figure 5  Mean values of RV volumes and ejection fraction obtained by MRI versus RT3DE imaging. Error bars indicate the standard deviation of measurements. RVEDV, RV end-diastolic volume; RVEF, RV ejection fraction; RVESV, RV end-systolic volume; RVSV, RV stroke volume.
3D in Mitral Valve Disease
Regurgitation

Round hole in a flat object

Perfect PISA hemisphere

Circular Vena Contrata
PISA, Vena Contracta Pitfalls

Assumptions

“Regurgitant orifice circular”

“Flow convergence perfect hemisphere”

“Vena contracta circular”

“1 frame in 1 view reflects whole Regurg”

“There is only one regurgitant orifice”
Quantification of Functional Mitral Regurgitation by Real-Time 3D Echocardiography

Comparison With 3D Velocity-Encoded Cardiac Magnetic Resonance

Nina Ajmone Marsan, MD,*§ Jos J. M. Westenberg, PhD,† Claudia Ypenburg, MD,* Victoria Delgado, MD,* Rutger J. van Bommel, MD,* Stijntje D. Roes, MD,‡ Gaetano Nucifora, MD,* Rob J. van der Geest, PhD,† Albert de Roos, MD, PhD,‡ Johan C. Reiber, PhD,† Martin J. Schalij, MD, PhD,* Jeroen J. Bax, MD, PhD*
3D Imaging to study Cardiac Remodeling

What is Cardiac Remodeling?
Remodeling

Remaking
Adjustment
Adaptation
Alteration
Conversion
Refitting
Transformation
Reformation
Reshaping
Distortion
Enlargement
Ventricular Remodeling

... more than chamber enlargement ...
Ventricular Remodeling

Physiologic
- Athletes
- Normal Growth

Pathologic
- Ischemia
- Other diseases
Cardiac Remodeling

Injury
Inflammation
Increased Load ➔

Molecular Pathways
Metabolic Pathways
Mechanical Pathways

Adaptive Remodeling

Adverse Remodeling
LV Remodeling
Ventricular Remodeling

- Structural Remodeling
  Size, Mass, Shape
Ventricular Remodeling

- Structural Remodeling
  Size, Mass, Shape

- Mechanical Remodeling
  Systole, Diastole
Ventricular Remodeling

- Structural Remodeling
  Size, Mass, Shape
- Mechanical Remodeling
  Systole, Diastole
- Electrical Remodeling
  Arrhythmias
Ventricular Remodeling

Why worry about Ventricular Remodeling?
Ventricular Dilatation
Myocardial Stretch

**Acute**
- Mechano-electrical coupling
  - Stretch-activated channels (esp non-selective channels, Na and Ca entering the cells)
  - Depolarization, Change in action potential duration
  - Arrhythmia

**Chronic**
- Gene expression activation
  - Growth factors
    - Angiotensin II
    - Endothelin-1
  - Cell proliferation
    - Hypertrophy
    - Fibrosis
Dilatation of LV and Arrhythmia After Myocardial Infarction

Dilation of the infarcted/non-infarcted zones
Increased dispersion in the refractoriness
Early afterdepolarizations
  (caused by an increased in wall stress; contraction-excitation feedback)

LVESV: continued enlargement in 1 year
  associated with high frequency of arrhythmias
  (CATS: captril and thrombolysis study)

J Cardiac Failure 1994; 1:3-11.
End Systolic Volume Index and Prognosis

Multitude of studies and trials...

Systolic Function

Diagnosis

Prognosis

Therapy
MADIT II

Probability of survival

Coronary Disease

EF < 30%

ICD

EF > 30%

VT

EPS

No. at risk
Defibrillator  742  503 (0.91)  274 (0.84)  110 (0.78)  9
Conventional  490  329 (0.90)  170 (0.78)  65 (0.69)  3

Year
LV Mass

Chiang et al. Circulation 41:31, 1970
Cooper et al. 65:441, 1990
Levy et al. NEJM 322:1561, 1990
Devereux et al. AJC 86:1090, 2000
Aurigemma et al. JACC 37:1042, 2001
Gardin et al. AJC 87:1051, 2001
LV Mass

- Independent Predictor of Morbidity
- Independent Predictor of Mortality
- Marker of Sudden Death
- Both in Preserved and Decreased EF
- Independent of Diastolic Dysfunction
- Neurohormonal Activation
- Deranged Myocyte Perfusion

References:
- Chiang et al. Circulation 41:31, 1970
- Levy et al. NEJM 322:1561, 1990
- Devereux et al. AJC 86:1090, 2000
- Aurigemma et al. JACC 37:1042, 2001
- Gardin et al. AJC 87:1051, 2001
LV Shape

Diagnostic Implications
Prognostic Connotations
Therapeutic Value
Ventricular Remodeling

• Determinant of heart failure and related complications
Ventricular Remodeling

Remodeling

Heart Failure
Ventricular Remodeling

- Impacts Survival

Need to reverse the process
Ventricular Remodeling

What methods to study Ventricular Remodeling?
Ventricular Remodeling

- Echocardiography
- Radionuclide Anhiography
- Magnetic Resonance
- Computed Tomography
Echocardiography

- Increased LVEDV and LVESV
- Concentric or Eccentric Hypertrophy
- Increased Volume/Mass Ratio
- Altered Geometry
- Reduced Ejection Fraction
- Increased global/regional wall stress
- Impaired diastolic function
- Ventricular dyssynchrony
- RV remodeling
- Atrial remodeling
- Valvular Disorder
Echocardiography

- **M-mode:** Dimension, %FS
- **2D Echo:** Volumes, EF, Shape, Mass
- **Doppler:** Hemodynamics, Flow disorders
Ventricular Remodeling

... more than
dimension/area increase ...

M-mode, 2DE
Limitations
Ejection Fraction Impact Numbers

- 50%
- 40%
- 35%
Problems in the 2D Echo
Quantification of Volumes and EF:

- Can’t see the borders
- Foreshortened views
- Off-axis views
- Translational motion
Life is not always easy ...
Problems in the 2D Echo
Quantification of Volumes and EF:

- Foreshortened views
- Off-axis views
- Translational motion

3D Echo improves the accuracy
3D Echo Quantification
3D Echo vs MRI for LV Volumes and EF

EDV 3D Echo vs EDV RMI

R = 0.95
p < 0.001

ESV 3D Echo vs ESV RMI

R = 0.93
p < 0.001

EF 3D Echo vs EF RMI

R = 0.88
p < 0.001

DIFF EDV (3D Echo - RMI)

Mean EDV (ml/m²)

DIFF ESV (3D Echo - RMI)

Mean ESV (ml/m²)

DIFF EF (3D Echo - RMI)

Mean EF (%)
3D quantitation of LV Geometry
3D Echo Quantitation of Ischemic Mass
The left atrial function and volume: prognostic markers in different cardiac diseases (arrhythmias, valvular and congenital disease)

Left Atrial Volume
A Powerful Predictor of Survival After Acute Myocardial Infarction

Jacob E. Møller, MD, PhD; Graham S. Hillis, MBChB, PhD; Jae K. Oh, MD; James B. Seward, MD; Guy S. Reeder, MD; R. Scott Wright, MD; Seung W. Park, MD, PhD; Kent R. Bailey, PhD; Patricia A. Pellikka, MD

Left Atrial Volume as an Index of Left Atrial Size: A Population-Based Study

Allison M. Pritchett, MD,* Steven J. Jacobsen, MD, PhD,+ Douglas W. Mahoney, MS,+ Richard J. Rodeheffer, MD, FACC,* Kent R. Bailey, PhD,+ Margaret M. Redfield, MD, FACC*

Rochester, Minnesota
M-mode and 2D methods to measure LA size

**Monoplane volume (M-mode, Teicholz formula)**

\[
\frac{EDD^3 \times 7}{2.4 + EDD}
\]

**Monoplane volume (area/length, Dodge correction)**

\[
\frac{(area \ planimetry^2 \times 8)}{3 \times \pi \times long \ axis}) \times 0.951) - 3
\]

**Biplane volume (area/length, Dodge correction)**

\[
\frac{(area \ planimetry \ 1 \times area \ planimetry \ 2 \times 8)}{3 \times \pi \times smallest \ long \ axis}
\]
LA Volumes

LA volume in heart failure patients

Regression of 3D and 2D LA volumes

\[ y = 0.753x + 3.5646 \]
\[ R^2 = 0.9236, p = 0.0001 \]
95% CI: 0.564 to 0.865
RV Dysfunction and Outcome

SAVE Investigators
J Am Coll Cardiol 2002 May 1;39(9):1450-5
Studies examining RV Function and Outcomes in Heart Failure

<table>
<thead>
<tr>
<th>Study</th>
<th>Date</th>
<th>#pts</th>
<th>NYHA</th>
<th>Technique</th>
<th>Endpoint</th>
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<tr>
<td>Polak JF, et al.</td>
<td>1983</td>
<td>34</td>
<td>N/A</td>
<td>RVG</td>
<td>survival</td>
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<td>Baker BJ, et al.</td>
<td>1984</td>
<td>25</td>
<td>N/A</td>
<td>RVG</td>
<td>exer</td>
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<td>Lewis JF, et al.</td>
<td>1993</td>
<td>67</td>
<td>II-IV</td>
<td>ECHO(rva/lva)</td>
<td>survival</td>
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<td>DiSalvo TG, et al.</td>
<td>1995</td>
<td>67</td>
<td>III-IV</td>
<td>RVG</td>
<td>ex/surv</td>
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<tr>
<td>Gavazzi A, et al.</td>
<td>1995</td>
<td>142</td>
<td>III-IV</td>
<td>Thermodilution</td>
<td>survival</td>
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<tr>
<td>Sun JP, et al.</td>
<td>1997</td>
<td>100</td>
<td>I-IV</td>
<td>ECHO(rva/lva)</td>
<td>survival</td>
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<td>DeGroote P, et al.</td>
<td>1998</td>
<td>205</td>
<td>II-III</td>
<td>RVG</td>
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<td>Karasatakis GT, et al.</td>
<td>1998</td>
<td>40</td>
<td>II-IV</td>
<td>ECHO(tapse)</td>
<td>survival</td>
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<td>Hung J, et al.</td>
<td>1998</td>
<td>117</td>
<td>II-IV</td>
<td>ECHO(tr)</td>
<td>survival</td>
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<tr>
<td>Ghio S, et al.</td>
<td>2000</td>
<td>140</td>
<td>II-IV</td>
<td>ECHO(tapse)</td>
<td>survival</td>
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<tr>
<td>Ghio S, et al.</td>
<td>2001</td>
<td>377</td>
<td>II-IV</td>
<td>Thermodilution</td>
<td>survival</td>
</tr>
</tbody>
</table>

Diagnosis
Clinical expression
Prognosis
Therapeutic decision making
Implications for assist devices
Patients waiting
For Transplant

LVAD, RVAD or Both?
Tricuspid Annular Velocity in the Identification of Systolic RV dysfunction (RV EF < 40%)

<table>
<thead>
<tr>
<th></th>
<th>TDI &lt; 9</th>
<th>TDI &lt; 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitivity</td>
<td>57% (95%CI 35-79%)</td>
<td>57% (95%CI 35-79%)</td>
</tr>
<tr>
<td>Specificity</td>
<td>92% (95%CI 80-100%)</td>
<td>77% (95%CI 58-95%)</td>
</tr>
<tr>
<td>Accuracy</td>
<td>80% (95%CI 62-97%)</td>
<td>70% (95%CI 50-90%)</td>
</tr>
<tr>
<td>PPV</td>
<td>80% (95%CI 62-97%)</td>
<td>57% (95%CI 35-79%)</td>
</tr>
<tr>
<td>NPV</td>
<td>80% (95%CI 62-97%)</td>
<td>77% (95%CI 58-95%)</td>
</tr>
</tbody>
</table>
Quantitation of RV volumes, EF
RV Volumes by Live 3D Echo

Linear regression with 95% Mean Prediction Interval

EDV (ml) Live 3D Echo

ESV (ml) Live 3D Echo

EF (%) Live 3D Echo

Bland-Altman Plots

Mean EDV (ml)

Mean ESV (ml)

Mean EF (%)
RV Volumes by Live 3D Echo

Linear regression with 95% Mean Prediction Interval

Bland-Altman Plots

EDV (ml) Live 3D Echo

ESV (ml) Live 3D Echo

EF (%) Live 3D Echo

Mean EDV (ml)

Mean ESV (ml)

Mean EF (%)
Heart Failure

Pharmacologic Rx

Mechanical Interventions

Transplantation

Novel Therapy
CRT - Issues

- QRS does not predict response
- QRS does not represent true dyssynchrony
Assessment of Dyssynchrony by 3D Echo

Before CRT

After CRT
Geometric Procedures
For Heart Failure
Surgical Ventricular Restoration

Constraint Devices

Support Device
PISA technique

Regurgitant volume
Regurgitant fraction
Regurgitant Orifice Area
PISA, Vena Contracta

Assumptions

“Regurgitant orifice circular”

“Flow convergence perfect hemisphere”

“Vena contracta circular”

“1 frame in 1 view reflects whole AR”

“There is only one regurgitant orifice
Regurgitation

Round hole
In a flat object

Perfect PISA hemisphere

Circular Vena Contrata

Real life
Regurgitant Orifices
Mitral Regurgitation

- Pts with post-MI MR more likely to experience combined end point of CV mortality, severe HF, or recurrent MI
  - SOLVD trial 1997
  - 47% vs. 29%
  - P < .001
- Independent predictor of CV mortality
  - (relative risk, 2.00; 95% CI, 1.28 to 3.04)
Geometric Distortion Contributing to MR

Regional LV dilation/dysfunction

Global LV dilation/dysfunction
Surgical Annuloplasty for Functional
MR in CHF

First 48 patients*

Operative Mortality = 2.1%

LOS = 9 ± 4 d (5-37)

Expanded series - 92 patients*

30 d Operative Mortality = 5.4%

Sicker pts, Less experienced Surgeon

Operative Mortality = ?

*Bolling S et al
Catheter device
3D Imaging in Heart Failure

3D Echo vs. CMR

Widely available

Easy to use in any setting
3D Imaging in Heart Failure

- Better appraisal of functional morphology
- More accurate study of remodeling
- Aid to innovative therapeutic procedures
- Good investigative tool to study the heart
Thank you!