Evolution of Echocardiography

1D
M-mode

2D
Cut plane

3D
Reconstruction
Real-time
3D Reconstructive Methods

Spatial Locators
Mechanically Driven transducers

Gated Sequential Acquisition

Off-line 3D Image Processing and Reconstruction
Real-Time 3D Acquisition: Sparse Array

Sparse Array (~300 elements)
Volumetrics

Courtesy of Dr. Masood Ahmad, UTMB Galveston

Real-Time 3D Acquisition: Matrix Array
Matrix Array: Advanced Technologies

Microelectronics in the Transducer

>150 Boards

Electronics needed for 3000 Elements

Compressed into Application Specific ICs (Next Generation ASICs)

Compressed into Ergonomic Housing

Matrix TTE&TEE Probe: 2007

Good 2D Equals Good 3D
Modes of Acquisition

Narrow volume

3D Zoom

Wide angle/Full volume

Different Modes of Acquisition

Live 3D

Full Volume 3D

3D Zoom

NY Style Pizza

Chicago Style Pizza
Narrow Volume

Zoom Mode
Zoom Mode

- Indications:
  - Prolapse
  - Flail
  - Perforation
  - Stenosis
- Less prone to artifacts
- Beware of losing spatial orientation

3D Full Volume Acquisition
Low Frame Rate

High Frame Rate
↑ Number of Sub-volumes = ↑ Frame Rate

↓ Depth = ↑ Frame Rate

Depth
13 cm

Depth
16 cm
# Uses of 3D Echocardiography

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<th>Recommended Applications</th>
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How do we Assess LV Function?

- Subjective
- Experience dependent
- Lack of standardization
- Large inter- and intra-observer variability

Qualitative Assessment

Eye ball

Quantitation of 2D Echocardiography: 2015

- Correct view? Foreshortening?
- Correct shape? Geometry dependent?
- Tracing errors? Correct trace?
Why is 3D More Accurate?

True Apex

Foreshortening Error

Segmental Dilatation


RT3DE volume measurements:

Validation by MRI

EDV, ESV

Excellent correlation ($r^2 > 0.85$)

but RT3DE underestimates volumes

Sources of error: Tracing?

- **Latex balloon:**
  - True volume: 150 ml

- **Human ventricles:**
  - Tracing error is the most important factor contributing to LV volume underestimation

- Mor-Avi V. et al, *JACC Cardiovasc Img* 2008: 1: 413-423

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<tr>
<td><strong>EDV</strong></td>
<td>r</td>
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<tr>
<td>0.92</td>
<td>-15 mL</td>
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<tr>
<td>0.93</td>
<td>-4 mL</td>
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<tr>
<td>0.86</td>
<td>1.4 %</td>
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Generally, an RVEF of <45% represents abnormal RV systolic function
RV Volumes and EF

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<tr>
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<th>Men</th>
<th>Women</th>
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<tr>
<td>RV EDV/BSA</td>
<td>61.3±13</td>
<td>53±10.5</td>
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<tr>
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<td>35-87</td>
<td>32-74</td>
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<tr>
<td>RV ESV/BSA</td>
<td>27±8.5</td>
<td>22±7</td>
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<td>10-44</td>
<td>8-36</td>
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3D of the right ventricle is not easy

Good dataset

Poor dataset
Curvature: the amount by which a geometric object deviates from being flat.

\[ k = \frac{1}{r} \]
LV Shape Analysis

Salgo I, Tsang W, Lang RM et al.,

LA Volumes

Mor-Avi V, Lang RM et al.: Real-time 3D echocardiographic quantification of left atrial volume: Multicenter study for validation with magnetic resonance imaging. JACC Imaging 2012.
RT3DE measurements of LV mass

- Direct measurement without geometrical assumptions about cavity shape and hypertrophy distribution
- More accurate than the linear or the 2D measurements
- Higher inter-measurement and test/retest reproducibility
- Better discriminates small changes within a patient

Normal values less well established
Dependent on image quality
Patients cooperation required

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The Mitre typically worn by popes and cardinals

Andreas Vesalius
De Humani Corporis
Fabrica
1543
Surgeon’s View of the MV


Mitral Stenosis
Mitral Stenosis
PBMV in Mitral Stenosis

Mitral Stenosis
Challenging the Hemispheric Assumption of Flow Convergence

3DE Evaluation of MR

- Vena contracta (VC)
- Anatomic regurgitant orifice area (AROA)
- Proximal isovelocity surface area (PISA)
3DE Vena Contracta

- True VC cross-sectional area can be measured on 3D allowing recognition of the non-hemispheric shape of PISA and VC in the majority of patients
- Improves classification of MR in patients with eccentric MR and functional MR


Good Agreement: AROA and PISA
Worse Agreement: MROA and PISA

Automatic 3D PISA Surface Area Detection Methods

3-D Surface Area: 5.44 cm²
M-mode

2D Echocardiography

Anterior

Septal

Anterior

Septal

Posterior

Septal

The TV on

3D Echo

S

A

PA

P

S

A

P

RV perspective

RA perspective

Transthoracic 3D Echocardiography

Transthoracic 3D Echocardiography
How many leaflets does the TV have?

P-S Commissure: Correct Position

• 38 year old female with a history of mitral stenosis post mechanical MV replacement

**Thrombosed Mechanical Prosthesis**

**Uses of 3D Echocardiography**

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Dehisced Mitral Valve

Dehisced Mitral Valve
Number of Leaks

Percutaneous Repair of Prosthetic Mitral Valve Dehiscence
Percutaneous Repair of Prosthetic Mitral Valve Dehiscence
Percutaneous Repair of Prosthetic Mitral Valve Dehiscence
Mitral Clip

Inter-atrial Septal Puncture

Alfieri Stich

Procedural Planning of Mitral Valve Repair with Clip and Plug

3D Printed modeling of MV

Procedural Planning

Clinical Procedure

MitraClip at A2/P2
ASD occluder within P2

Little et al. JACC Intervention 2016
Valve in Valve

Tricuspid Valve in Ring
Tricuspid Valve in Ring

Interventional Echocardiography

- Displays anatomy intuitively
- Pre-procedure assessment
- Intra-procedure guidance
- Post-procedure follow-up

Bhave and Lang, Atlas of 3D Echocardiography, ed. Gill,
FUSION IMAGING

3D Printing
Virtual Reality
Computer-generated simulation of a three-dimensional image that can be interacted with by a person using special electronic equipment (helmet with a screen inside or gloves fitted with sensors).

Virtual Reality Set-Up

Headset and controllers

Room sensors

Computer
3D Holography: Photographic technique that records the light scattered from an object, and then presents it in a way that appears 3D.
The future has arrived. Are we ready?

Karima Addetia and Roberto M. Lang*

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Artificial Intelligence
Fusion Imaging
3D Printing
Virtual Reality
Holography

@RobertoMLang