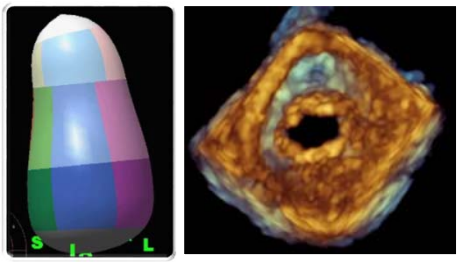
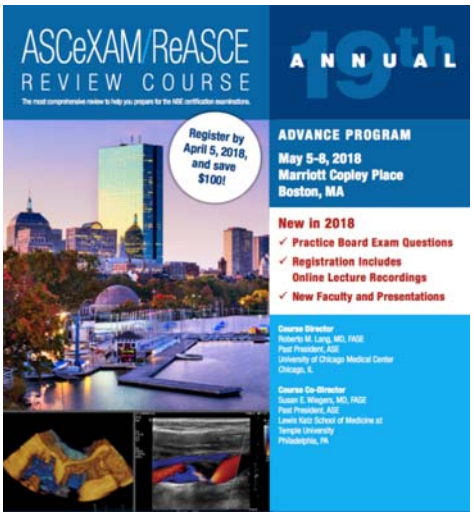
3D Echocardiography: Principles & Applications



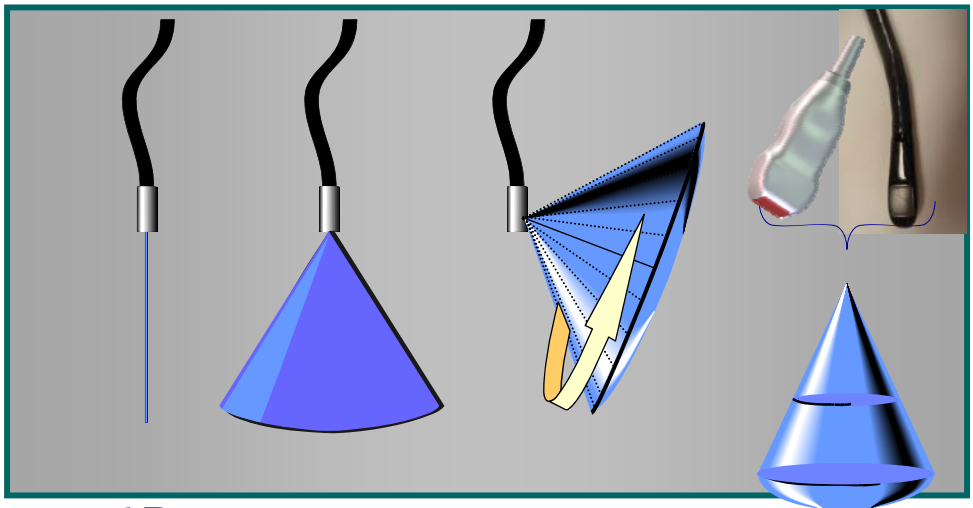


THE UNIVERSITY OF CHICAGO
CARDIAC IMAGING CENTER

Roberto M Lang, MD

@RobertoMLang

Evolution of Echocardiography

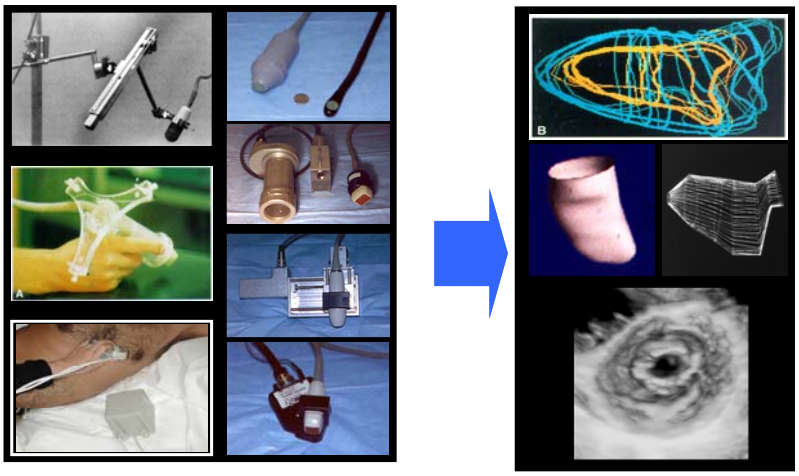


1D M-mode

2D Cut plane

3D Reconstruction Real-time

3D Reconstructive Methods



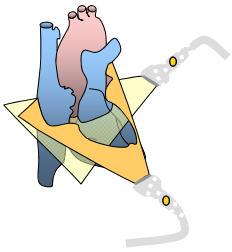
Spatial Locators

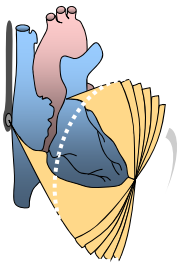
Mechanically Driven transducers

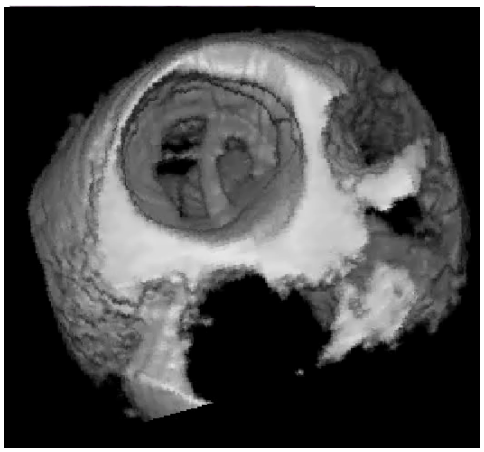
Gated Sequential Acquisition

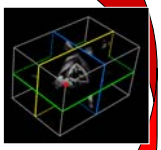
Off-line 3D

Image Processing and Reconstruction







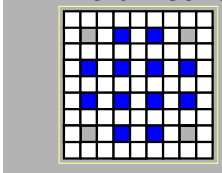


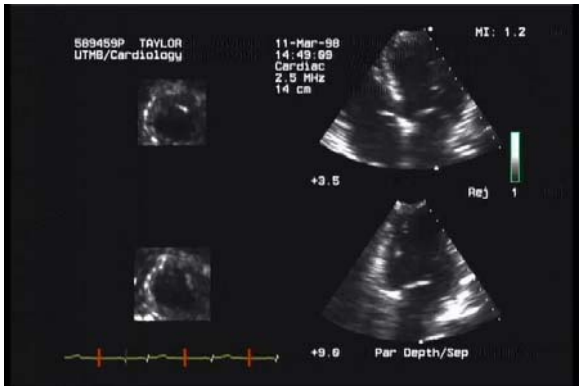
Echo Lab

U of C

Real-Time 3D Acquisition: Sparse Array

Sparse Array
(~300 elements)
Volumetrics



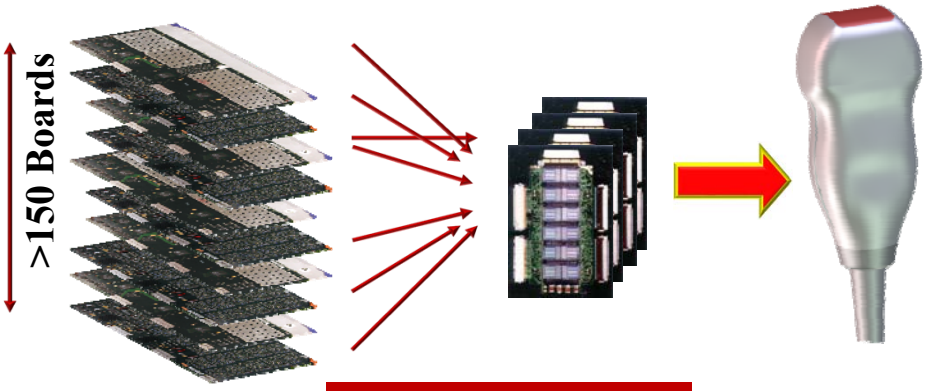


Courtesy of Dr. Masood Ahmad, UTMB Galveston

Real-Time 3D Acquisition: Matrix Array

Matrix Array: Advanced Technologies

Microelectronics in the Transducer

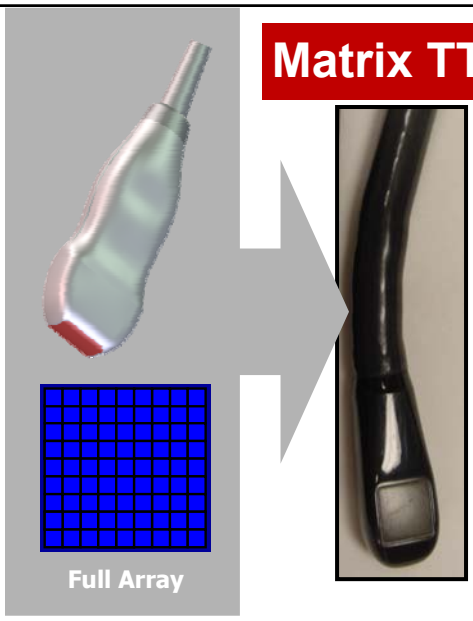


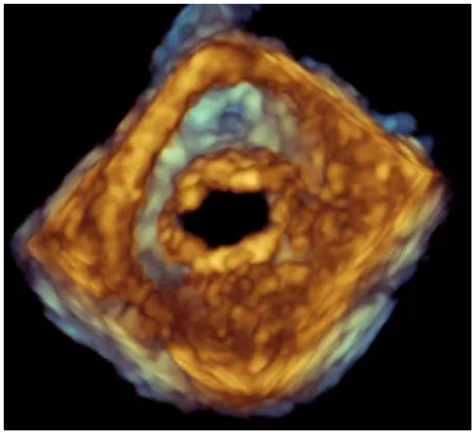
Electronics needed for 3000 Elements

Compressed into Application Specific Ics (Next Generation ASICs)

Compressed into Ergonomic Housing

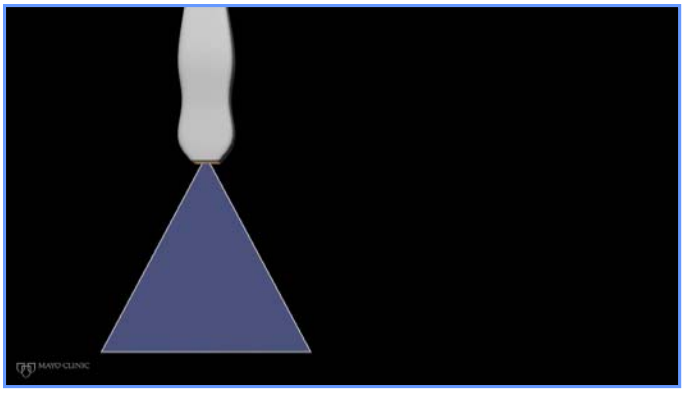
Matrix TTE&TEE Probe: 2007





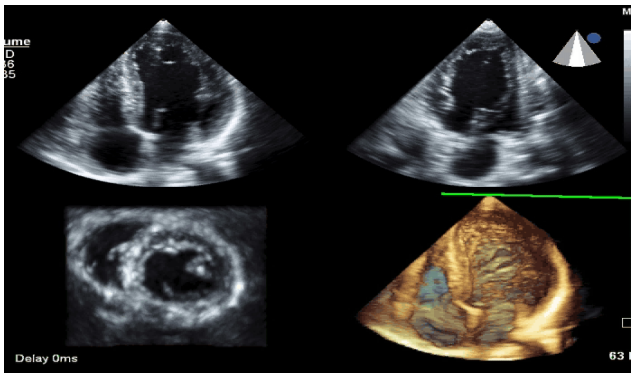
Sugeng L, Shernan SK, Salgo IS, Weinert L, Shook D, Raman J, Jeevanandam V, DuPont F, Settlemier S, Savord B, Fox J, Mor-Avi V, Lang RM. *J Am Coll Cardiol* 2008 August 5;52(6):446-449

2D *vs* 3D Echocardiography

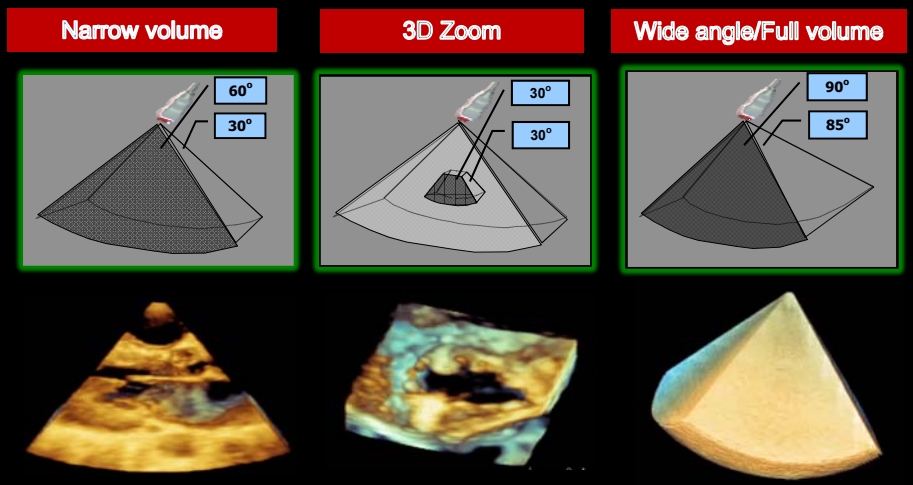


Courtesy of J. Maalouf

Good 2D Equals Good 3D



Modes of Acquisition

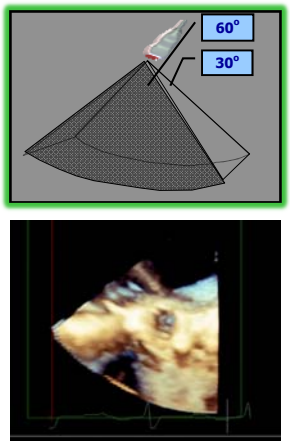


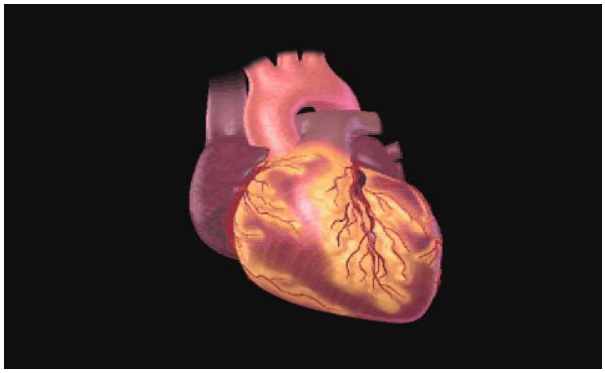
Different Modes of Acquisition

Live 3D **Full Volume 3D** **3D Zoom**

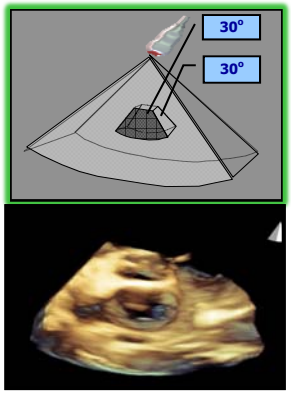
NY Style Pizza Chicago Style Pizza

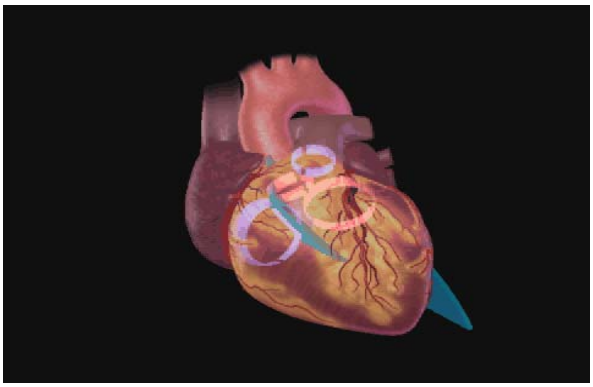
Narrow Volume





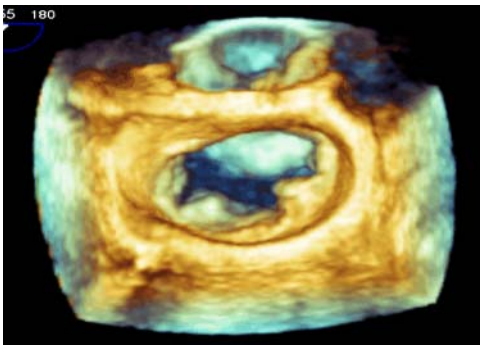
Zoom Mode



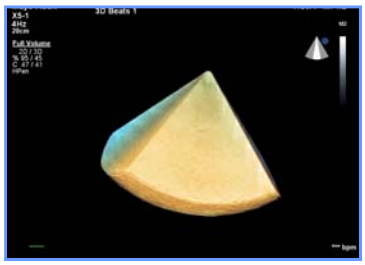


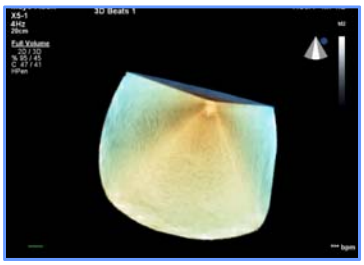
Zoom Mode

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

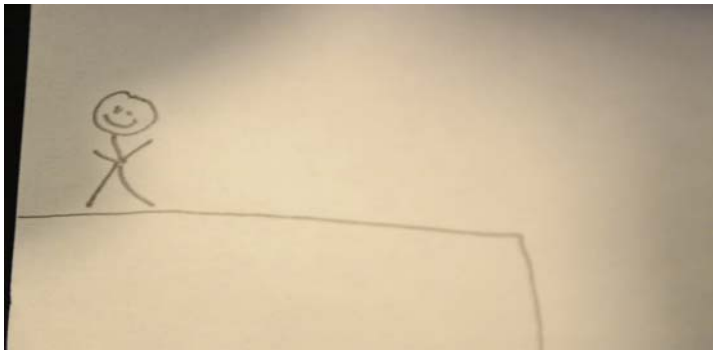


3D Full Volume Acquisition

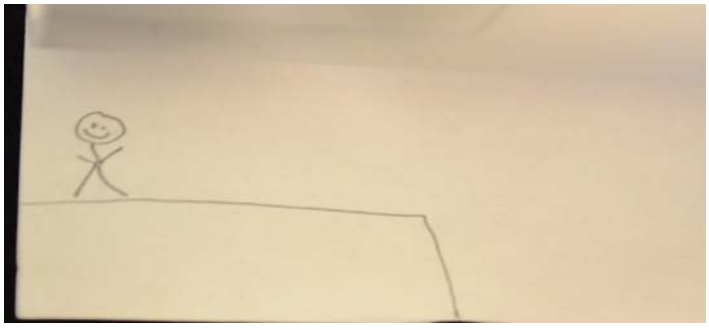




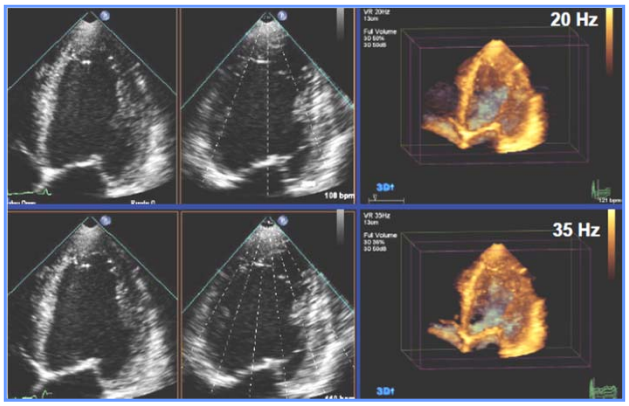
Low Frame Rate



High Frame Rate



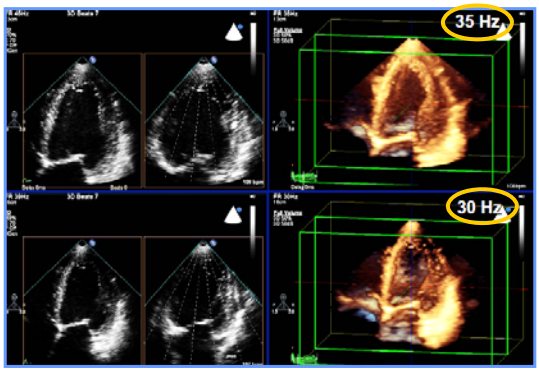
↑ Number of Sub-volumes = ↑ Frame Rate



↓ Depth = ↑ Frame Rate

Depth
13 cm

Depth
16 cm

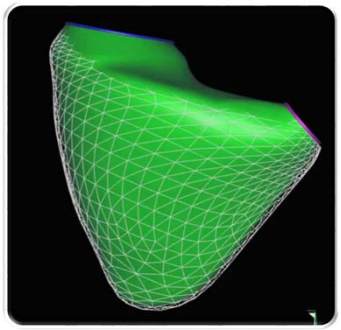


Uses of 3D Echocardiography

	Recommended Applications	Under Active Investigation	Future Applications
LV/RV Volumes	✓		
LV/RV Shape		✓	
LV Mass		✓	
LA Volumes		✓	
Mitral Valve Assessment			
• Anatomy	✓		
• Stenosis	✓		
• Regurgitation		✓	
Tricuspid Valve Assessment			
• Anatomy		✓	
• Regurgitation		✓	
Aortic Annulus Measurement		✓	
Prosthetic Valves		✓	
Guidance of Transcatheter Procedures			
• Percutaneous Mitral Valve	✓		
• Percutaneous Tricuspid Valve		✓	
3D Printing		✓	
Virtual Reality			✓
Holography			✓

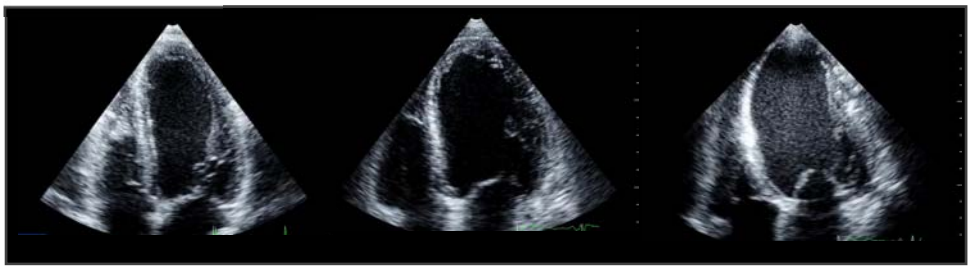
Uses of 3D Echocardiography

	Recommended Applications	Under Active Investigation	Future Applications
LV/RV Volumes	✓		
LV/RV Shape		✓	
LV Mass		✓	
LA Volumes		✓	



Eye ball

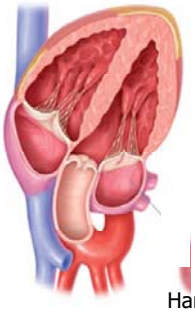
How do we Assess LV Function ?

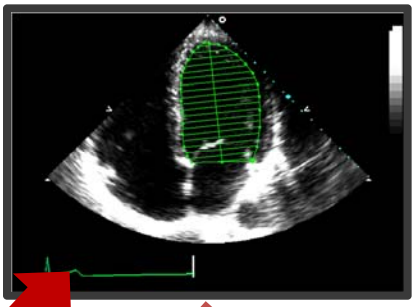


Qualitative Assessment

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

Quantitation of 2D Echocardiography: 2015





Hand tracing

Correct view? Foreshortening?

Correct shape? Geometry dependent?

Tracing errors? Correct trace?

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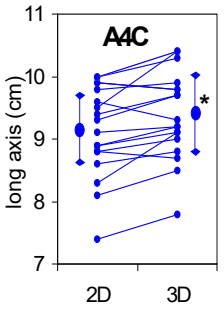
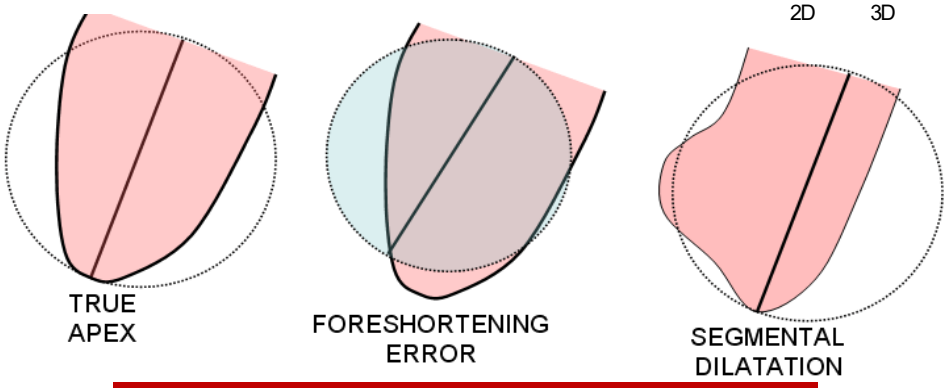
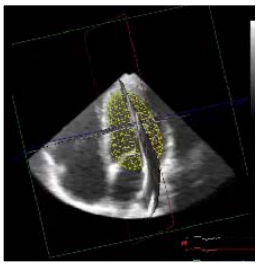
Why is 3D More Accurate?





Mor-Avi V, Lang RM et al., *Circulation* 2004. 110: 1814-1818.

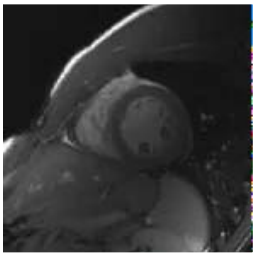
RT3DE volume measurements: Validation by MRI



EDV, ESV

Excellent correlation (r^2>0.85)

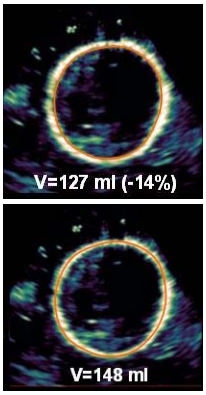
but RT3DE underestimates volumes



- Jacobs LD, et al. *Eur Heart J 2005; 27:460-8*
- Sugeng L, et al. *Circulation 2006; 114:654-61*
- Jenkins C, et al. *J Am Soc Echocardiogr 2007; 20:962-8*
- Soliman OI, et al. *Am Soc Echocardiogr 2007; 20:1042-9*

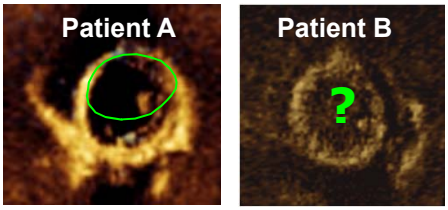
Sources of error: Tracing?

- **Latex balloon:**



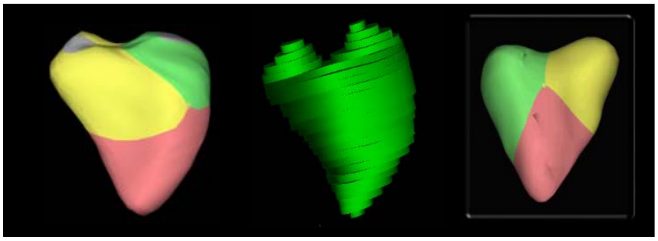
True volume: **150 ml**

- **Human ventricles:**



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

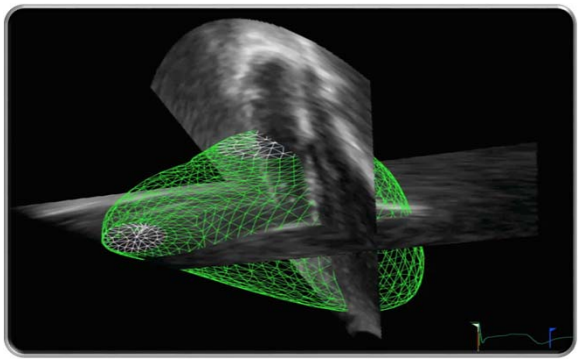
- Mor-Avi V. et al, *JACC Cardiovasc Img 2008: 1: 413-423*

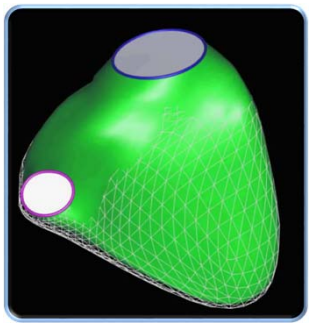


	Muraru D... Badano LP et. al. EHJ Cardiovascular Imaging 2015			Medvedofsy D, Addetia K...Lang RM et. al. JASE 2015		
	r	Bias	LOA	r	Bias	LOA
EDV	0.92	-15 mL	±45 mL	0.95	-11mL	±40 mL
ESV	0.93	-4 mL	±28 mL	0.96	-0.3 mL	±31 mL
RVEF	0.86	1.4 %	±9.7 %	0.83	-3.3%	±15%

Generally, an RVEF of <45% represents abnormal RV systolic function

RV Volumes and EF





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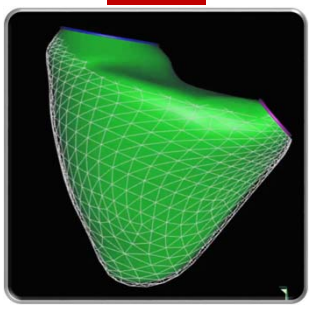


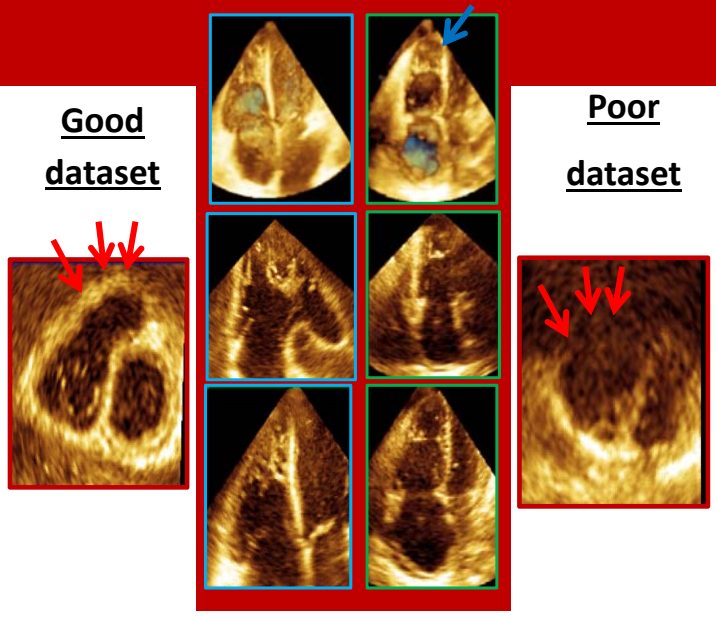
RV EDV/BSA, Men	61.3±13	35-87
RV EDV/BSA, Women	53±10.5	32-74

RV ESV/BSA, Men	27±8.5	10-44
RV ESV/BSA, Women	22±7	8-36

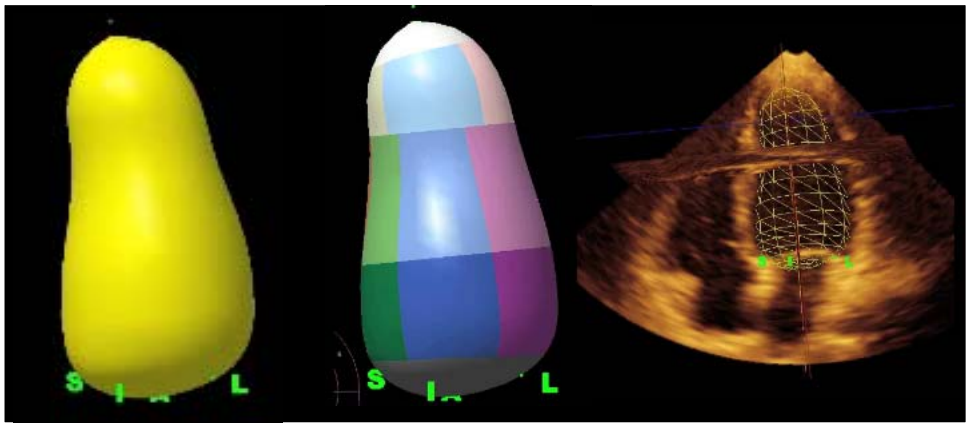
3D of the right ventricle is not easy

Good dataset

Poor dataset

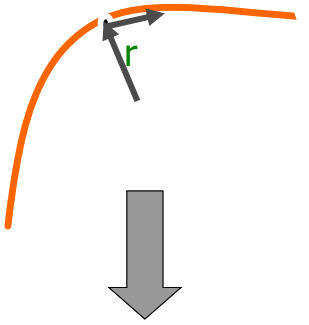


LV Curvature

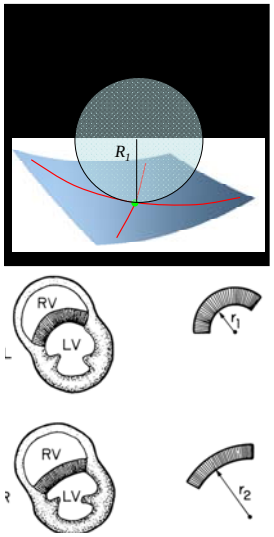


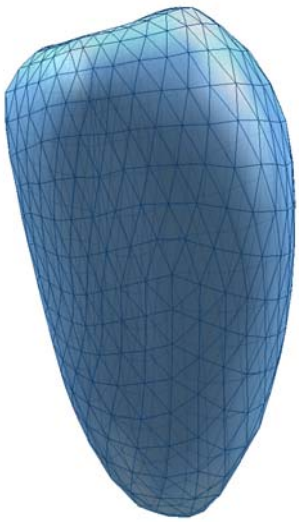
Salgo, Tsang, Lang et al. JASE 2011: 25(1):80-8

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

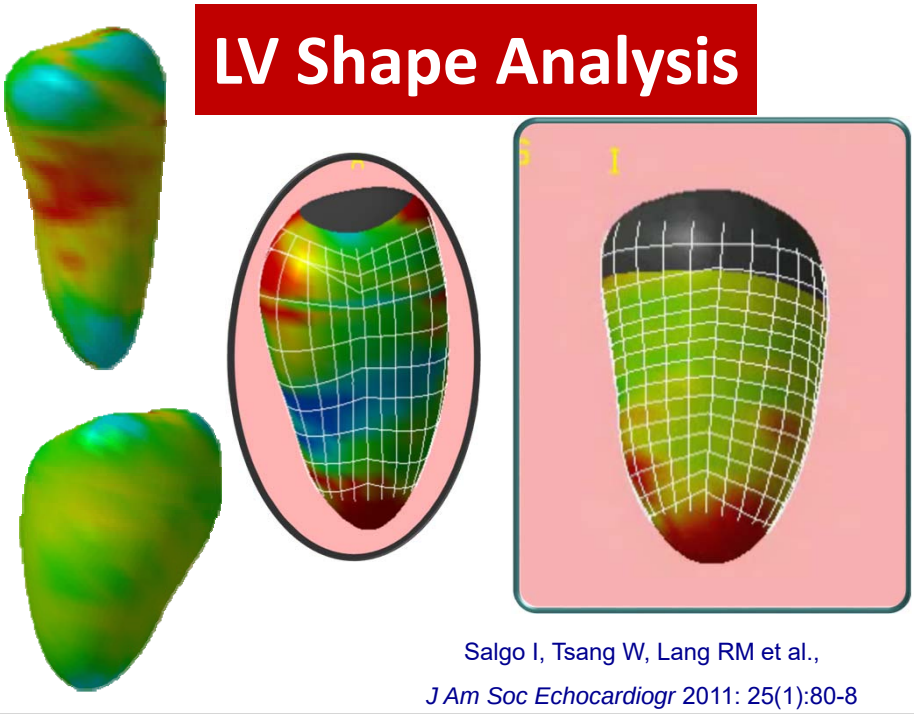


$k = 1/r$





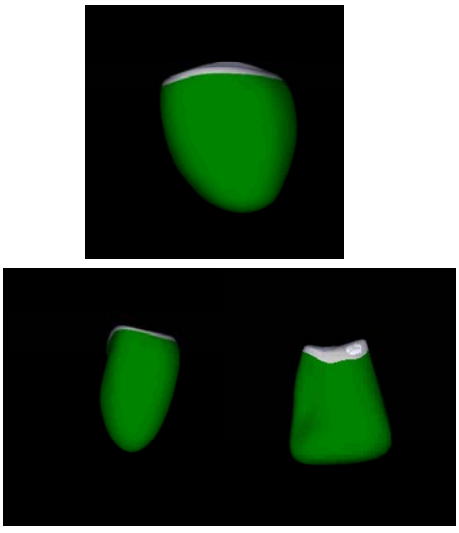
LV Shape Analysis

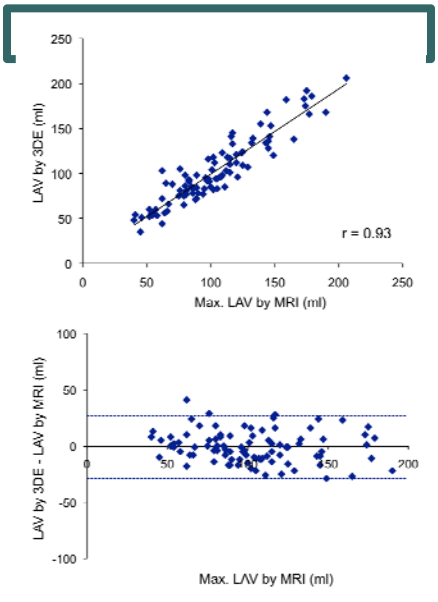


Salgo I, Tsang W, Lang RM et al.,

J Am Soc Echocardiogr 2011: 25(1):80-8

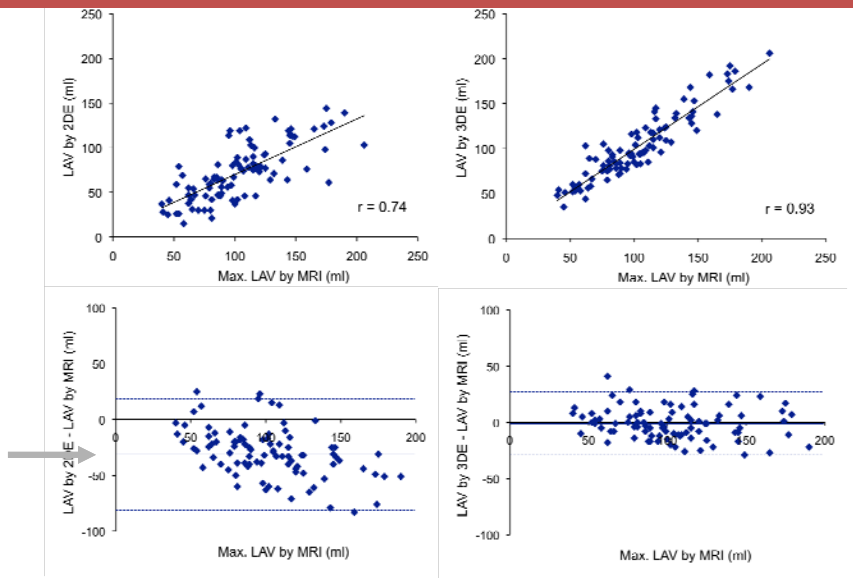
LA Volumes





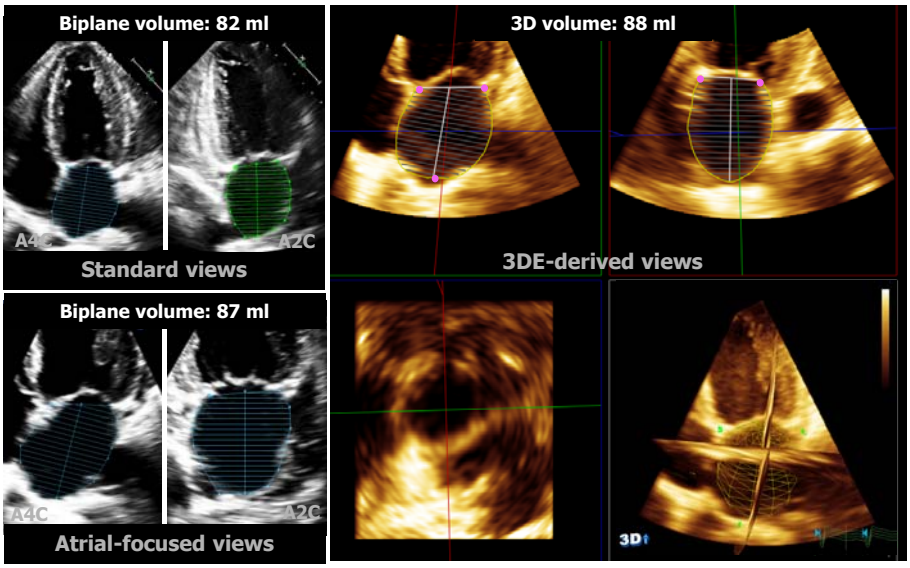
Mor-Avi V, Lang RM et al., *JACC Cardiovasc Imaging. 2012 Aug;5(8):769-77.*

2DE vs. 3DE for LA Volume Quantification



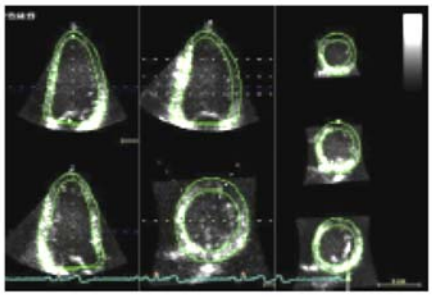
Mor-Avi V ,Lang RM et al.: Real-time 3D echocardiographic quantification of left atrial volume: Multicenter study for validation with magnetic resonance imaging. JACC Imaging 2012.

Left atrial volume on 2DE



RT3DE measurements of LV mass

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



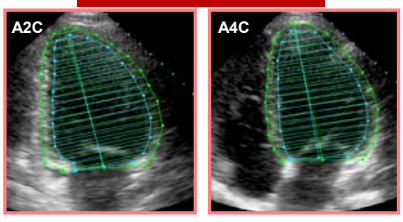
Normal values less well established

Dependent on image quality

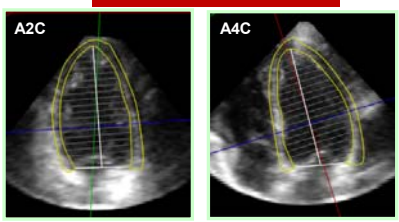
Patients cooperation required

RT3DE measurements of LV mass

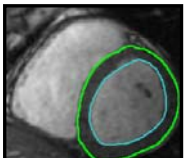
2D biplane

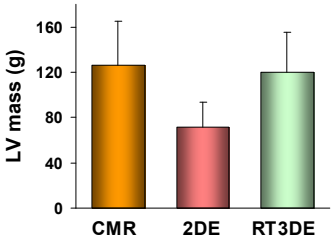


3D-guided biplane



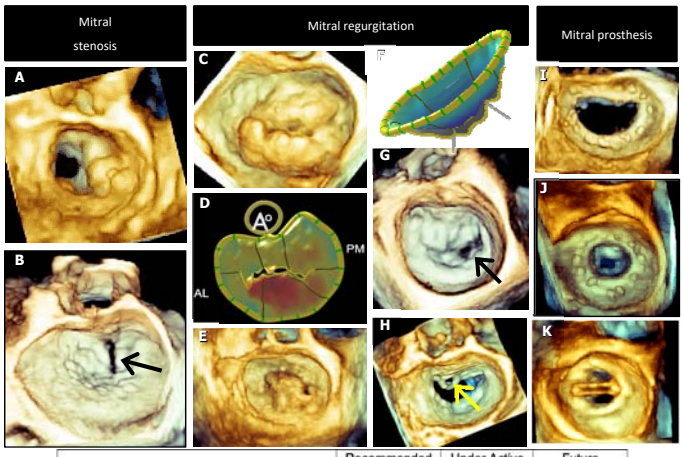
MRI reference





- Mor-Avi V, et al. *Circulation 2004; 110, 1814-1818*

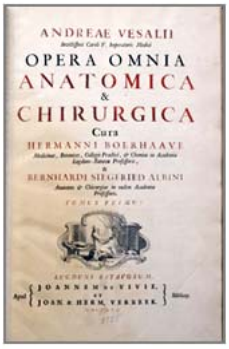
Uses of 3D Echocardiography

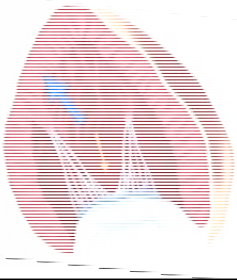


	Recommended Applications	Under Active Investigation	Future Applications
Mitral Valve Assessment			
• Anatomy	✓		
• Stenosis	✓		
• Regurgitation		✓	
Tricuspid Valve Assessment			
• Anatomy		✓	
• Regurgitation		✓	
Aortic Annulus Measurement		✓	
Prosthetic Valves		✓	

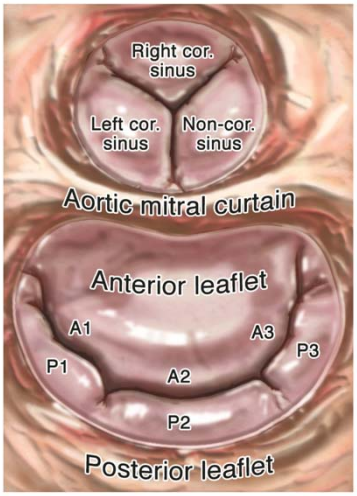
The Mitre typically worn by popes and cardinals

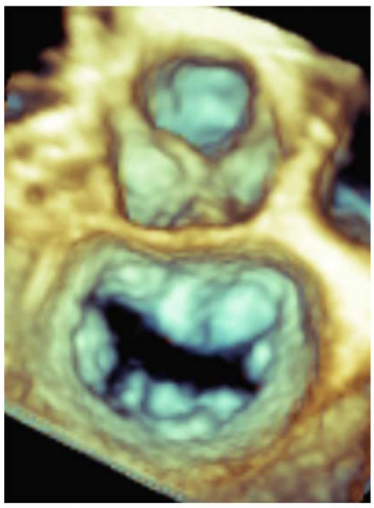
Andreas Vesalius
De Humani Corporis Fabrica
1543





Surgeon's View of the MV

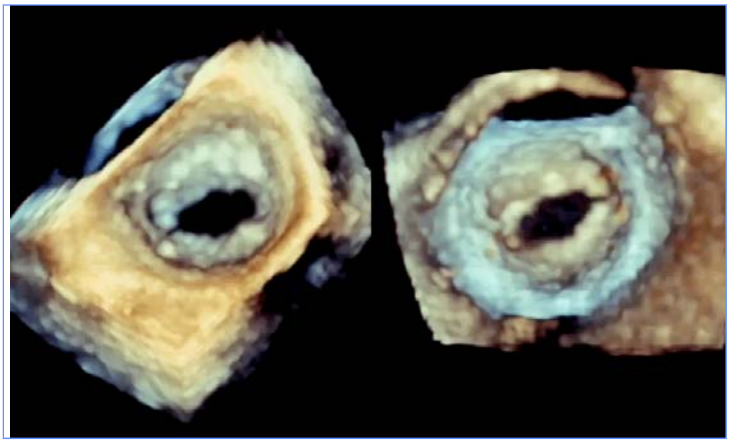


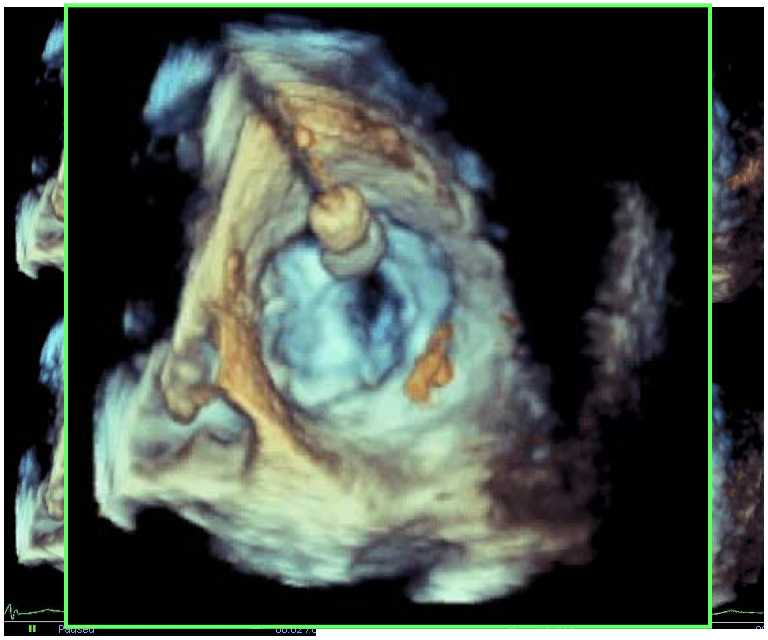


Lang RM, Tsang W, Weinert L, Mor-Avi V, Chandra S. J Am Coll Cardiol 2011 November 1;5 8(19):1933-1944.

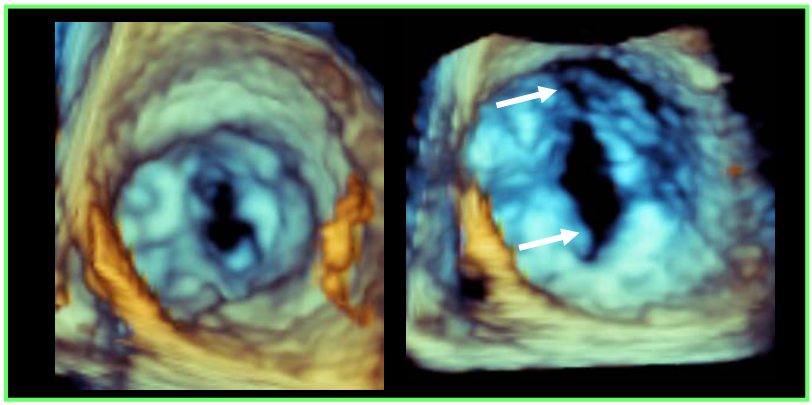
Mitral Stenosis

Mitral Stenosis

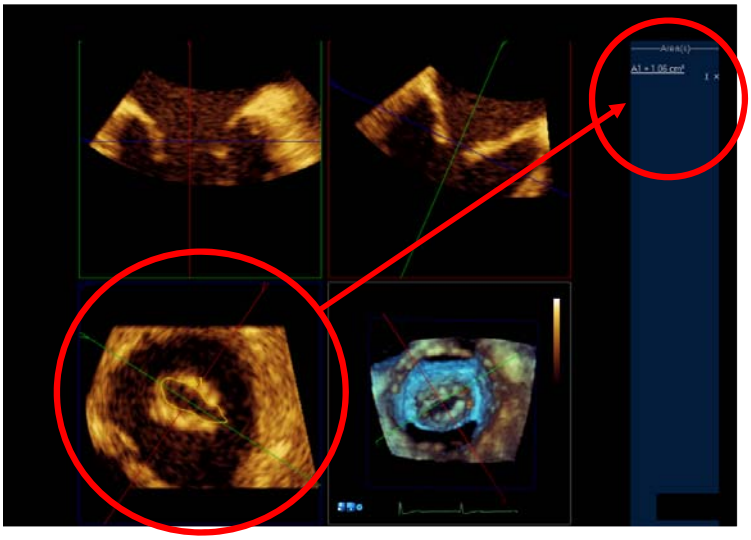




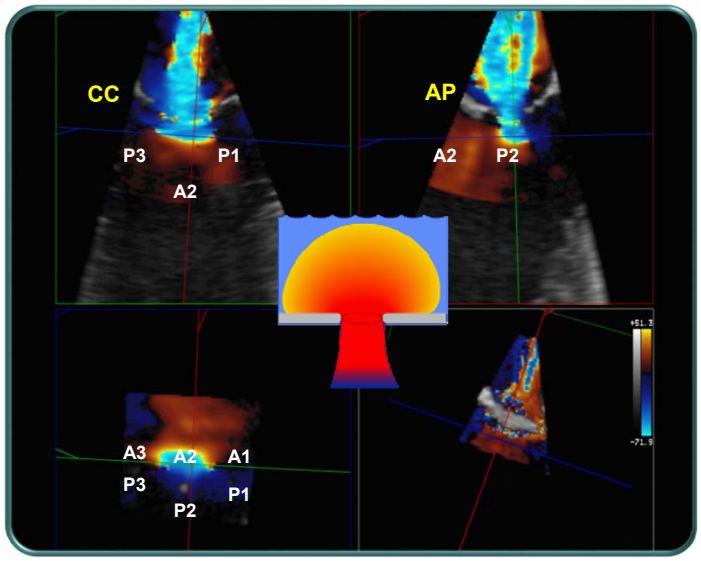
PBMV in Mitral Stenosis



Mitral Stenosis

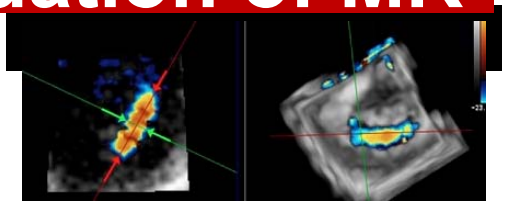


Challenging the Hemispheric Assumption of Flow Convergence

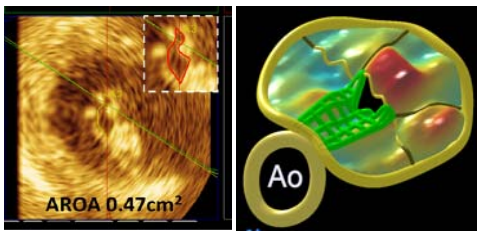


3DE Evaluation of MR

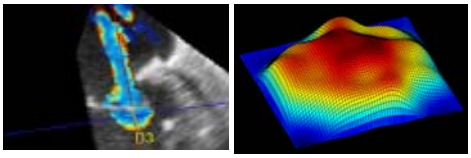
Vena contracta (VC)



Anatomic regurgitant orifice area (AROA)

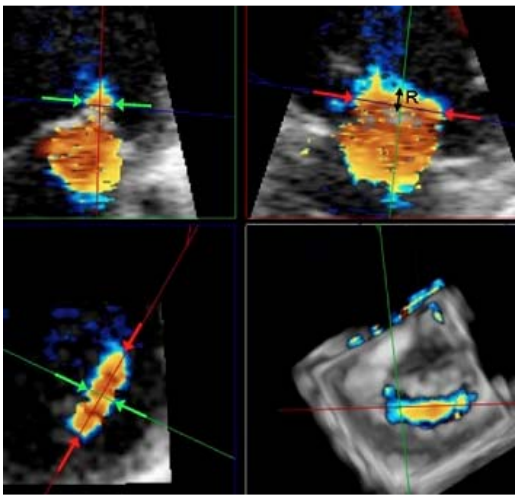


Proximal isovelocity surface area (PISA)



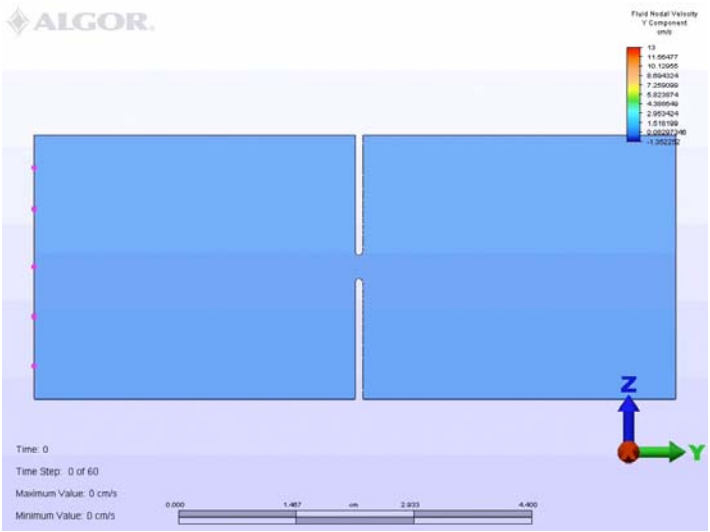
3DE Vena Contracta

- 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

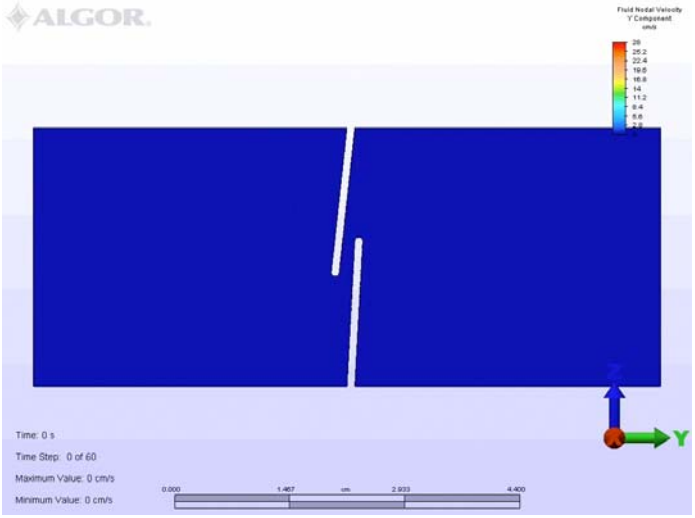


Yosefy et al. Am J. Cardiol 2009:104;978, Kahlert et al. JASE 2008:21;912

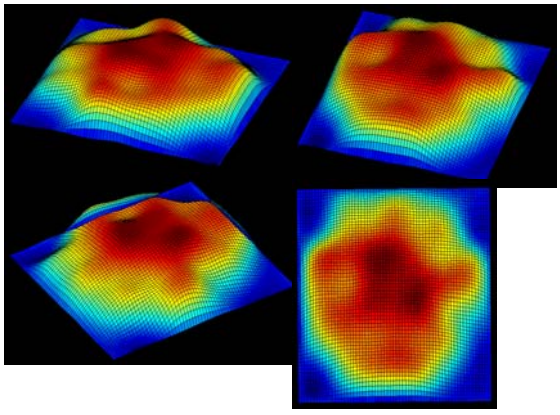
Good Agreement: AROA and PISA

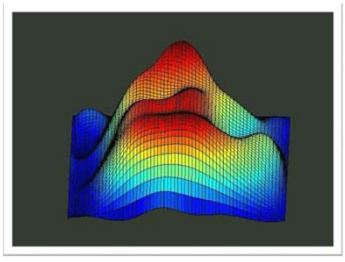


Worse Agreement: MROA and PISA

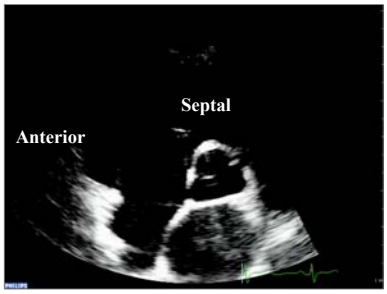


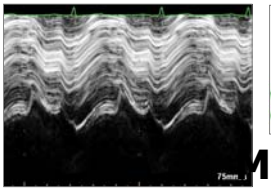
Automatic 3D PISA Surface Area Detection Methods

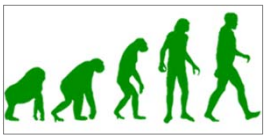




3-D Surface Area: 5.44 cm^2

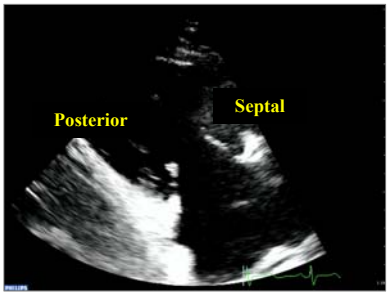


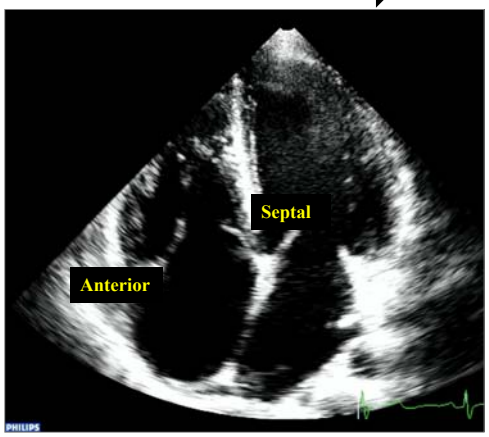




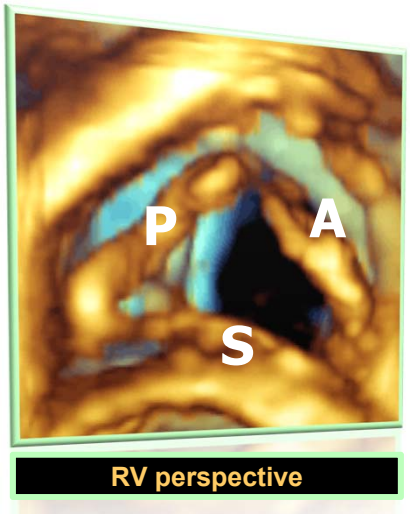
M-mode

2D Echocardiography

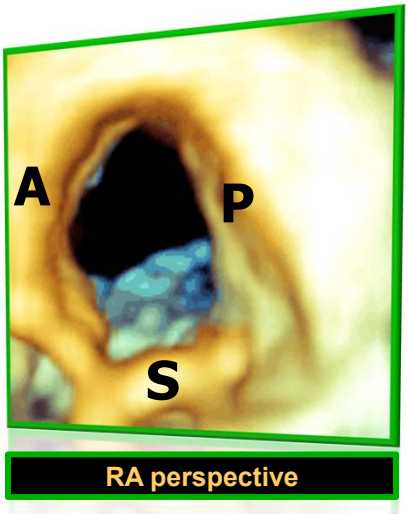




Transthoracic 3D Echocardiography

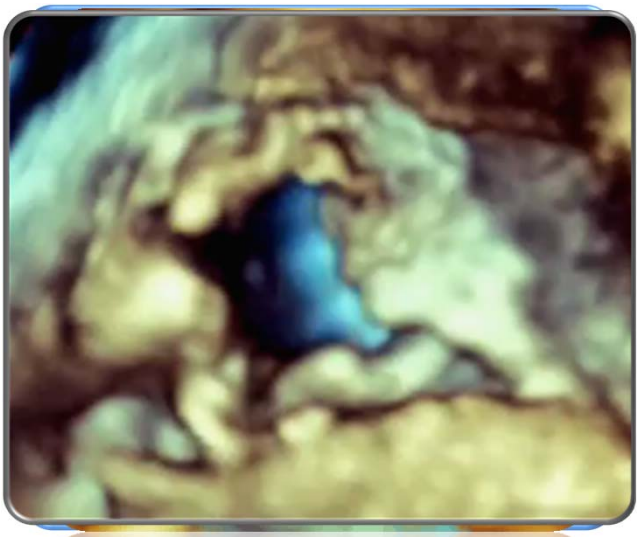


RV perspective



RA perspective

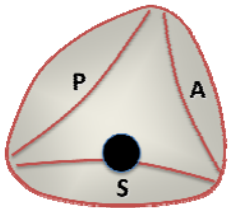
How many leaflets does the TV have?

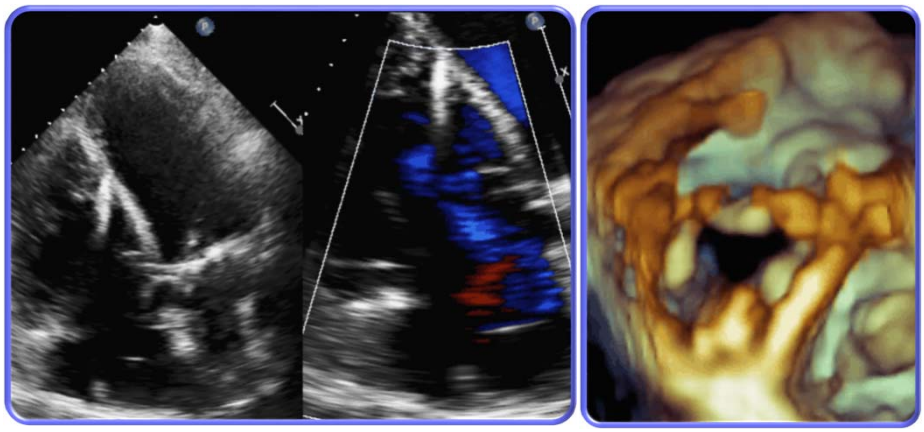


P-S Commissure: Correct Position

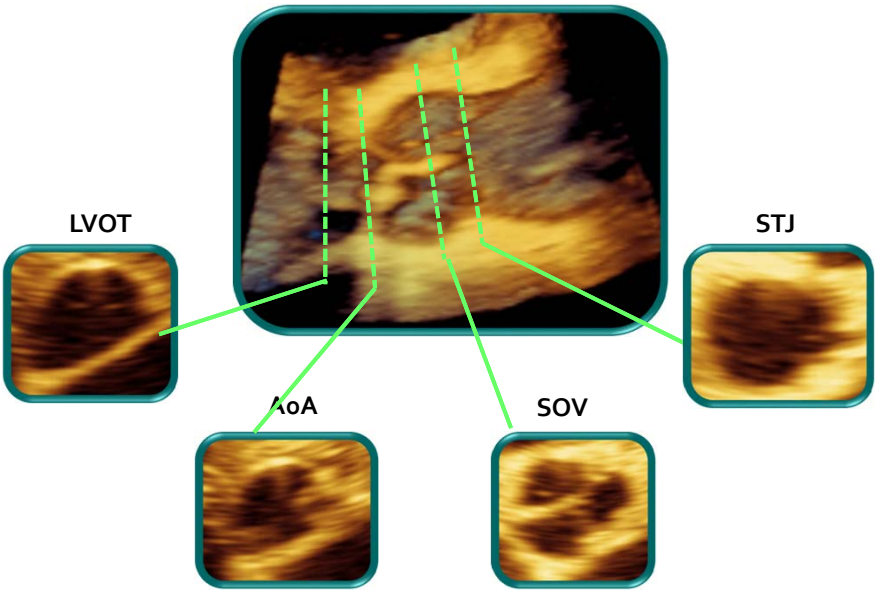
Mediratta A, Addetia K, Moss JD, Nayak HM, Yamat M, Weinert L, **Mor-Avi V**, Lang RM: 3D echocardiographic location of implantable device leads and mechanism of associated tricuspid regurgitation. *J Am Coll Cardiol Cardiovasc Img* 2014; 7:337-347

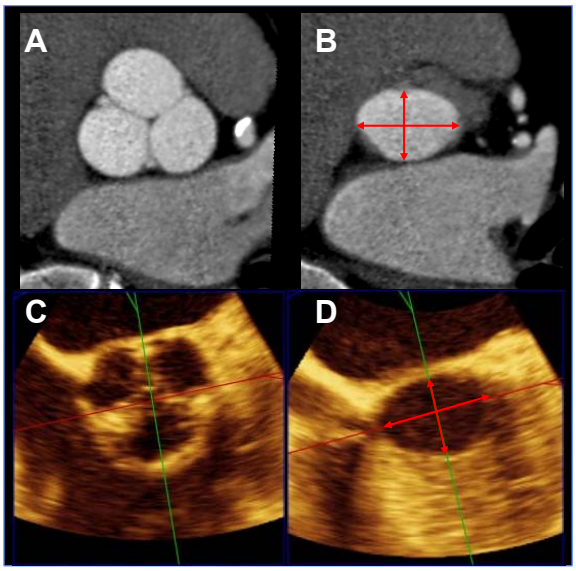
Pacemaker Lead Impingment

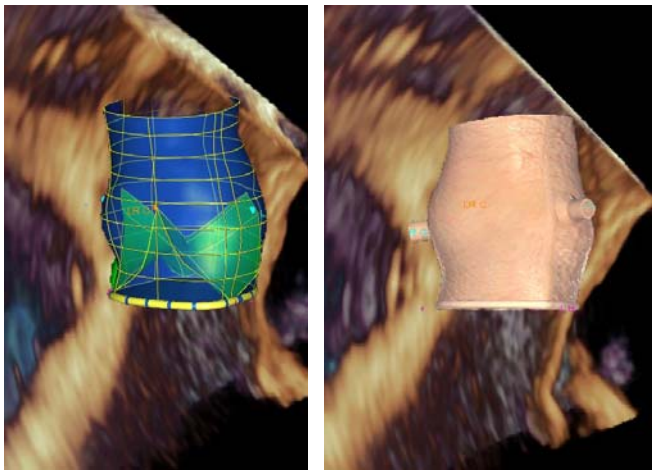




Elliptical Aortic Annulus



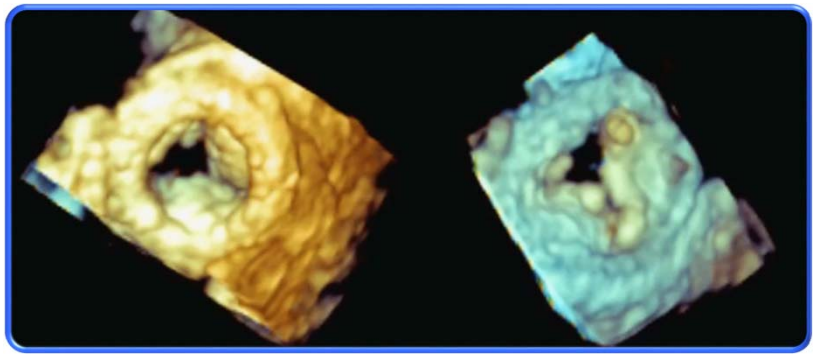




Fig

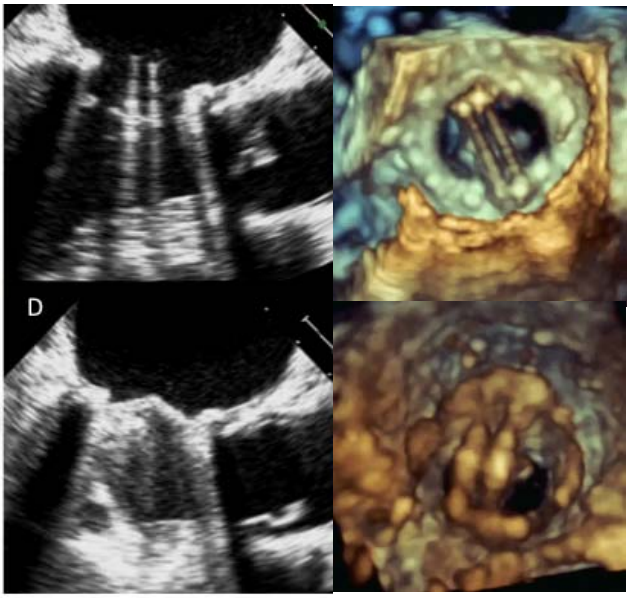
Stenotic Bioprosthetic MV

From LA

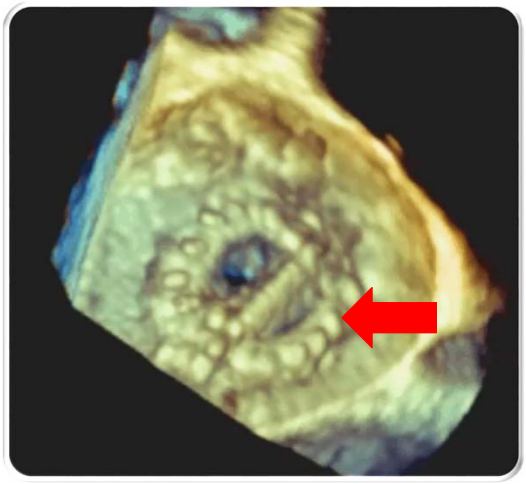


From LV

Mechanical Bileaflet Aortic Valve



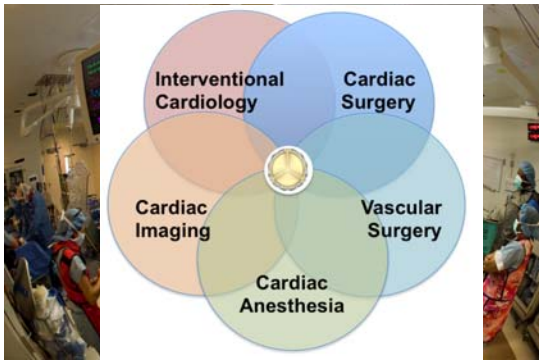
Thrombosed Mechanical Prosthesis



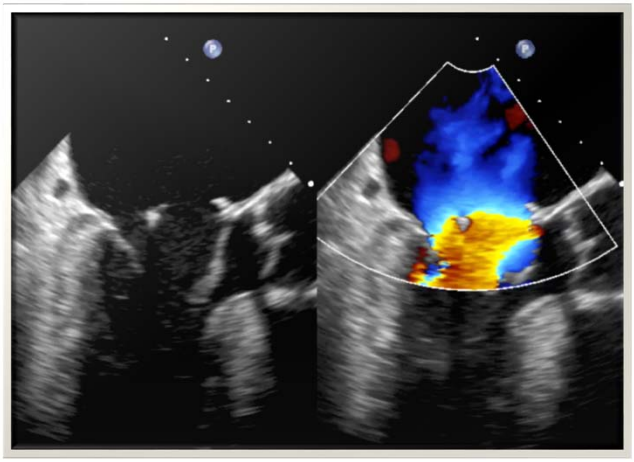
- 38 year old female with a history of mitral stenosis post mechanical MV replacement

Uses of 3D Echocardiography

	Recommended Applications	Under Active Investigation	Future Applications
Guidance of Transcatheter Procedures			
• Percutaneous Mitral Valve	✓		
• Percutaneous Tricuspid Valve		✓	
3D Printing		✓	
Virtual Reality			✓
Holography			✓



Dehisced Mitral Valve



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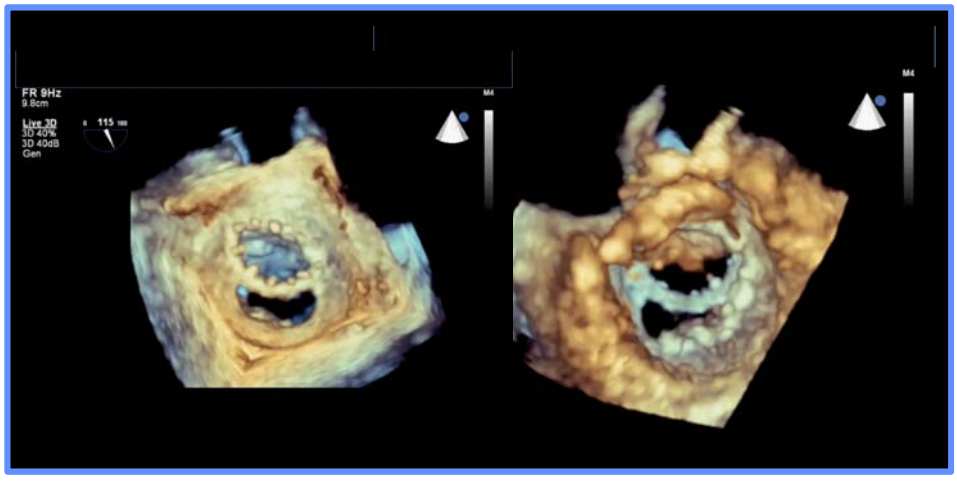
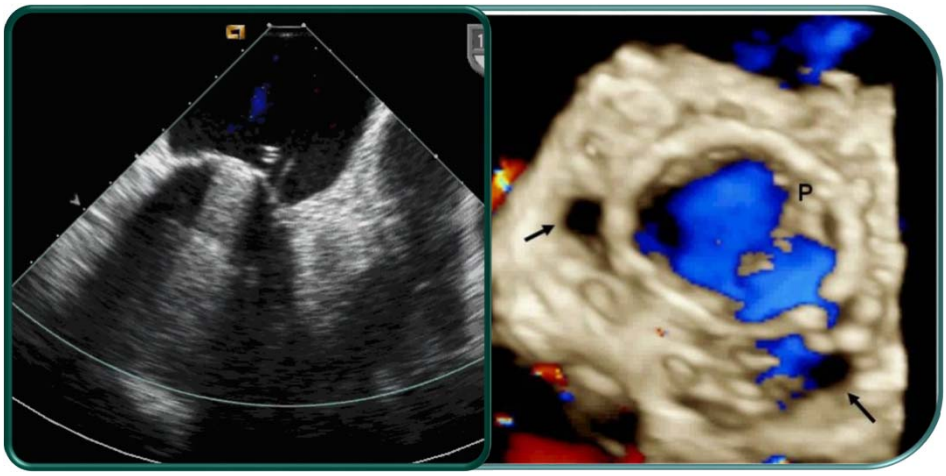
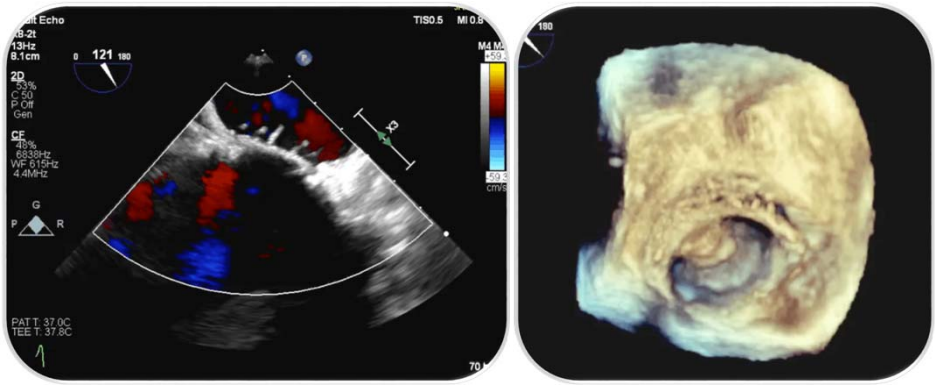


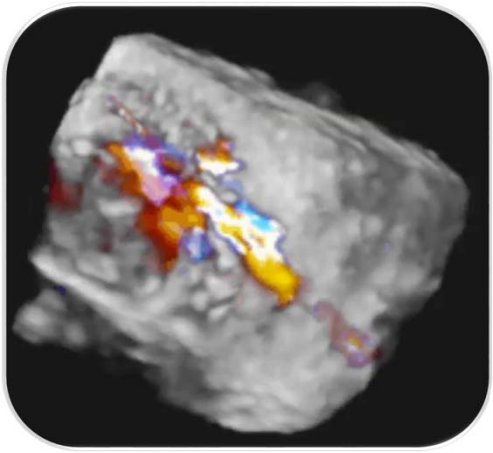
Number of Leaks



Percutaneous Repair of Prosthetic Mitral Valve Dehiscence



Percutaneous Repair of Prosthetic Mitral Valve Dehiscence



Percutaneous Repair of Prosthetic Mitral Valve Dehiscence

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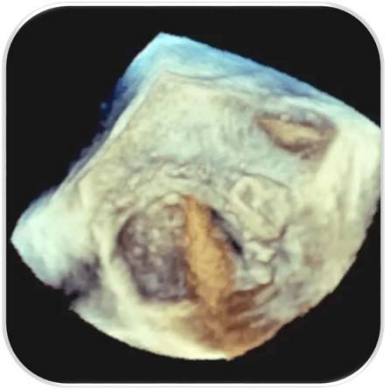
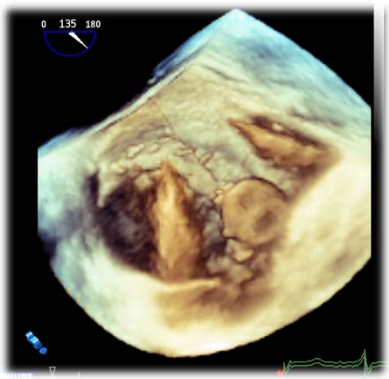
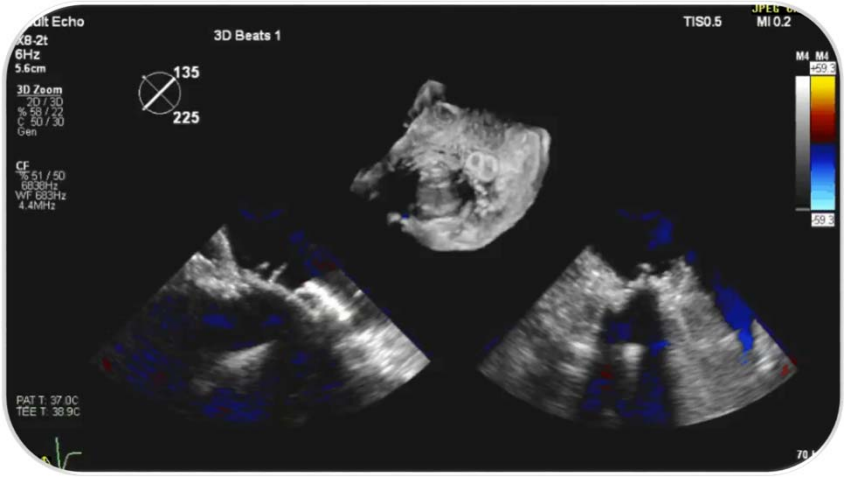
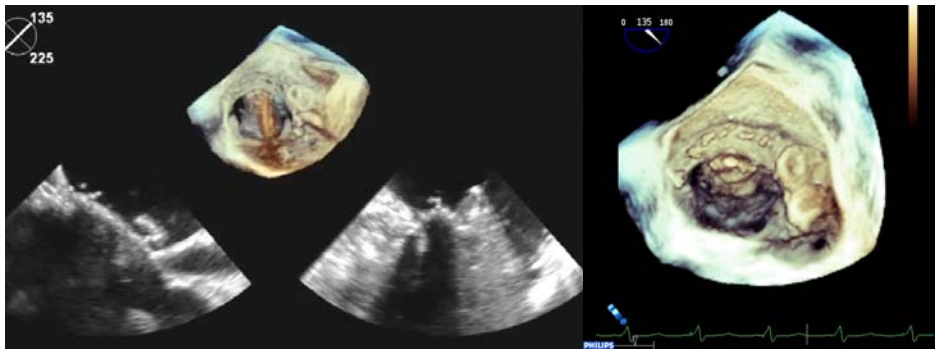




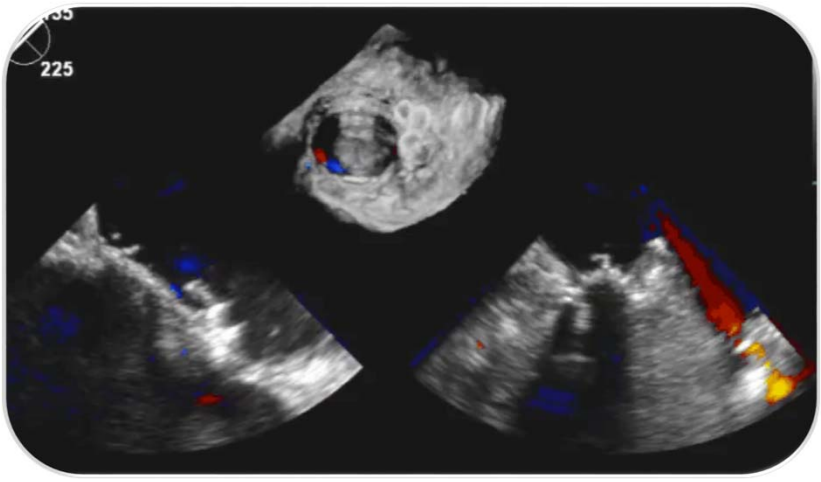
Percutaneous Repair of Prosthetic Mitral Valve Dehiscence



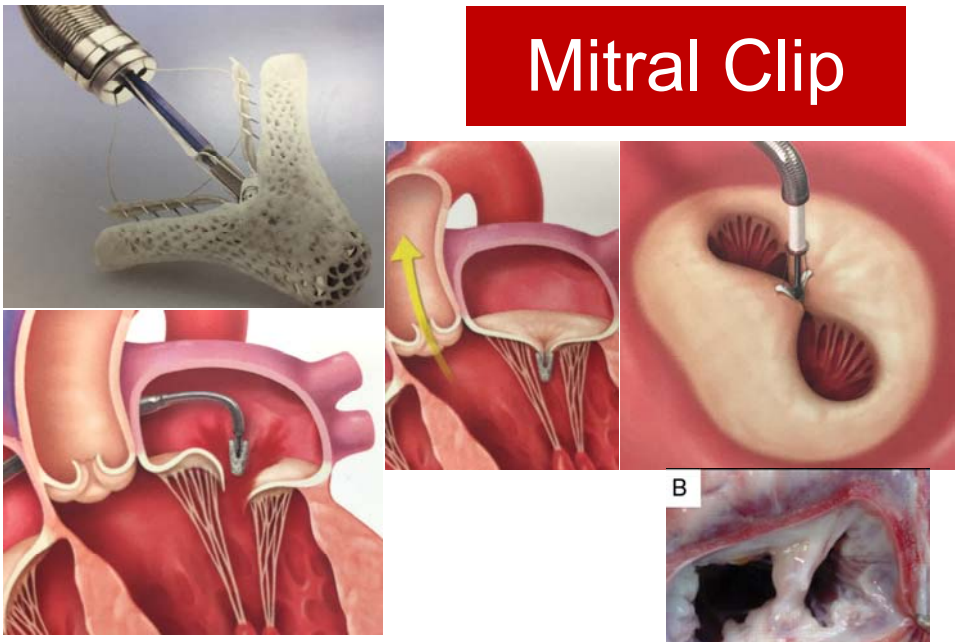
Percutaneous Repair of Prosthetic Mitral Valve Dehiscence



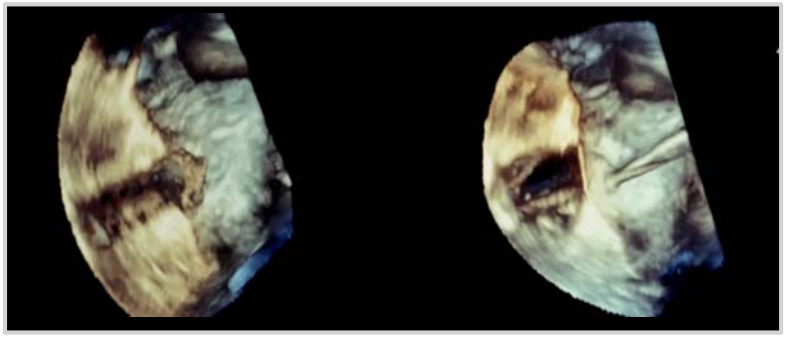
Percutaneous Repair of Prosthetic Mitral Valve Dehiscence



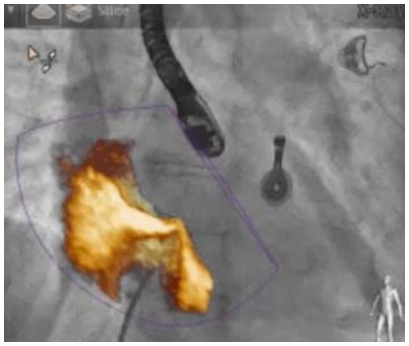
Mitral Clip



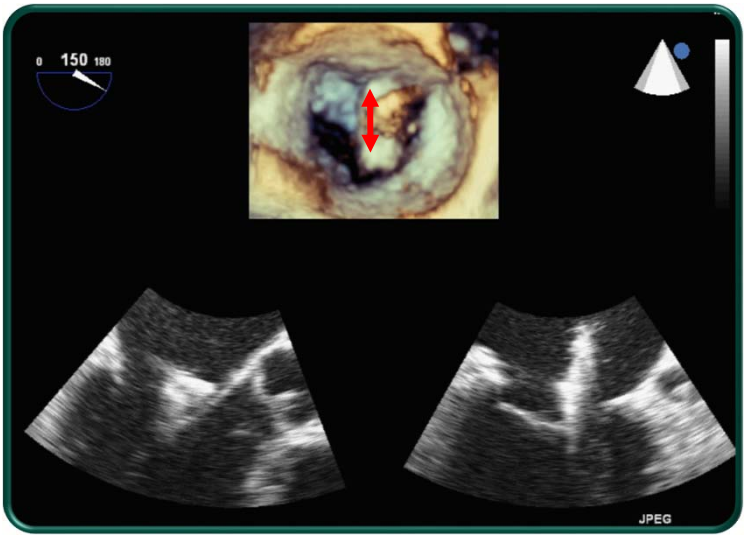
Steinberg D H et al. Eur Heart J Suppl 2010;12:E2-E9



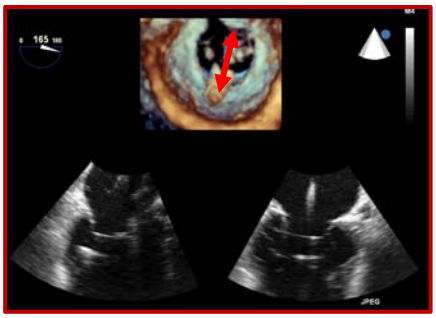
Inter-atrial Septal Puncture



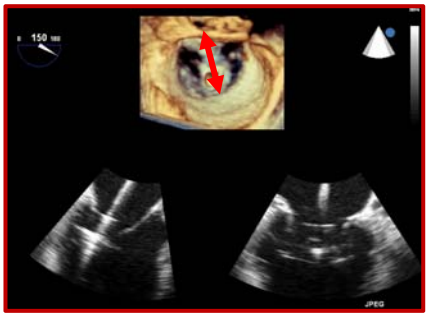
Position and Orient Clip



Grasping the Leaflet

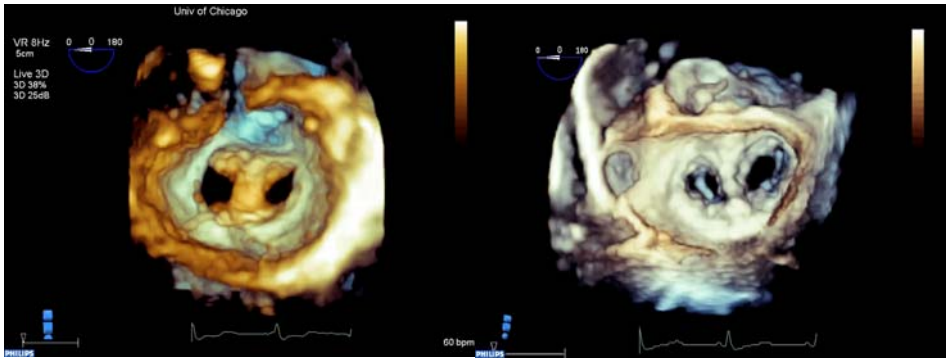


Ventricular Side

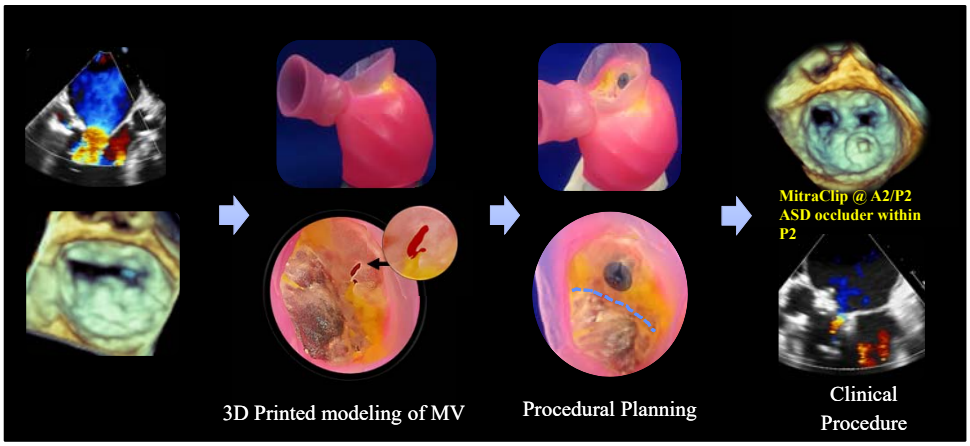


Atrial Side

Alfieri Stich

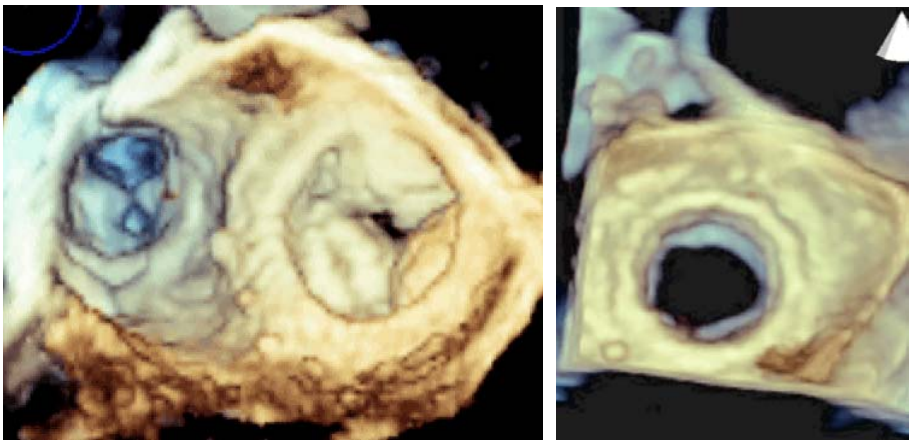


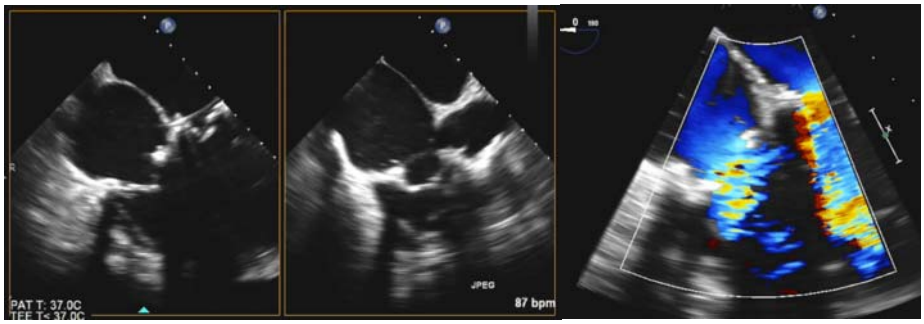
Procedural Planning of Mitral Valve Repair with Clip and Plug



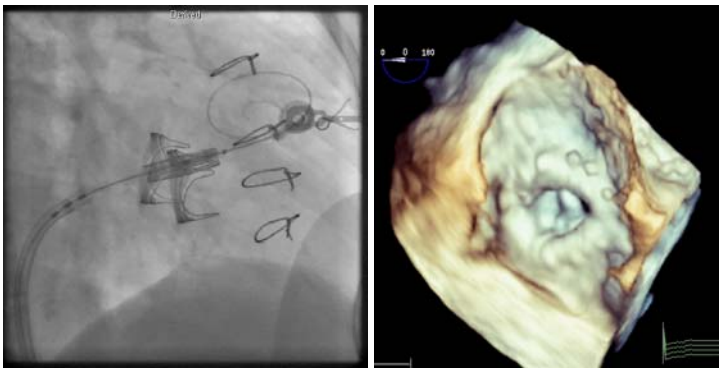
Little et al. JACC Intervention 2016

Valve in Valve

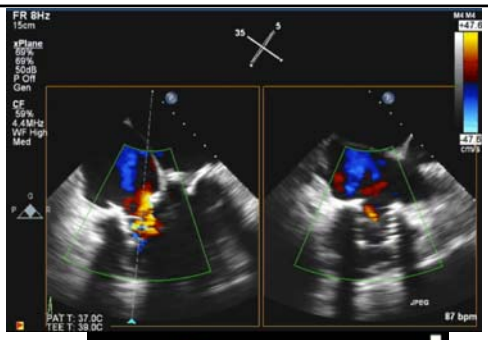


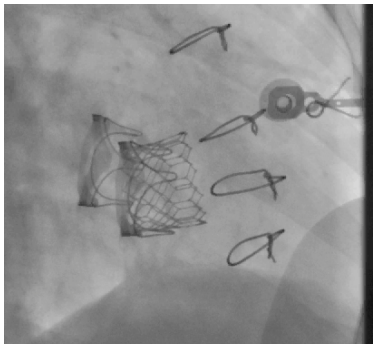


Tricuspid Valve in Ring



Tricuspid Valve in Ring



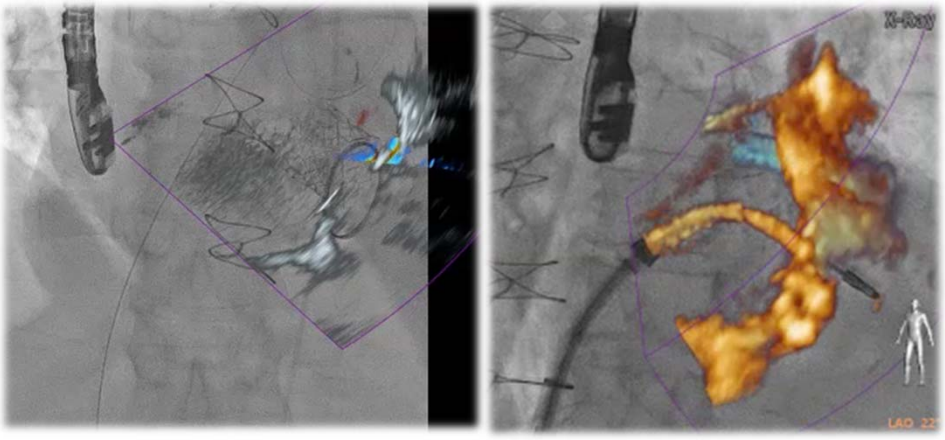


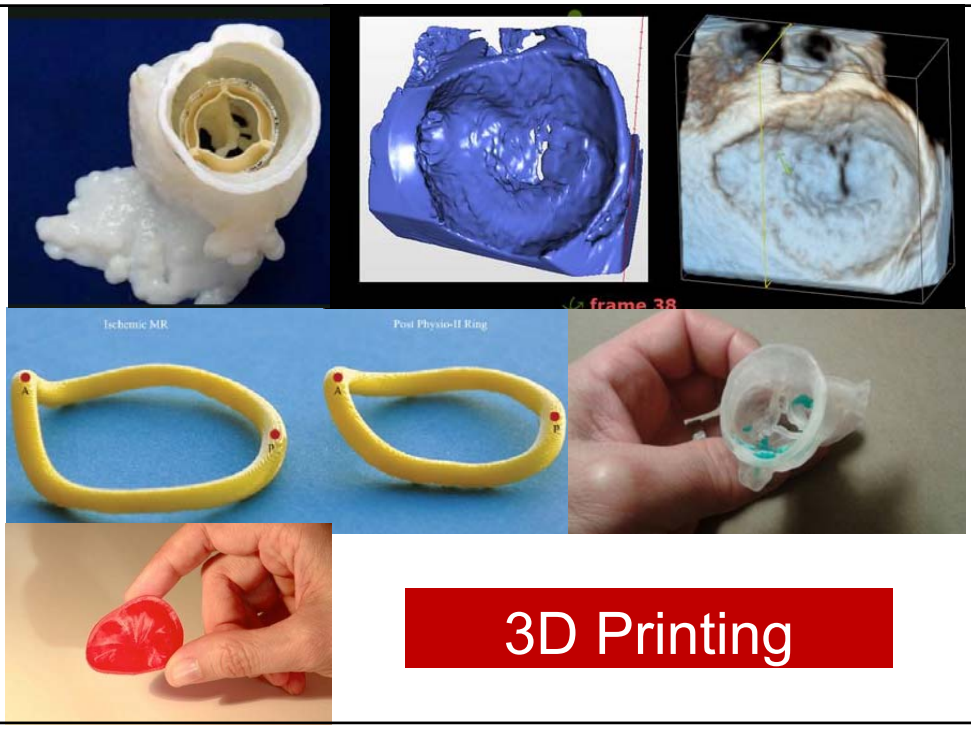
Interventional Echocardiography

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

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

FUSION IMAGING

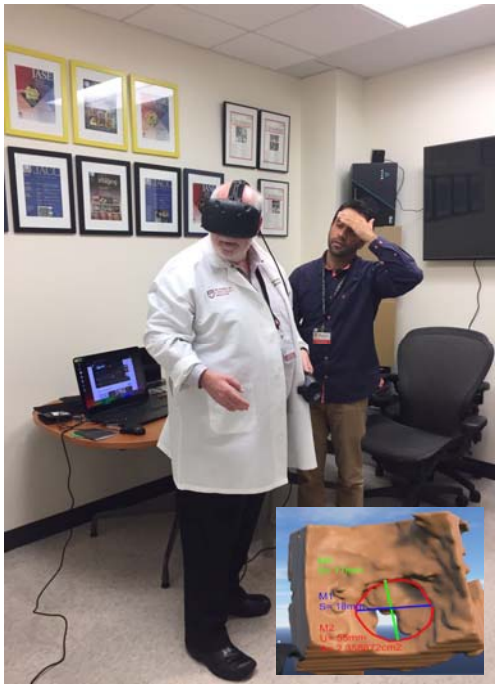




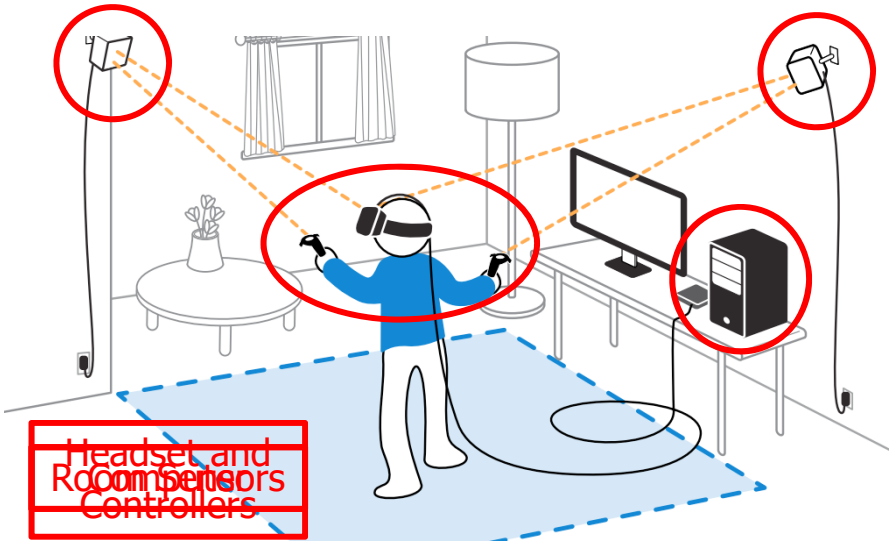
3D Printing

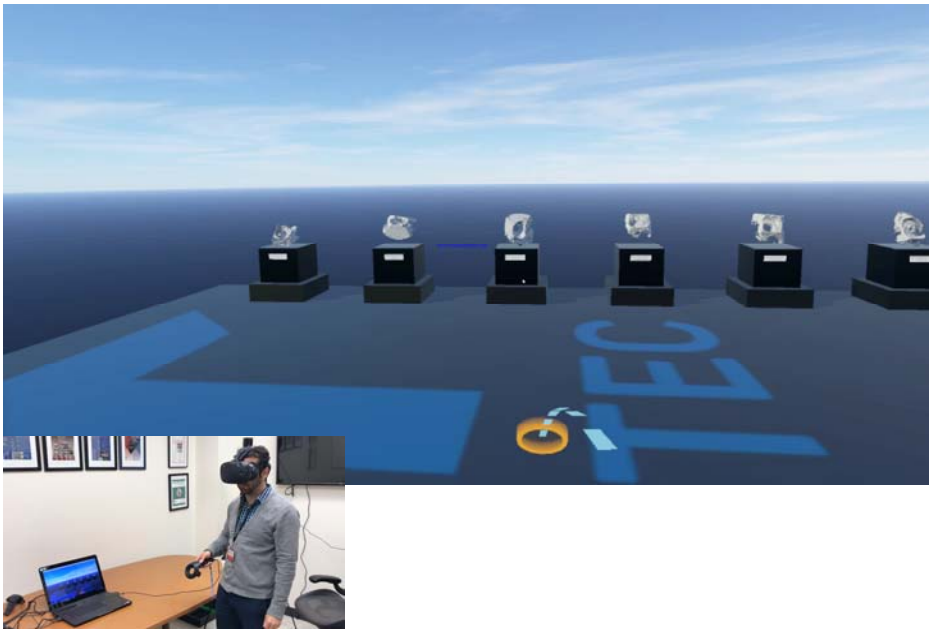
Virtual Reality

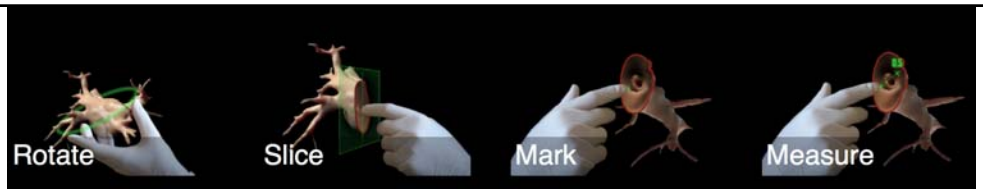
Computer-generated simulation of a three-dimensional image that can be interacted with by a person using special electronic equipment (helmet with a screen inside or gloves fitted with sensors.

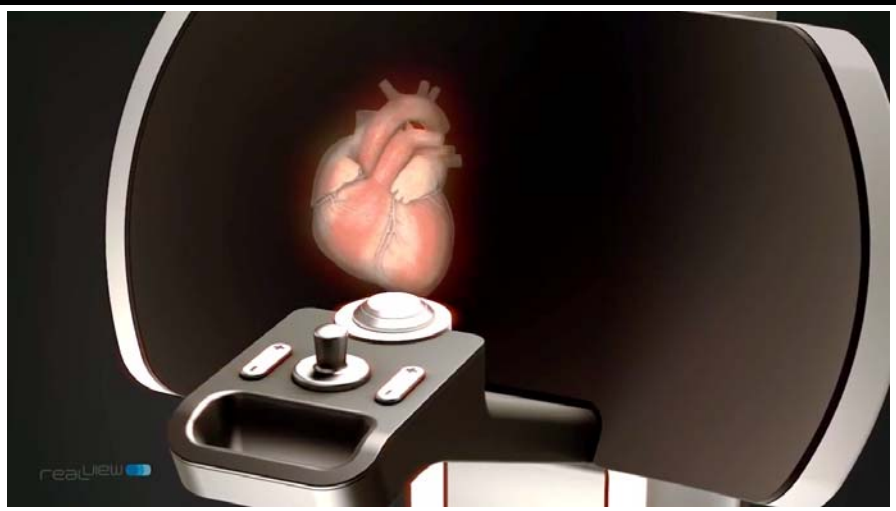


Virtual Reality Set-Up









Courtesy RealView Imaging .

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EDITORIAL

The future has arrived. Are we ready?

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Artificial Intelligence

Fusion Imaging

3D Printing

Virtual Reality

Holography

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