

# Image-guided Minimally-invasive Cardiac Interventions

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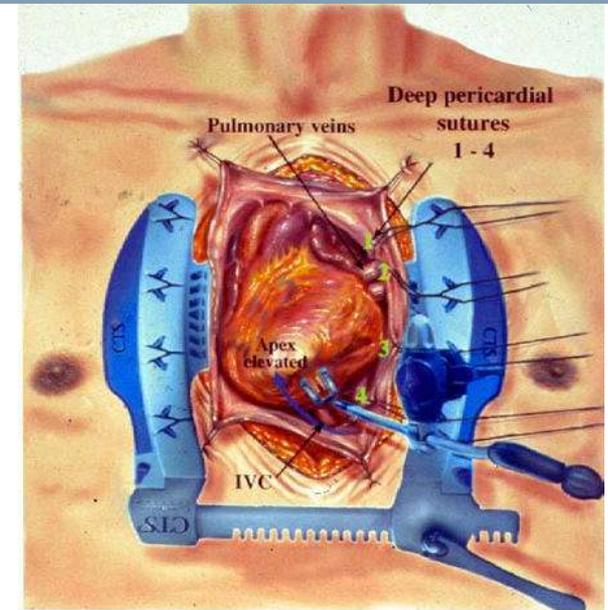
Imaging Research Labs - Robarts Research Institute



# Surgical Cardiac Intervention

- **Cardiac Surgical Procedures**

- Coronary Artery Bypass
- Valve repair/replacement
- Atrial–Septal Defect Repair
- Arrhythmia therapy
  - Surgery
  - Electrophysiological ablation



- **Conventional Approach**

- Sternotomy
- Cardiopulmonary bypass
- Cardiac arrest



# Sequelae of standard approach

- Lengthy healing times
- Increased risk of infection
- Systemic immune response
- Dislodged plaques
  - Neurological – Stroke
  - Cardiac – Heart attack
  
- “Surgery is a side-effect of therapy”

*G rard M. Guiraudon MD*

# Minimally Invasive Cardiac Intervention

## Motivation:

- Avoid sternotomy
- Avoid heart–lung machine
- Reduce recovery time
- Reduce costs
- Perform *therapy* on surface vessels or inside heart while avoiding (minimizing) *surgery*
- Validate therapy at time of procedure

# MI Cardiac Procedures

- **Electrophysiologically motivated**
  - Map abnormal EP responses
  - Ablate tissue responsible for Atrial Fibrillation etc
  - Pacemaker lead placement for Cardiac Resynchronization Therapy
- **Intracardiac Repair**
  - Valves
  - Atrial Septal Defect
- **Coronary Artery Bypass**
  - Robotic Cardio-pulmonary Bypass Grafting (Da Vinci)

# Minimally Invasive – Need Imaging

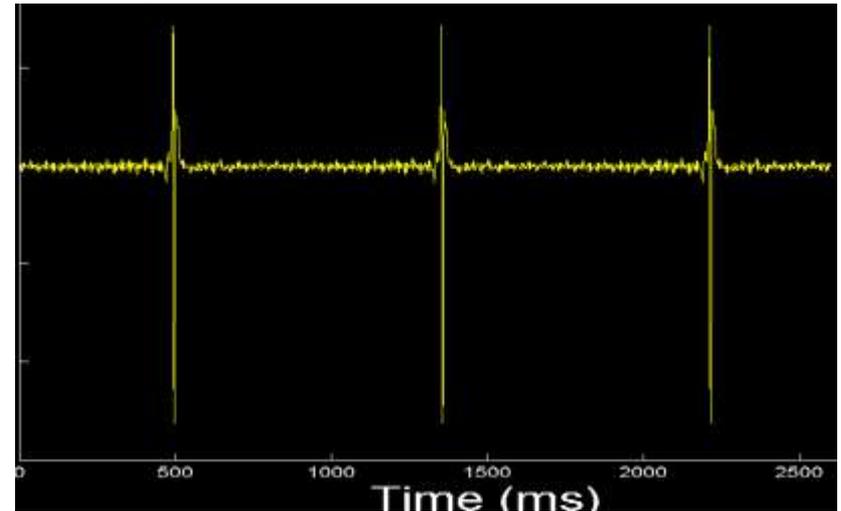
- **Real-time intra-op Imaging (MRI, US, X-ray)**
  - 2D or 3D imaging tracks instruments with respect to organ/target
- **Pre-op imaging only (MRI-CT)**
  - Register to patient
  - Navigate w.r.t. image model
  - Unfortunately targets move!
- **Hybrid – Intra-op US/MR/Xray – Pre-op MRI/CT**
  - US/MR tracks target and movement of organ
  - Tools represented virtually in image
  - Registered pre-op image provides global context
- **Multi-model image fusion**

# Electrophysiological Cardiac Mapping

- Cardiac Map – Spatial representation of cardiac electrophysiological (EP) activation

- Measured through:

- Body Potentials
- Epicardium
- Endocardium



- Key tool in study of cardiac rhythm disorders (arrhythmias)

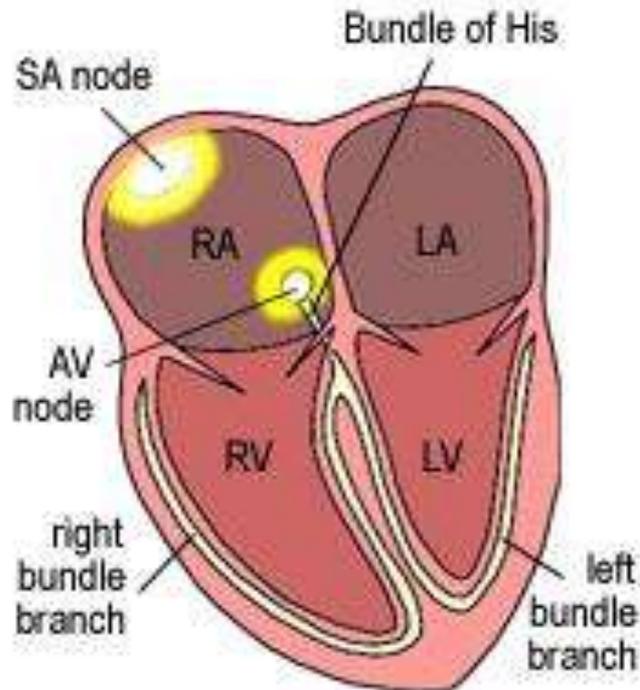
- Nature of Arrhythmia
- Location

# Atrial Fibrillation

- Atrial Fibrillation (AF) – Cardiac arrhythmia causes rapid irregular heart beats
- Most common significant arrhythmia, affecting over 2.5 million people in North America
- Prevalence increases with age
- May lead to:
  - blood pooling (causing clots)
  - cardiac disease
  - stroke

# Atrial Fibrillation

## Regular Heart

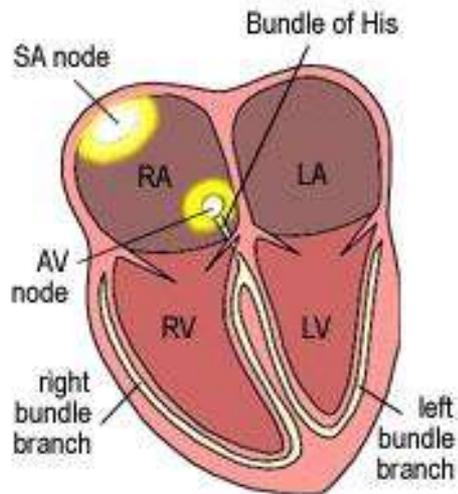


RA – Right Atrium  
LA – Left Atrium  
RV – Right Ventricle  
LV – Left Ventricle  
SA – Sinoatrial Node  
AV – Atrioventricular Node

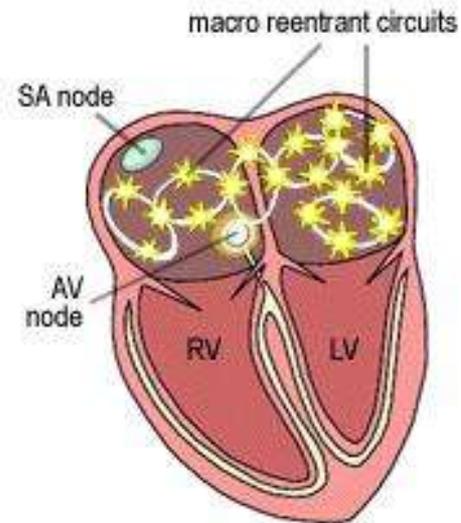
- **Electrical impulses originate from SA node**
- **Travels simultaneously to LA and AV node**
- **Continues to RV and LV branches**

# Atrial Fibrillation

## Regular Heart



## Arrhythmic Heart

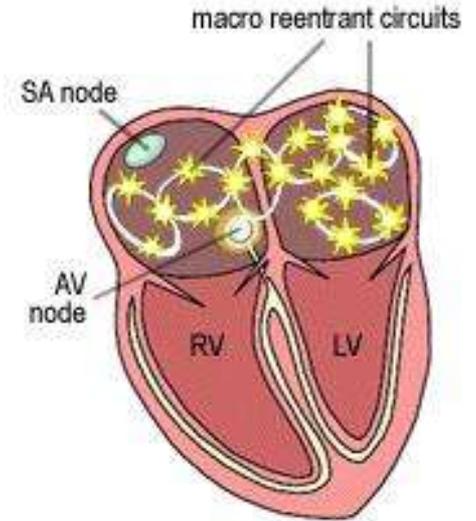


Images from "The Atrial Fibrillation Page" website

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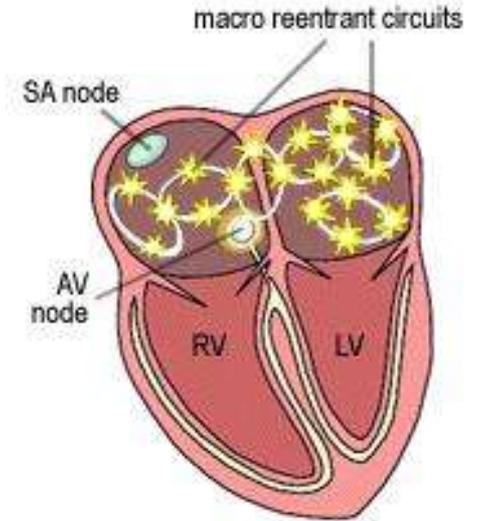
# Study and Treatment

- Study of Atrial Fibrillation:
  - Focal or Reentry?



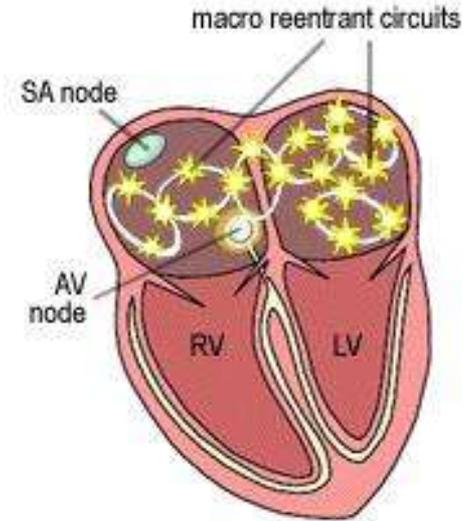
# Study and Treatment

- Study of Atrial Fibrillation:
  - Focal or Reentry?
  - Single or Multiple Sources?



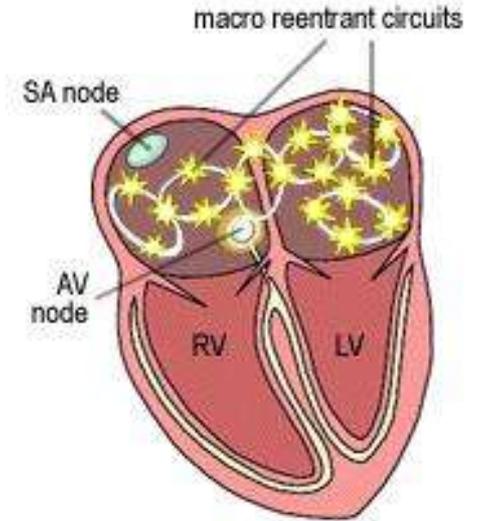
# Study and Treatment

- Study of Atrial Fibrillation:
  - Focal or Reentry?
  - Single or Multiple Sources?
  - Myogenic or Neurogenic?



# Study and Treatment

- Study of Atrial Fibrillation:
  - Focal or Reentry?
  - Single or Multiple Sources?
  - Myogenic or Neurogenic?
- Treating Atrial Fibrillation:
  - Medication



# Study and Treatment

- Study of Atrial Fibrillation:
  - Focal or Reentry?
  - Single or Multiple Sources?
  - Neurogenic or Myogenic?
- Treating Atrial Fibrillation:
  - Medication
  - Catheter Ablation
    - Single region or electrical “fence”

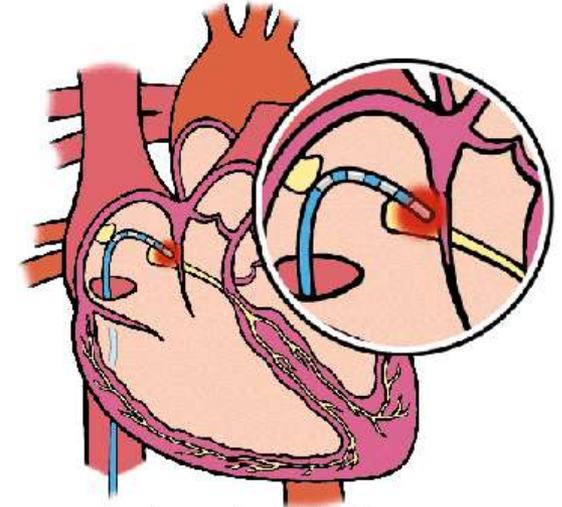


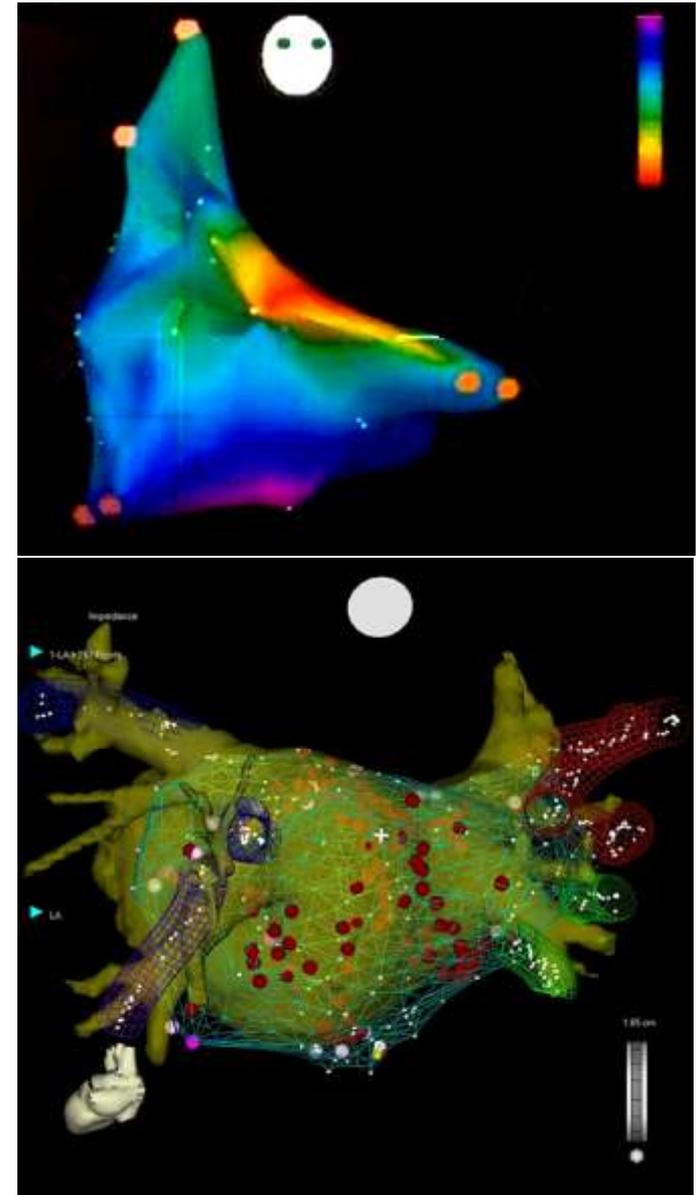
Image courtesy of Medtronic, Inc.

# Cardiac Mapping/Ablation Systems

- Cardiac Map – Spatial representation of cardiac electrophysiological (EP) activation
- Image–guidance system to create accurate cardiac maps and guide catheter ablation therapy
- Emerging technologies include:
  - Mapping/Ablation/US imaging Catheters
  - Monitoring
  - Tracking
  - Visualization

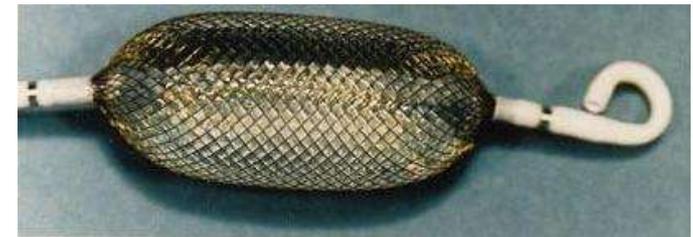
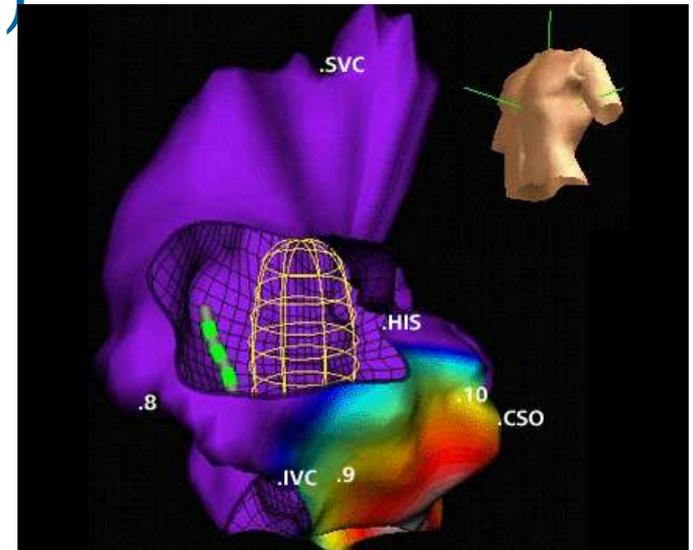
# Contact Mapping

- CARTO™ XP EP Navigation System (Biosense-Webster)
  - Point-based contact mapping
- Magnetic tracking with mapping/ablation catheter
- Reconstructs anatomy based on sampled locations
- Map samples to 3D CT
- RF or cryo ablation



# Non-Contact Mapping

- EnSite System (St Jude Medical)
- Multielectrode Array (MEA)
  - Records electrograms from blood pool
  - Interpolates back onto CT surface model
- Ablation catheter
  - Tracked by MEA/surface electrode patches
  - Perform Ablation (RF or Cryo)



# EP Ablation

- Identify abnormalities
- Map EP responses on surface model
- Observe catheter model within 3D display
- Guide catheter to target
- Ablate target
- Monitor ECG signals to ensure effective ablation

# Cardiac Mapping/Therapy Systems

- **Advantages:**

- 3D visualization for studying cardiac arrhythmias
- Anatomy and Electrophysiology
- Image guidance for targeting and delivering therapy

- **Limitations:**

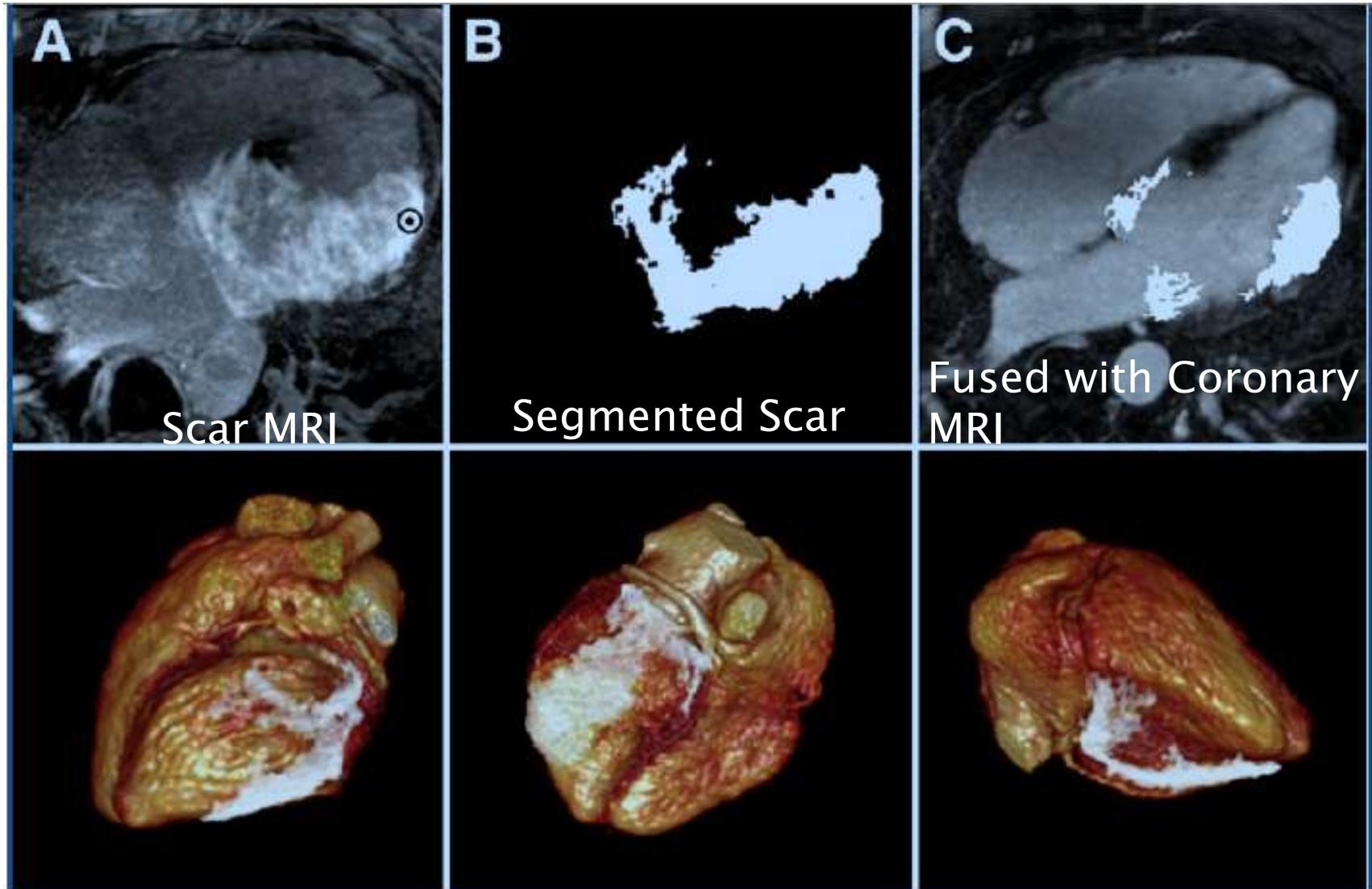
- Static representation of dynamic environment
- Cardiac map geometry seldom based on patient-specific data

# Cardiac Resynchronization Therapy

White et al. JACC Cardiovascular Imaging 3:9. 2010

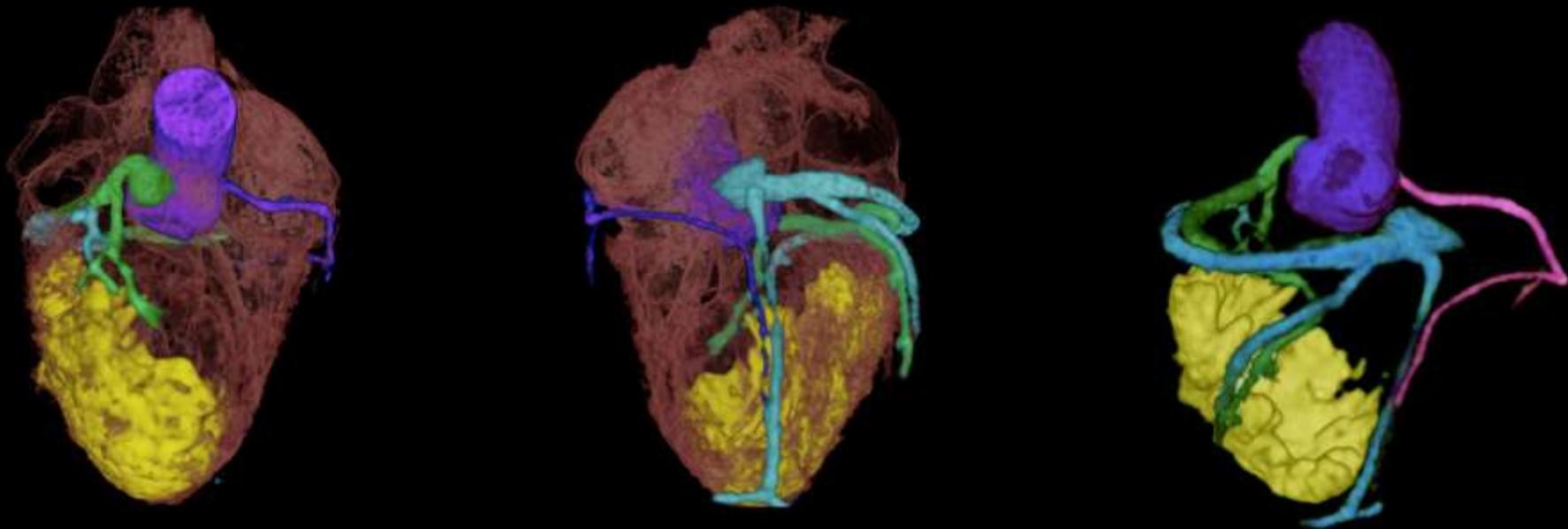
- Vascular-based interventions mitigated by scar in myocardium.
- Fuse 3D myocardial scar and coronary imaging
  - guide Coronary Resynchronization Therapy (CRT) or Coronary Artery Revascularization (CAR)
- Pre-procedural fused volumetric imaging of scar and vasculature
  - identify scar regions

# Image fusion



Volume Rendered Fused Views

# Fused 3D coronary MRA/3D scar map (3T)

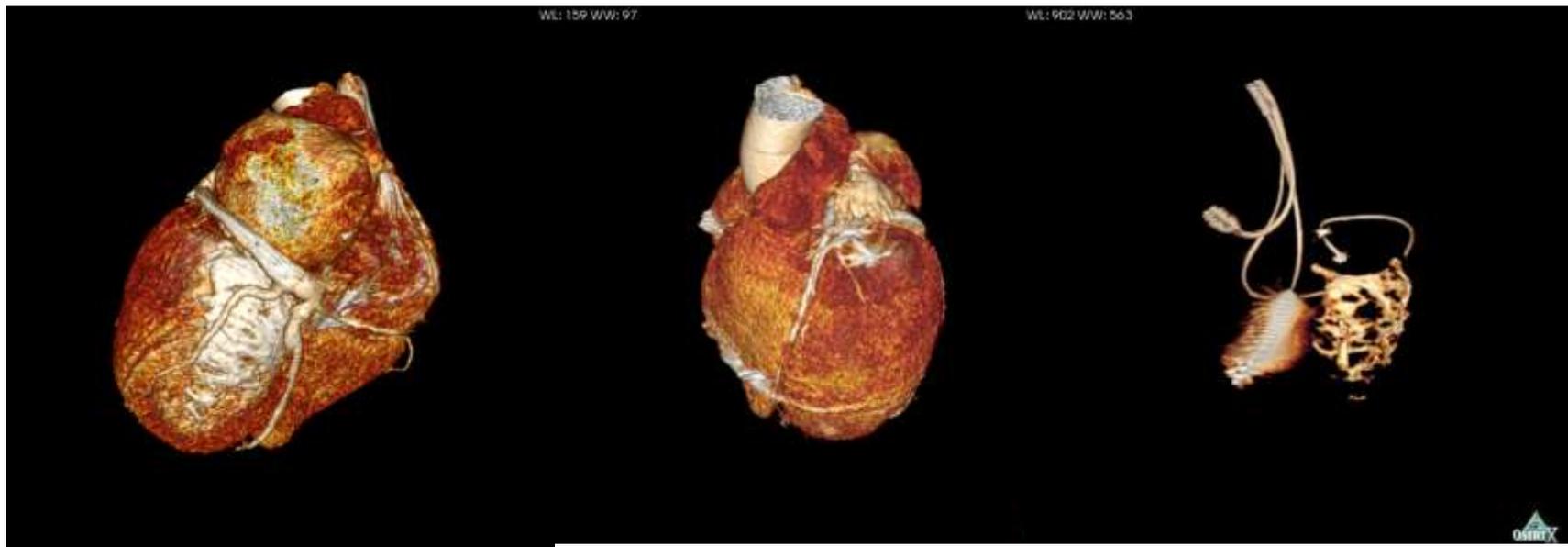


Patient with Ventricular Tachycardia

# Lead Placement based on Image Guidance

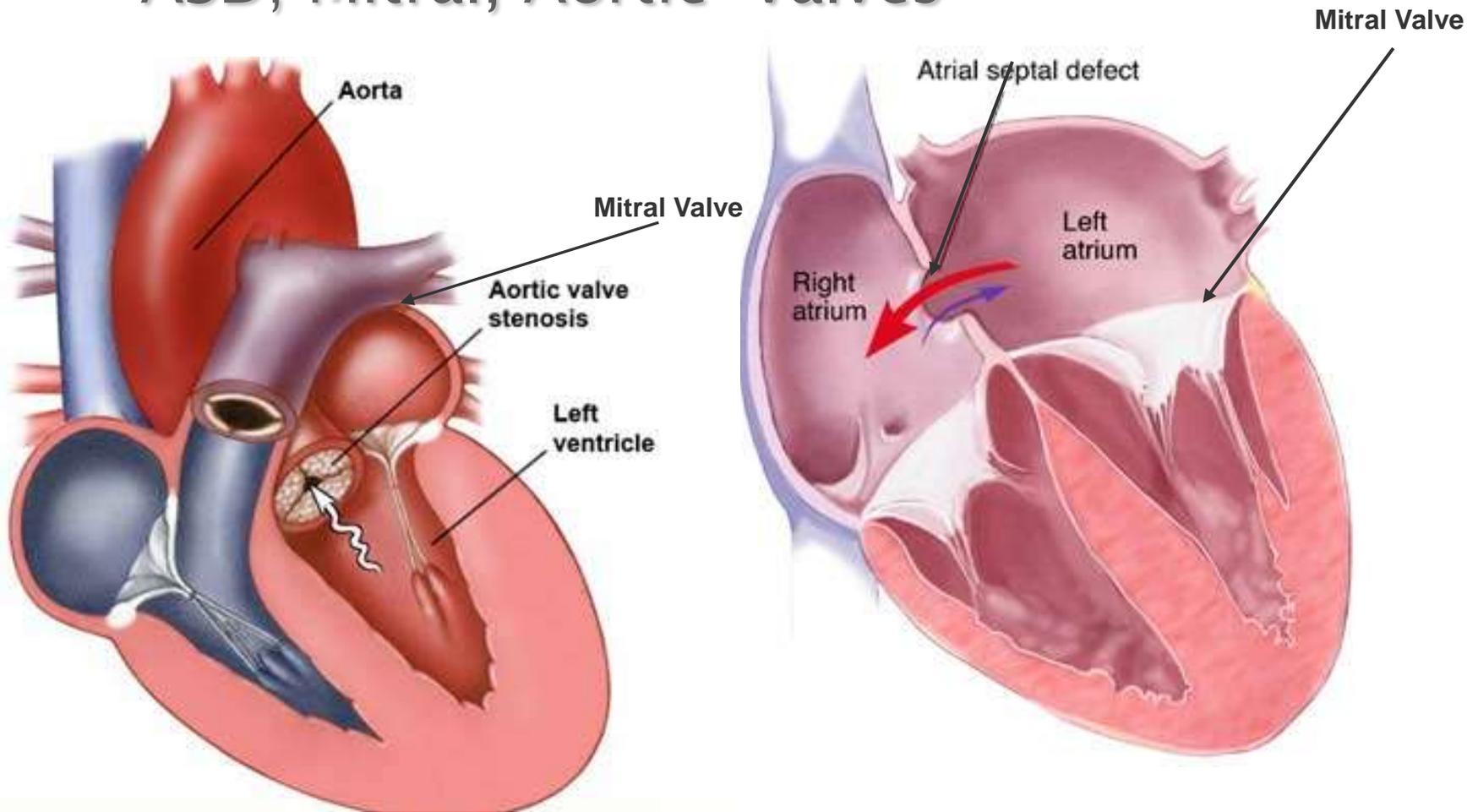
3D coronary CT in patient undergoing CRT showing transmural calcified scar – leads directed distally under X-ray guidance.

Next step – fuse scar MR image with X-ray fluoro



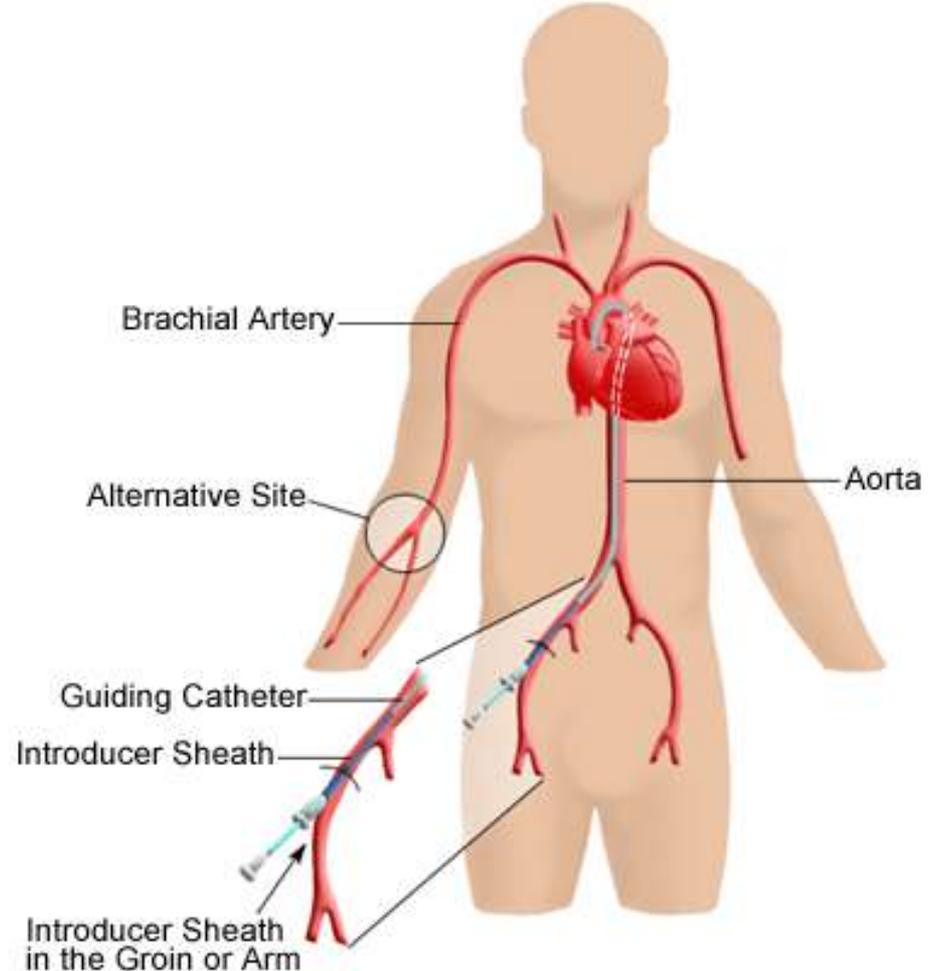
# Intra-Cardiac Targets

- ASD; Mitral, Aortic Valves



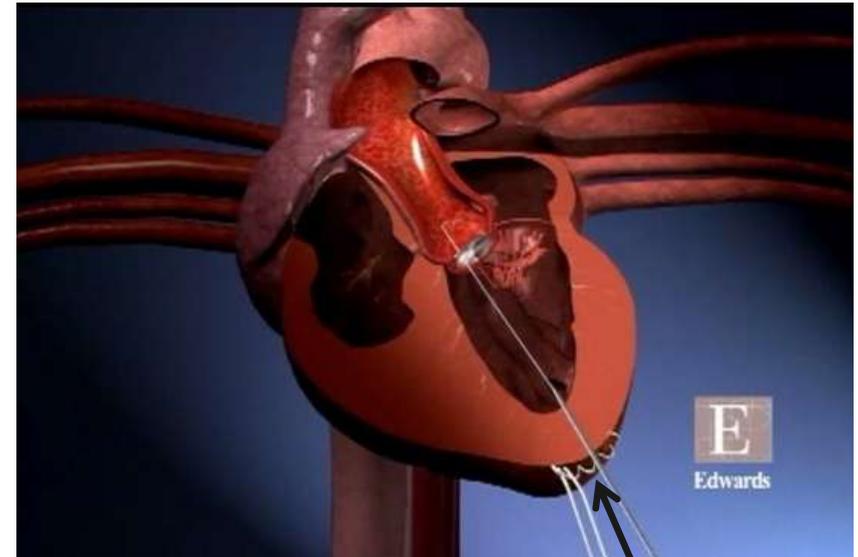
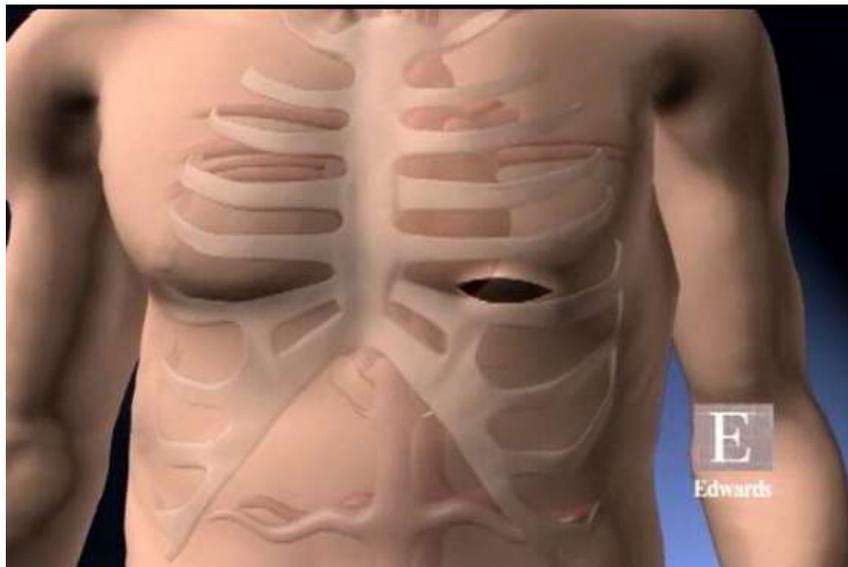
# Minimally-invasive access

- Trans catheter approach
  - Introduce instrument/ device through vascular system
  - Passive guidance –
    - manipulate catheter from distal end
  - Active guidance –
    - “drag” catheter tip with magnetic field: “Stereotaxis”
  - Stent-based device fixation
    - ASD
    - Aortic valve



# Minimally-invasive access

- Trans thoracic approach
  - Minithoracotomy
  - Introduce devices via
    - Apex
    - Atrial appendage



“Purse-string”  
suture

# Guiraudon Universal Cardiac Introducer (GUCI)

Introduce bulky objects  
into chambers

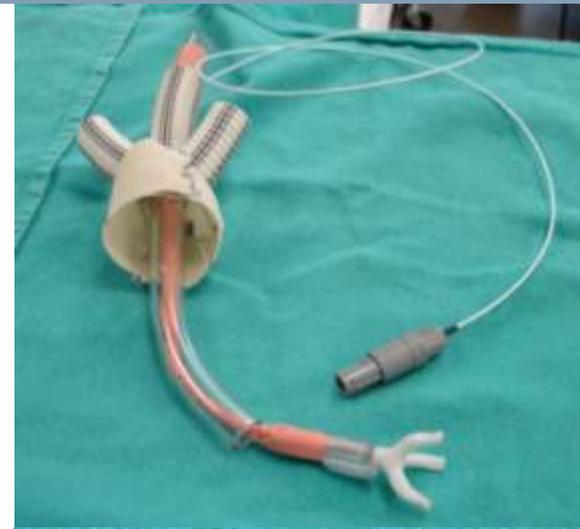
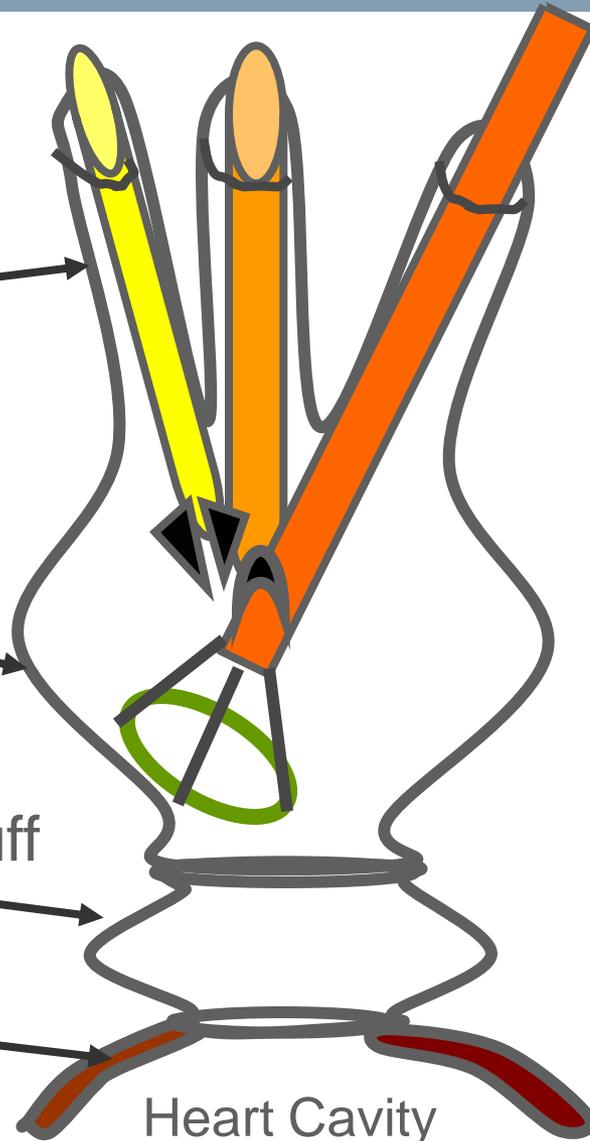
Introduced tools

Versatile removable  
Dacron® introductory  
chamber

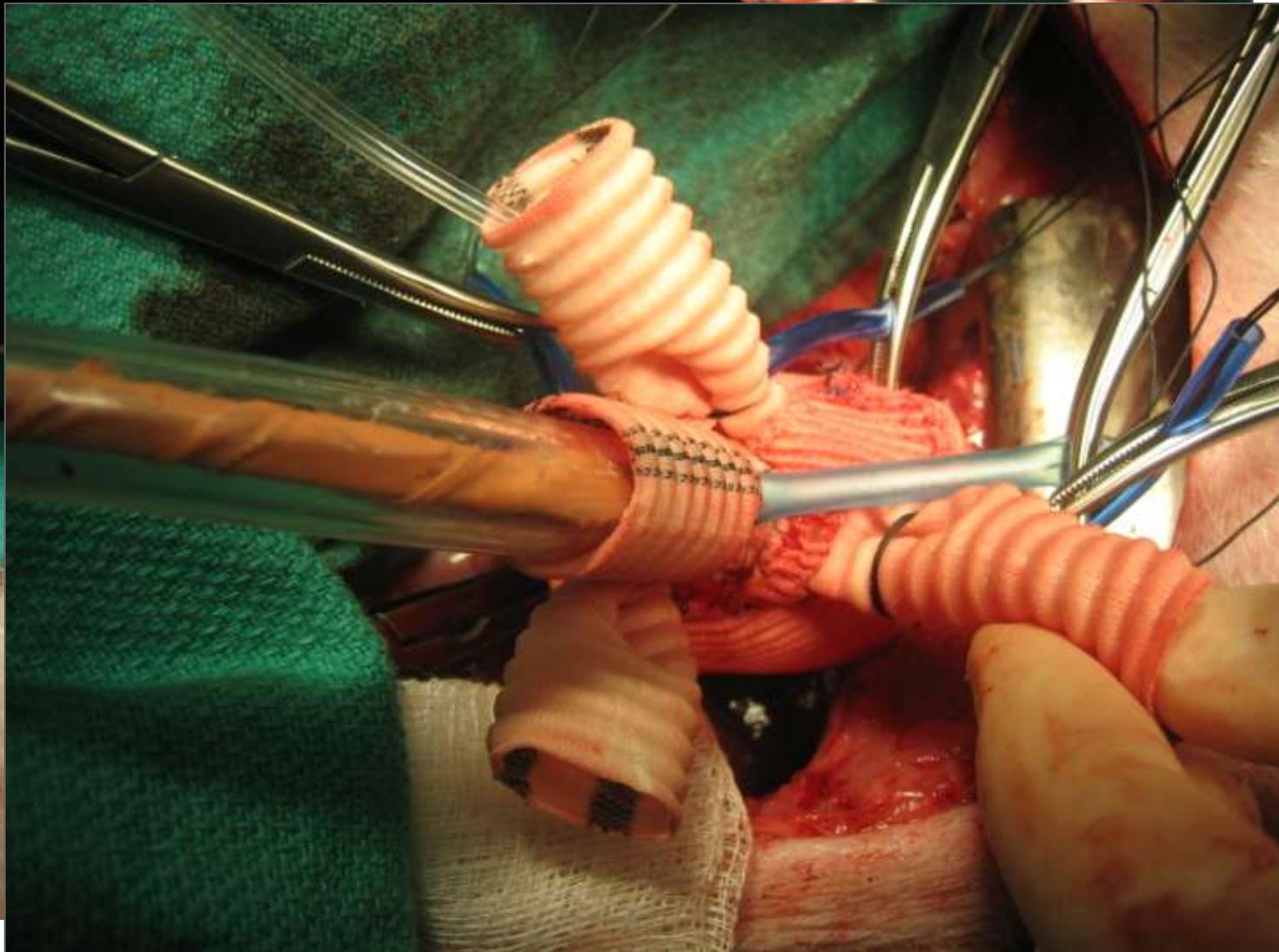
Safety attachment cuff

Heart port access  
LA Appendage

Heart Cavity



# Applying GUCI to Left Atrial Appendage



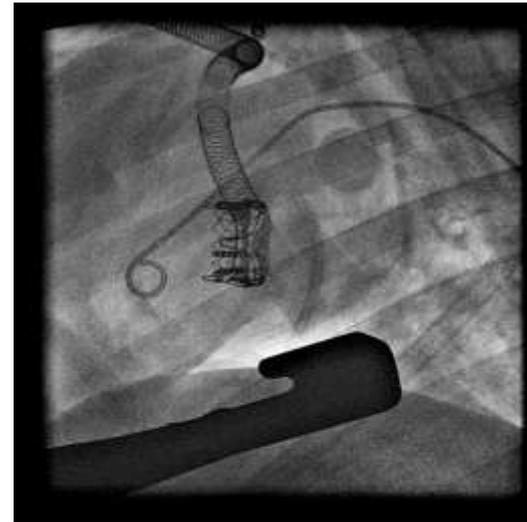
# Without direct vision, need to know...

- Location of target
- Position of instrument with respect to target
- Orientation of instrument(s)
- Orientation of prosthesis
- Accuracy of prosthesis positioning

# Fluoroscopy

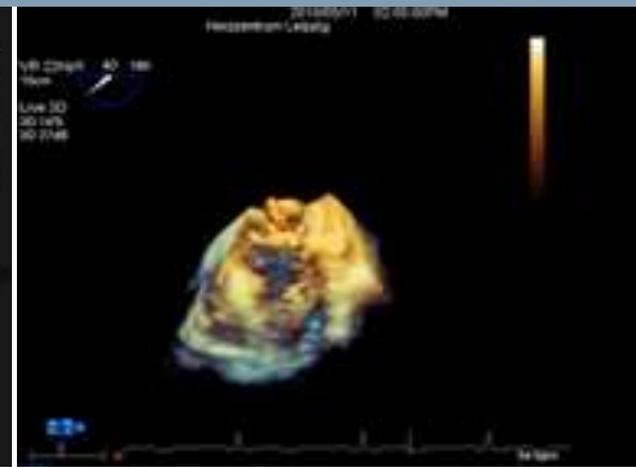
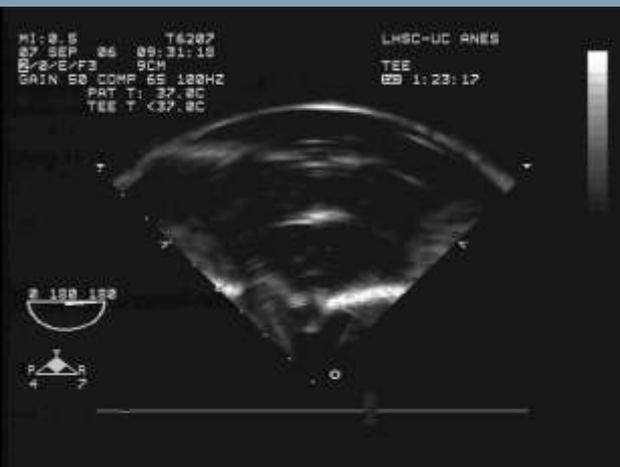


- Advantages
  - Real time
  - Present standard of care



- Disadvantages
  - X-ray dose
    - Patient, staff
  - Cannot see target
  - 2D image only
  - Cannot visualize valve prosthesis with respect to annulus or coronary ostia.

# Ultrasound (Echo)



- Trans-esophageal echo

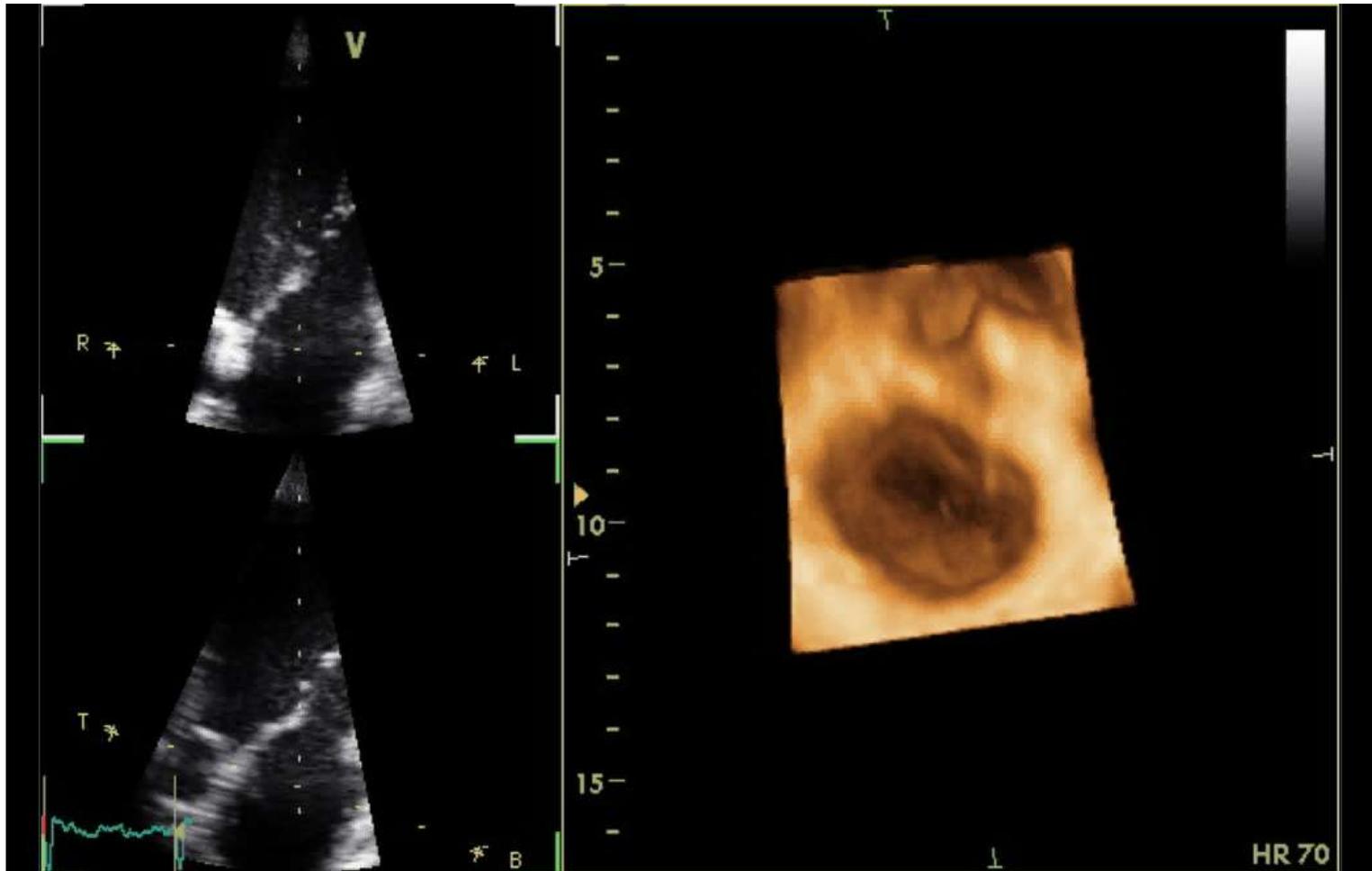
## Advantages:

- Cost effective
- Real-time
- OR compatible

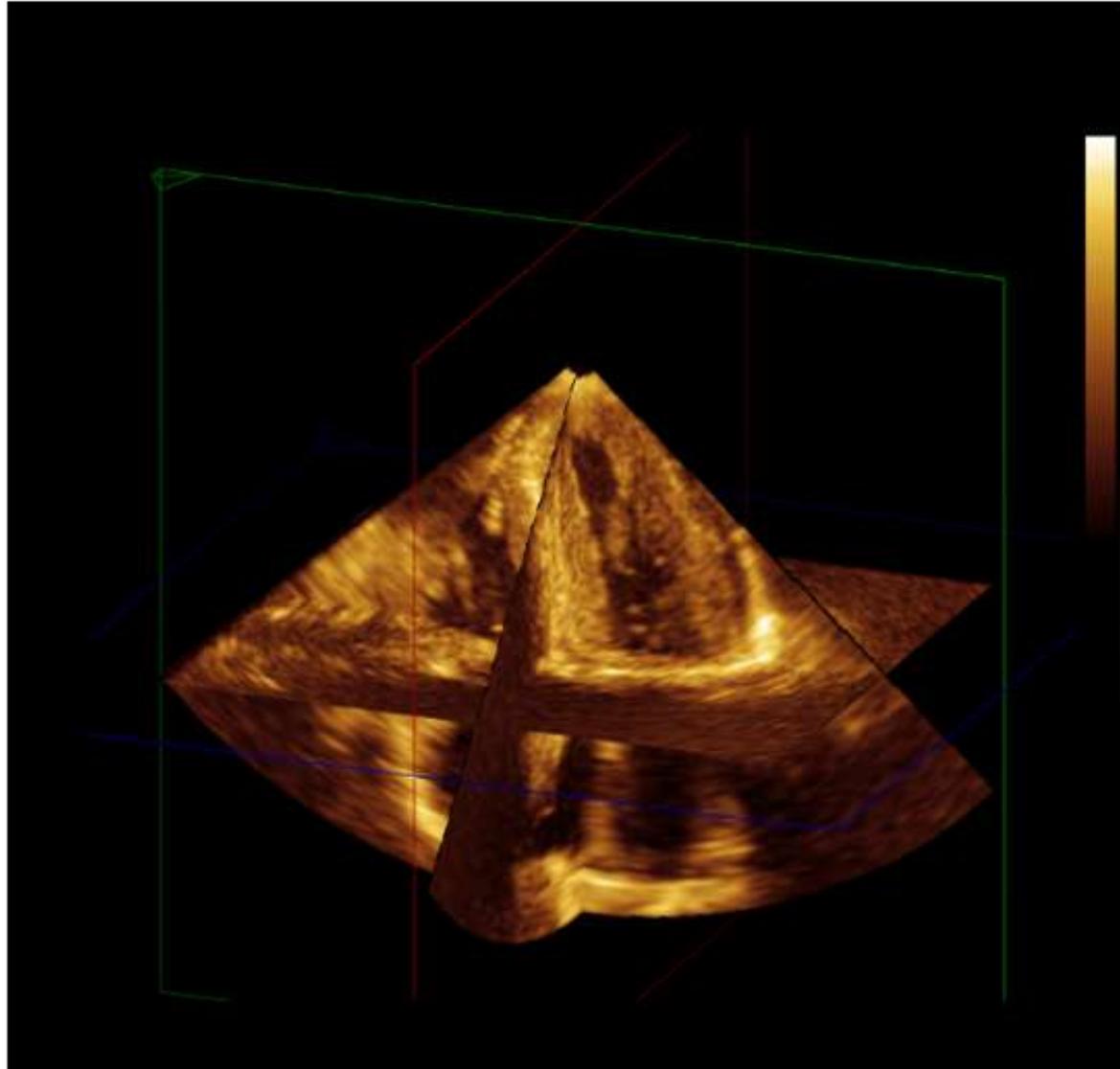
## Limitations:

- Lack of context
- Poor perception
- Limited field-of-view
- Shading of view by instruments in field
- Limited availability of *streaming* 3D TEE

# 3D Transesophageal Echo (TEE)

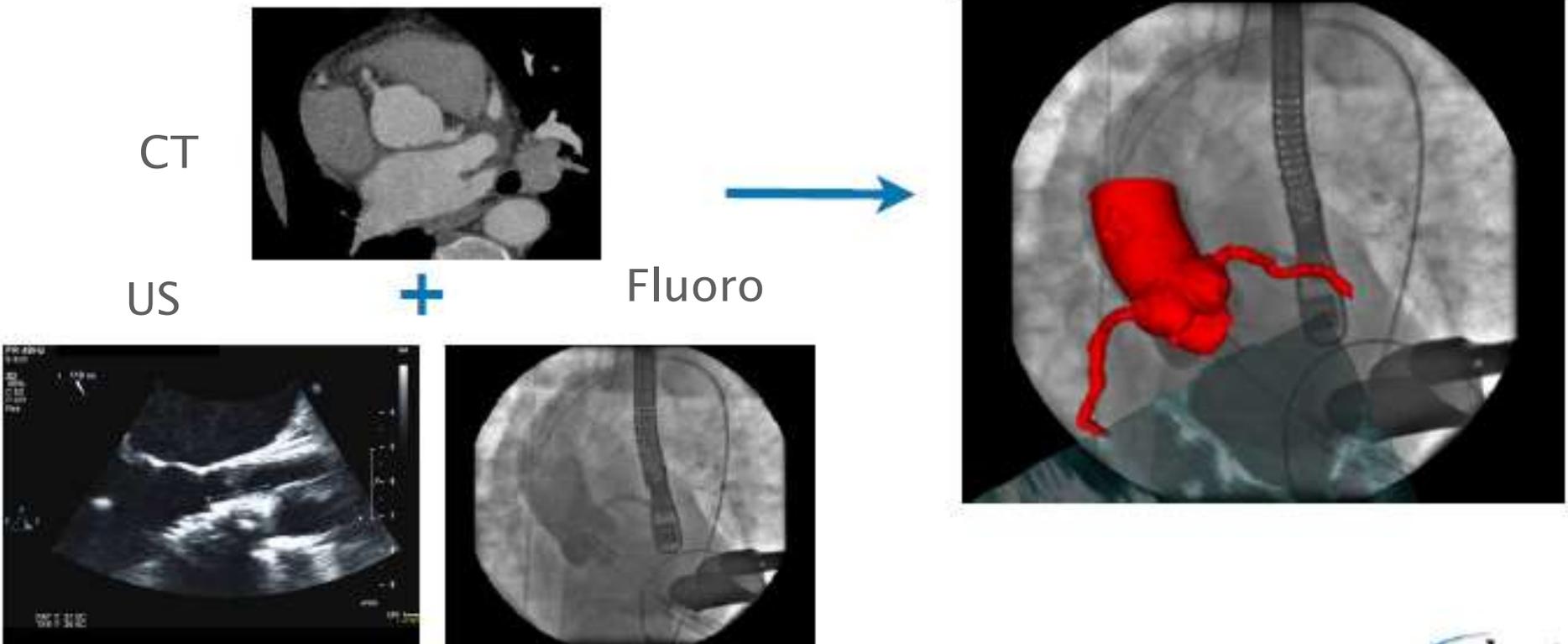


# 3D Transesophageal Echo (TEE)

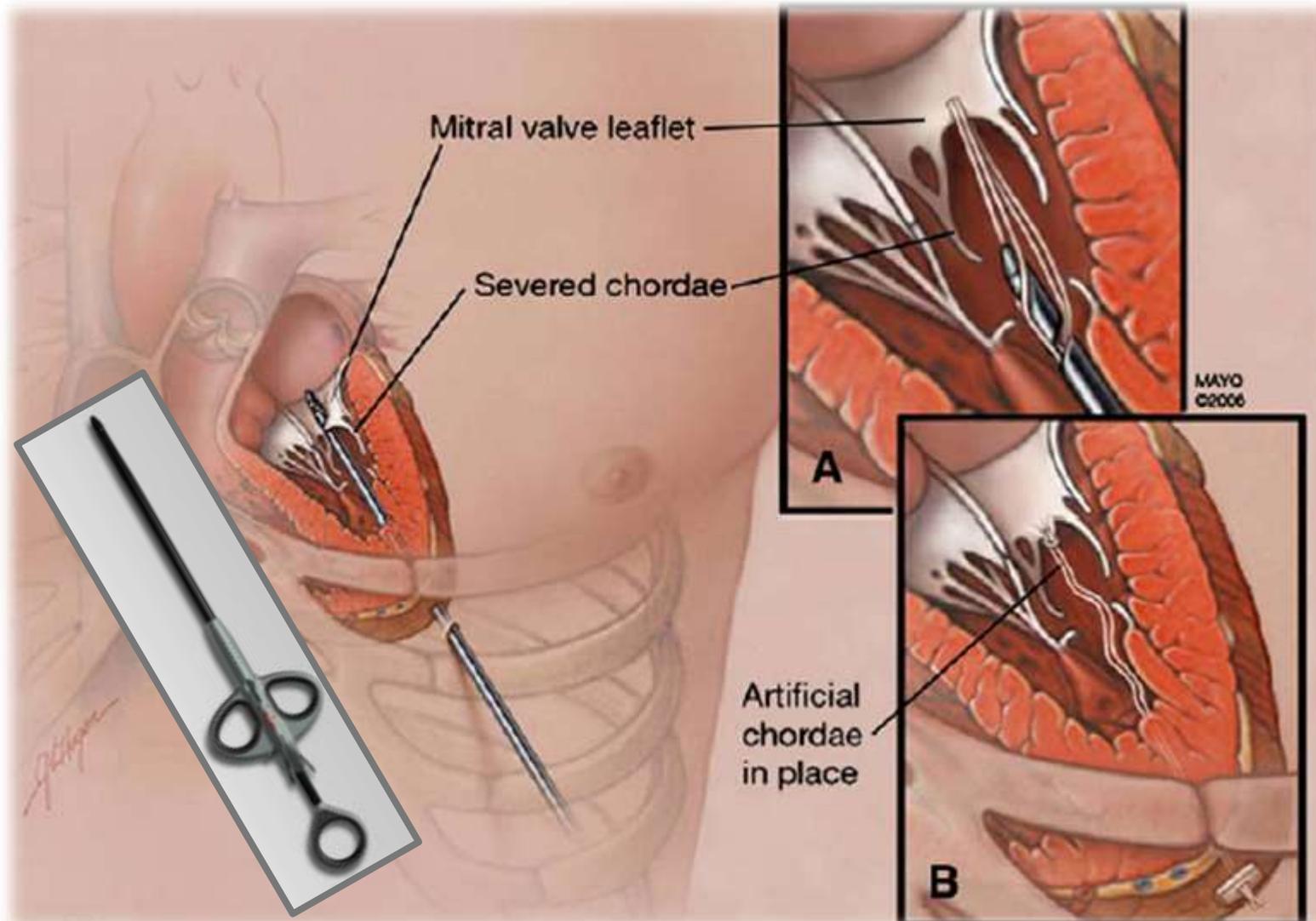


# Multi-modal fusion for TAVI

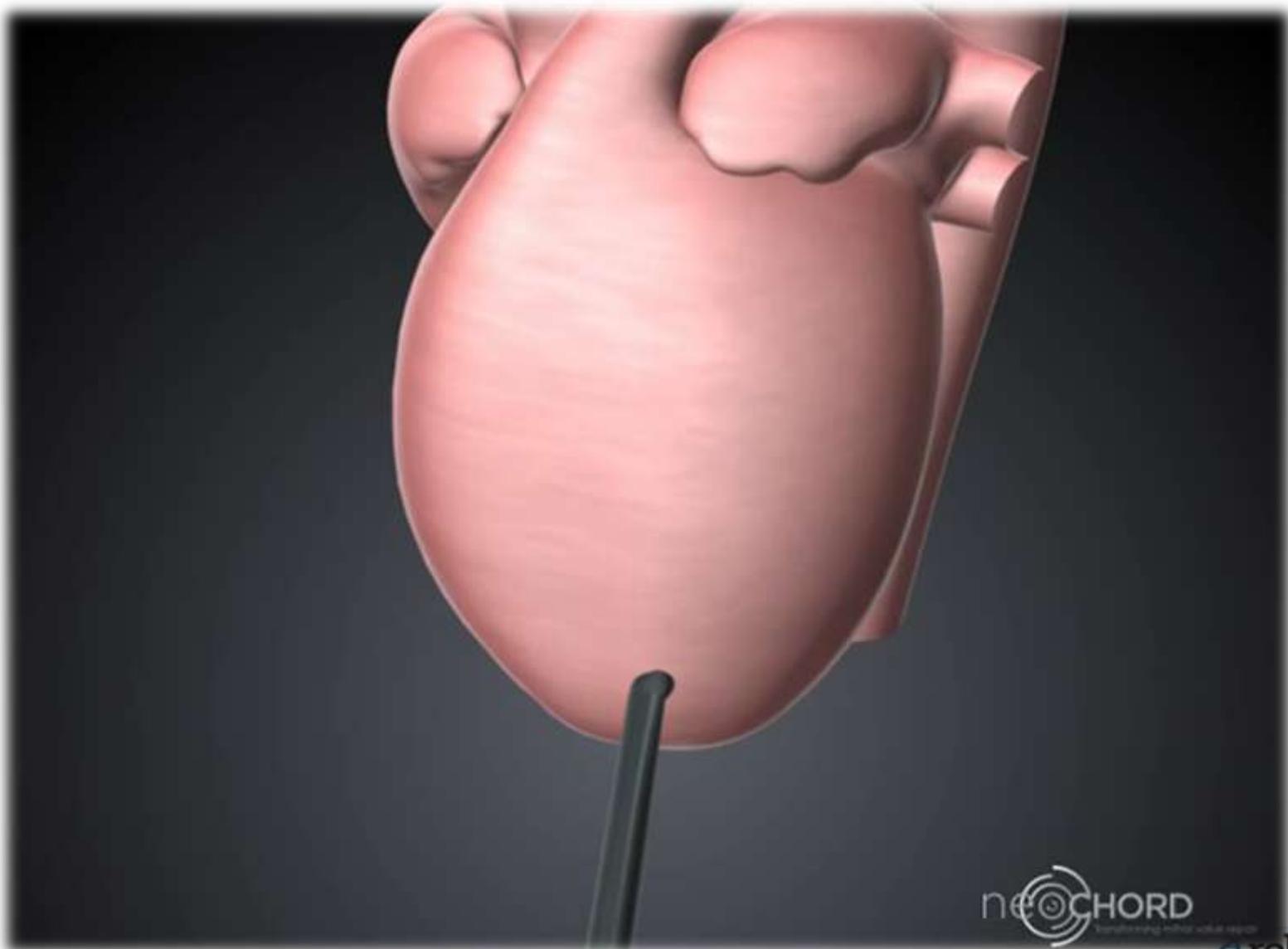
## Transcatheter Aortic-Valve Implantation



# Transapical Beating-heart MV repair



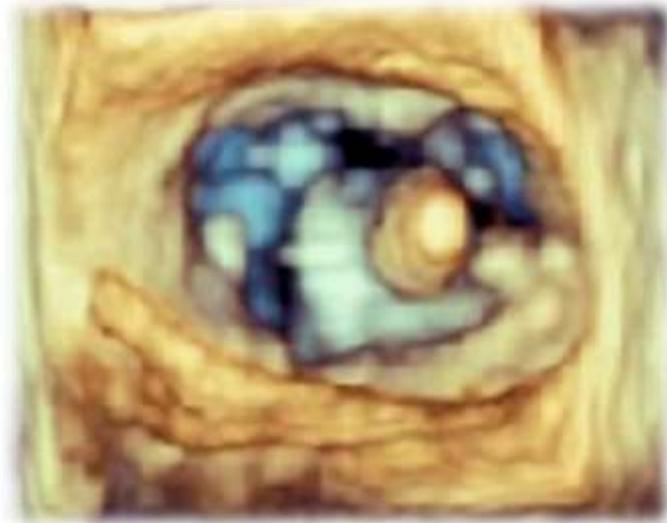
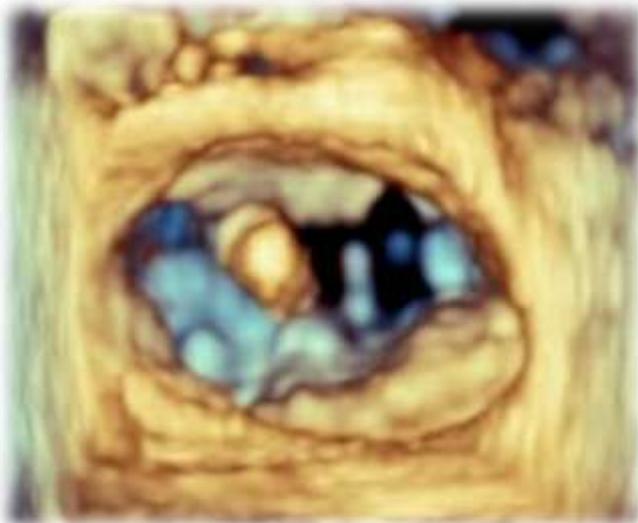
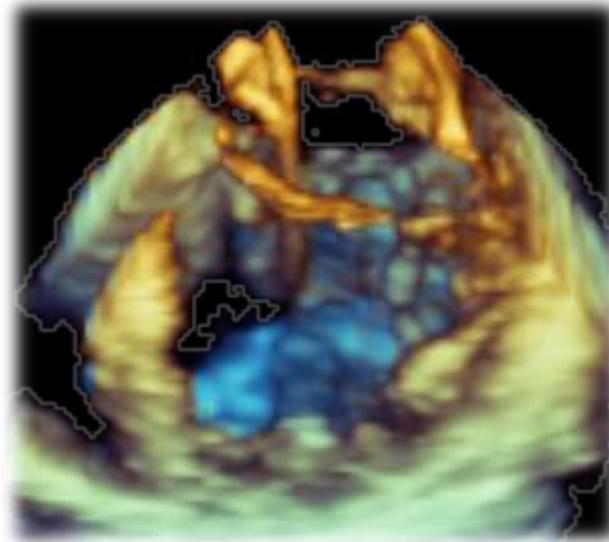
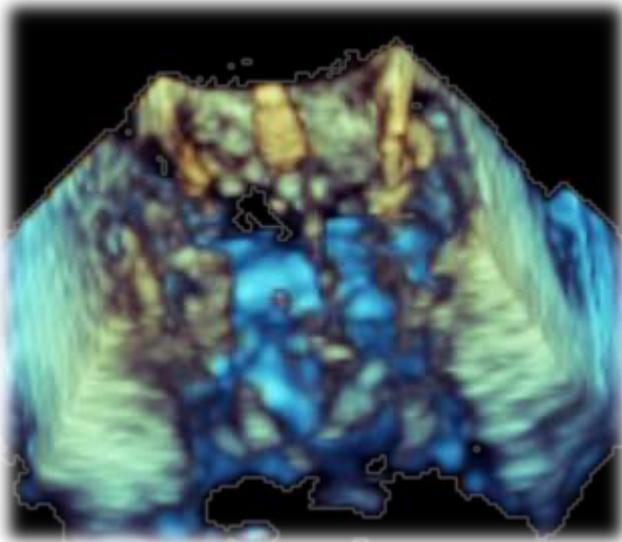
# NeoChord procedure



neoCHORD  
Transforming mitral valve repair

robarths  
IMAGING

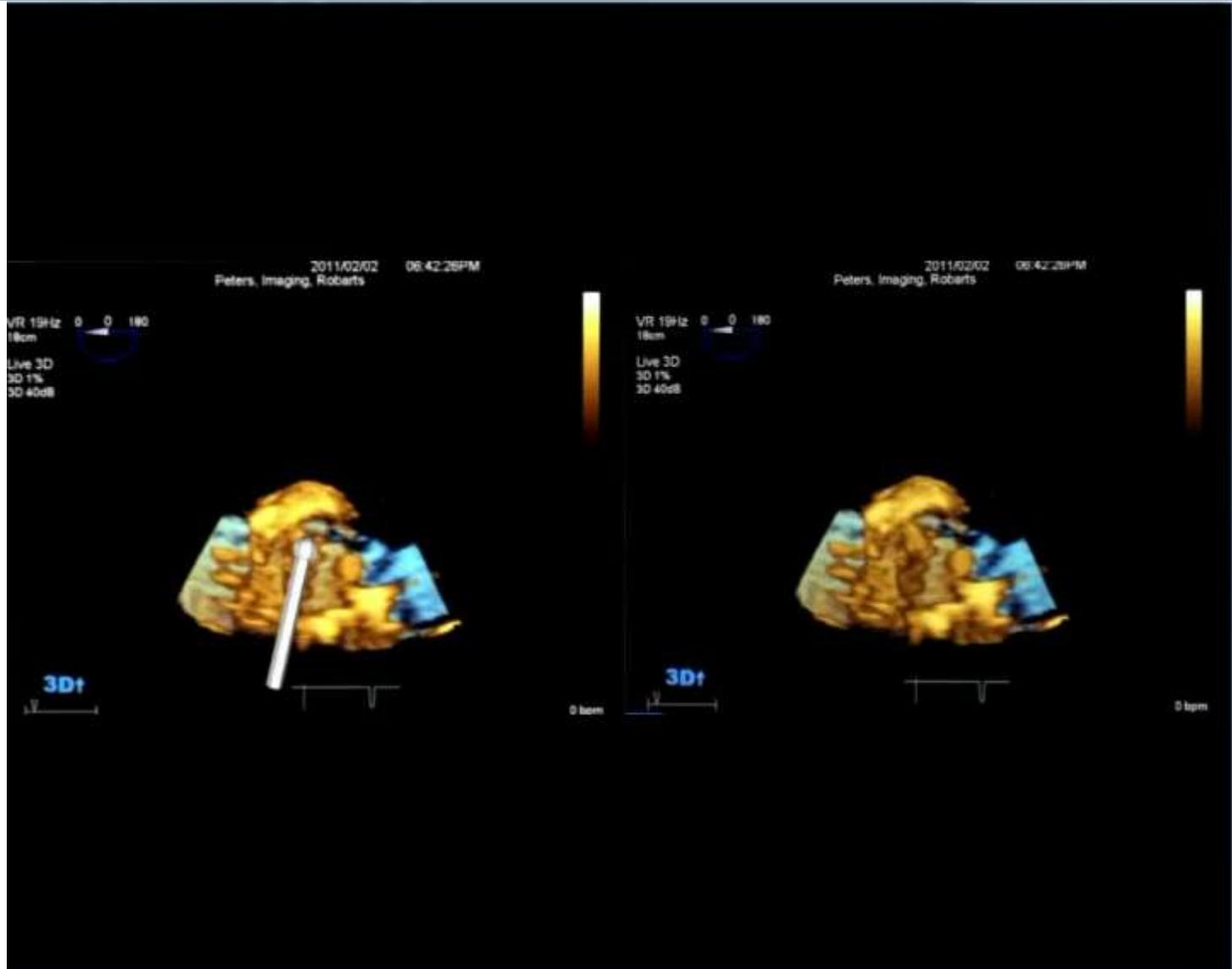
# 3D visualization



# Limitations of US alone

- Limited field of view in real-time mode
- Poor resolution
- Lack of detail
- Difficult to accurately track position and orientation of tools
- Artefacts introduced by instruments in field

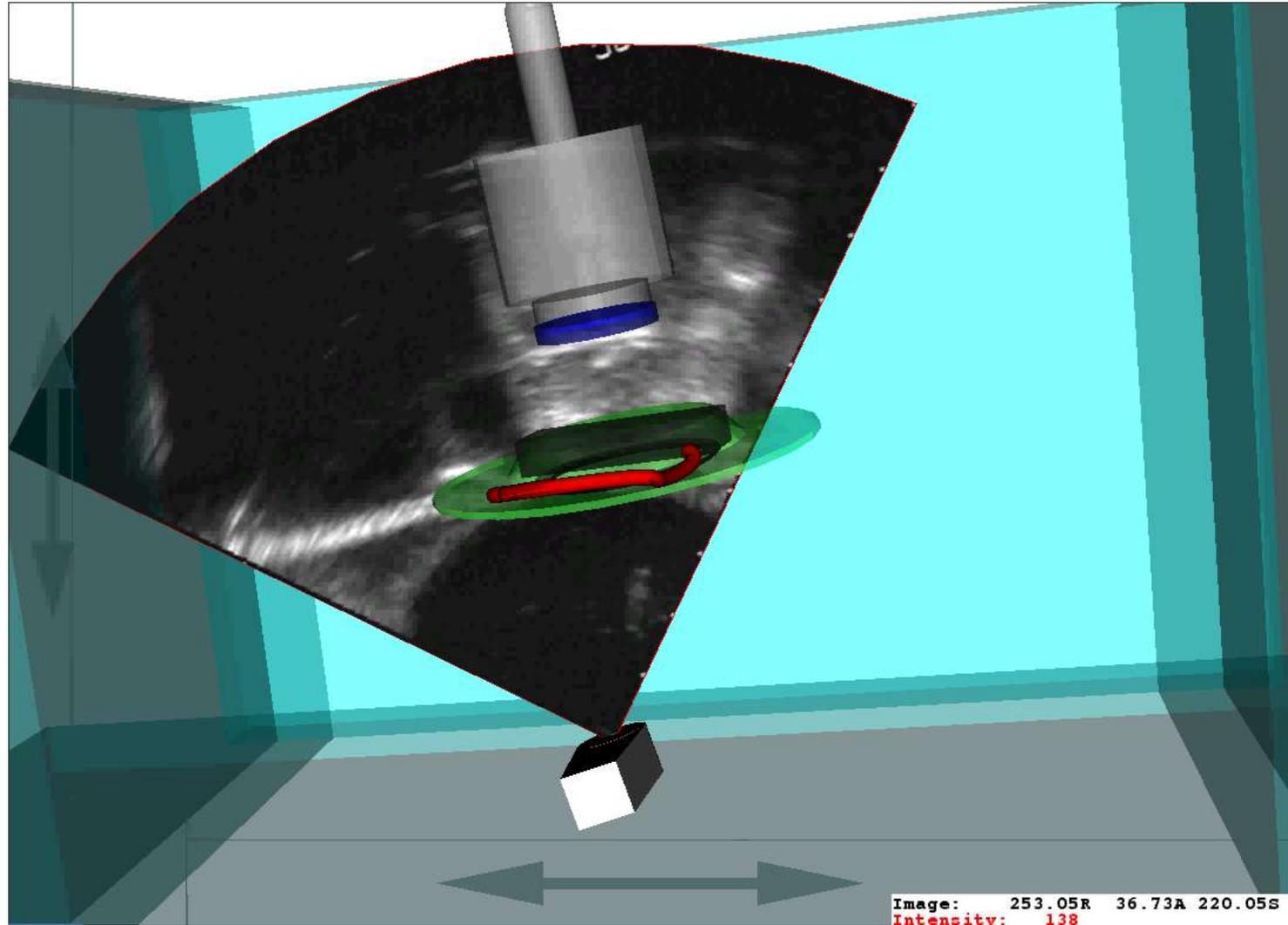
# Tool Navigation: Image vs AR



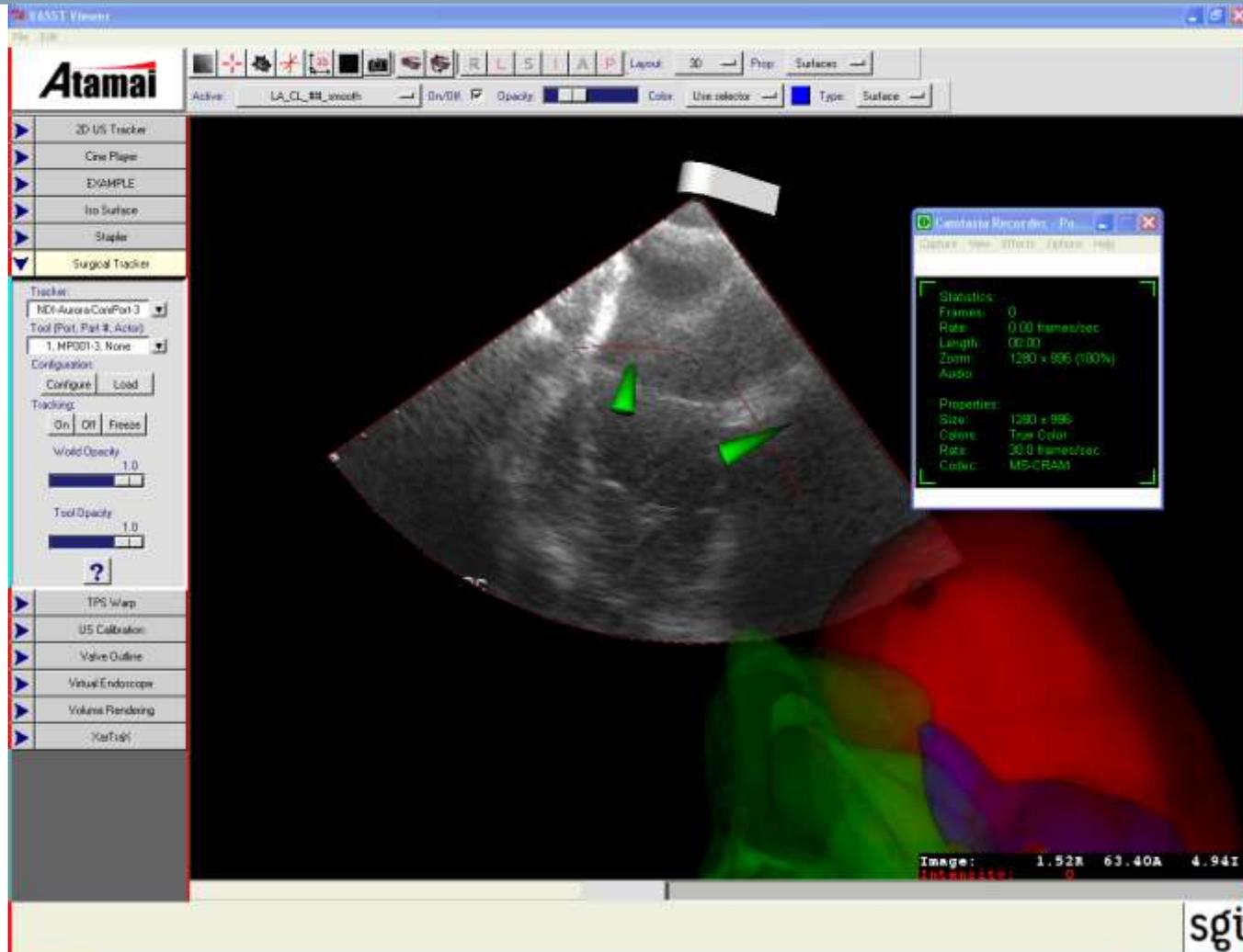
# Solution...

- Register pre-operative image of environment to US to provide context
- Track instruments with magnetic tracking (e.g. NDI Aurora™, Ascension Micro-bird™)
- Generate virtual representations of tools
- Represent instruments, Pre-op images and US transducer in common coordinate system
- Display US image in Virtual Reality environment with tools and pre-op data

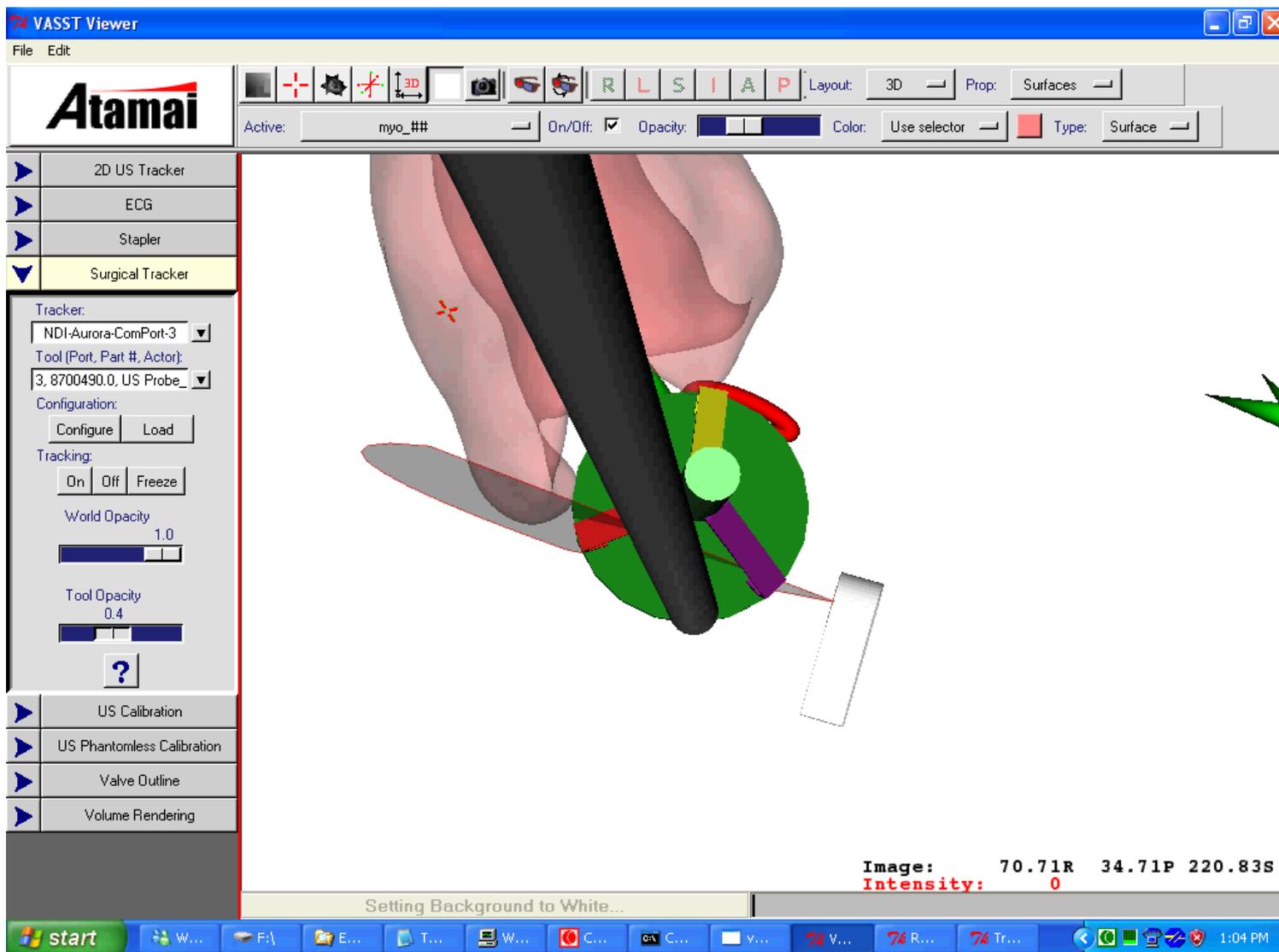
# Tool Navigation & Fastening



# Registering dynamic model



# Guidance for ASD patch placement



# Future Directions and Challenges

- Robust integration of pre-operative imaging into therapy guidance will enable new procedures
- Ultrasound seems ideal candidate for bridging pre-op images with patient
- Pre-op imaging/US may eliminate need for intra-op X-ray
- Intra-cardiac beating heart procedures will depend on image-guidance
- Challenges
  - 3DUS image acquisition rate
  - Dynamic image registration
  - Deforming pre-op model during procedure
  - Image/Display latency
  - Information overload

