Image-guided Minimally-invasive Cardiac Interventions

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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”
  
  Gérard M. Guiraudon MD

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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

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

Regular Heart

Arrhythmatic 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

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  – Focal or Reentry?
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  – Myogenic or Neurogenic?
Study and Treatment

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  – 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”
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 Ablaltion

- Identify abnormalities
- May 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

Scarf MRI

Segmented Scar

Fused with Coronary MRI

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
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

CT + US + Fluoro
Transapical Beating-heart MV repair

NeoChord procedure
3D visualization

Michael Borger, Joerg Seeburger, Fred Mohr
Heart Center Leipzig,
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
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