Multimodality imaging for guiding electrophysiology

Benoit Desjardins, MD, PhD
Associate Professor
Radiology and Medicine
University of Pennsylvania

no financial conflicts

cardiac MRI with Gad is off-label
Introduction

- cardiac electrophysiology (EP) is the study of arrhythmia

- imaging has proven useful in EP
  - cardiac structure plays key role in arrhythmogenesis
  - imaging is great to depict cardiac structure
  - imaging is now integral part of EP procedures

- this talk: use and benefit of multimodality imaging techniques
  - during atrial and ventricular EP procedures (esp. ablation)
  - pre-, intra- and post-procedural imaging
Electro-anatomic (EA) mapping

- modern cardiac electrophysiology
  - uses catheters to assess electric properties of the heart
    - intravascular or intrapericardial
  - tip of catheter can
    - measure intracardiac surface voltages
    - deliver RF ablation lesions
- EP systems can track 3D position of catheter tip
  - 3D position used to define **coarse** 3D anatomy
  - voltage measurements used to define scar
    - low voltage (red) corresponds to scar
Imaging integration

- anatomy generated by EP systems is limited
- imaging can be integrated to generate **better** anatomic information

principles of integration

- 3D anatomy by MRI/CT/echo
- coarse 3D point cloud by EP system
- these two 3D datasets can be registered

objectives of integration

- minimizing radiation exposure
  - by replacing the need for fluoroscopy
- enhancing procedural outcomes
- minimizing potential of complications
Scar: MRI vs EA maps

- MRI most often integrated to EP because of ability to depict scar
- high signal on DE-MRI
- low voltage of EA mapping
- good match between the two

Desjardins, Heart Rhythms 2009
Sampling: MRI vs EA maps

- MRI: uniform sampling
- EAM: non-uniform sampling
- sometimes discrepancies

- here, MRI says “scar” but EA mapping says “no scar”
- incomplete sampling on EAM

Desjardins, Heart Rhythms 2009
Scar distribution

- Two big advantages of MRI over EAM
  - Better sampling
  - Better wall depth assessment
- MRI much better than EA maps to assess
  - Complex distribution of scar (NICM)
  - Diffuse scar (HCM)
  - Intramural scar
- EAM can be normal or difficult to interpret when scar distribution is complex or patchy
Atrial arrhythmia: pre-procedural imaging

- atrial fibrillation
- arrhythmia originates at PV ostia
- goal: electrically isolate PVs

**Role of imaging**
- facilitates catheter selection and manipulation
- identify landmark for registration
- rule out atrial thrombi
Other structures

- Phrenic nerve
  - right pericardiophrenic artery
  - close to right phrenic nerve
  - identify anatomy more vulnerable to phrenic nerve injury

- Esophagus
  - close contact to LA wall
  - may lie within ablation zone
  - marked variation in the anatomic relationship

Horton, Heart Rhythm 2010

Lemola, Circ 2004
LA scarring

- long term atrial fibrillation can result in scar in LA wall
- can be imaged by MRI ("controversial", with limited reproducibility)
- scar predicts rate of recurrence of afib following ablation (Oakes, Circ 2009)
- might help select appropriate candidates for afib ablation
Intra-procedural imaging

- interactive 3D anatomy (virtual reality)
  - guidance of catheter
  - visualization of location of ablation lesions
    - series of adjacent punctiform lesions
  - replaces long periods of fluoroscopy
Intra-cardiac echocardiography (ICE)

- **advantages**
  - real-time visualization of anatomy
  - real-time guidance of catheter
  - visualize esophagus to avoid collateral damage
  - helps recognize complications

- **acoustic radiation force imaging**
  - assess tissue elasticity
  - ablation lesions are stiffer
  - so can detect gaps between ablation lesions during the procedure

Eyerly, Heart Rhythm 2012
Contact force sensing

- ablation requires **good contact** of catheter with myocardium
  - usually assessed by impedance and echocardiography

- new technique: contact force sensing
  - assesses contact by pressure detectors on catheter
  - improve clinical outcomes, shorten fluoroscopy times, reduce the risk of cardiac perforation

LA ablation outcomes

- poorer outcomes:
  - persistent AF, obesity, ↑ LA size, ↑ age, HTN, LA fibrosis

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Success</th>
</tr>
</thead>
<tbody>
<tr>
<td>meds only</td>
<td>23%</td>
</tr>
<tr>
<td>single ablation</td>
<td>57-86%</td>
</tr>
<tr>
<td>multiple ablations</td>
<td>71%</td>
</tr>
<tr>
<td>multiple ablations + meds</td>
<td>77%</td>
</tr>
<tr>
<td>12 months</td>
<td>9-58%</td>
</tr>
</tbody>
</table>

gaps can develop in ablation lines over time

HRS/EHRA/ECAS Catheter and Surgical Ablation, Europace 2012
Post-procedural imaging

- Ablation lesions must be **confluent without gaps**
  - Gaps can result in PV reconnection and recurrence of fib (Badger, Circ AE 2010, Ranjan, Circ AE 2011)
- MRI used to identify gaps in ablation lines (Peters, Radiology 2007)
  - Ablation lesions on DE-MRI show as bright signal

McGann, JACC 2008
Complications

- PV stenosis
- atrial wall edema
- atrio-esophageal fistula

Pre and post images:

- Okada JACC 2007 49 1436
- Schley Europace 2006 8(3): 18
Ventricular arrhythmia: pre-procedural imaging

- ventricular tachycardia/fibrillation
  - surviving muscle bundles within scar likely responsible for arrhythmia (Bolick, Circulation 2006)
- **scar contains majority of the arrhythmogenic substrate** (critical sites) (Desjardins, Heart rhythm 2009, Bogun, JACC 2009)
- goal: target ("burn") arrhythmogenic substrate
- EA maps reflects location of scar (Marchlinski, Circ 2000)
Effectiveness of LV ablation guided by EA maps

- **Prospective**
  - Tanner, JCE 2010 (N=63, F/U 12mo)
    - 81% success, 37% recurrence
  - Stevenson, Circ 2008 (N=231, F/U 6mo)
    - 49% success, 47% recurrence

- **Clinical trial: ICD vs ICD + ablation**
  - Reddy, NEJM 2007 (N=128, F/U 24mo)
    - shocks: post ablation 9%, controls 31%
  - Kuck, Lancet 2010 (N=107, F/U 24mo)
    - no VTs: post ablation 47%, controls 29%
    - recurrence VT: post ablation 19mo, controls 6mo
Imaging to improve scar detection

- MRI provides **better** assessment of scar
  - gold standard (Kim, Circ 1999)
  - helpful in localizing scar
  - guide and target arrhythmogenic tissue
    (Bogun, JACC 2009, Njeim, J Cardio Electro 2015)

- CT can also be used to assess scar
  - bright signal on delayed imaging, similar to DE-MRI
  - wall thinning + hypoperfusion
    (Komatsu, Circ AE 2013)
Scar characteristics can help identify targets

- Scar distribution involving 25-75% of wall thickness predictive of inducible VT
- Grey zone
  - Mix of scar and normal tissue
  - Strong predictor of arrhythmia

Nazarian Circ 2005 112:2821-25

Roes, Circ CV Imag 2009
Scar distribution to determine access

- non-ischemic cardiomyopathy
  - scar predominantly intramurally (Neilan, JACC Cardio Im 2013)
  - is epicardial procedure necessary? (Sosa, J Cardio Electro 1996)
- pre-procedural imaging with MRI is helpful
  - location of scar on MRI correlated with planning and outcomes of ablation (Bogun, JACC 2009)

Diagram:

- Do DE-MRI
  - Scar
    - Endocardial
      - Ablate endo, high success
    - Endocardial, Intramural extension
      - Ablate endo, lower success
    - Epicardial
      - Ablate epi, high success
    - Intramural
      - No ablation
  - No scar
    - Ablate endo, lower success

Desjardins, Heart Rhythms 2009
Bogun, JACC 2010
Sympathetic denervation

- viable but *denervated myocardium prone to arrhythmias*
- denervation defect usually larger than scar
- SPECT imaging (MIBG, norepinephrine analog)
- PET imaging (HED, epinephrine analog)

SPECT
Klein, Circ AE 2015

PET
Sasano, JACC 2008
Ventricular ablation: *intra*-procedural imaging

- display of
  - cardiac chambers
  - vessels
  - scar (yellow)
  - surrounding structures
Intra-cardiac echocardiography

- ICE (CARTOSound)
  - ICE catheter in RV or RA
  - gated, 90-degree sector images to generate 3D volume
  - for registration of CT or MRI images
    - better than registration with EA mapping (Bunch, J Cardio Electro 2010)
  - identify complications (eg thrombus)
  - identify scar tissue in animals (Callans, Circ 1999)
    - wall thinning
    - increased echo density (Bala, Circ AE 2011)
Papillary muscles

- integration of catheter tip into ultrasound image
- helps locate catheter tip on ICE
- important to target arrhythmias in locations constantly moving (eg papillary muscles)

(Good, Heart Rhythm 2008)
Post procedure imaging

- MRI
  - assess lesion formation (Ilg, JACC Cardio Im 2010)
  - not used to assess success of VT ablation
    - kinetics requires too long a delay for DE-MRI (90 mins)

Dickfeld, JACC 2006
Current limitations

- still further room for improvement
- spatial resolution of scar imaging can be improved
- registration with imaging is not perfect
- display of fiber orientation may be important for arrhythmogenesis
  - in vivo imaging is problematic
- ICE for identification of ablation lesions needs further development

concerns

- cost-effectiveness limits availability
- superior outcomes have not yet been demonstrated
Thank you