Imaging and Modeling in Atrial Fibrillation:

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\[ \overline{J}_e = g_{ix} \frac{\partial \Phi_e}{\partial x} + g_{iy} \frac{\partial \Phi_e}{\partial y} + g_{iz} \frac{\partial \Phi_e}{\partial z} \]
\[ \overline{J}_i = g_{ix} \frac{\partial \Phi_i}{\partial x} + g_{iy} \frac{\partial \Phi_i}{\partial y} + g_{iz} \frac{\partial \Phi_i}{\partial z} \]
Infarct
Ischemia
VT
The VENTRICLES
Reentry

The ATRIA
Fibrillation
Flutter
The ATRIA

Fibrillation

Flutter
What is Atrial Fibrillation?
= Afib = AF
Normal Contraction  Atrial Fibrillation
AF Prevalence

Projected Number of Persons With AF (millions)

Year

2000
2005
2010
2015
2020
2025
2030
2035
2040
2045
2050

0
2
4
6
8
10
12
14
16

Current age-adjusted AF incidence
Increased age-adjusted AF incidence


The University of Utah

SCI

The University of Utah

CARMA

Comprehensive Arrhythmia Research and Management
20% of Strokes

$20\ billion/\text{year}$
What Causes AFib?
Substrate + Trigger
Substrate: Fibrosis


Complex Propagation

de Groot, ..., Allessie MA. Circ. 2010: 1674-1682.
Substrate: Extension of muscle sleeves
Triggers

Left Atrium

Pulmonary Veins

* * *
Nervous System

Clinical Result

Normal conduction

Atrial fibrillation

SA Node

Normal electrical signals

Disorganized electrical signals
Clinical Result
Treatment?
Catheter Ablation

- Superior Vena Cava
- Atrial Septum
- Right Atrium
- Left Atrium
- Left Ventricle
- Right Ventricle
- Pulmonary Veins
- Triggering Foci
- Ablation Catheter
- Mapping Catheter
Electroanatomical Mapping
Imaging?
MR Angiography

Pre  First Pass  Subtraction
Dark Blood MRI

Pre-treatment

24 Hrs Post

3 Months Post
Late Gadolinium Enhancement

Pre-treatment  3 month Post
Patient Workflow

Evaluation → Treatment → Followup
Fibrosis and Outcome Evaluation

Enhanced (fibrosis?)

Low-voltage

Normal

Enhanced (fibrosis?)

Low-voltage

Normal
Utah Scoring Scheme

Evaluation

Utah I: < 5%
Utah II: 5-20%
Utah III: 20-35%
Utah IV: > 35%

Fibrosis Imaging Evaluation

Pixel Intensity Frequency

LA
Ao

LA
Ao

 Frequency

Pixel Intensity
Corview Evaluation
Patient Workflow

Evaluation → Treatment → Followup
Ablation Guidance
Real Time MRI

Treatment
Real Time MRI
Experiments!
Experiments!
Real Time MRI
Patient Workflow

Evaluation → Treatment → Followup
EAM vs. MRI

Pre-abilation

Post-ablation

Followup
Repeat Ablation

Patient 1

Incomplete Isolation
First PVAI - Posterior
Left

Complete Isolation
Second PVAI - Posterior
Left

Patient 2

Incomplete Isolation
First PVAI - Posterior
Left

Complete Isolation
Second PVAI - Posterior
Left

McGann et al. JACC, 52(15): 1263-1272, 2008
Predicting Success

LGE (pre)  T2w (<1hr)  LGE (<1 hr)  LGE (3 mo)
Open Challenges

Evaluation → Treatment → Followup

- Image quality
- Signal Acq./Proc.
- LA Segmentation
- Fibrosis Detection
- Scar Detection
- Lesion Imaging
- Case Simulation
Animal Models of AFib
Utah Cooperative Arrhythmia Program

Development of chronic AF animal model

DE-MRI of structural changes

MRI analysis and fibrosis quantification

Pathology and histology of fibrosis

Electro-physiological studies

Serum markers of inflammation

Utah Cooperative Arrhythmia Program (UCAP)

Utah State University

UCAIR, Radiology

Hematology

Pathology

SCI

Clinical EP, Cardiology
Modeling and Simulations
Figure 1. A series of left atrial MRI 3D reconstructions displayed in the RAO and PA projections illustrating areas of fibrosis (bright green) across the 4 stages of fibrosis. Utah stage 1: <5% fibrosis, Utah stage 2: 5–20% fibrosis, Utah stage 3: 20–25% fibrosis, Utah stage 4: >35% fibrosis.

Data Analysis
Statistical analysis was performed using STATA 11 (StataCorp, College Station, TX, USA). Continuous variables are reported as means and standard deviations and categorical variables are reported as percentages of the cohort. Student's t-test was used to compare continuous variables and Chi-square test to compare proportions. A Cox proportional hazard multivariate regression model was used to determine significant predictors of AF recurrence following ablation. To avoid overfitting, nonsignificant predictor variables were removed from the regression model in a stepwise fashion. Two-sided P-values < 0.05 were considered significant.

Results
Pre-Ablation Fibrosis/Structural Remodeling Based Staging
DE-MRI scans were of adequate quality to obtain quantification of pre-ablation SRM in 120 of the 144 total patient cohort (85%). Motion artifact often due to AF at the time of MRI acquisition was the main contributing factor for poor scans quality.

Of the 120 patients successfully quantified, the average pre-ablation fibrosis was 18.06 ± 13.49% of the LA wall volume. These patients were then divided into 4 categories as follows: Utah stage 1 or minimal fibrosis (at least 1 standard deviation below the cohort mean, i.e., <5% enhancement), Utah stage 2 or mild fibrosis (5–20% enhancement), Utah stage 3 or moderate fibrosis (20–35% enhancement) and Utah stage 4 or extensive fibrosis (greater than 35% enhancement). Figure 1 shows examples of patients in each of these stages. Of the patients with successful quantification, 10 (7%) were in Utah stage 1, 71 (49%) in Utah stage 2, 23 (16%) in Utah stage 3 and 16 (11%) in Utah stage 4. Age at the time of initial MRI acquisition, prevalence of hypertension, coronary artery disease, congestive heart failure, diabetes and left ventricular ejection fraction were comparable across the 4 groups. The patients' characteristics are detailed in Table 1.

<table>
<thead>
<tr>
<th>Utah Stage</th>
<th>Number (N)</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Utah stage 1</td>
<td>10</td>
<td>7%</td>
</tr>
<tr>
<td>Utah stage 2</td>
<td>71</td>
<td>49%</td>
</tr>
<tr>
<td>Utah stage 3</td>
<td>23</td>
<td>16%</td>
</tr>
<tr>
<td>Utah stage 4</td>
<td>16</td>
<td>11%</td>
</tr>
</tbody>
</table>

Table 1: Characteristics of 120 Patients with Preablation Quantification of Left Atrial Fibrosis

- Age (years): 58 ± 14, 62 ± 13, 67 ± 13, 68 ± 8 (ns)
- HTN (%): 50.0, 53.5, 56.5, 43.8 (ns)
- Diabetes (%): 10, 7.0, 21.7, 6.3 (ns)
- Coronary disease (%): 30, 12.7, 13.0, 18.8 (ns)
- CHF (%): 10, 5.6, 4.3, 12.5 (ns)
- LV EF (%): 57.2 ± 3.5, 51.8 ± 9.5, 49.7 ± 11.4, 44.8 ± 13.2 (ns)
- Paroxysmal/persistent AF (%): 60/40, 45/55, 35/65, 25/75 (ns)

ns = nonsignificant.
Be Brave!!!

The ATRIA

Fibrillation
www.sci.utah.edu  carmacenter.org