MRI Assessment of Treated Substrate

Eugene G. Kholmovski

UCAIR,CARMA Center, University of Utah

Salt Lake City, Utah, USA

Introduction

- Radiofrequency (RF) ablation is used to treat Atrial Fibrillation (AF) and Ventricular Tachycardia (VT)
- Success rates of these procedures are moderate
- The main cause of procedure failure is tissue recovery (temporal injury)
- MRI can be used to acutely assess RF lesions (permanent lesion vs. temporal injury)

Motivation

MRI based RF ablation EP procedures can achieve higher success rate by validating tissue destruction intermediately through the procedure, and performing targeted re-ablation in acute settings if it is required.

Kholmovski, E. SCMR 2015

Main Aims

- To examine RF ablation lesions using various MRI techniques acutely and up to 3 months post-ablation
- To compare the lesion measurements from MRI with analysis of excised hearts
- To identify the best MRI technique to discriminate between permanent and temporary injury and predict dimensions of permanent lesions

Study Design

Animals: canines (n=8, weight 25-37 kg)

Study Groups: Group 1 (4 animals), Group 2 (4 animals)

Group 1: RF Ablation, Acute MRI (< 1 hour post-ablation), Euthanasia, Pathology, and Histology

Group 2: 1st RF Ablation, MRI sessions: acute, 1 week, 2 weeks, 1 month, 2 months, 3 months, 2nd RF Ablation, Acute MRI, Euthanasia, Pathology, and Histology

Study Design

Ablation hardware: CARTO and ThermoCool catheter (Biosense Webster, Diamond Bar, CA, USA)

Ablation procedure: ventricular and atrial RF ablations, power settings of 30 Watts for 30 second

MRI hardware: 3 Tesla Verio (Siemens Healthcare, Erlangen, Germany), 32 channel cardiac coil (RAPID MR International, Columbus, OH, USA)

Contrast agent: 0.15 mmol/kg, MultiHance (Bracco Diagnostic Inc., Princeton, NJ, USA)

MRI Protocol

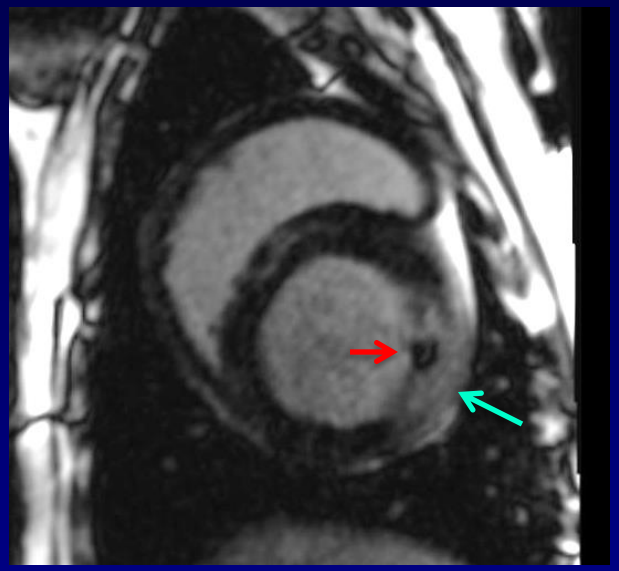
Pre-contrast

1. Quantitative T1 and T2 mapping
2. T1-weighted MRI
3. T2-weighted MRI (edema imaging)

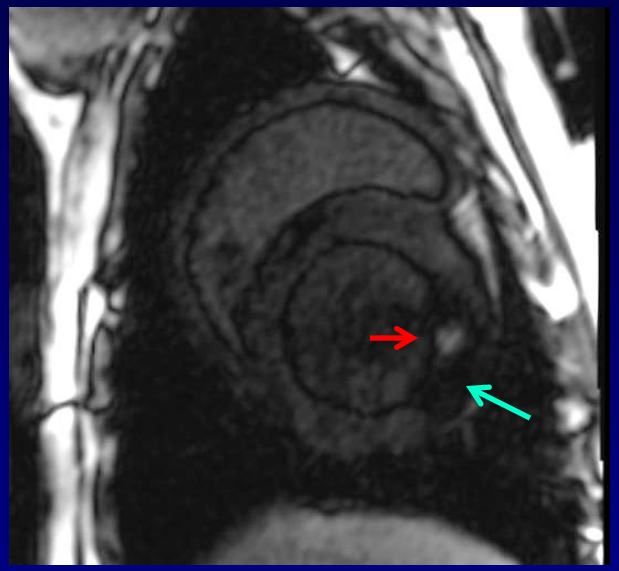
Post-contrast

1. T1-weighted MRI at different time points after contrast injection
2. LGE

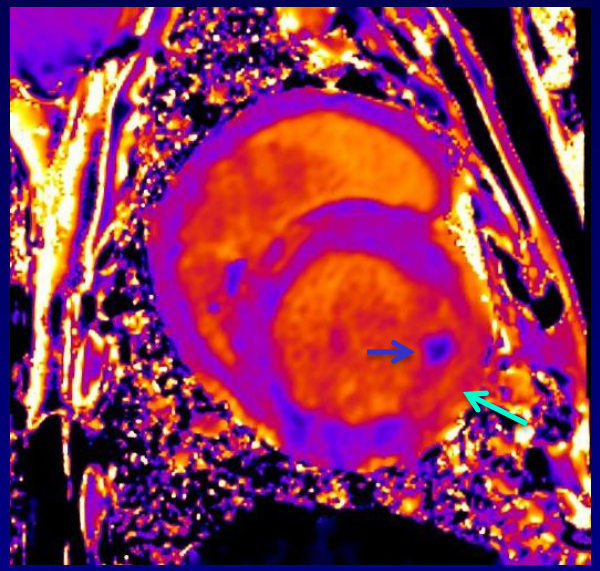
Acute: Lesion T1 Mapping



TI = 630 ms



TI = 790 ms



T1 Map

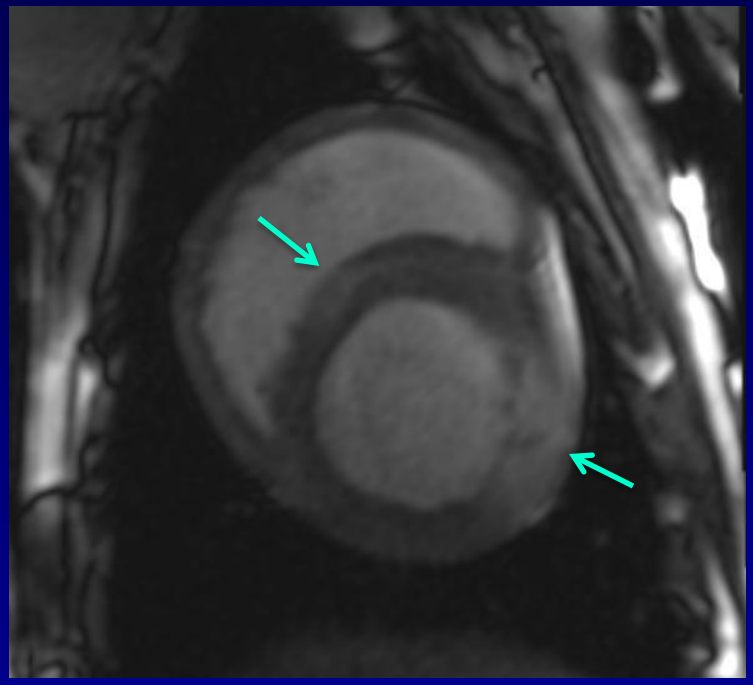
Lesion core (↑) has shorter T1 relaxation time than the surrounding edema (↑) and normal myocardium.

Two-compartment model for lesion core: short T1 (irreversibly destroyed tissue) and long T1 (edema) compartments.

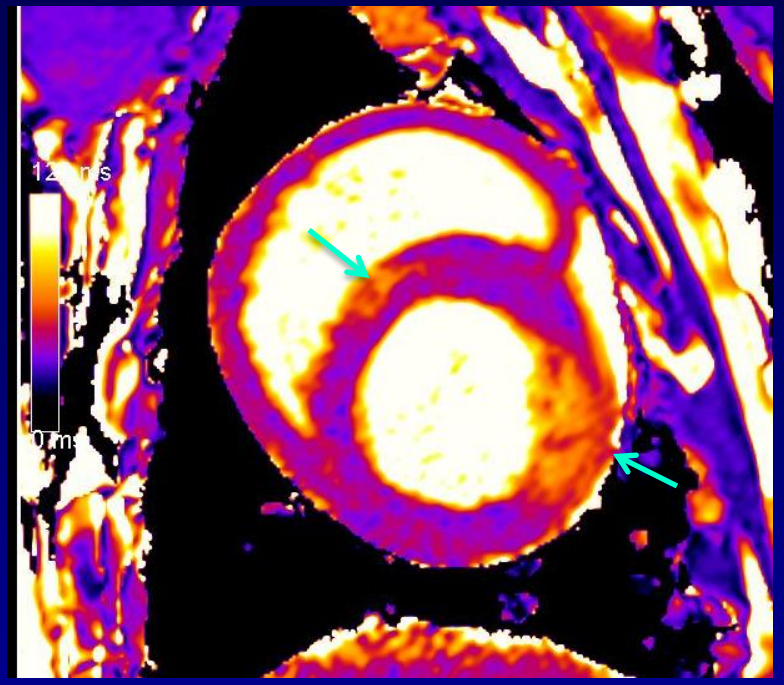
The University of Utah
Utah Center for Advanced Imaging Research

Kholmovski, E. SCMR 2015

Acute: Lesion T2 Mapping



TE = 50 ms



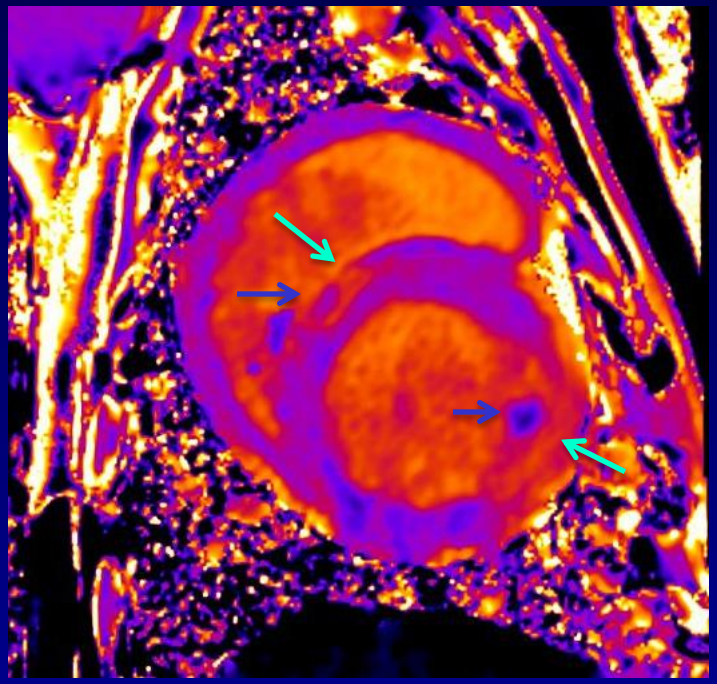
T2 Map

Lesion and surrounding edema have longer T2 than normal myocardium.

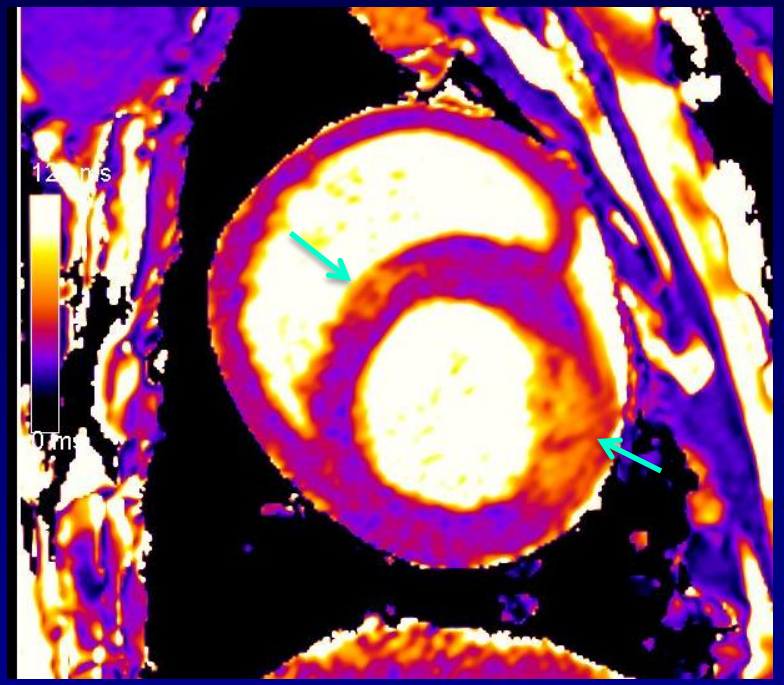
The University of Utah
Utah Center for Advanced Imaging Research

Kholmovski, E. SCMR 2015

Acute: Lesion T1 and T2 Mapping



T1 Map



T2 Map

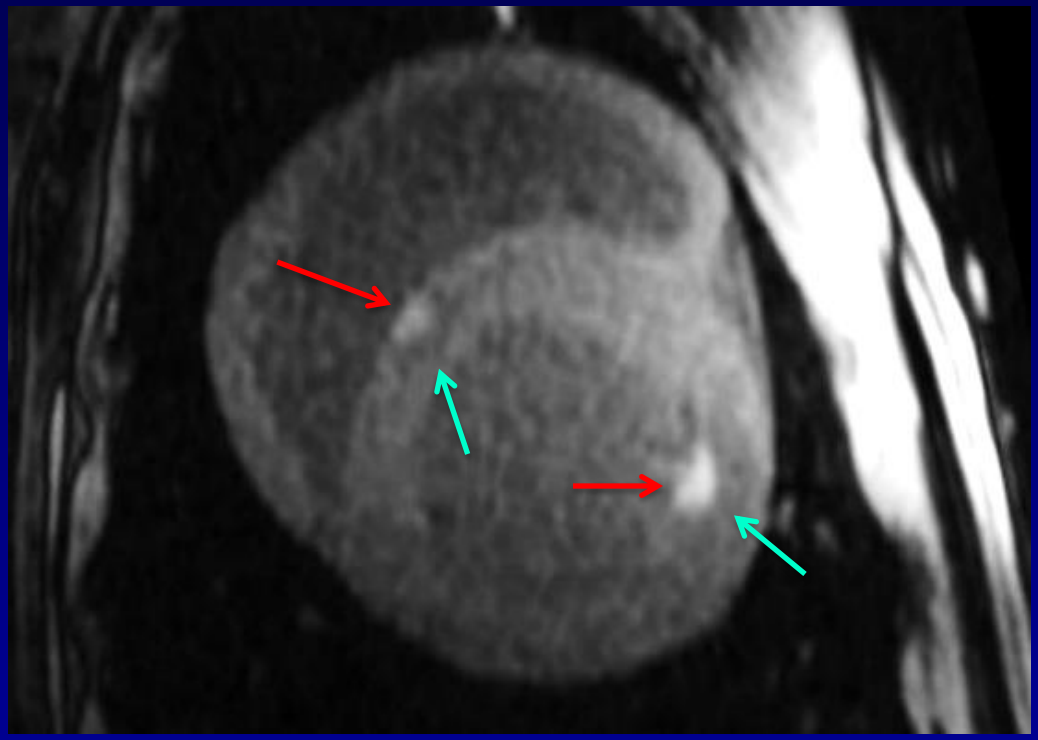
Lesion core and surrounding edema may be discriminated based on T1 values. Longer T2 value of edema may be used to discriminated injury from normal myocardium.

The University of Utah
Utah Center for Advanced Imaging Research

Kholmovski, E. SCMR 2015

Acute: T1-weighted MRI

3D T1w sequence with spatial resolution of 1.25x1.25x2.5 mm

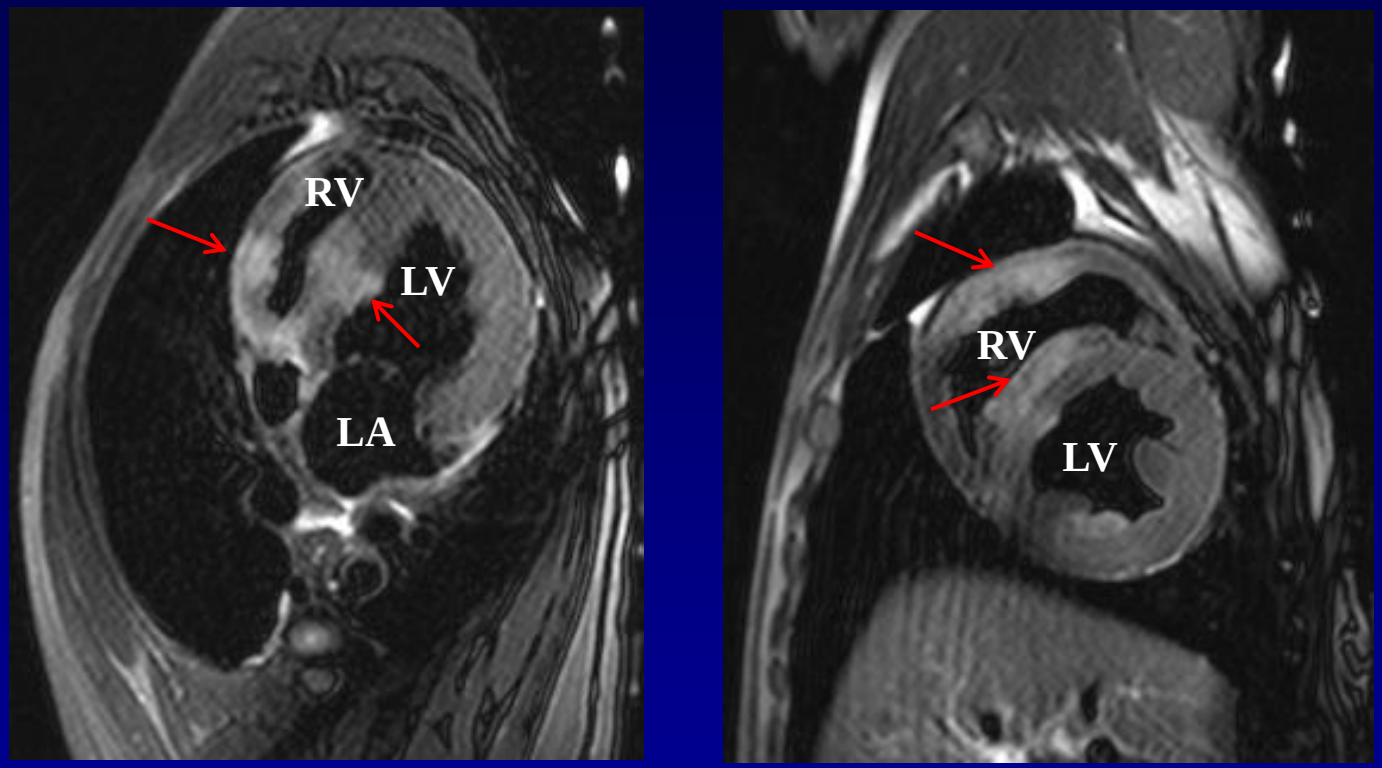


T1 preparation is required to suppress signal from edema and enhance contrast between lesion core (irreversibly destroyed tissue) and normal myocardium.

The University of Utah
Utah Center for Advanced Imaging Research

Kholmovski, E. SCMR 2015

Acute: T2-weighted MRI

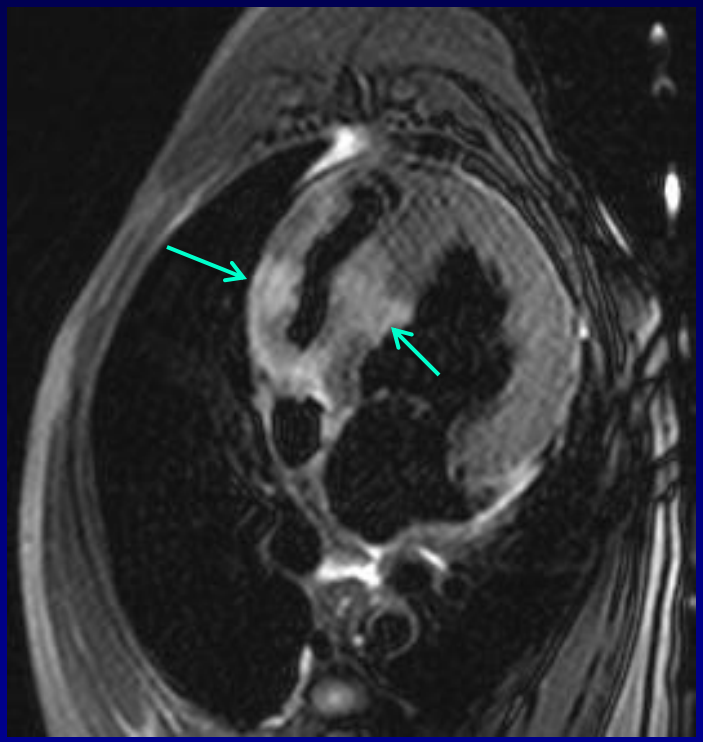


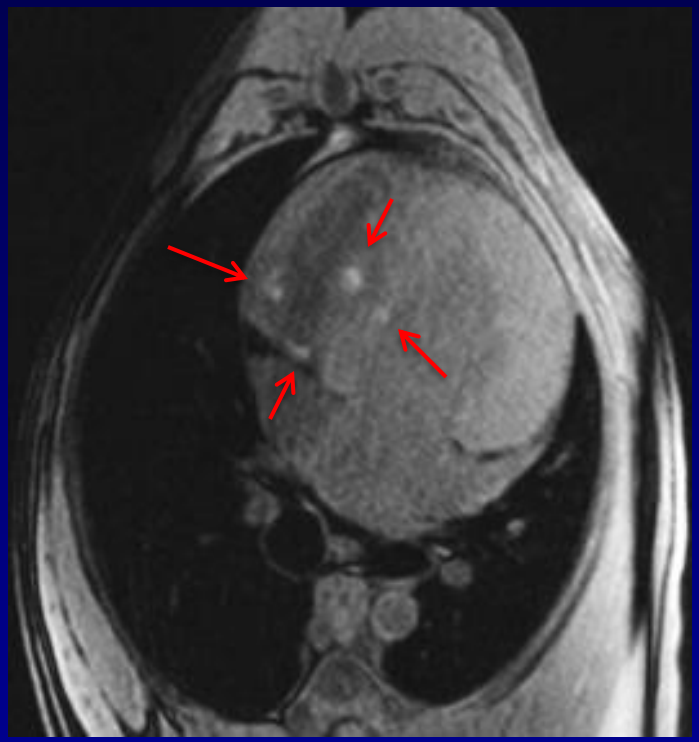
Acute Study: Significant edema (↑) presents in the regions subjected to RF ablation.

The University of Utah
Utah Center for Advanced Imaging Research

Kholmovski, E. SCMR 2015

Acute: T1w vs. T2w MRI





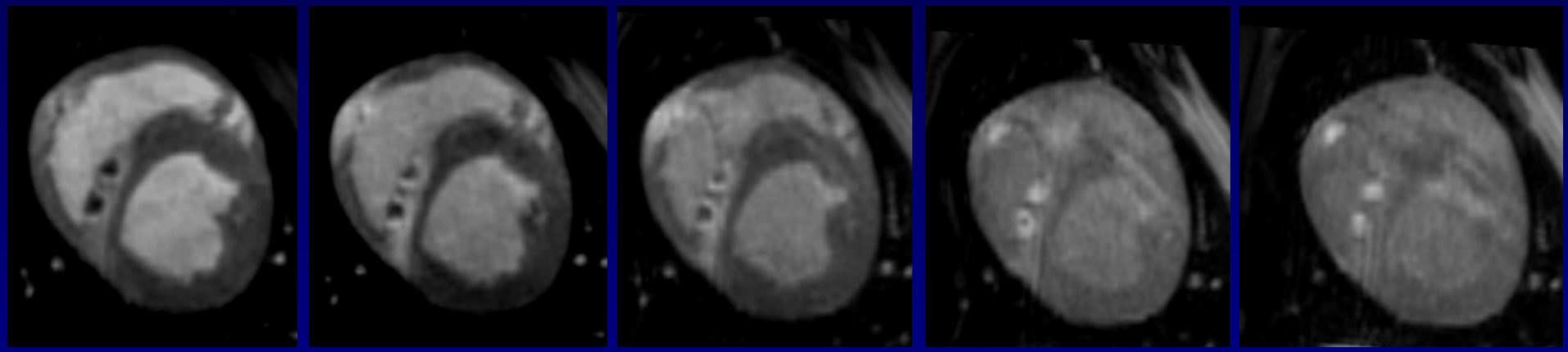
Enhanced regions in T1w images (↑) are noticeably smaller than surrounding edema (↑).

The University of Utah
Utah Center for Advanced Imaging Research

Kholmovski, E. SCMR 2015

Acute: Post-contrast T1w MRI

0.15 mmol/kg, Multihance, images are acquired at different time points after contrast injection.



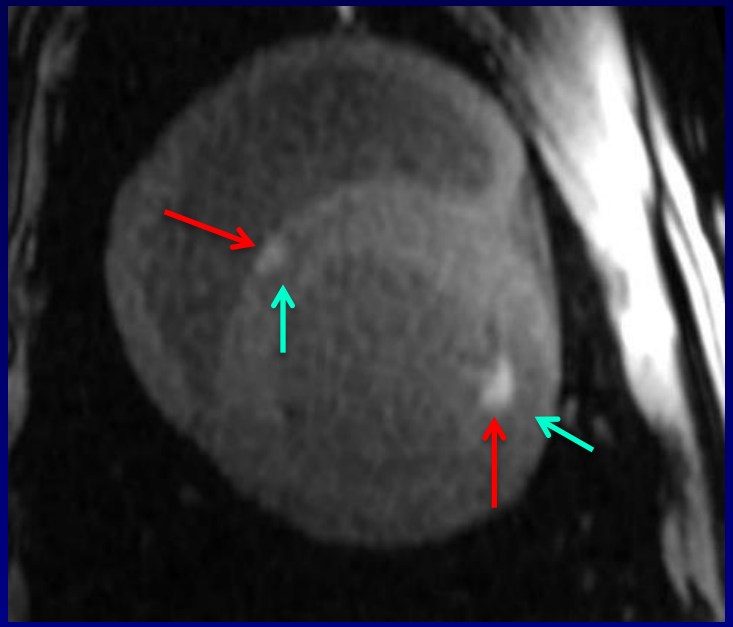
3 min 6 min 10 min 25 min 30 min

Earlier scans: lesion (no-reflow) surrounded by enhanced edema
Later scans: enhanced lesion
Edema region: fastest contrast wash-in and wash-out
Normal myocardium: intermediate contrast wash-in and wash-out
Lesions: slowest contrast wash-in and wash-out

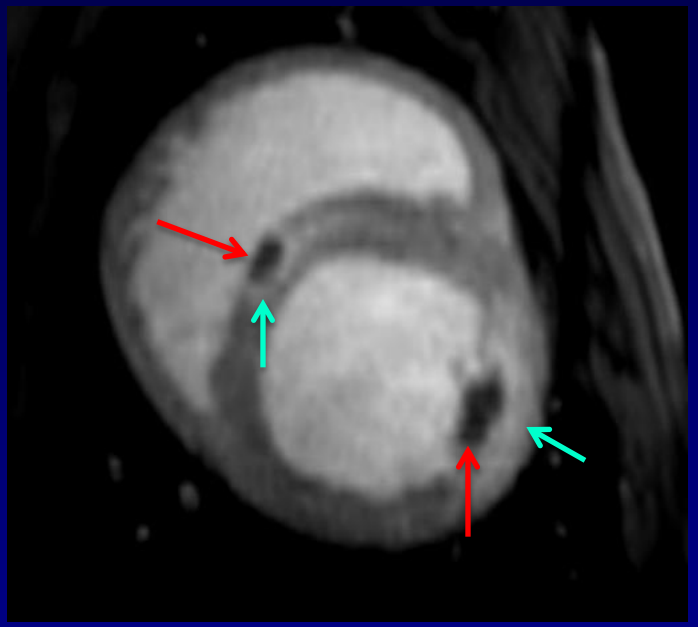
The University of Utah
Utah Center for Advanced Imaging Research

Kholmovski, E. SCMR 2015

Acute: Non- vs. Post Contrast T1w



Non-Contrast



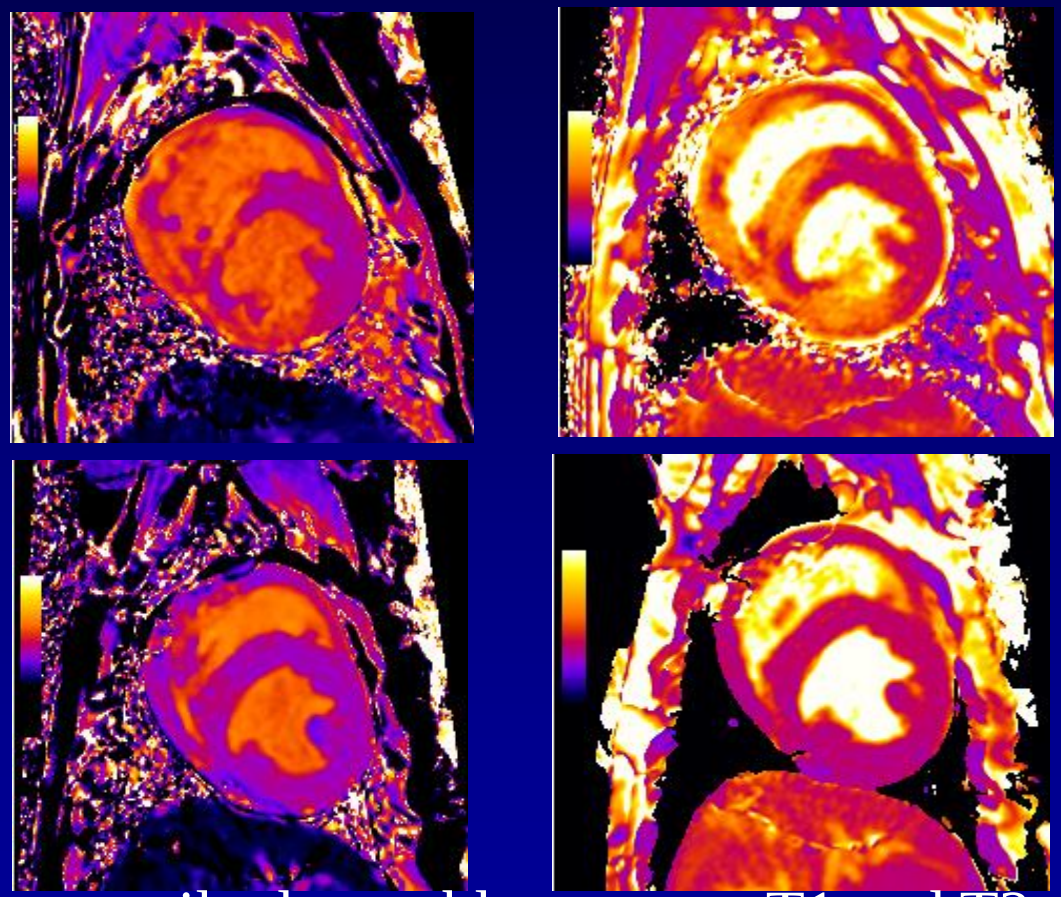
3 minutes after contrast

Acute Study: Lesion core and surrounding edema can be discriminated on non- and contrast enhanced (CE) images. No-reflow regions in earlier CE images are larger than enhanced regions in non-contrast images.

The University of Utah
Utah Center for Advanced Imaging Research

Kholmovski, E. SCMR 2015

T1 and T2 Maps: Acute vs. 1 week



Injured regions are easily detectable on acute T1 and T2 maps.

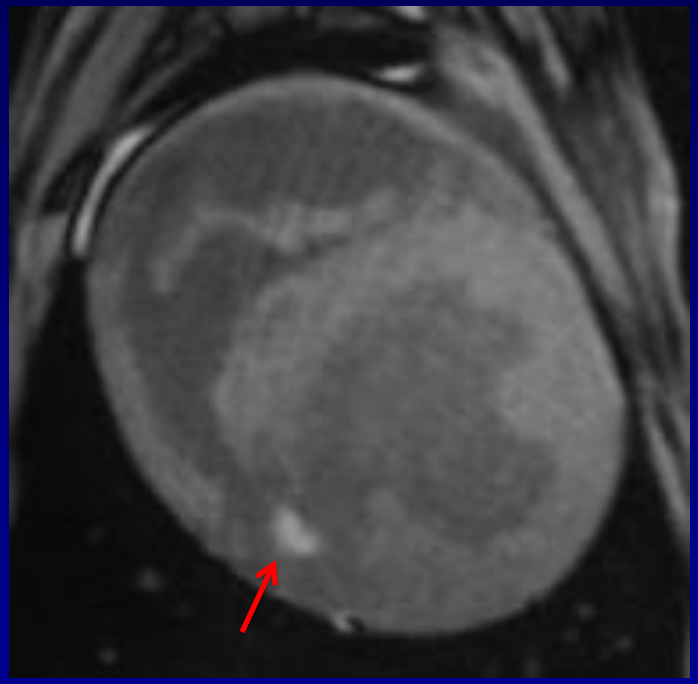
The regions are barely detectable on 1 week maps.

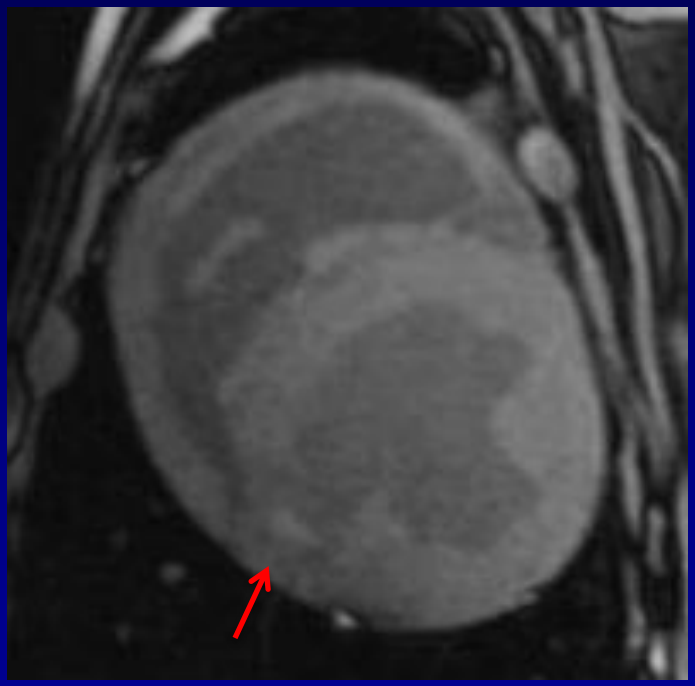
The University of Utah
Utah Center for Advanced Imaging Research

Kholmovski, E. SCMR 2015

T1w MRI: Acute vs. 48-hours

3D T1w sequence with spatial resolution of 1.25x1.25x2.5 mm



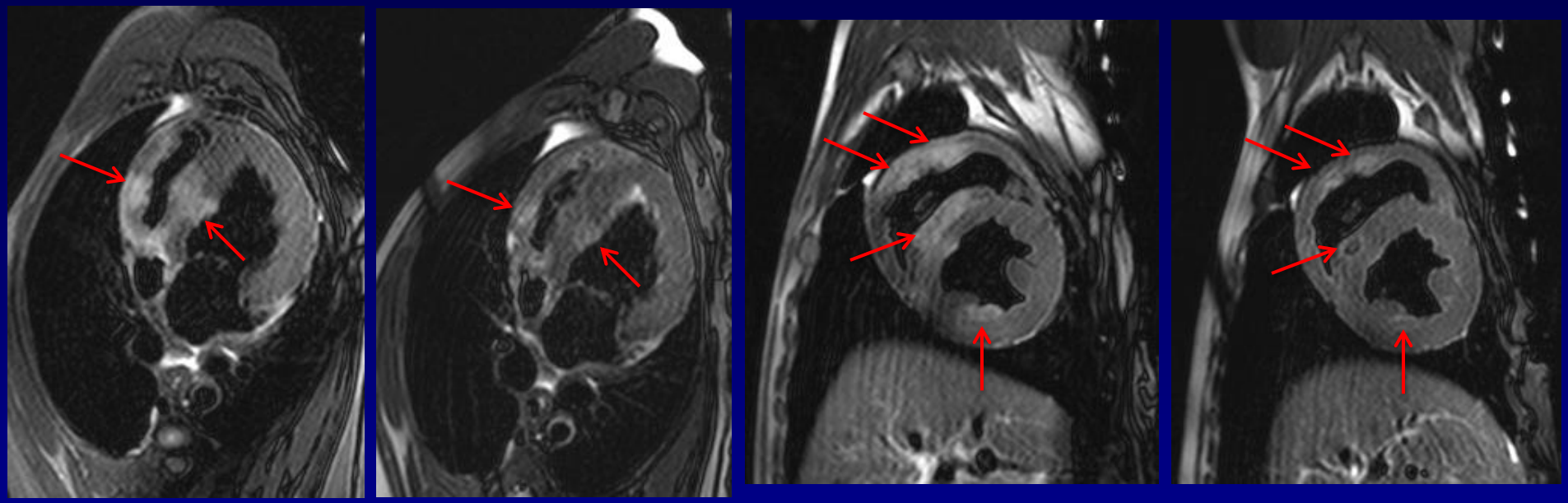


T1w contrast of RF lesions is drastically reduced in the first 48 hours.

The University of Utah
Utah Center for Advanced Imaging Research

Kholmovski, E. SCMR 2015

T2w MRI: Acute vs. 1 week



Acute 1 week Acute 1 week

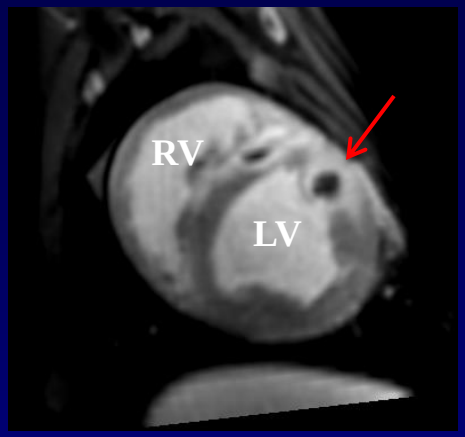
Edema is significantly reduced 1 week post-ablation (mainly lesion core). Presence of hemosiderin deposits can be observed on lesions boundaries (dark edges).

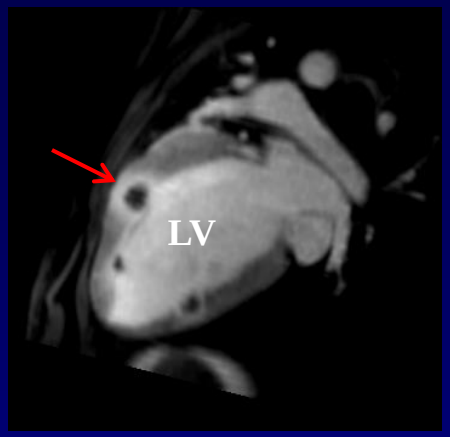
The University of Utah
Utah Center for Advanced Imaging Research

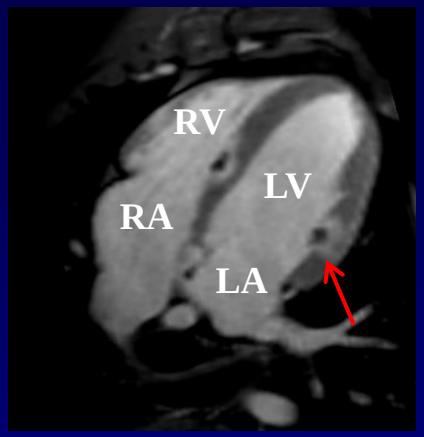
Kholmovski, E. SCMR 2015

Acute vs. 1 week: Post-contrast T1w MRI

Acute

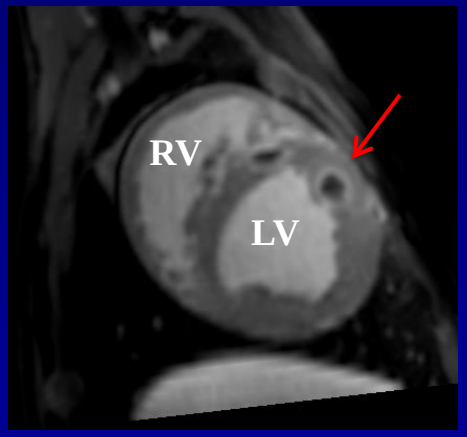


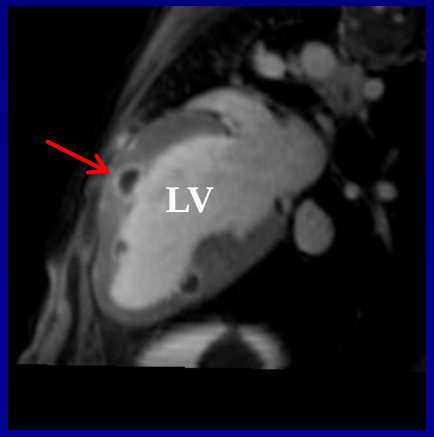


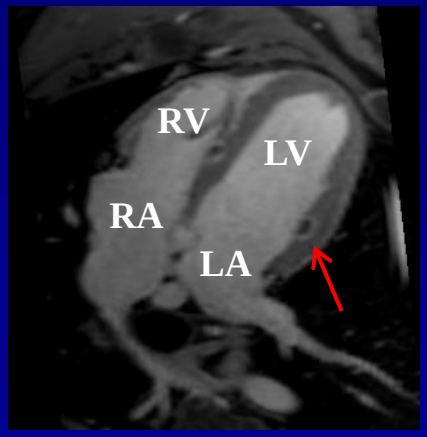


3 min

1 week





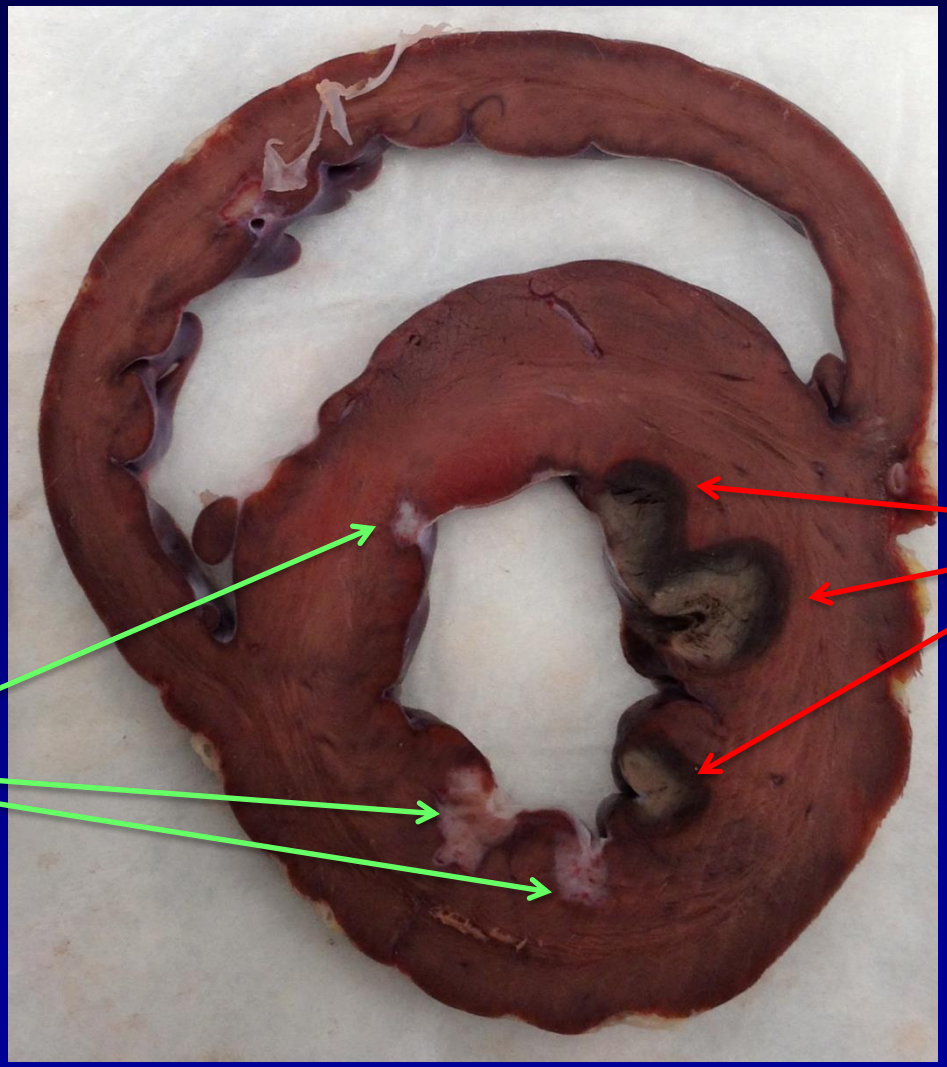


No-reflow areas are observed on acute and 1 week post-ablation scans. Enhancement in edema regions only presents on acute scans.

The University of Utah
Utah Center for Advanced Imaging Research

Kholmovski, E. SCMR 2015

Pathology



TTC Staining

The University of Utah
Utah Center for Advanced Imaging Research

Kholmovski, E. SCMR 2015

Pathology

Acute Lesions

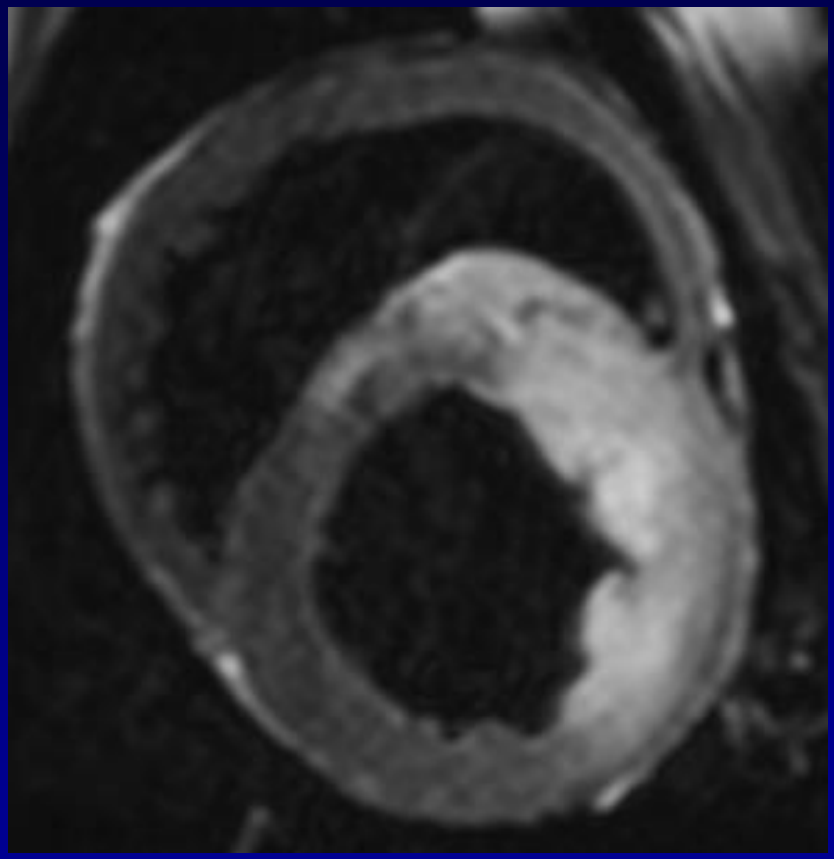
Kholmovski, E. SCMR 2015

Pathology

Chronic (3 months post ablation) Lesions

Kholmovski, E. SCMR 2015

Pathology vs. T2w (Edema) MRI

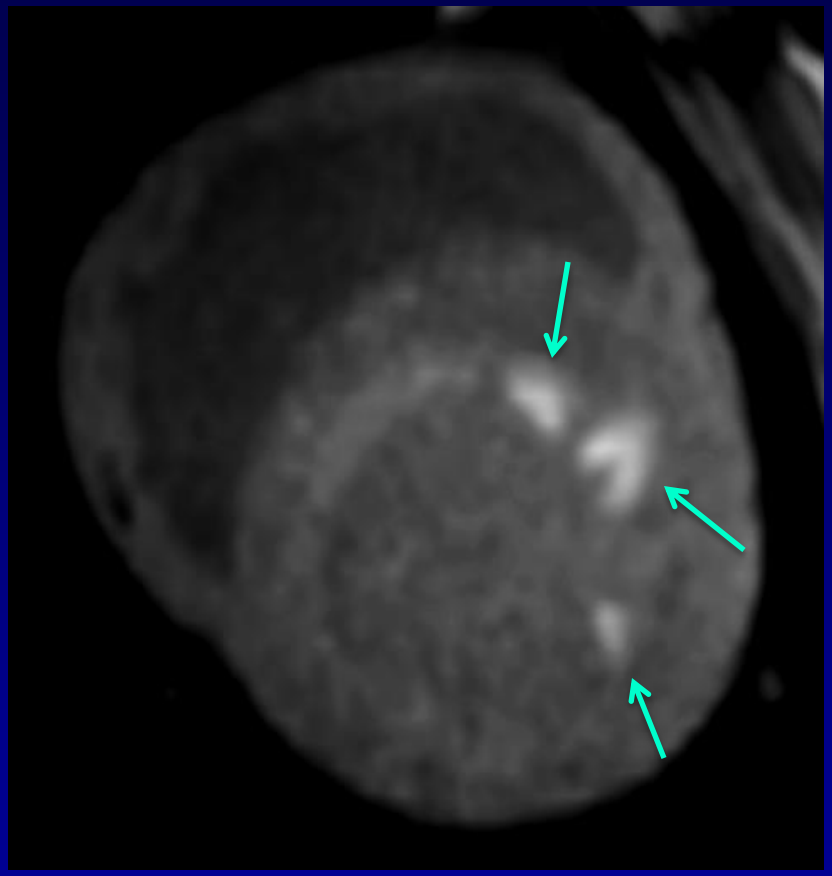


Acute Study: Edema extends far beyond the ablation regions. Individual lesions and gaps between lesions cannot be discriminated in T2w MRI.

The University of Utah
Utah Center for Advanced Imaging Research

Kholmovski, E. SCMR 2015

Pathology vs. Non-Contrast T1w MRI

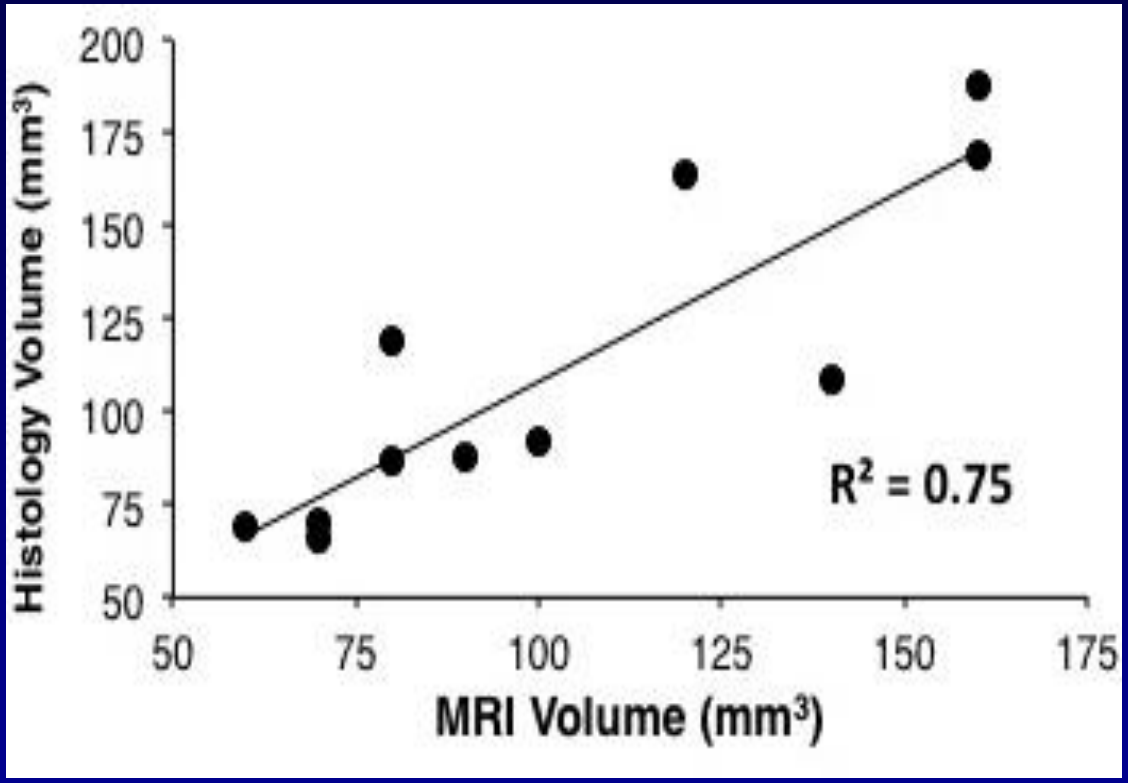


Acute Study: Non-contrast T1w MRI detects individual ablation lesions. Non-contrast T1w MRI accurately estimates lesion core.

The University of Utah
Utah Center for Advanced Imaging Research

Kholmovski, E. SCMR 2015

Pathology vs. Non-Contrast T1w MRI

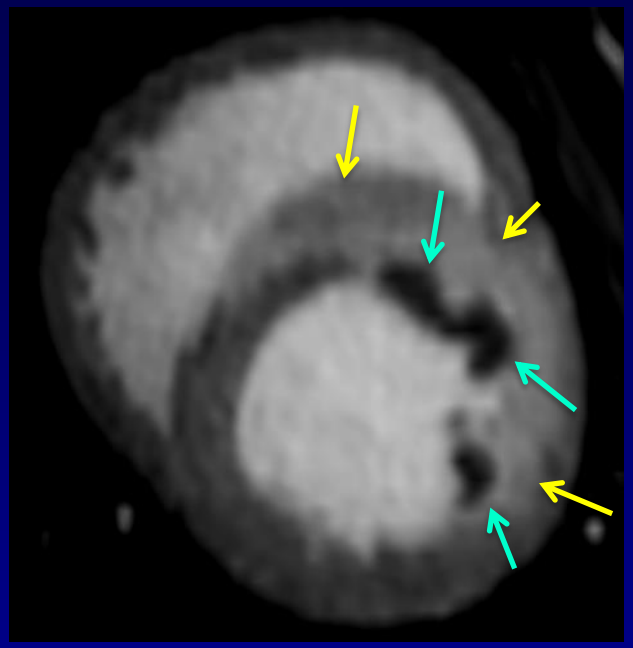


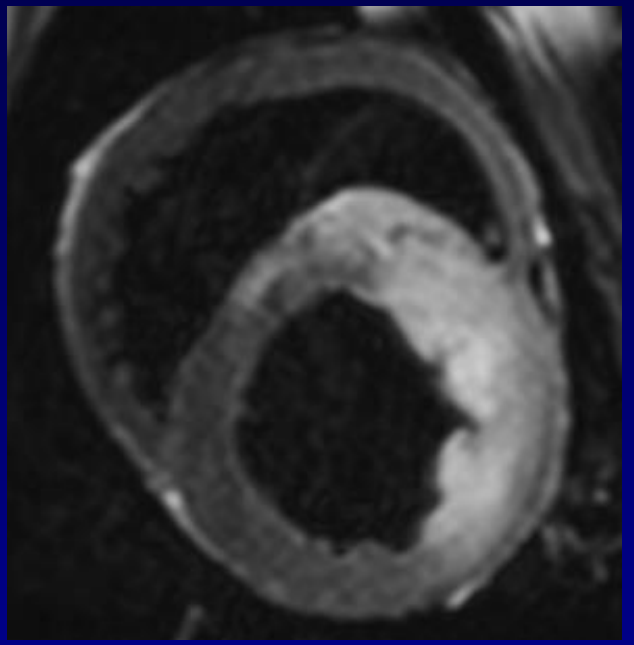
Lesion dimensions from non-contrast T1w are well correlated with pathology results for permanent (3-month post-ablation) lesions: a slope of 1.07 and correlation coefficient R^2=0.75

The University of Utah
Utah Center for Advanced Imaging Research

Kholmovski, E. SCMR 2015

Pathology vs. Post Contrast T1w MRI



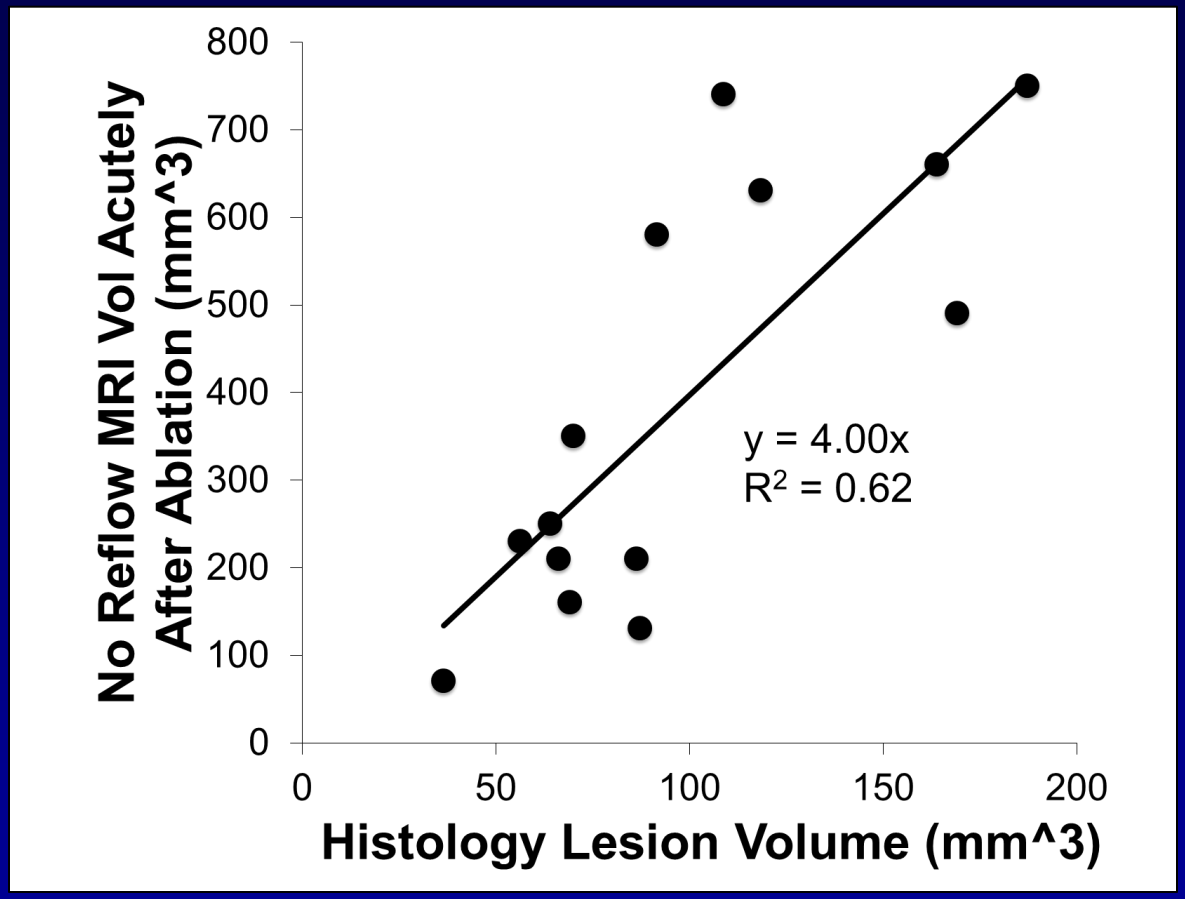


Acute Study: T1w MRI acquired earlier (< 5 mins) after contrast injection detects both individual ablation lesions (no-reflow areas (↑)) and surrounding edema (↑). No-reflow = Core + Rim

The University of Utah
Utah Center for Advanced Imaging Research

Kholmovski, E. SCMR 2015

Pathology vs. Post Contrast T1w MRI

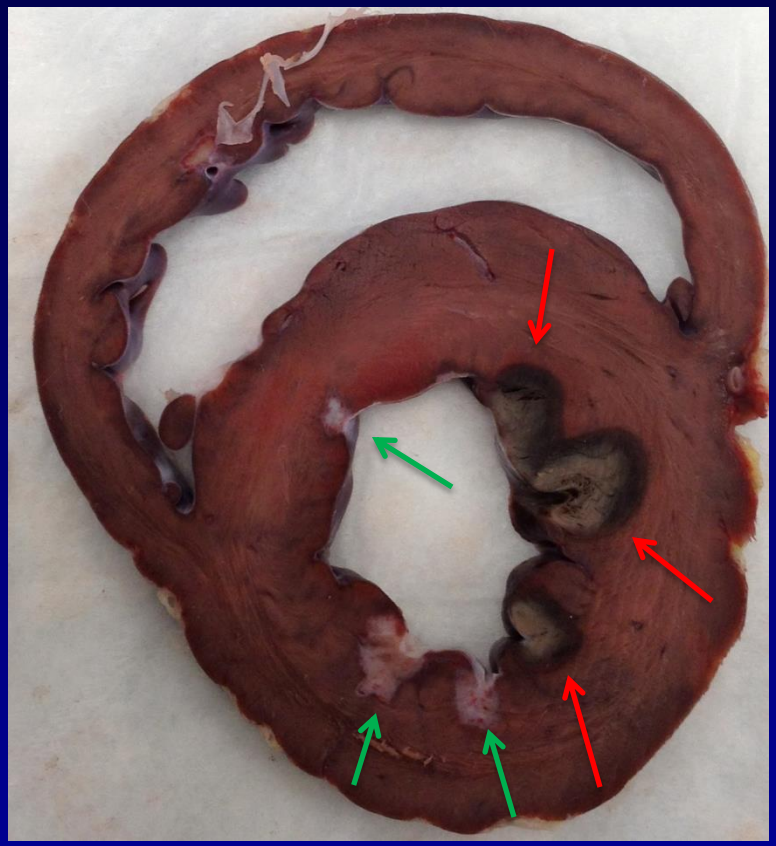


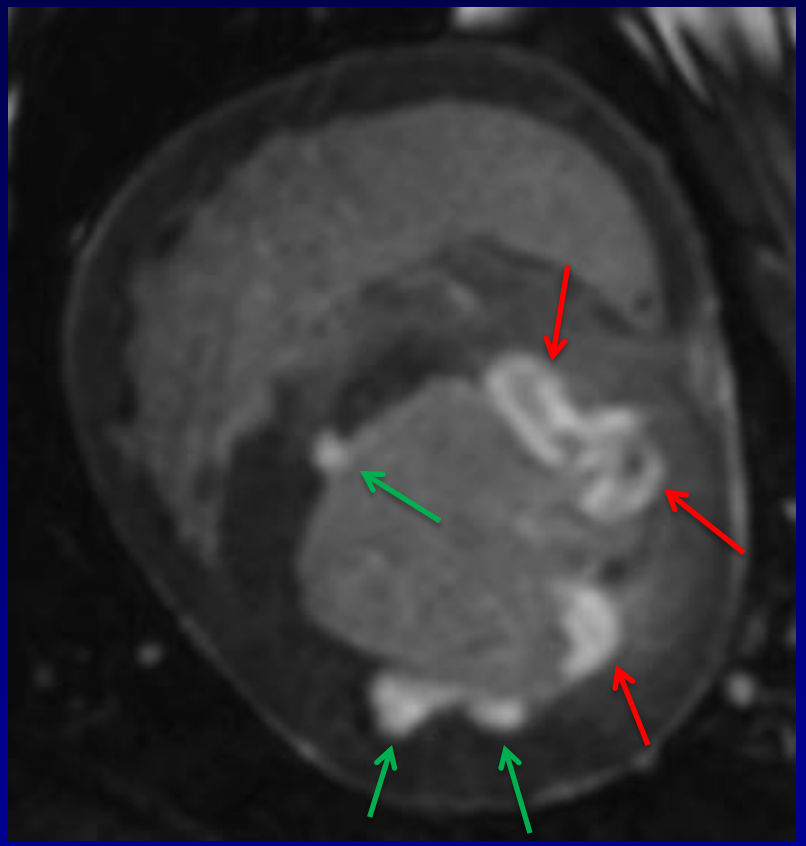
No-reflow in T1w MRI acquired earlier (< 5 mins) after contrast injection overestimates volume of 3-month post-ablation lesions.

The University of Utah
Utah Center for Advanced Imaging Research

Kholmovski, E. SCMR 2015

Pathology vs. LGE-MRI



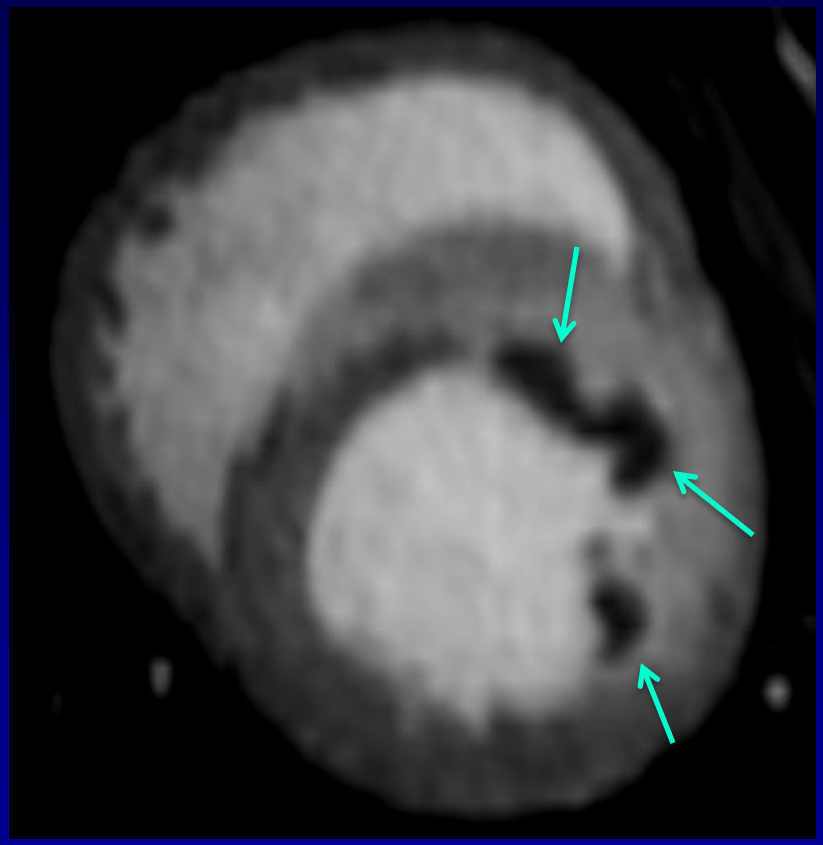


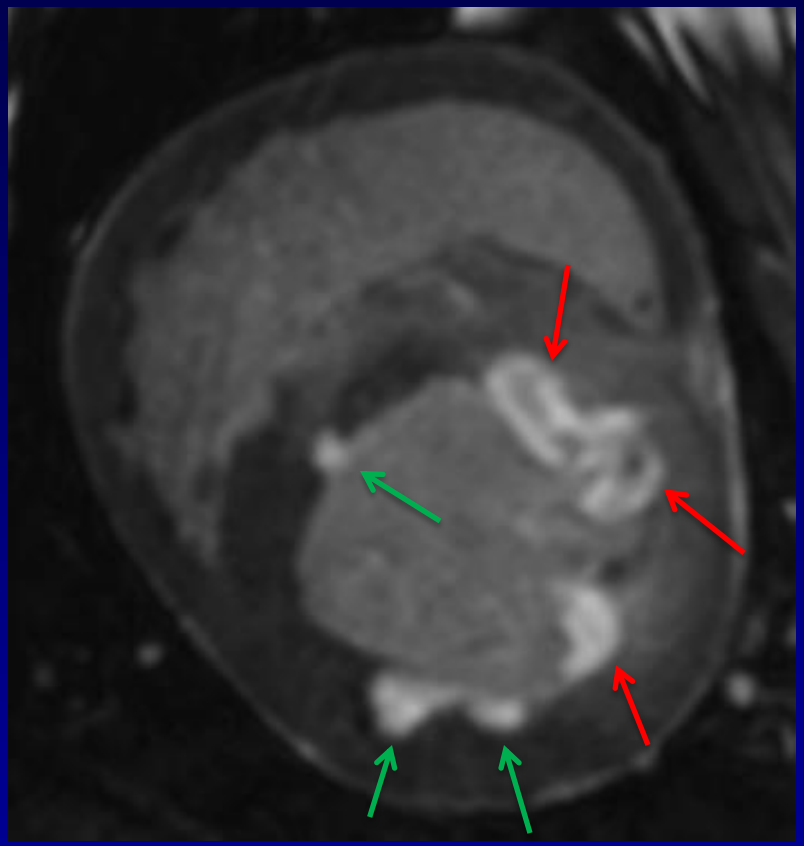
LGE-MRI (> 45 mins post contrast) detects both acute injuries (↑) and chronic ablation lesions (↑). LGE gives accurate description of chronic lesions but it overestimates dimensions of acute lesions.

The University of Utah
Utah Center for Advanced Imaging Research

Kholmovski, E. SCMR 2015

EGE-MRI vs. LGE-MRI





No-reflow regions (↑) in EGE-MRI (< 5 min) are similar to the enhanced regions corresponding to acute ablations (↑) in LGE-MRI (> 45 mins post contrast).

The University of Utah
Utah Center for Advanced Imaging Research

Kholmovski, E. SCMR 2015

Summary

- Core of RF ablation lesion may be described by two-compartment model: short T1 (irreversibly destroyed tissue) and long T1 (edema).
- Acute RF ablation lesions may be detected by non-contrast T1-weighted MRI. T1w enhancement correlates well with dimensions of lesion core acutely and 3 months post-ablation scar.
- Significant edema presents in ablated regions. Edema highly overestimates lesion dimensions in acute studies.
- No-reflow is observed in earlier post-contrast T1-weighted scans. No-reflow and LGE overestimate permanent lesion dimensions.

Acknowledgement

Nassir Marrouche, MD
Ravi Ranjan, MD, PhD
Josh Silvernagel, MS
Sathya Vijayakumar, MS
Nathan Angel, MS
Josh Blauer, MS
Christopher McGann, MD
Rob MacLeod, PhD

This study was supported in part by Biosense Webster and Marrek Inc.

The University of Utah
Utah Center for Advanced Imaging Research

Thank you for your attention!

Questions?

ekhoumov@ucair.med.utah.edu