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Cardiac Imaging

Dark Regions of No-Reflow on Late Gadolinium Enhancement Magnetic Resonance Imaging Result in Scar Formation After Atrial Fibrillation Ablation

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Objectives The aim of this study was to assess acute ablation injuries seen on late gadolinium enhancement (LGE) magnetic resonance imaging (MRI) immediately post-ablation (IPA) and the association with permanent scar 3 months post-ablation (3moPA).

Background Success rates for atrial fibrillation catheter ablation vary significantly, in part because of limited information about the location, extent, and permanence of ablation injury at the time of procedure. Although the amount of scar on LGE MRI months after ablation correlates with procedure outcomes, early imaging predictors of scar remain elusive.

Methods Thirty-seven patients presenting for atrial fibrillation ablation underwent high-resolution MRI with a 3-dimensional LGE sequence before ablation, IPA, and 3moPA using a 3-T scanner. The acute left atrial wall injuries on IPA scans were categorized as hyperenhancing (HE) or nonenhancing (NE) and compared with scar 3moPA.

Results Heterogeneous injuries with HE and NE regions were identified in all patients. Dark NE regions in the left atrial wall on LGE MRI demonstrate findings similar to the "no-reflow" phenomenon. Although the left atrial wall showed similar amounts of HE, NE, and normal tissue IPA (37.7 ± 13%, 34.3 ± 14%, and 28.0 ± 11%, respectively; p = NS), registration of IPA injuries with 3moPA scarring demonstrated that 59.0 ± 19% of scar resulted from NE tissue, 30.6 ± 15% from HE tissue, and 10.4 ± 5% from tissue identified as normal. Paired *t*-test comparisons were all statistically significant among NE, HE, and normal tissue types ($p < 0.001$). Arrhythmia recurrence at 1-year follow-up correlated with the degree of wall enhancement 3moPA ($p = 0.02$).

Conclusions Radiofrequency ablation results in heterogeneous injury on LGE MRI with both HE and NE wall lesions. The NE lesions demonstrate no-reflow characteristics and reveal a better predictor of final scar at 3 months. Scar correlates with procedure outcomes, further highlighting the importance of early scar prediction. (J Am Coll Cardiol 2011;58:177–85) © 2011 by the American College of Cardiology Foundation

Atrial fibrillation (AF) is the most common cardiac rhythm disturbance affecting more than 2 million people in the United States (1,2). Pulmonary vein isolation using radiofrequency ablation (RFA) is effective in symptomatic, drug-refractory AF and can result in cure. With current technology, the procedure is guided using x-ray fluoroscopy, with tissue viability and lesion localization provided by electroanatomical mapping (EAM) systems. Catheter navigation has been enhanced by use of 3-dimensional (3D) left atrial (LA) angiograms acquired with magnetic resonance imaging (MRI) or computed tomography. Despite these advancements in technology, reported success rates of the procedure vary significantly with AF recurrence ranging from 25% to 60% (3–6). The high failure rate is in part

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Abbreviations and Acronyms

3D = 3-dimensional
3moPA = 3 months post-ablation
AF = atrial fibrillation
HE = hyperenhancing
IPA = immediately post-ablation
LA = left atrial
LGE = late gadolinium enhancement
MRI = magnetic resonance imaging
NE = nonenhancing
RF = radiofrequency
RFA = radiofrequency ablation

attributable to the limited information on the location, extent, and permanence of LA wall injury during and after ablation, which has proven difficult to assess with EAM alone.

More recently, powerful tools to better assess RFA lesions have been developed with MRI. Visualization and characterization of RFA lesions were demonstrated by Lardo et al. (7) in a canine model with T2-weighted and contrast-enhanced T1-weighted imaging. Late gadolinium enhancement (LGE) and T2-weighted (T2w) double inversion recovery (DIR) sequences are now used in humans to evaluate periprocedural injuries, and these imaging advances have helped define the early and late tissue events and the atrial remodeling process after ablation. Transient injury has been demonstrated on T2w DIR imaging and reflects edema and the inflammatory process (8–10). Permanent injury with LA wall scarring has been well studied using LGE in the weeks to months after the procedure. The location and degree of scarred tissue appears bright on LGE MRI and has been associated with procedure outcomes. Furthermore, LGE can help guide follow-up ablations by identifying gaps in ablation lines after unsuccessful pulmonary vein isolation (11–14).

Though these imaging advances have helped define post-ablation injuries, early imaging markers to predict permanent injury remain elusive. In this study, we set out to characterize early atrial wall injury immediately post-ablation (IPA) using LGE MRI and its potential to predict permanent scar 3 months post-ablation (3moPA).

Methods

Patients. From July 2009 to January 2010, 46 patients who underwent first ablation for AF in our electrophysiology-MRI suite were included in the study. This group was selected on the basis of patients who completed MRI scans at baseline, IPA, and 3moPA. Further selection criteria included LGE images acquired 15 ± 3 min after contrast injection in the IPA and 3moPA scans. The protocol was approved by the institutional review board at the University of Utah and was compliant with the Health Insurance Portability and Accountability Act of 1996. Scanning was performed using a 3-T Verio MR scanner (Siemens Medical Systems, Erlangen, Germany). MRI for IPA scans was performed <1 h after completion of the RFA procedure.

MRI acquisitions. High-resolution LGE images of the left atrium were acquired 15 ± 3 min after the injection of 0.1 mmol/kg gadolinium contrast (Multihance, Bracco Diagnostics, Inc., Princeton, New Jersey) using a 3D respiratory navigated, inversion recovery prepared gradient echo pulse sequence (repetition time 3.0; echo time 1.4 ms; flip angle 14°; bandwidth 740 Hz/pixel; field of view 400 × 400 × 110 mm; matrix size 320 × 320 × 44; 9% oversampling in the slice encoding direction; voxel size 1.25 × 1.25 × 2.5 mm; phase-encoding direction: left to right; fractional readout 87.5%; partial Fourier acquisition: 90% in phase-encoding direction and 92.5% in slice-encoding direction; generalized autocalibrating partially parallel acquisitions with R = 2 in phase-encoding direction). An inversion pulse was applied every heartbeat, and fat saturation was applied immediately before data acquisition. Data acquisition was limited to 15% of the RR cycle and was performed during LA diastole. To preserve magnetization preparation in the image volume, the navigator was acquired immediately after data acquisition block. Typical scan time for the LGE study was 4 to 8 min, depending on heart rate and respiratory pattern.

Ablation procedure. The details of the pulmonary vein isolation in addition to posterior wall and septal debulking have been described elsewhere (13). Briefly, the left atrium was accessed through 2 transseptal punctures under intracardiac echocardiographic guidance using a phased-array catheter (Acunav, Siemens Medical Solutions USA, Inc., Mountain View, California). A 10-pole circular mapping catheter (Lasso, Biosense Webster, Diamond Bar, California) and a 3.5-mm Thermocool ablation catheter (Biosense Webster) were advanced into the left atrium for mapping and ablation. A 14-pole catheter (TZ Medical, Portland, Oregon) was used to record right atrial and coronary sinus electrograms and was used as the reference catheter for 3D electroanatomical mapping with CARTO (Biosense Webster). Radiofrequency (RF) energy was delivered with 50 W at a catheter tip temperature of 50°C for 5 s, guided by electrogram abolition recorded on the Lasso catheter. Ablation lesions were placed in a circular fashion in the pulmonary vein antral region until electrical isolation of the pulmonary veins was achieved. Additional lesions were placed along the LA posterior wall and septum.

Image processing and analysis. All magnetic resonance images were evaluated and processed by 2 expert operators using Seg3D image analysis software. The LA wall in the 3D LGE MRI acquisitions was manually segmented with careful tracing of the endocardial and epicardial borders. Tissue types were determined using a threshold-based lesion detection algorithm previously described (9,15). Briefly, tracings were performed to confine the region of interest to the LA wall alone and to avoid the blood pool. Normal, nonenhanced (NE), and hyperenhanced (HE) tissue was defined on the basis of 3 distinct modes of LA wall tissue intensities. Each patient scan was evaluated independently, with the mean normal LA wall segments first defined for each patient. HE and NE tissue injury was defined at 3 standard deviations above and below the normal tissue mean pixel intensity, respectively. Tissue characterizations were