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Evaluation of Left Atrial Lesions After Initial and Repeat Atrial Fibrillation Ablation

Lessons Learned From Delayed-Enhancement MRI in Repeat Ablation Procedures

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Background—We evaluated scar lesions after initial and repeat catheter ablation of atrial fibrillation (AF) and correlated these regions to low-voltage tissue on repeat electroanatomic mapping. We also identified gaps in lesion sets that could be targeted and closed during repeat procedures.

Methods and Results—One hundred forty-four patients underwent AF ablation and received a delayed-enhancement MRI at 3 months after ablation. The number of pulmonary veins (PV) with circumferential lesions were assessed and correlated with procedural outcome. Eighteen patients with AF recurrence underwent repeat ablation. MRI scar regions were compared with electroanatomic maps during the repeat procedure. Regions of incomplete scar around the PVs were then identified and targeted during repeat ablation to ensure complete circumferential lesions. After the initial procedure, complete circumferential scarring of all 4 PV antrum (PVA) was achieved in only 7% of patients, with the majority of patients (69%) having <2 completely scarred PVA. After the first procedure, the number of PVs with complete circumferential scarring and total left atrial wall (LA) scar burden was associated with better clinical outcome. Patients with successful AF termination had higher average total left atrial wall scar of 16.4%±9.8 (P=0.004) and percent PVA scar of 66.2±25.4 (P=0.01) compared with patients with AF recurrence who had an average total LA wall scar 11.3%±8.1 and PVA percent scar 50.0±24.7. In patients who underwent repeat ablation, the PVA scar percentage was 56.1%±21.4 after the first procedure compared with 77.2%±19.5 after the second procedure. The average total LA scar after the first ablation was 11.0%±4.1, whereas the average total LA scar after second ablation was 21.2%±7.4. All patients had an increased number of completely scarred pulmonary vein antra after the second procedure. MRI scar after the first procedure and low-voltage regions on electroanatomic mapping obtained during repeat ablation demonstrated a positive quantitative correlation of R^2=0.57.

Conclusions—Complete circumferential PV scarring difficult to achieve but is associated with better clinical outcome. Delayed-enhancement MRI can accurately define scar lesions after AF ablation and can be used to target breaks in lesion sets during repeat ablation. **(*Circ Arrhythm Electrophysiol*. 2010;3:249-259.)**

Key Words: atrial fibrillation ■ catheter ablation ■ MRI ■ pulmonary vein antrum isolation ■ left atrial scar lesions

Pulmonary vein antrum (PVA) isolation is a treatment option for patients with atrial fibrillation (AF) that uses high-frequency energy to induce myocardial necrosis at anatomic landmarks within the left atrium (LA).[1,2] This strategy aims at creating contiguous and confluent ablation lesions around the PVA to electrically isolate the LA from arrhythmogenic foci located in the pulmonary veins (PV).[3] Procedure failure is often attributed to resumption of conduction between the PVs and LA and thought to be due to incomplete ablation lesion sets.[4]

Clinical Perspective on p 259

Delayed-enhancement MRI (DE-MRI) is a noninvasive imaging modality used to visualize radiofrequency-induced scar in the LA wall after AF ablation.[5–8] Regions of nonviable or scarred myocardium have increased image intensity in DE-MRI scans because of the slow washout kinetics of the gadolinium-based contrast agents in injured tissue.[9–11] Three-dimensional models of the LA can be generated to display the anatomic location and size of ablation-induced scar lesions

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after catheter-based procedures.[5] However, there are no reports verifying the accuracy of DE-MRI in depicting the location and extent of ablation lesions. Although there is a prior pilot study demonstrating a correlation between the number of PVs with circumferential lesions and outcome, this was obtained in a limited patient series and has not been studied thoroughly.[12] Moreover, no studies exist using DE-MRI to identify breaks in ablation lesion sets that can be targeted and closed during repeat procedure, as well as examining outcome data after repeat procedures.

The aim of this study was the following: (1) correlate anatomic scar data including total LA scar percentage, total PVA scar percentage, and number of complete scarred PVA after initial and repeat AF ablation procedures; (2) correlate DE-MRI scar lesions after AF ablation with regions of low-voltage tissue obtained using electroanatomic (EA) mapping during repeat procedure; and (3) examine the ability to identify regions of interrupted ablation-lesion sets that could be targeted and closed during repeat ablation.

Methods

Study Population

Between October 2006 and April 2008, 235 patients presented to the University of Utah for catheter ablation of AF. Of theses patients, 144 received an interpretable DE-MRI scan 3 months after ablation. Twenty-four patients with AF recurrence elected to undergo repeat ablation procedures. Eighteen of these patients met the following criteria: (1) quality DE-MRI 3 months after the initial procedure, (2) quality DE-MRI 3 months after the repeat procedure, and (3) 6-month follow-up after the second ablation procedure. Six patients were excluded from our study for the following reasons: 3 were ineligible for MRI and received CT scans; 2 patients had poor-quality DE-MRI scan after the first procedure; and 1 patient had a poor-quality DE-MRI scan after the second procedure. Of the 18 patients, 13 had quality EA maps (defined as >100 points). Table 1 lists the clinical characteristics of the 144 patients included.

PVA Isolation and Posterior Wall and Septal Debulking

The methods for PVA isolation with posterior wall and septal debulking under intracardiac echocardiogram guidance have been described previously.[5] The technique is briefly summarized below. After venous access was obtained, a 14-pole coronary sinus catheter was placed into the coronary sinus via the right internal jugular access (TZ Medical Inc, Portland, Ore, or Bard EP, Lowell, Mass) for use as a mapping reference. A phased-array ultrasound catheter was positioned in the mid right atrium (Siemens AG Inc, Malvern, Pa) and used to guide a double transseptal puncture, through which was placed a 10-pole circular mapping catheter (Biosense Webster Inc) and a 3.5-mm Thermocool irrigated tip ablation catheter (Biosense Webster Inc). Using fluoroscopy and EA mapping (CARTOMERGE, Biosense-Webster, Inc) for catheter navigation, intracardiac potentials in the PVA, the posterior wall, and septum were mapped during sinus rhythm or AF and were targeted for ablation. Circular mapping–guided radiofrequency delivery was performed, using circular mapping electrogram artifacts to confirm ablation catheter tip location relative to the substrate of interest. Lesions were delivered using 50 W with a 50°C temperature limit, for a duration of 10 seconds (maximum, 15 seconds), with the end point being abolition of local electrograms. When all targets had been ablated, the entire region was resurveyed for any return of electric activity and any such regions were retreated. In addition, entry block in all 4 PVs was confirmed with the circular mapping catheter after debulking was accomplished. At the end of all redo procedures, 15 μg of isopretrenol per minute in addition to burst atrial pacing at 200 ms was performed to rule out initiation of AF or atrial flutter.

Table 1. Demographic Data

	Total	Patients Without Recurrence (n=102)	Patients With Recurrence (n=42)	*P* Value
Sex				0.212
Male	102	64	38	
Female	42	30	12	
Age, y	63±13	63±14	64±9	0.598
AF type				0.516
Paroxysmal	57	40	17	
Persistent	87	62	25	
Average follow-up, d	330±160	340±164	330±180	0.709
Radiofrequency burn time, s	2800±890	2700±950	2800±600	0.658
Myocardial infarction	5	3	2	0.456
Coronary artery disease	20	14	6	0.559
Valve surgery	3	3	0	0.352
Smoker	26	16	10	0.180
Hypertension	73	51	22	0.470
Diabetes	15	11	4	0.543
Congestive heart failure	10	7	3	0.601

Postablation Imaging

At 3 months after both the initial and repeat ablation procedures, a DE-MRI scan was performed to assess LA scar using methods previously described.[5] Three months after the procedure was chosen as the time point for lesion assessment because it has previously been shown to indicate chronic scar formation.[6] Briefly, patients underwent a DE-MRI sequence on a 1.5-T Avanto clinical scanner (Siemens Medical Solutions, Erlangen, Germany) using a TIM phased-array receiver coil. High-resolution DE-MRI was acquired approximately 15 minutes after contrast agent injection (0.1 mmol/kg; Multihance, Bracco Diagnostic Inc, Princeton, NJ) using a 3D inversion recovery, respiration navigated, ECG-gated, gradient echo pulse sequence. Typical acquisition parameters were free-breathing using navigator gating, a transverse imaging volume with voxel size=1.25×1.25×2.5 mm (reconstructed to 0.625×0.625×1.25 mm), TR/TE=5.5/2.3 ms, inversion time (TI)=270 to 310 ms, GRAPPA with R=2, and 50 reference lines. ECG gating was used to acquire a small subset of phase-encoding views during the diastolic phase of the LA cardiac cycle. The time interval between the R-peak of the ECG and the start of data acquisition was defined using the cine images of the LA. To preserve magnetization preparation in whole-image volume, navigator was acquired immediately after data acquisition block. Fat saturation was used to suppress fat signal. The TE of the scan (2.3 ms) was chosen such that fat and water are out of phase and the signal intensity of partial volume fat-tissue voxels was reduced allowing improved delineation of the LA wall boundary. The TI value for the DE-MRI scan was identified using a scout scan and was chosen to minimize intensity of normal myocardium. Typical scan time for the DE-MRI study was 5 to 10 minutes, depending on subject respiration and heart rate. If the first acquisition of 3D DE-MRI did not have an optimal TI or had suboptimal image quality, the scan was repeated.

DE-MRI Image Processing

After acquisition of the delayed enhancement scan, images were processed into 3D models by manually segmenting the LA in the maximum intensity projection and volume-rendering the image. A smooth table opacity and application of a color-look-up-table (CLUT) was then applied to better visualize scar regions. The LA

Table 2. Patients With Repeat Ablation

				Procedure 1			Procedure 2			
Patient	Age, y	Sex	AF Type	Scar, %	No. PVs Isolated	PV Scar, %	Scar, %	No. PVs Isolated	PV Scar, %	AF Recurrence
1	50	M	Persistent	11.5	0	44	34.8	2	72	Yes
2	71	F	Paroxysmal	11.1	1	40	17.9	1	64	No
3	73	F	Persistent	9.8	1	40	11.1	1	45	Yes
4	68	F	Persistent	3.5	0	32	13.4	3	86	No
5	73	M	Persistent	18.3	3	92	14.9	4	100	No
6	54	M	Persistent	7.9	1	50	18.1	2	64	Yes
7	59	M	Persistent	16.3	2	90	22.4	4	100	No
8	69	M	Persistent	4.3	0	20	24.3	1	44	No
9	64	M	Paroxysmal	9.9	1	65	18.3	2	77	No
10	67	M	Persistent	7.8	1	44	17.5	4	100	No
11	71	M	Persistent	5.3	1	66	19.4	3	86	No
12	63	M	Persistent	14	1	62	18.9	3	80	Yes
13	64	M	Persistent	11.8	2	93	28.1	4	100	No
14	78	M	Persistent	8.9	1	56	31.6	4	100	No
15	68	F	Persistent	10.1	0	34	11.7	1	56	No
16	59	M	Persistent	11.5	1	69	22.4	2	73	Yes
17	74	M	Paroxysmal	15.9	1	43	20.7	2	57	No
18	79	M	Persistent	17.9	1	70	36.7	2	75	No

model was then used for analysis of scar patterns around each PVA and to identify regions of interrupted lesions. Each patient had images generated of the right and left PVs with contoured outlines of the right superior PV, right inferior PV, left superior PV, and left inferior PV. The number of PVs that exhibited complete and contiguous scarring as agreed on by 2 independent and blinded reviewers was then recorded. The extent of PVA scar percentage was obtained by dividing each PVA into 8 equal segments and then estimating the extent containing scar lesions within each segment. Quantification of scar in the LA wall was then performed by tracing the epicardial and endocardial borders using custom image display and then analyzed by software written in Matlab (The Mathworks Inc, Natick, Mass). Normal and injured tissue were defined based on a bimodal distribution of pixel intensities within the LA wall. The first mode of lower pixel intensities was chosen as normal tissue. Injured tissue was defined at 3 standard deviations above the normal tissue mean pixel intensity. Regions defined as lesions were visualized independently to ensure appropriateness of lesion detection. Three months after the second ablation procedure, DE-MRI was again performed and the 3D models of the LA were generated to analyze PVA scarring from second procedure similar to the methods described above.

Correlation Between DE-MRI and EA Mapping

A quantitative and qualitative analysis was performed to correlate low-voltage regions on EA maps and enhancement on DE-MRI using methods previously described.[13] Thirteen patients with high-quality CartoXP maps (defined as >100 voltage points evenly spread throughout the atrium) were selected. The LA on the EA map and 3D DE-MRI was subdivided into 18 specific regions; 9 on the posterior wall and 9 on the anterior and septal wall. Four blinded reviewers (2 experts in cardiac MRI and 2 experts in AF ablation) scored the MRI models and EA maps on a 0 to 3 scale. For MRI models, 0 was no enhancement, 1 was mild, 2 was moderate, and 3 was extensive enhancement. For the EA maps, 0 was considered healthy tissue (voltage >1 mV, purple on EA maps), 1 was mildly decreased tissue voltage (voltage between >0.1 mV and <0.5 mV), 2 was moderate decreased tissue voltage (presence of low voltage tissue [voltage >0.1 mV and <0.5 mV] as well as fibrotic scar [voltage <0.1 mV]), and 3 was extensively decreased tissue voltage (voltage <0.1 mV, red on EA maps). The overall score was an average sum of all 9 regions for both the posterior wall and the septum.

Postablation Management

After the procedure, all patients were placed on a telemetry unit for 24-hour observation. Patients were discharged with patient-triggered and autodetected event monitoring for 8 weeks. Patients continued anticoagulation therapy with warfarin (international normalized ratio, 2.0 to 3.0) for a minimum of 3 months. Patients were assessed for AF recurrence at 3 months, 6 months, 1 year, and then every year after the procedure with 8-day Holter monitoring and ECG while at clinic. Patients in this study required a minimum of 6 months follow-up after their second procedure. Procedural success was defined according to recent *Heart Rhythm Society Guidelines* as freedom from AF, atrial tachycardia, and atrial flutter while off antiarrhythmic medications 2 months after ablation (ie, 2-month blanking period).[14]

Statistical Analysis

Normal continuous variables are presented as mean±standard deviation. Differences were considered statistically significant with a 2-sided $P<0.05$. Statistical analysis was performed using the SPSS 17.0 Statistical Package (SPSS Inc, Chicago, Ill), and Microsoft Excel 2007 (Microsoft Corporation, Redmond, Wash). A quantitative analysis of the relationship between DE-MRI and EA maps was performed using linear regression. Kaplan-Meier analysis for AF recurrence was performed on PVA scar percentage after ablation and[4] number of pulmonary veins with complete antral scarring after ablation.

Results

Patient Population

One hundred forty-four patients underwent PVAI with posterior wall and septum debulking for the treatment of AF. Of these patients, 42 (28.2%) had recurrence of AF after their ablation procedure. Average time to AF recurrence was 5.11±2.84 months. The average follow-up in this study was 10.23±5.14 months (range, 6 to 20 months). There was no

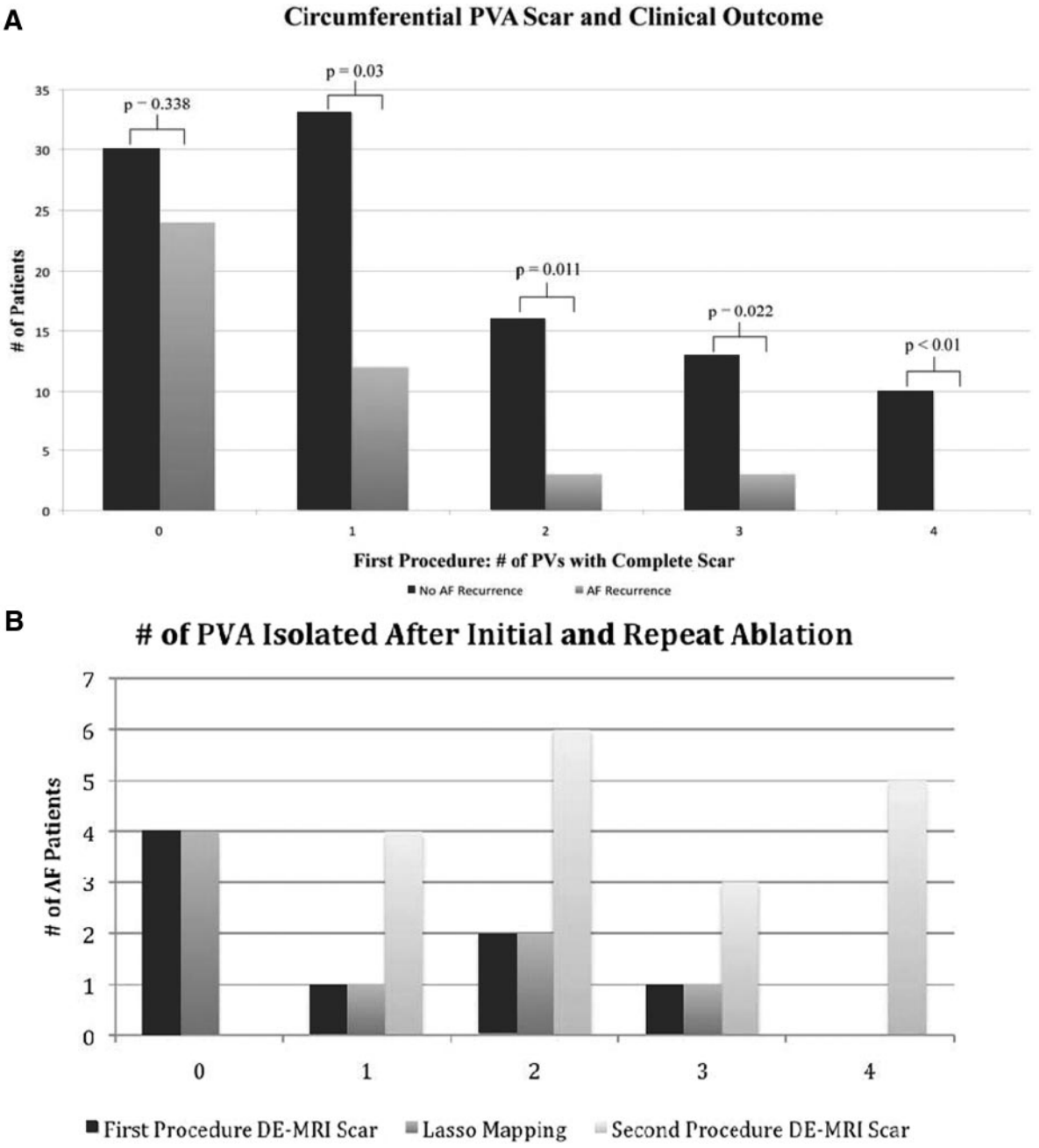

Figure 1. A, Correlation of circumferential PVA scar from first ablation procedure and recurrence. B, Patients with PVA isolated after initial and repeat ablation procedures.

statistical difference between the 2 groups with regard to sex, age, AF type, radiofrequency burn time, or other baseline patient characteristics (Table 1).

Eighteen patients underwent a repeat ablation procedure. There were 14 men and 4 women, with an average age of 66.0±8.7 years among men and 70.0±2.5 years among women (Table 2). Three patients had paroxysmal and 15 patients had persistent AF. Average ejection fraction was 51.1±7.8%. Of the 18 patients, 5 (27.8%) had recurrence of AF after the second procedure. Although all patients had varying degrees of preablation enhancement, no patients had significant enhancement to register with the scar quantification code used to detect postablation scarring.

Ablation Scarring After the First Procedure and Outcome

After the initial procedure, patients with 4 completely scarred PVA (10 patients) had 100% procedure success, whereas patients with 3 PVA (16 patients, 76.9% successful outcome), 2 PVA (19 patients, 84.2% procedure success), 1 PVA (45 patients, 73.3% procedure success, and zero PVA (54 patients, 55.5% procedure success) all had lower success rates. Figure 1A depicts this relationship.

Patients with successful AF termination had higher average total LA wall scar of 16.4±9.8% (P=0.004) and percent PVA scar of 66.2±25.4 (P=0.01) compared with patients with AF recurrence who had an average total LA wall scar 11.3±8.1% and PVA percent scar 50.0±24.7.

Table 3. Pulmonary Vein Antrum Scar Analysis

	Total	No AF Recurrence (n=102)	AF Recurrence (n=42)	*P* Value
Pulmonary veins isolated				0.012
0	54	30	24	
2	45	33	12	
3	19	16	3	
4	16	13	3	
5	10	10	0	
LIPV isolated	71	55	16	0.049
LSPV isolated	43	39	4	0.001
RIPV isolated	32	25	7	0.211
RSPV isolated	17	15	2	0.079
LIPV scar	73.6±30.0%	77.9±27.6%	63.2±33.2%	0.007
LSPV scar	56.4±33.7%	63.4±32.9%	39.4±29.4%	0.001
RIPV scar	52.6±30.6%	55.8±30.8%	45.0±29.0%	0.054
RSPV scar	44.5±30.0%	47.6±30.7%	36.9±27.2%	0.056

LI indicates left inferior; LS, left superior; RI, right inferior; and RS, right superior.

Frequency of Complete Circumferential PVA Lesions

Only 10 of 144 (6.9%) patients had circumferential scarring of all 4 PVA, 16 of 144 (11.1%) had 3 completely scarred PVA, 19 of 144 (13.2) had 2 completely scarred PVA, 45 of 144 (31.3%) had 1 completely scarred PVA, and 54 of 144 (37.5%) had no completely scarred PVA (Table 3). Figure 1B shows the frequency of PVA scarring. The left inferior PV was most frequently circumferentially scarred PV occurring in 71 of 144 (49.3%) patients. The left superior PV had complete scarring in 43 of 144 (29.9%) patients. The right inferior PV had complete scar in 32 of 144 (22.2%) patients. The right superior PV was the most difficult PV in which to achieve circumferential scarring, occurring in only 17 of 144 (11.8%) patients.

Ablation Lesions Before and After Repeat Procedure

Eighteen patients underwent repeat ablation. After the initial ablation, complete circumferential scarring was demonstrated around no PVA in 4 patients (22.2%), 1 PVA in 11 patients (61.1%), 2 PVA in 2 patients (11.1%), and 3 PVA in 1 patient (5.5%). No patients had complete scarring of all 4 PVA after the initial procedure. After the repeat procedure, all patients had an increased number of completely scarred PVA: 5 patients (27.8%) had complete circumferential scarring of all 4 PVA and 3 patients (16.7%) had complete circumferential scarring of 3 PVA. Five patients (33.3%) had complete circumferential scarring in 2 PVA and 4 patients (22.2%) had complete scarring of one PVA. The numbers of veins scarred after the first and second procedures are demonstrated in Figure 1B.

Figure 2 depicts a patient with incomplete isolation of all 4 PVA (top row) after his first procedure. Before the repeat ablation, the regions of interrupted ablation lesions were targeted (yellow arrows) and given to the electrophysiologists before the procedure. Electric recovery was present in all 4 PVA. After the procedure, DE-MRI was obtained (bottom row), which demonstrated complete circumferential lesions around all 4 PVA.

In the study, all patients had an increase in total LA scar percentage after the second procedure. The average circumferential PV antral scar after first ablation was 56.1±21.4%, whereas the average PVA scar after the second ablation was 77.2±19.5%. The average total LA scar after the first ablation was 11.0±4.1%, whereas the average total LA scar after second ablation was 21.2±7.4%. The increase in posterior wall scarring of 3 patients is shown in Figure 3. Thirteen of the 18 patients (72.2%) had successful suppression of AF after the second ablation procedure. All 5 patients with AF recurrence after the second procedure demonstrated at least 1 incomplete circumferential PVA lesion. Figure 4 demonstrates 2 examples of patients with incomplete ablation lesion sets who had AF recurrence after the second ablation procedure.

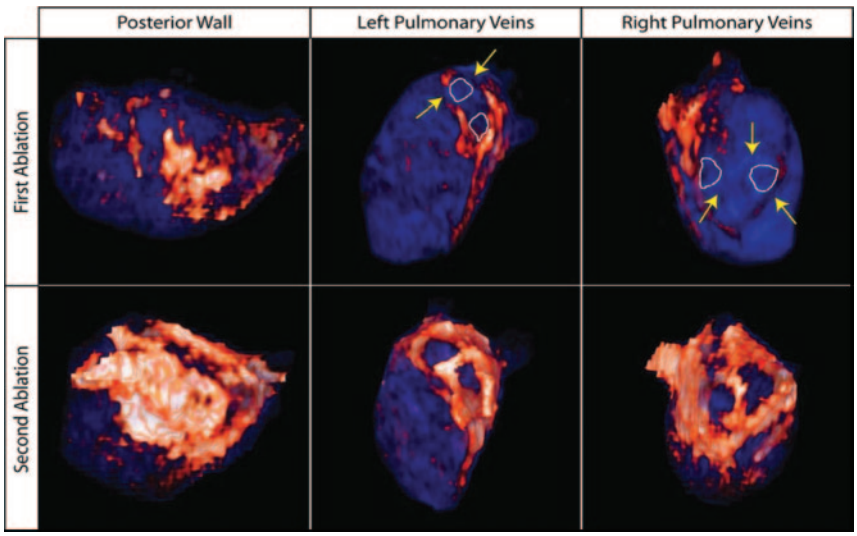

Figure 2. Three-dimensional MRI model of the LA after failed PVA isolation (First) and repeat successful PVA isolation (Second). After the initial failed ablation, all 4 PVs showed incomplete PVA scar as evident by lack of continuous scar (orange/white) around each pulmonary vein ostia (white outline). Gap lesions of healthy myocardium (blue) were identified and targeted (yellow arrows) before repeat ablation. After the successful repeat procedure, all 4 PVA had continuous scar lesions.

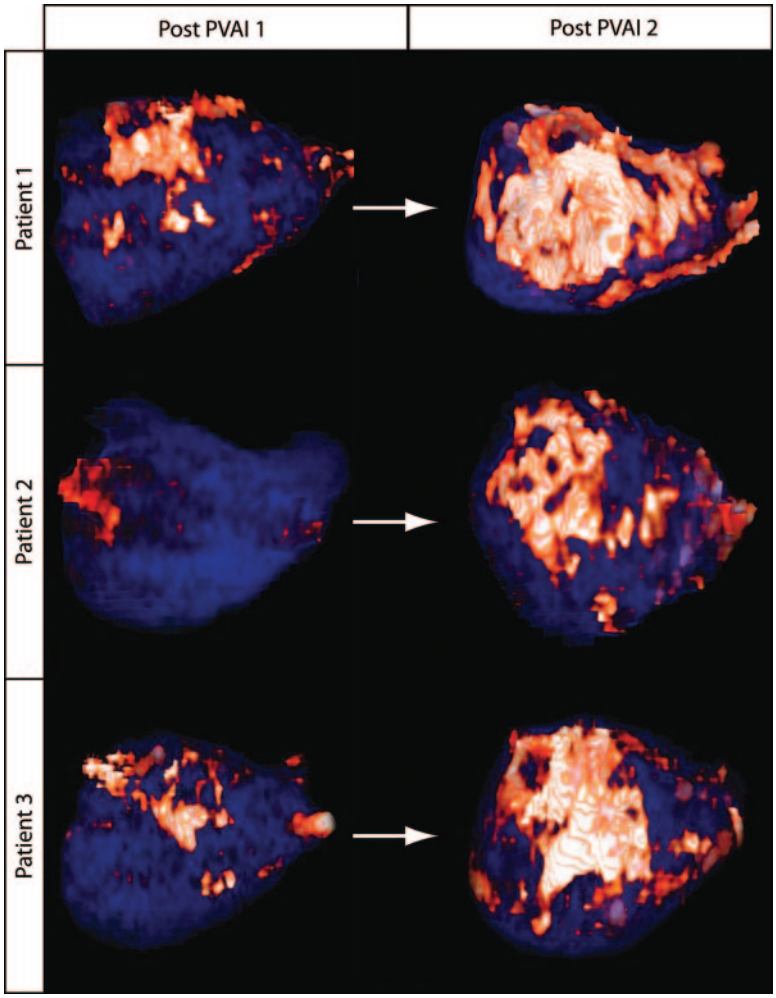

Figure 3. Increased posterior wall scar formation. The first column (left) represents posterior wall scar (orange/white) after the first procedure in 3 different patients. The second column (right) represents the scar formation after the second ablation procedure. The repeat procedure induced significantly more posterior wall scarring during the second debulking procedure. This was associated with increased total LA wall scar in each patient.

Correlation of DE-MRI Scar With EA Mapping and Recovery of Conduction

A qualitative correlation between regions of enhancement on DE-MRI and low-voltage regions on EA maps were seen in all patients. Figure 5 demonstrates 3 patients. Patients 1 and 3 had DE-MRI scar (red) located along the posterior wall and right PVA, which correlated with the distribution of low-voltage tissue (red) on EA maps. Patient 2 had minimal scar after the first procedure and had normal voltage tissue on the EA map. Quantitative analysis of this relationship demonstrated a positive correlation of $R^2=0.57$ (Figure 6).

Recovery of Electric Potential and Gap Lesions

All patients with incomplete ablation sets marked by identifiable gap lesions had recovery of electric activity on repeat electrophysiological study. Figure 7 shows recovery of conduction into the left superior PV as demonstrated by PV potentials within the PV, which was abolished during the

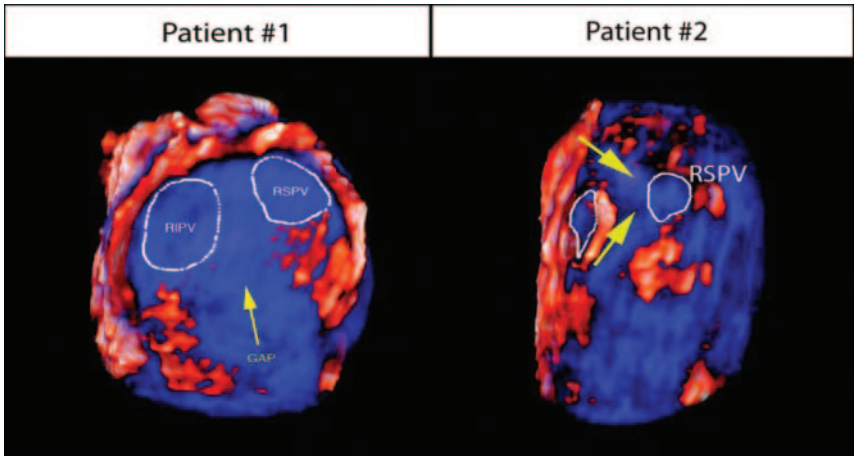

Figure 4. Identification of gap lesions after procedure failure. In our patient series, 5 patients had recurrence of AF after the second procedure. All patients had significant gap lesions on their follow-up MRI. Below is an example of 2 patients who had significant gap lesions (blue tissue, marked by yellow arrow) on their right PVs.

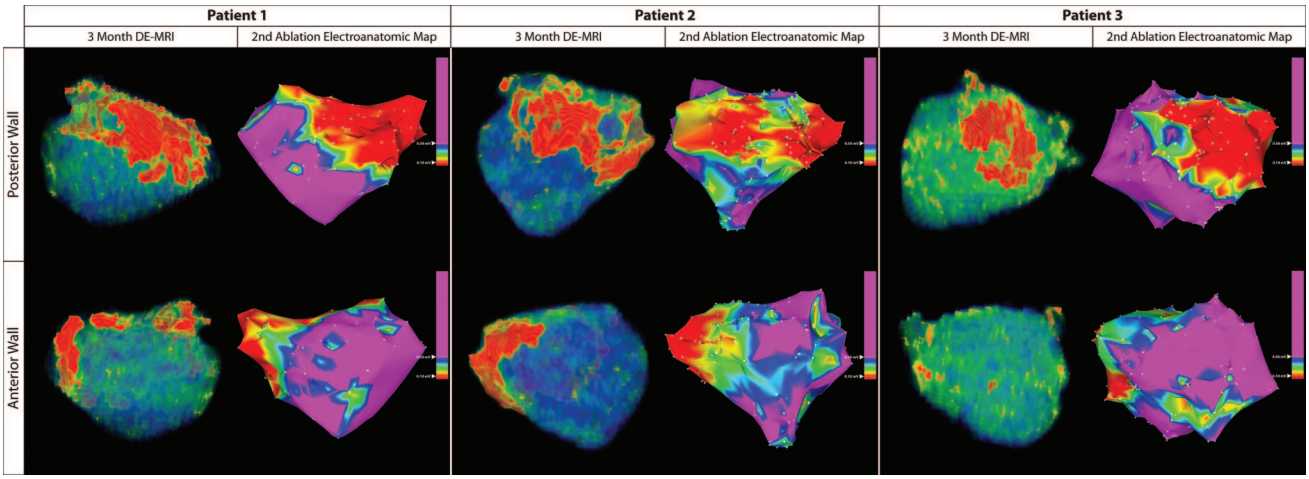

Figure 5. Correlation between DE-MRI after a failed ablation procedure with the EA map obtained during the repeat procedure for 3 patients. The images on the left demonstrate PA (top) and AP (bottom) views of the DE-MRI color model scar patterns. The images on the right are the EA map obtained during repeat procedure. There is a strong correlation in the size and distribution of MRI scar (red tissue) with low-voltage regions (<0.1 mV; red) of the EA map.

initial procedure. This recovery occurs in a vein with only minimal scarring and incomplete circumferential lesions. In contrast, Figure 8 represents a patient with complete circumferential lesion (orange/white) of the right inferior PV with no evidence of electric activity during the repeat electrophysiological study. No patients in the series had complete circumferential scar around the PVA and electric recovery.

Discussion

This report describes the analysis of LA scar lesions after initial and repeat AF ablation. Our study indicates the number of circumferentially scarred PVA is associated with better clinical outcome and confirm earlier studies that total LA scar burden is associated with AF termination. However, although associated with excellent procedure outcomes, only a small minority of patients (6.9%) had complete and contiguous scarring of all 4 PVA. We found that DE-MRI can accurately depict the location and extent of scar lesions based on the correlation of these lesions with low-voltage LA regions on EA maps. We also demonstrate that DE-MRI can be used to identify the location of breaks in ablation lesions, which correlates with recovery of electric conduction that could be responsible for AF recurrence after ablation. Completing circumferential PVA scarring and redebulking the posterior wall during repeat procedure appears to improve procedural success. This novel MRI-based method could be used as a measure to guide a repeat AF ablation procedure.

Complete Circumferential Anatomic Isolation

PVA isolation is a technically challenging procedure requiring confluent ablation lesions within the complex and heterogeneous LA-PV anatomy.[15,16] The use of circumferential

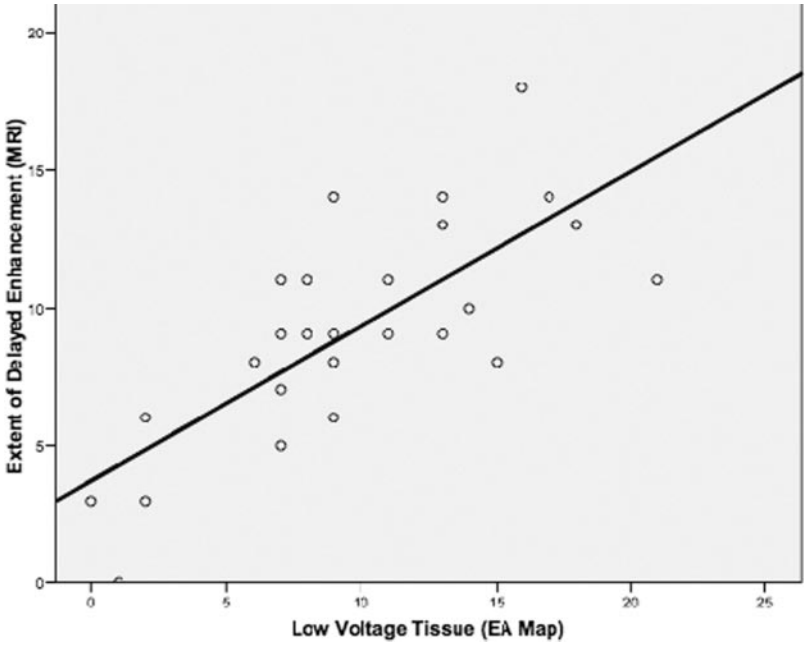

Figure 6. Quantitative correlation between DE-MRI scar and low-voltage tissue on EA mapping.

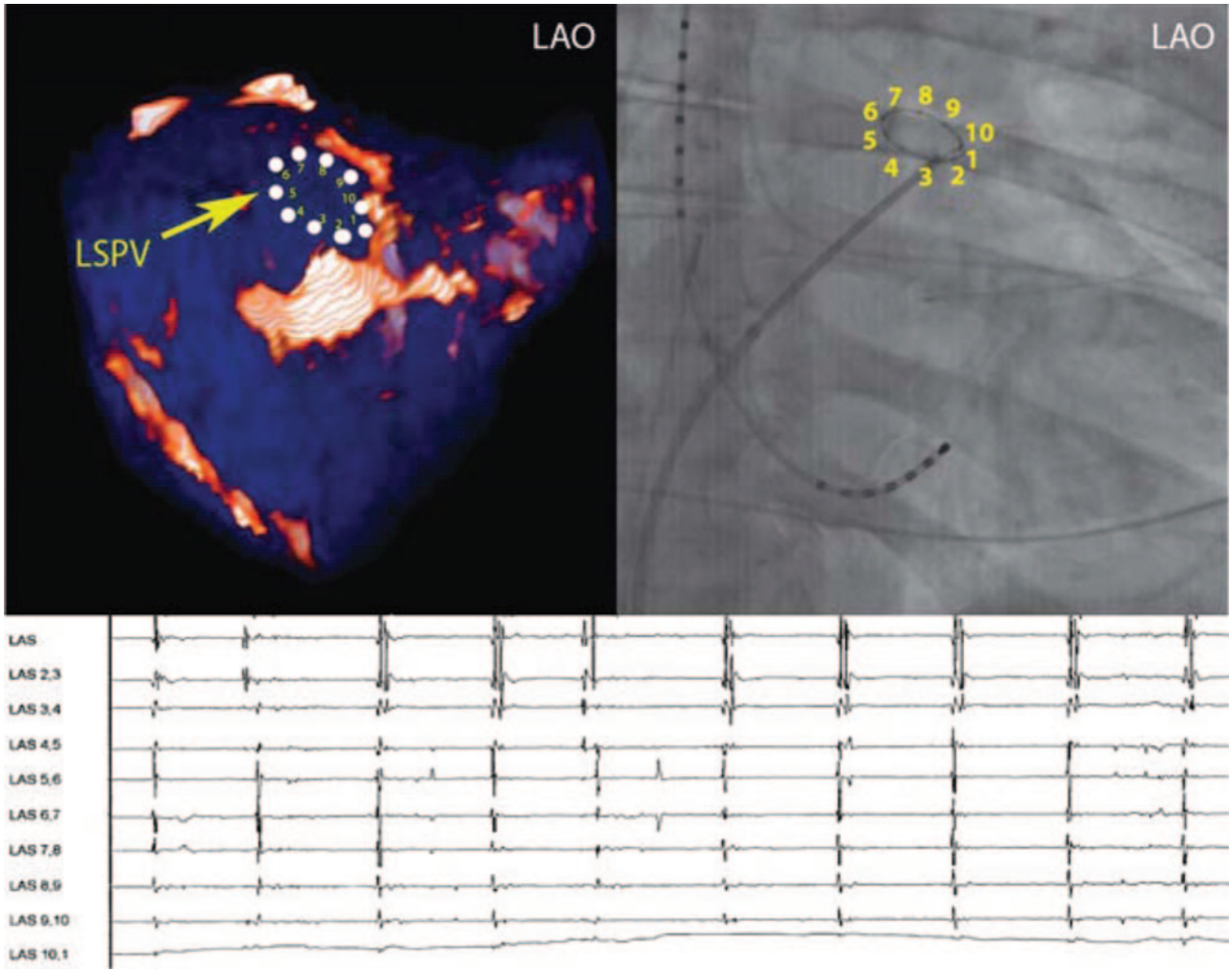

Figure 7. Recovery of electric potentials that correlate with incomplete scar lesions. In this patient example, the upper left image demonstrates incomplete PVA scarring of the left superior PV. This vein demonstrated recovery of previously isolated electric potentials that correlated with the lack of complete anatomic scarring.

mapping and anatomic guidance with EA maps can assist in creating contiguous scar lesions around the PVA. However, these modalities have questionable accuracy,[17] and creating a continuous ablation scar around each antrum remains a difficult task to achieve.[18] Our study was consistent with prior reports because only 6.9% of patients had complete circumferential scarring of all 4 PVA. This indicates that obtaining complete circumferential isolation is a difficult procedure end point to achieve and might be occurring less frequently than previously suspected, even if initial PV isolation was achieved. Our data do support the notion that a greater the number of veins with complete anatomic scarring increases the likelihood of successful procedure outcome. However, many patients remained in normal sinus rhythm even though they had incomplete PVA scarring, suggesting other factors influencing AF recurrence after ablation.

LA Substrate Modification

There is substantial evidence that the mechanisms of AF are multifactorial.[19] Triggers outside of the PVs, including the LA posterior wall, appear to contribute to both AF initiation and maintenance.[20–24] Modified ablation techniques have been adapted to address the role of the posterior wall in the chronic fibrillatory process.[25] Substrate modification relies on decreasing the amount of viable LA tissue capable of harboring AF by debulking significant portions of the LA posterior wall.[26] Pappone et al[2] have speculated that the extent of LA ablation (>30%) is a more important prognostic indicator for procedure success than PV isolation. This finding was supported in a recent analysis of scar patterns performed by our group in which LA scar burden was a significant predictor of AF termination.[5] This study confirmed these earlier findings in a larger patient population. Likewise, in this study, each patient had an increase in total LA wall scar burden, primarily located within the LA posterior wall (Figure 6) after the second procedure.

Accuracy of DE-MRI

Delayed-enhancement MRI was recently introduced as a noninvasive technique to visualize the effects of the ablation procedure.[5–8] To our knowledge, our study is the first to examine whether or not the hyperenhanced tissue identified by DE-MRI correlates with low-voltage detected using invasive EA mapping. In our study, all patients demonstrated

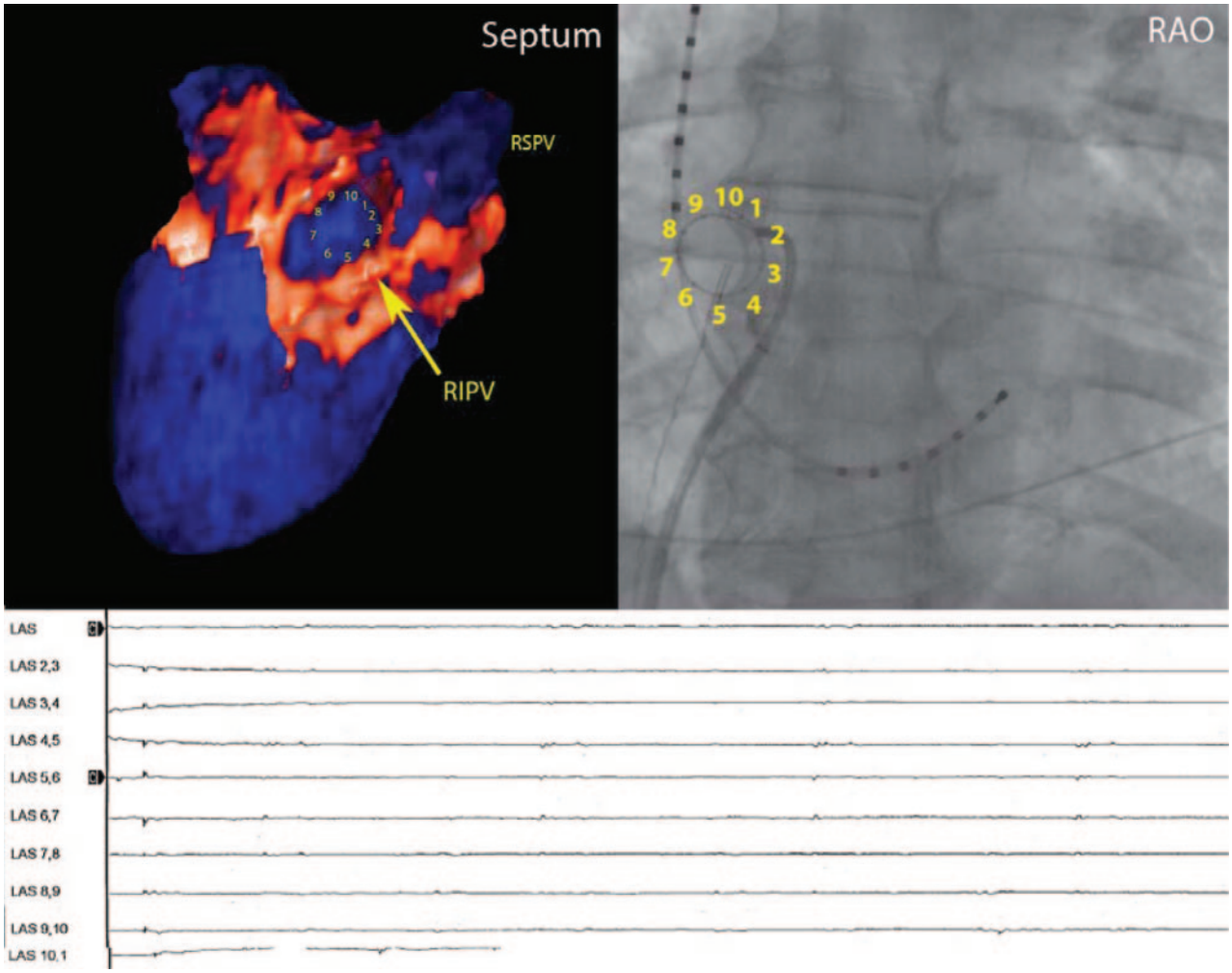

Figure 8. Complete anatomic and electric isolation. Patients who demonstrated complete anatomic scar on DE-MRI had no recovery of electric potentials on repeat examination. In this example, the upper left image demonstrates a lesion with complete anatomic scarring of the right superior PV. This vein demonstrated no recovery of electric potentials on repeat electrophysiology study.

similar distribution in the extent and location of low-voltage tissue on EA maps and scar tissue on DE-MRI. Although some patients' examples demonstrated scar tissue on EA maps that did not correlate with MRI findings, this was often in regions not targeted during the initial ablation procedure. Many physiological processes other than ablation-induced scar could account for the low-voltage LA regions, such as preprocedural fibrosis from LA structural remodeling.[13]

Identification of Breaks in Ablation Lesion Sets

Numerous prior reports have detailed the relationship between resumption of PV-LA conduction and AF recurrence after PVA isolation.[4,27] These authors speculate that interrupted ablation lesions play a contributing factor to procedural failure. Our study demonstrated that all patients who had AF recurrence after the initial and repeat procedures demonstrated significant gaps between lesions, which correlated with recovery of local electrograms or PV electric conduction. The ability of DE-MRI to noninvasively and accurately evaluate the integrity of scar lesions could provide a valuable feedback tool to assess whether successful lesion placement was achieved. This imaging modality could potentially aid electrophysiologists in identifying regions of healthy myocardium after failed ablation procedures that can be targeted during repeat ablation to close all lesion sets. As demonstrated in this article, the ability to locate regions of incomplete or recovered scarring before the repeat procedure did help focusing our ablation lesions around the PVA and the LA posterior wall and septum, hence increasing the amount of scarring in those areas, as demonstrated in Figure 8.

Study Limitations

The limited number of patients who underwent repeat ablation in this series is a limitation of our study. Because of the similar procedural technique used for all patients, we were unable to distinguish which scar patterns (substrate modification versus anatomic isolation) are most responsible for procedure success. Additional studies that examine this topic would be beneficial in understanding the most appropriate and efficacious ablation strategy. Likewise, additional studies that use a control group that does not use DE-MRI assessment of scar for repeat ablation would be of benefit in comparing clinical outcomes. It is also acknowledged that asymptomatic AF is a difficult to detect, and that may influence the reported

ablation success rates. Studies examining segmental analysis of early electric activation and propagation with MRI scar in antral regions are also needed for further validation of the correlation between electric activity and ablation scar detected by MRI. Likewise, additional studies comparing voltage areas and MRI scar specifically within in the antrum regions are needed for a better comparison of the utility of MRI in guiding ablation procedures.

Conclusion

We report using DE-MRI to correlate LA scar patterns after initial and repeat AF ablation. We found that the number of circumferential PVA lesions and total LA scar was important in procedure success. Moreover, we found that obtaining complete circumferential PVA lesions around the PV is a difficult end point to achieve long term. However, we found that DE-MRI can display gaps or recovered sites within ablation lesions that can be targeted during repeat procedures. We postulate that this imaging modality can help assist in achieving complete and contiguous PVA scarring after repeat ablation procedures.

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Disclosures

None.

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CLINICAL PERSPECTIVE

Catheter ablation for atrial fibrillation creates areas of atrial scar to isolate the pulmonary veins and damage areas involved in fibrillation. Atrial recovery from incomplete lesions is not uncommon, resulting in the need for repeat procedures to identify and reablate recovered regions that are important for the arrhythmia. Delayed-enhancement MRI (DE-MRI) provides a noninvasive assessment of left atrial ablation scar and therefore lesions after catheter ablation. In this study, analysis of DE-MRI after catheter ablation found a correlation between the extent of scarring and procedure success. In patients having repeat procedures, DE-MRI scar correlated with low-voltage left atrial regions on electroanatomic mapping. These findings suggest that DE-MRI can potentially be used to identify breaks in ablation lesion sets that could be targeted during repeat catheter ablation procedures.