

# Left Atrial LGE and Arrhythmia Recurrence Following Pulmonary Vein Isolation for Paroxysmal and Persistent AF



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## ABSTRACT

**OBJECTIVES** The aims of this study were to: 1) use a novel method of late gadolinium enhancement (LGE) quantification that uses normalized intensity measures to confirm the association between LGE extent and atrial fibrillation (AF) recurrence following ablation; and 2) examine the presence of interaction and effect modification between LGE and AF persistence.

**BACKGROUND** Recurrent AF after catheter ablation has been reported to associate with the baseline extent of left atrial LGE on cardiac magnetic resonance. Traditional methods for measurement of intensity lack an objective threshold for quantification and interpatient comparisons of LGE.

**METHODS** The cohort included 165 participants (mean age  $60.0 \pm 10.2$  years, 77% men, 57% with persistent AF) who underwent initial AF ablation. The association of baseline LGE extent with AF recurrence was examined using multivariable Cox proportional hazards models. Multiplicative and additive interactions between AF type and LGE extent were examined.

**RESULTS** During  $10.2 \pm 5.7$  months of follow-up, 63 patients (38.2%) experienced AF recurrence. Baseline LGE extent was independently associated with AF recurrence after adjusting for confounders (hazard ratio: 1.5 per 10% increased LGE;  $p < 0.001$ ). The hazard ratio for AF recurrence progressively increased as a function of LGE. The magnitude of association between LGE  $>35\%$  and AF recurrence was greater among patients with persistent AF (hazard ratio: 6.5 [ $p = 0.001$ ] vs. 3.6 [ $p = 0.001$ ]); however, there was no evidence for statistical interaction.

**CONCLUSIONS** Regardless of AF persistence at baseline, participants with LGE  $\leq 35\%$  have favorable outcomes, whereas those with LGE  $>35\%$  have a higher rate of AF recurrence in the first year after ablation. These findings suggest a role for: 1) patient selection for AF ablation using LGE extent; and 2) substrate modification in addition to pulmonary vein isolation in patients with LGE extent exceeding 35% of left atrial myocardium. (J Am Coll Cardiol Img 2016;9:142-8)  
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Manuscript received May 27, 2015; revised manuscript received September 16, 2015, accepted October 8, 2015.

**A**trial fibrillation (AF) is associated with increased risk for mortality, heart failure, and thromboembolic events and has a worldwide prevalence of >33.5 million (1-3). Catheter ablation of AF is evolving as an effective therapy for symptomatic AF (4). Recurrent AF after ablation, however, remains a problem and has been reported to associate with the baseline extent of left atrial (LA) late gadolinium enhancement (LGE) on cardiac magnetic resonance (CMR) (5). Mechanistically, persistent AF appears to be more reliant on fibroblast proliferation and myocyte-fibroblast coupling than paroxysmal AF, which is dependent primarily on pulmonary vein triggers (6-8). Therefore, we sought to: 1) confirm the association of LA LGE with recurrent AF following ablation; and 2) examine the presence of interaction and/or effect modification between LGE and AF persistence prior to ablation.

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## METHODS

**PATIENT CHARACTERISTICS.** The Johns Hopkins Institutional Review Board approved the study, and all patients provided written informed consent. Between November 2011 and December 2013, 171 consecutive patients with drug-refractory AF who were referred for initial catheter ablation procedures, were scheduled for a pre-procedural CMR, and consented to participate were prospectively enrolled.

**CMR.** All subjects underwent pre-procedural CMR as previously described (9-11). Images were acquired using a 1.5-T CMR scanner (Avanto, Siemens, Erlangen, Germany) with a phased-array cardiac coil. Pulse oximetry, blood pressure, and electrocardiographic monitoring were maintained during the CMR examination. Contrast-enhanced 3-dimensional fast low-angle shot magnetic resonance angiographic images were used to define LA and pulmonary vein anatomy. LGE CMR scans were acquired approximately 20 min after 0.2 mmol/kg gadolinium injection (gadopentate dimeglumine, Bayer Healthcare Pharmaceuticals, Montville, New Jersey). The LGE sequence was a 3-dimensional inversion recovery prepared respiratory triggered and navigated, electrocardiographically gated, and fat-suppressed fast spoiled gradient echo sequence (repetition time 2.5 to 5.5 ms, echo time 1.52 ms, field of view 340 mm, flip angle 10°, inversion time 240 to 300 ms, 1.3 × 1.3 mm in-plane spatial resolution, 2-mm slice thickness).

**LA LGE EXTENT QUANTIFICATION.** The LGE CMR images were processed using QMass MR software version 7.2 (Leiden University Medical Center,

Leiden, the Netherlands). The LA myocardium was defined by manual placement of epicardial and endocardial contours by observers who were masked to clinical data (approximately 30 min of analysis time per image set). The image intensity ratio (IIR), a previously described (10,11) LGE CMR analysis technique that normalizes the myocardial image intensity by blood pool intensity, was used. The extent of LA LGE was quantified using the 0.97 image intensity threshold previously validated against LA bipolar voltage <0.5 mV (11). For this study, we used a threshold of <0.5 mV given prior use of this threshold to demarcate abnormal LA myocardium (12). LA volume measurements included the LA appendage as well as pulmonary vein antra and were limited anteriorly to the mitral valve plane.

**CATHETER ABLATION.** All patients underwent wide-area circumferential pulmonary vein isolation (PVI) as previously described (10,11). Briefly, a double transatrial septal puncture was performed under fluoroscopic guidance. An endocardial map of the left atrium was created with an electroanatomic mapping system (CARTO, Biosense Webster, Diamond Bar, California) and superimposed on the pre-existing CMR image of the chamber. With routine hemodynamic and electrocardiographic monitoring, a 4-mm-tipped irrigated ablation catheter (Thermocool, Biosense Webster) was advanced under fluoroscopic guidance to the left atrium. Circumferential lesions were applied surrounding the pulmonary veins. Additional ostial lesions were targeted to remaining pulmonary vein potentials using a circular multipolar electrode-mapping catheter (Lasso, Biosense Webster). Entrance block into the pulmonary veins was confirmed in all patients as the primary procedural endpoint. Additionally, when possible by demonstration of pulmonary vein capture, exit block was documented. To prevent short-term recurrences of AF, previously ineffective antiarrhythmic medications were continued for at least 3 months.

**CLINICAL FOLLOW-UP.** Recurrent AF was defined on the basis of the 2012 Heart Rhythm Society consensus document as symptomatic or asymptomatic AF, atrial tachycardia, or atrial flutter of >30 seconds in duration after a 3-month blanking period (4). Close communication via clinic visits and phone was maintained with all patients following the ablation. If symptoms suggestive of an arrhythmia occurred, patients were asked to undergo 24-h Holter monitoring or 30-day event monitoring depending on symptom frequency. In the absence of reported symptoms, patients were evaluated for recurrence at 6 and 12 months.

## ABBREVIATIONS AND ACRONYMS

**AF** = atrial fibrillation  
**CI** = confidence interval  
**CMR** = cardiac magnetic resonance  
**HR** = hazard ratio  
**IIR** = image intensity ratio  
**LA** = left atrial  
**LGE** = late gadolinium enhancement  
**PVI** = pulmonary vein isolation

**TABLE 1 Patient Demographics**

|  | Total<br>(n = 165) | Paroxysmal<br>(n = 94) | Persistent<br>(n = 71) | p Value |
|--|--------------------|------------------------|------------------------|---------|
| Age, yrs                                     | 60.0 ± 10.2        | 60.9 ± 10.6            | 58.8 ± 9.5             | 0.189   |
| Male   | 127 (77.0)         | 65 (69.2)              | 62 (87.3)              | 0.006   |
| Caucasian ethnicity                          | 144 (87.8)         | 84 (89.4)              | 60 (85.7)              | 0.644   |
| Hypertension                                 | 76 (46.1)          | 40 (42.6)              | 36 (50.7)              | 0.298   |
| Diabetes                                     | 11 (6.7)           | 5 (5.3)                | 6 (8.5)                | 0.425   |
| Congestive heart failure                     | 19 (11.5)          | 7 (7.5)                | 12 (16.9)              | 0.060   |
| Prior stroke/TIA                             | 10 (6.1)           | 7 (7.5)                | 3 (4.2)                | 0.265   |
| Coronary/peripheral vascular disease         | 20 (12.1)          | 9 (9.6)                | 11 (15.5)              | 0.249   |
| Obstructive sleep apnea                      | 39 (23.6)          | 20 (21.3)              | 19 (26.8)              | 0.412   |
| Body mass index, kg/m <sup>2</sup>           | 28.9 ± 5.9         | 27.7 ± 5.1             | 30.5 ± 6.4             | 0.003   |
| CHA <sub>2</sub> DS <sub>2</sub> -VASc score | 1.6 ± 1.5          | 1.6 ± 1.5              | 1.5 ± 1.3              | 0.517   |
| AF duration, yrs                             | 5.6 ± 6.4          | 5.3 ± 5.5              | 6.0 ± 7.4              | 0.546   |
| Left ventricular ejection fraction, %        | 57.3 ± 6.8         | 58.2 ± 6.2             | 56.1 ± 7.3             | 0.044   |
| LA volume, ml                                | 153.8 ± 50.4       | 145.8 ± 45.4           | 164.2 ± 54.8           | 0.021   |
| LA LGE extent, % of LA myocardium            | 35.9 ± 14.8        | 31.9 ± 13.1            | 41.1 ± 15.3            | <0.001  |
| Number of image planes per patient           | 21.9 ± 2.7         | 21.8 ± 2.7             | 22.1 ± 2.4             | 0.536   |

Values are mean ± SD or n (%).  
AF = atrial fibrillation; LA = left atrial; LGE = late gadolinium enhancement; TIA = transient ischemic attack.

**STATISTICAL ANALYSIS.** Continuous variables are presented as mean ± SD. Categorical variables are presented as frequencies and percentages. Differences between group means were evaluated with Student *t* tests (continuous variables) or chi-square analysis (categorical variables) as appropriate. The association of baseline LA LGE extent with recurrent AF was examined using multivariable Cox proportional hazards models adjusting for potential confounders including age, LA volume, AF type, and history of congestive heart failure or coronary or peripheral vascular disease. To explore a potential nonlinear association between LA LGE extent and recurrent AF, we used a restricted cubic spline model with incorporated knots at the 5th, 50th, and 95th percentiles (13). Results were also visualized using Kaplan-Meier survival curves and log-rank tests. The possibility of multiplicative and additive interaction between our main effect variable (LA LGE extent) and AF type, as well as effect modification by AF type, was explored (14). Additive interaction was explored using the relative excess risk due to interaction, the attributable proportion due to interaction, and the synergy index (15,16). Statistical analyses were performed using Stata version 12 (StataCorp LP, College Station, Texas).

## RESULTS

**PATIENTS' CHARACTERISTICS.** Of 171 patients, 6 (3.5%) were excluded because of poor CMR image

quality that precluded analysis by consensus of 2 observers. Detailed demographics of the remaining 165 patients are summarized in **Table 1**. The mean age was 60.0 ± 10.2 years, and 71 (43.0%) had persistent AF. The mean CHA<sub>2</sub>DS<sub>2</sub>-VASc score (17) was 1.6 ± 1.5. Of all patients, 76 (46.1%) had histories of hypertension, and 19 (11.5%) had histories of congestive heart failure. The mean baseline LA LGE extent (corresponding to bipolar voltage <0.5 mV) (11) was 35.9 ± 14.8% (median 35%; range 7% to 72%).

Patients with persistent AF were more likely to be male (87.3% vs. 69.2%; *p* = 0.006), to have higher body mass index values (30.5 ± 6.4 kg/m<sup>2</sup> vs. 27.7 ± 5.1 kg/m<sup>2</sup>; *p* = 0.003), to have lower left ventricular ejection fractions (56.1 ± 7.3% vs. 58.2 ± 6.2%; *p* = 0.044), to have higher LA volumes (164.2 ± 54.8 ml vs. 145.8 ± 45.4 ml; *p* = 0.021), and to have greater LA LGE extent than those with paroxysmal AF (41.1 ± 15.3% vs. 31.9 ± 13.1%; *p* < 0.001). The mean LGE sequence duration was 5.5 ± 1.6 min. Eighteen patients (10.9%) were in AF during CMR image acquisition. Image quality was adequate in the subset of patients with AF; however, CMR scan duration was longer for those in AF (7.4 ± 2.2 min vs. 5.2 ± 1.3 min; *p* < 0.001).

**AF RECURRENCE.** Of 165 patients, 63 (38.2%) had AF recurrence during the follow-up duration of 307 ± 170 days. Of 71 patients with persistent AF, 29 (40.9%) had AF recurrence, whereas of 94 patients with paroxysmal AF, 34 (36.2%) had AF recurrence. In univariate analyses, age, history of congestive heart failure, CHA<sub>2</sub>DS<sub>2</sub>-VASc score, and the extent of LA LGE were associated with AF recurrence (**Table 2**).

In unadjusted analysis, each 10% increase in the extent of baseline LA LGE was associated with 1.5-fold increased hazard of AF recurrence (hazard ratio [HR]: 1.5; 95% confidence interval [CI]: 1.3 to 1.8; *p* < 0.001). In a multivariable Cox proportional hazards model adjusting for age, LA volume, AF type, and history of congestive heart failure or coronary or peripheral vascular disease, each 10% increase in the extent of baseline LA LGE remained independently associated with AF recurrence (HR: 1.5; 95% CI: 1.3 to 1.8; *p* < 0.001). The multivariable adjusted spline regression model revealed no evidence for nonlinear effects (**Figure 1**). The HR for AF recurrence progressively increased with increasing extent of baseline LA LGE extent.

The extent of LA LGE extent was stratified at the median. In the multivariable Cox proportional hazards model adjusting for age, LA volume, AF type, and history of congestive heart failure or coronary or peripheral vascular disease, baseline LGE extent >35% was associated with AF recurrence (HR: 3.8;

95% CI: 2.1 to 6.8;  $p < 0.001$ ). **Figure 2** demonstrates Kaplan-Meier plots for time to AF recurrence in patients stratified by median LGE extent. Patients with LGE  $\leq 35\%$  of LA myocardium had prolonged freedom from AF (15% with AF recurrence at  $288 \pm 40$  days) compared with those with LGE extent  $>35\%$  (15% with AF recurrence at  $140 \pm 18$  days).

**EFFECT MODIFICATION AND STATISTICAL INTERACTION WITH AF TYPE.** There was no evidence of multiplicative interaction between AF type and baseline LA LGE extent in the multivariable Cox proportional hazards model of the association between LGE extent and AF recurrence ( $p = 0.511$ ). Similarly, the measures relative excess risk due to interaction (1.29; 95% CI:  $-1.32$  to 3.90), attributable proportion due to interaction (0.31; 95% CI:  $-0.23$  to 0.84), and synergy index (1.68; 95% CI: 0.53 to 5.35) did not suggest additive interaction between AF type and baseline LA LGE extent. However, as demonstrated in **Figure 3**, the magnitude of association between baseline LGE extent  $>35\%$  and AF recurrence was attenuated when the cohort was stratified on the basis of AF type. In patients with paroxysmal AF, the HR for AF recurrence with baseline LGE extent  $>35\%$  was 3.6 (95% CI: 1.7 to 7.7;  $p = 0.001$ ) after adjusting for age, LA volume, and history of congestive heart failure or coronary or peripheral vascular disease. In contrast, in patients with persistent AF, the HR for AF recurrence with LGE extent  $>35\%$  was 6.5 (95% CI: 2.1 to 19.6;  $p = 0.001$ ) after adjusting for the same covariates. **Figure 4** demonstrates Kaplan-Meier plots for time to AF recurrence in patients stratified by median LGE extent as well as AF persistence. Patients with LGE  $\leq 35\%$  of LA myocardium had prolonged freedom from AF regardless of AF persistence prior to ablation (15% with AF recurrence at  $252 \pm 45$  days and  $294 \pm 7.6$  days for patients with paroxysmal and persistent AF, respectively). In contrast, those with LGE extent  $>35\%$  had early recurrence regardless of AF persistence prior to ablation (15% with AF recurrence at  $156 \pm 47$  days and  $126 \pm 22$  days for patients with paroxysmal and persistent AF, respectively).

**DISCUSSION**

The main finding of the present study is that regardless of AF persistence at baseline, LGE  $\leq 35\%$  of LA myocardium, measured using the IIR, is associated with a favorable outcome, whereas LGE  $>35\%$  is associated with early AF recurrence post-ablation.

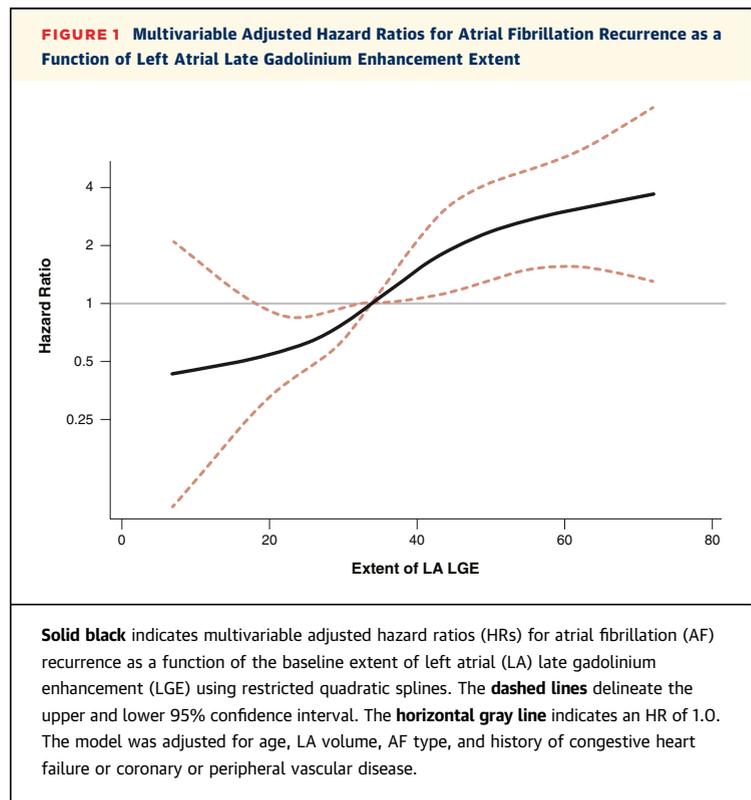
**PRIOR STUDIES OF THE ASSOCIATION OF LA LGE WITH AF RECURRENCE POST-PVI.** Our study is in agreement with prior reports of an association between AF recurrence and LA LGE extent. Peters

**TABLE 2 Characteristics of Patients With Versus Those Without Atrial Fibrillation Recurrence**

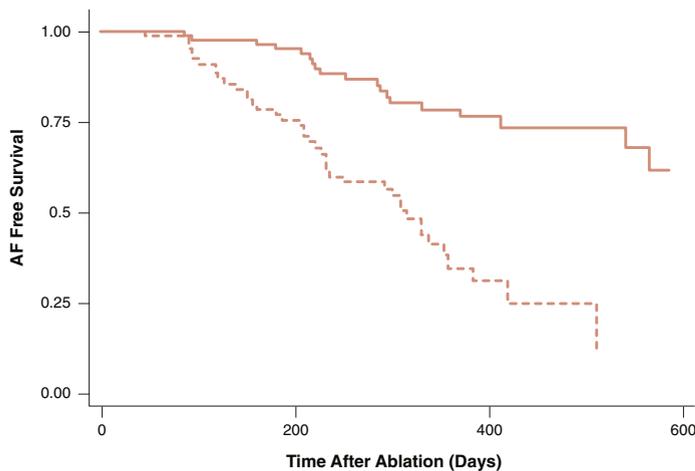
|  | Total (n = 165)  | No AF Recurrence (n = 102) | AF Recurrence (n = 63) | p Value |
|--|------------------|----------------------------|------------------------|---------|
| Persistent AF                                | 71 (43.0)        | 42 (41.2)                  | 29 (46.0)              | 0.541   |
| Age, yrs                                     | 60.0 $\pm$ 10.2  | 58.6 $\pm$ 10.4            | 62.4 $\pm$ 9.3         | 0.018   |
| Male   | 127 (77.0)       | 81 (79.4)                  | 46 (73.0)              | 0.343   |
| Caucasian ethnicity                          | 144 (87.8)       | 87 (86.1)                  | 57 (90.5)              | 0.771   |
| Hypertension                                 | 76 (46.1)        | 46 (45.1)                  | 30 (47.6)              | 0.752   |
| Diabetes                                     | 11 (6.7)         | 5 (4.9)                    | 6 (9.5)                | 0.248   |
| Congestive heart failure                     | 19 (11.5)        | 7 (6.9)                    | 12 (19.1)              | 0.017   |
| Prior stroke/TIA                             | 10 (6.1)         | 6 (5.9)                    | 4 (6.4)                | 0.903   |
| Coronary/peripheral vascular disease         | 20 (12.1)        | 9 (8.8)                    | 11 (17.5)              | 0.099   |
| Obstructive sleep apnea                      | 39 (23.6)        | 21 (20.6)                  | 18 (28.6)              | 0.241   |
| Body mass index, kg/m <sup>2</sup>           | 28.9 $\pm$ 5.9   | 28.3 $\pm$ 5.7             | 30.0 $\pm$ 6.0         | 0.064   |
| CHA <sub>2</sub> DS <sub>2</sub> -VASc score | 1.6 $\pm$ 1.5    | 1.4 $\pm$ 1.3              | 1.9 $\pm$ 1.6          | 0.041   |
| AF duration, yrs                             | 5.6 $\pm$ 6.4    | 5.6 $\pm$ 6.1              | 5.7 $\pm$ 6.8          | 0.922   |
| Left ventricular ejection fraction, %        | 57.3 $\pm$ 6.8   | 57.3 $\pm$ 6.9             | 57.3 $\pm$ 6.7         | 0.940   |
| LA volume, ml                                | 153.8 $\pm$ 50.4 | 151.3 $\pm$ 49.2           | 157.9 $\pm$ 52.5       | 0.423   |
| LA LGE extent, % of LA myocardium            | 35.9 $\pm$ 14.8  | 32.4 $\pm$ 13.3            | 41.5 $\pm$ 15.4        | <0.001  |
| Number of image planes per patient           | 21.9 $\pm$ 2.7   | 21.6 $\pm$ 2.9             | 22.3 $\pm$ 2.1         | 0.148   |

Values are n (%) or mean  $\pm$  SD.  
 Abbreviations as in **Table 1**.

et al. (18) were the first to use LGE magnetic resonance imaging for the detection of post-ablation PVI lesions within LA myocardium. Several follow-on studies reported that AF recurrence was negatively



**FIGURE 2 Kaplan-Meier Atrial Fibrillation-Free Survival Curves After Pulmonary Vein Isolation in Participants Stratified by Median Left Atrial Late Gadolinium Enhancement Extent**



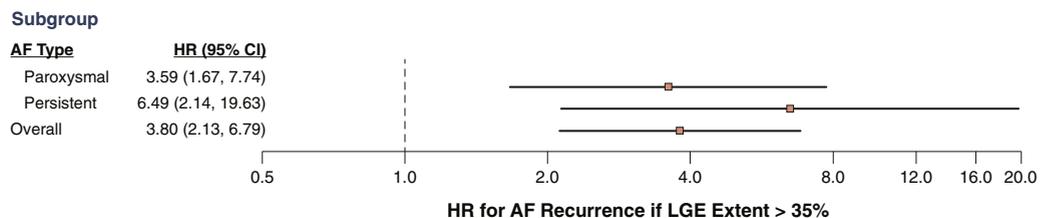
Time to first atrial fibrillation (AF) recurrence in 86 participants (52%) with late gadolinium enhancement (LGE) extent  $\leq 35\%$  (solid line) and 79 participants (48%) with LGE extent  $>35\%$  of left atrial myocardium (dashed line) ( $p < 0.001$ ).

associated with the extent of post-ablation LGE (19,20). Marrouche et al. (5) recently completed a multicenter, observational cohort study of magnetic resonance imaging prior to PVI in 272 patients with AF and reported a 1.06-fold increase in AF hazard with each 1% increase in LGE extent. In the study by Marrouche et al. (5), as well as all other prior studies of the association between LGE extent and AF recurrence, LGE extent was estimated by the relative intensity of contrast enhancement. CMR signal intensity is measured in “arbitrary units” with variable magnitude and scale across examinations. Although LA wall image intensity on LGE CMR varies

primarily as a function of gadolinium retention in fibrotic regions, it is also affected by parameters such as surface coil proximity, contrast dose, delay time of image acquisition after contrast injection, patient hematocrit, glomerular filtration rate, and body mass index. To overcome the limitations of the “arbitrary unit scale” as well as improve objectivity and generalizability, we used the IIR for quantification of LGE. In a prior study, we showed that the IIR is closely associated with local intracardiac bipolar LA voltage measures and exhibits favorable intraclass correlations ( $>0.9$ ) for interobserver and intraobserver variability and reliability of measurement (11). It should be noted, however, that given the variable methodologies for acquisition and analysis of LGE images, LGE prevalence and extent should not be compared among the different studies. It is our hope that the use of a standardized technique, as described here, will improve the future ability to compare results across cohorts. Nevertheless, the overall results are consistent, and increasing LGE appears to be associated with AF recurrence in all studies to date.

**INTERACTION AND EFFECT MODIFICATION WITH AF TYPE.** To our knowledge, this is the first study to examine the presence of interaction or effect modification between LGE and AF type. Paroxysmal AF appears to be related to triggered activity primarily from pulmonary vein foci (6). Therefore, it was expected that AF ablation with PVI would be more efficacious in the subgroup of patients with paroxysmal AF (21). In contrast, persistent AF appears to be more reliant on myocyte-fibroblast coupling, resulting in non-pulmonary vein triggered activity, as well as enhanced AF perpetuation due to fibroblast proliferation (7,8). We hypothesized that the association of AF recurrence with baseline LGE extent would be dependent on AF type prior to ablation. In this study,

**FIGURE 3 Forest Plot of Hazard Ratios for Atrial Fibrillation Recurrence if Late Gadolinium Enhancement Extent  $>35\%$  After Stratification by Atrial Fibrillation Type**



The forest plot summarizes multivariable adjusted hazard ratios (HRs) for atrial fibrillation (AF) recurrence. Models were adjusted for age, left atrial (LA) volume, AF type, and history of congestive heart failure or coronary or peripheral vascular disease. The magnitude of association between AF recurrence and late gadolinium enhancement (LGE) extent was higher among patients with persistent AF; however, there was no evidence for statistical interaction.

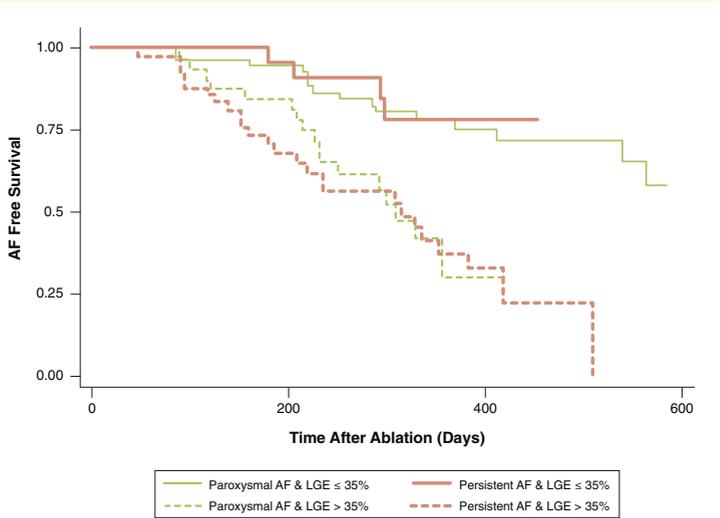
we found no evidence of statistical interaction or effect modification between AF type and LGE extent. However, the magnitude of association between LGE extent and AF recurrence was stronger in patients with persistent AF. As a result, patients with persistent AF who had  $\leq 35\%$  LGE had equivalent outcomes as those with paroxysmal AF and limited LGE. Similarly, patients with  $>35\%$  LGE had poor outcomes regardless of AF type. This important result is contrary to current beliefs regarding uniformly lower AF ablation efficacy in persistent AF that result in discouragement of many such patients from undergoing ablation. Additionally, extensive ablations in addition to PVI have been used with the goal of improving efficacy in patients with persistent AF. Recent results suggest that additional ablation does not necessarily reduce AF recurrence (22,23). Our results suggest that patients with persistent AF and LGE  $\leq 35\%$  are likely to benefit from PVI without additional extensive ablations.

**STUDY LIMITATIONS.** The study was performed at a single tertiary care center, so the sample size is relatively small, and the results may not be generalizable to centers with less experience with LGE CMR or lower PVI volumes. The limited sample size may have decreased the study’s power to detect statistical interaction between AF type and LGE extent. However, it is important to note that because of the protocol homogeneity of this single-center study, only 3.5% of patients had to be excluded because of poor image quality, compared with 17% in the comparable multicenter study (5). The LGE CMR sequence used in this study provided  $1.3 \times 1.3$  mm in-plane resolution. Atrial wall thickness may be near the limit of image resolution in some cases. Thus the LGE analysis may have included blood pool or epicardial fat in some cases. Data regarding the duration of continuous AF were unavailable in this cohort. The possibility of statistical interaction between baseline LGE extent and AF duration in their association with AF recurrence warrants further investigation. Finally, although patients were closely monitored via symptom-prompted and scheduled (6- and 12-month) electrocardiographic monitoring, continuous monitoring was not performed, and some asymptomatic recurrences may have been missed.

**CONCLUSIONS**

Regardless of AF persistence at baseline, and after adjusting for potential confounders, participants with LGE  $\leq 35\%$  had favorable outcomes, whereas those with LGE  $>35\%$  had early AF recurrence after ablation. These findings suggest that patients with LGE  $\leq 35\%$  of

**FIGURE 4** Kaplan-Meier Atrial Fibrillation-Free Survival Curves After Pulmonary Vein Isolation in Participants Stratified by Median Left Atrial Late Gadolinium Enhancement Extent and Atrial Fibrillation Type



Time to first AF recurrence in 60 participants (36%) with paroxysmal atrial fibrillation (AF) and late gadolinium enhancement (LGE) extent  $\leq 35\%$  (**thin solid line**), 26 participants (16%) with persistent AF and LGE extent  $\leq 35\%$  (**thick solid line**), 34 participants (21%) with paroxysmal AF and LGE extent  $>35\%$  (**thin dashed line**), and 45 participants (27%) with persistent AF and LGE extent  $>35\%$  of LA myocardium (**thick dashed line**) ( $p < 0.001$ ).

LA myocardium should be considered candidates for simple PVI regardless of AF persistence. Additionally, our results suggest that substrate modification ablation strategies in addition to PVI may have a role when LGE extent exceeds 35% of LA myocardium.

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**PERSPECTIVES**

**COMPETENCY IN MEDICAL KNOWLEDGE:** Among patients with paroxysmal or persistent AF, a baseline contrast CMR scan of the left atrium with  $>35\%$  LGE is associated with high AF recurrence following ablation. In contrast, regardless of AF persistence, LGE burden  $\leq 35\%$  is associated with a favorable response to ablation.

**TRANSLATIONAL OUTLOOK:** Future studies are warranted to examine: 1) the utility of CMR-based patient selection for AF ablation; and 2) modification of current ablation methodologies in patients with LGE extent exceeding 35% of LA myocardium.

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**KEY WORDS** atrial fibrillation, catheter ablation, late gadolinium enhancement, magnetic resonance imaging