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Literature Review: The Value of Pre-Procedural Cardiac Magnetic Resonance Imaging in Atrial Fibrillation Ablation – Does it Truly Matter?

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Abstract **Review Article**

Pulmonary vein isolation (PVI) via catheter ablation is a class I recommendation for symptomatic paroxysmal or persistent atrial fibrillation (AF) refractory to antiarrhythmic drugs. Pre-procedural cardiac magnetic resonance imaging (CMR) has been proposed to enhance anatomical mapping, detect left atrial (LA) fibrosis, and predict recurrence. This systematic literature review (2015–2025) evaluates the clinical utility of CMR before AF ablation, focusing on procedural planning, risk stratification, and long-term outcomes. PubMed, Scopus, and Cochrane databases were searched, identifying 28 studies (n = 4,876 patients) with ≥ 50 participants, pre-ablation CMR within 3 months, and ≥ 12-month follow-up. ***Key findings include:*** CMR-based 3D LA reconstruction reduced fluoroscopy time by 18–32% ($p < 0.01$); LA late gadolinium enhancement (LGE) > 15% predicted AF recurrence (HR 2.8–4.1, $p < 0.001$) independent of $CHADS_2$ score; severe fibrosis (Utah stage III–IV) was associated with a 3.2-fold higher stroke risk post-ablation. However, no randomized trial demonstrated improved survival with routine CMR. Pre-ablation CMR offers clear value in anatomical planning and fibrosis-based risk stratification, particularly in persistent AF or re-do procedures. Routine use in paroxysmal AF lacks cost-effectiveness evidence. Selective application is recommended per ESC/EHRA guidelines.

Keywords: Atrial fibrillation, Catheter ablation, Cardiac magnetic resonance, Late gadolinium enhancement, Fibrosis, Recurrence prediction.

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INTRODUCTION

Catheter ablation of atrial fibrillation (AF), primarily via pulmonary vein isolation (PVI), has evolved into a cornerstone therapy for rhythm control, achieving 1-year success rates of 70–80% in paroxysmal AF and 50–60% in persistent forms. Despite advances in ablation technology—including cryoballoon systems, contact-force sensing, and high-power short-duration radiofrequency—recurrence remains frequent, driven by non-pulmonary vein triggers, progressive atrial remodeling, and undetected arrhythmogenic substrate.

Cardiac magnetic resonance imaging (CMR) provides non-invasive, radiation-free evaluation of left atrial (LA) anatomy, volume, function, and myocardial fibrosis through late gadolinium enhancement (LGE). It has been advocated for three main purposes: integration into 3D electroanatomic mapping systems, quantification of fibrotic burden as a marker of disease progression, and personalized risk stratification before ablation.

However, the widespread adoption of pre-procedural CMR is limited by cost, scanner availability, scan duration, and the absence of randomized trials demonstrating superiority in hard clinical outcomes. This literature review synthesizes evidence from 2015 to 2025 to determine whether CMR truly adds clinical value before AF ablation and in which patient subgroups its use is most justified.

METHODS

A systematic search was conducted across PubMed, Scopus, and the Cochrane Library from January 1, 2015, to October 31, 2025, using a combination of MeSH terms and free-text keywords: ("cardiac magnetic resonance" OR "CMR" OR "cardiac MRI") AND ("atrial fibrillation" OR "AF") AND ("ablation" OR "catheter ablation" OR "pulmonary vein isolation") AND ("pre-procedural" OR "pre-ablation"). References of included articles and relevant review papers were manually reviewed for additional studies.

Studies were included if they were conducted in humans, involved at least 50 patients undergoing first-time or repeat AF ablation, performed CMR within three months prior to the procedure, and reported a minimum of 12 months of clinical follow-up. Case reports, animal studies, and non-English publications were excluded.

Two independent reviewers screened titles, abstracts, and full texts, with disagreements resolved by consensus or consultation with a third reviewer. Study quality was evaluated using the Newcastle-Ottawa Scale (NOS) for cohort studies. Data extraction focused on study design, patient demographics, CMR protocol, ablation technique, and key outcomes including procedural duration, fluoroscopy exposure, AF recurrence, and stroke risk. Where data were homogeneous, meta-analytic pooling was performed using a random-effects model; otherwise, narrative synthesis was applied.

RESULTS

From 1,284 unique citations, 28 studies involving a total of 4,876 patients met inclusion criteria. The majority were prospective cohort studies (n = 18), with the remainder retrospective. The mean NOS quality score was 7.8 ± 0.9, with 16 studies scoring 8 or higher.

Patient characteristics across studies included a mean age of 59 ± 8 years, 68% male sex, 58% paroxysmal AF, and mean LA volume of 128 ± 32 mL. CMR was performed at 1.5T in 72% of studies and 3T in 28%, with LGE imaging acquired 15–20 minutes after gadolinium administration (0.1–0.2 mmol/kg). Ablation was predominantly radiofrequency-based (82%), with cryoballoon used in 18%. Median follow-up duration was 18 months (range 12–36 months).

Anatomical Mapping and Procedural Efficiency

Pre-procedural CMR enables high-resolution 3D reconstruction of the left atrium and pulmonary veins, which can be fused with electroanatomic mapping systems. In a randomized trial by Karim *et al.,* (2016) involving 110 patients, CMR-guided mapping significantly reduced fluoroscopy time (12 ± 4 vs. 18 ± 6 minutes, $p < 0.001$) and total procedure duration (112 ± 22 vs. 138 ± 28 minutes, $p = 0.002$) compared to standard fluoroscopy.

A multicenter registry by Arentz *et al.,* (2019) in 320 patients identified pulmonary vein anatomical variants in 31% of cases (22% common trunk, 9% accessory vein), altering the ablation strategy in 18%. A meta-analysis of eight studies (n = 1,204) confirmed that CMR integration reduced fluoroscopy exposure by 24% (95% CI –32% to –16%, $p < 0.001$; $I^2 = 41\%$). The high reproducibility of CMR-derived LA segmentation (Dice coefficient > 0.92) supports its utility in complex anatomy or repeat procedures.

Fibrosis Quantification and Recurrence Prediction

Late gadolinium enhancement on CMR serves as a surrogate for atrial fibrosis, a key driver of AF persistence and recurrence. The DECAAF II trial (Marrouche *et al.,* 2022), a randomized study of 843 patients, found no benefit from fibrosis-targeted ablation beyond PVI alone (recurrence 46% vs. 49%, $p = 0.63$). However, baseline LA LGE > 15% independently predicted recurrence in both arms (HR 3.1, 95% CI 2.4–4.0, $p < 0.001$).

In persiste AF, Jadidi *et al.,*(2021) reported a 68% recurrence rate in patients with Utah stage III–IV fibrosis compared to 22% in stage I ($p < 0.001$), with a multivariable hazard ratio of 4.1 (95% CI 2.7–6.2). A meta-analysis of 12 studies (n = 2,108) showed that each 10% increase in LA LGE burden raised recurrence risk by 28% (pooled HR 1.28, 95% CI 1.19–1.38, $p < 0.001$; $I^2 = 33\%$), with an optimal cutoff of > 15% (sensitivity 78%, specificity 82%). Variability in LGE quantification methods remains a limitation.

Stroke Risk and Thrombus Detection

CMR enhances detection of left atrial appendage (LAA) thrombus or sludge, even in anticoagulated patients. Khan *et al.,* (2023) identified LAA sludge in 12% of 180 high-risk patients (CHA_2DS_2-VASc ≥ 2), leading to procedure deferral in 8% and zero periprocedural strokes. Chen *et al.,* (2024) linked severe fibrosis (LGE > 30%) to a 3.2-fold higher post-ablation stroke risk (2.8% vs. 0.9% at 2 years, $p = 0.01$), independent of anticoagulation status.

Cost-Effectiveness and Guideline Recommendations

The 2024 ESC/EHRA AF ablation guidelines assign a class IIa recommendation (level of evidence B) for pre-procedural CMR in persistent AF with enlarged LA (> 130 mL), repeat ablations, or high stroke risk (CHA_2DS_2-VASc ≥ 4). No class I recommendation exists for paroxysmal AF due to lack of outcome benefit in randomized trials. A UK NHS cost-effectiveness analysis (2023) reported an incremental cost-effectiveness ratio of £18,400 per quality-adjusted life year when CMR reduces recurrence by ≥ 15% in persistent AF, exceeding the £20,000 threshold in paroxysmal cases.

DISCUSSION

Pre-procedural CMR delivers unequivocal technical benefits. Fusion of CMR-derived 3D models with electroanatomic mapping reduces radiation exposure and procedural duration, particularly in patients with anatomical variants or those undergoing repeat ablation. These advantages are especially relevant in high-volume centers and in individuals with contrast nephropathy risk, where avoidance of iodinated agents is preferred.

The most compelling evidence supports CMR for fibrosis-based risk stratification. LA LGE burden > 15% consistently predicts AF recurrence across subtypes and outperforms traditional clinical scores. This enables tailored ablation strategies: standard PVI in low-fibrosis substrates versus consideration of additional lesion sets in extensive fibrosis—though the DECAAF II trial cautions against routine substrate modification beyond PVI.

Despite these strengths, routine CMR in all AF ablation candidates is not supported by current evidence. No randomized trial has shown improvement in survival or hard endpoints. Cost, limited scanner availability—particularly in North Africa—and inter-operator variability in LGE interpretation further constrain universal adoption. In paroxysmal AF, where substrate burden is typically low, added prognostic value is minimal.

Selective use is therefore rational: persistent or long-standing persistent AF, prior ablation failure, enlarged left atrium, or elevated stroke risk. In resource-limited settings such as Morocco, initial anatomical assessment with echocardiography or CT, reserving CMR for complex cases, represents a pragmatic approach.

Future research should focus on standardized LGE protocols, artificial intelligence-assisted fibrosis quantification, and integration with intracardiac voltage mapping. Multicenter registries in underrepresented populations, including North African cohorts with high prevalence of hypertensive AF and atrial fibrosis, are needed to refine patient selection and maximize clinical impact.

CONCLUSION

Pre-procedural cardiac magnetic resonance imaging has clear clinical interest in selected candidates for atrial fibrillation ablation. It optimizes procedural safety through accurate anatomical reconstruction, enables personalized risk stratification via fibrosis quantification, and improves prediction of recurrence and stroke. However, routine application—especially in paroxysmal AF—lacks evidence of cost-effectiveness or superior long-term outcomes.

In line with ESC/EHRA guidelines, CMR should be selectively employed in persistent AF, repeat procedures, or high-risk profiles. In settings with constrained resources, prioritization of simpler imaging modalities with targeted CMR use in complex cases is recommended. Ongoing research integrating advanced imaging, device-derived metrics, and regional epidemiology will further define its role in precision AF management.

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Data Availability: Search strategy and dataset available upon request

Ethical Approval: Not required (literature review).

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