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Imaging for Risk Stratification in Atrial Fibrillation with Heart Failure

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Introduction

Current Guideline

Atrial Fibrillation (AF) and Heart Failure (HF) are associated with similar risk factors and are often present concomitantly^{1, 2}. AF is a potent risk factor for adverse clinical outcomes in patients with heart failure with preserved ejection fraction (HFpEF) or heart failure with reduced ejection fraction (HFrEF)³. However, there are no specific recommendations for AF patients with HF in the current ACCF/AHA and ESC guidelines (Figure 1)^{4, 5}. The main recommended goals of therapy for AF patients with HF continues to focus on the prevention of thromboembolism and symptom relief. Per the guidelines, rate control and rhythm control are considered at par in patients with HF who develop AF, as rhythm control therapy has not been shown to be superior to a rate control therapy⁶. As a result, catheter ablation is still considered as a second line therapy. On the other hand, for patients who develop HF following AF, per the guidelines an aggressive rhythm control strategy should be considered. This is because patients who have newly developed HF in the presence of AF with rapid ventricular response the likely cause is tachycardia-induced cardiomyopathy.

Role of Imaging modality

Cardiac imaging modalities plays an important role in the diagnosis of underlying structural heart disease, if any, that may cause heart failure and aid in guiding treatment of AF patients. The use of a particular imaging modality should be based on the information being sought

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after from a clinical decision making perspective. The use of the different imaging modalities for an AF and HF perspective are briefly outlined below:

Echocardiography

Among the different imaging modalities, echocardiography is the most commonly used and a very useful tool in patients with suspected HF, in terms of availability, safety and cost⁷. Especially, transthoracic echocardiography (TTE) is the most common tool used in the assessment of cardiac systolic and diastolic function as well as chamber sizes of both the atria and the ventricles⁸. Transesophageal echocardiography is not routinely used to assess HF but it can be a valuable tool in patients with valvular heart disease, congenital heart disease, and suspected intracardiac thrombi in AF patients requiring cardioversion or catheter ablation.

Cardiac computed tomography

Cardiac computed tomography (CT) in patients with HF is mainly used as a non-invasive way to visualize the coronary anatomy and its severity to exclude the diagnosis of coronary artery disease. Moreover, perfusion CT may have a potential to distinguish abnormal voltage areas from normal tissue⁹. The high spatial resolution does provide a detailed cardiac structure and four dimensional CT can provide left atrial (LA) fractional change and LA-EF that are well correlated with CMR (Figure 2). It is less invasive than coronary angiography but higher level of X-ray exposure is an issue but that seems to be getting better with improvement in technology¹⁰. Also, the iodinated contrast medium may induce acute kidney injury so one has to be careful when using this on a routine basis^{11, 12}.

Cardiac magnetic resonance imaging

Cardiac magnetic resonance imaging (CMR) is well known as the gold standard for the measurements of volume, muscle mass, and ejection fraction. Moreover, CMR is unique in being the imaging modality that can assess myocardial fibrosis and scar using late gadolinium enhancement (LGE). Quantitative T1 mapping has also been used to assess the extracellular volume using CMR. CMR is also useful in establishing HF etiology and to distinguish between ischemic versus non-ischemic cardiomyopathy^{13, 14}. In addition, CMR may be able to predict the tachycardia-induced cardiomyopathy by estimating RV dysfunction¹⁵. The limited availability of CMR, the higher expertise required for some of these assessments and cost are some of the limitations preventing broader use of CMR in these situations. In addition, there are other limitations like patients with metallic implants, claustrophobia, and severe chronic kidney disease that are not good candidates.

Prediction of HF in AF patients

Structural tissue remodeling, including increased collagen disposition, loss of myocytes, and fibrosis has been shown to be related with AF¹⁶. Azadani et al.¹⁷ have reported the higher levels of LA fibrosis detected by LGE-CMR in patients who subsequently develop heart failure. LV fibrosis measured by 2-dimensional echo using integrated backscatter might contribute to LV diastolic dysfunction and the high prevalence of HFpEF in AF patients¹⁸.

Moreover, not only older age but also LA pressure 11 mmHg, and peak systolic mitral annular velocity 9.3 cm/s measured by TTE were independent predictors of early HFpEF¹⁹. In patients who developed new onset HF, 80% were found to have a preserved left ventricular EF and were classified as having HFpEF. More studies are needed to confirm the definition of early HF using imaging.

Prediction of AF in HF patients

Several studies have reported predicting of AF in HF patients using different imaging modalities and measurement. The sub-study from TOPCAT study showed that decreased peak A wave velocity measured by TTE was positively correlated with the risk of AF in HFpEF patients²⁰. In this study, the diastolic parameter of LA function was possibly more important tool in AF risk assessment than LA dilatation like large LA area and volume. Also, left ventricular filling pressure measured by TTE was reported as a good predictor of new-onset AF in HF patients²¹. Noninvasive evaluation of the total atrial conduction time measured by tissue doppler imaging has also been reported to be useful tool in predicting AF occurrence in HF patients²². Moreover, in terms of AF occurrence in HFrEF patients, several studies have reported that echo parameters like LA size are a well-accepted risk factor for AF^{23, 24}.

Predicting future cardiac events in HF patient with AF

AF is a potential risk factor for adverse clinical outcomes with HFpEF or HFrEF³. Regardless of the EF, the presence and extent of LGE enhancement identified by CMR is an independent predictor of MACE in patients with AF²⁵. Even in cardiac resynchronization therapy (CRT) recipients, patients who develop new-onset AF had less echocardiographic response to CRT and more adverse cardiac events²⁶. Therefore, clinicians should focus on treatment of AF in HFpEF or HFrEF patients and consider maintaining sinus rhythm.

Ablation for AF with HF

Several prospective randomized control trials have shown the effectiveness of catheter ablation in AF patients with HFrEF (Table 1)^{27–33}. On the other hand, few reports are available on the impact of catheter ablation in AF patients with HFpEF. Meta-analysis has shown significant improvement of LVEF, especially, in patients with significantly reduced EF at baseline^{34, 35}. Recently, technological advancement has made catheter ablation safer and more effective than before. Despite this progress, arrhythmia recurrence following catheter ablation continues to be clinical reality and more needs to be done to improve outcomes³⁶. In summary, indications for catheter ablation in HFrEF patients with concomitant AF should be carefully evaluated preoperatively using imaging modality and the procedures should be performed in experienced centers with experienced operators.

Imaging before procedure

Atrial fibrotic change is well known to be associated with AF^{37, 38}. CMR has been shown to detect this pre-ablation LA fibrosis. The atrial tissue fibrosis amount detected by LGE-CMR was independently related to arrhythmia recurrence post ablation³⁹. In the subgroup of

patients with extensive atrial fibrosis, arrhythmia free survival at day 375 was only 31.6%. This result can be useful in preoperatively identifying the patients who are poor candidates for aggressive rhythm control therapy and catheter ablation. These patients with extensive LA fibrosis based on CMR also had quite enlarged LA so the chamber size can also be used as a surrogate. Meanwhile, there are limitations to using CMR for LA fibrosis detection including setting the threshold⁴⁰. And as a result, the use of CMR to detect LA fibrosis and predict ablation outcomes has not been universally reported. Sramko et al.⁴¹ reported that the extent of LA-LGE did not predict AF recurrence after ablation. More recently, contrast enhanced perfusion CT has also been reported to identify low LA voltage areas⁹. Further studies are needed to confirm the methodology and reproduce the outcomes.

Pre-imaging with MRI can also be used to define both the atrial structure as well structures including the esophagus (Figure 3) around it⁴². The esophagus is a mobile structure so the pre-imaging location might not be useful when ablating. Recent report has shown that if the gap between the posterior wall of the LA and the vertebral body is less than 4.5 mm then the OR of the esophagus not moving is 9.25 (95% confidence interval: 1.72 to 49.67)⁴². This can be quite useful when planning for ablation to minimize any esophageal injury. Figure 2 also shows how the higher image resolution in CT can be used to detect small structural perturbations in the LA that can be useful when targeting gaps to get complete PV isolation.

Imaging during procedure

Intracardiac echocardiography (ICE) is used to provide high-resolution real-time visualization of cardiac structures, catheter location, and early recognition of procedural complications. Recently, a three-dimensional (3D) ICE system has also been developed and has the advantage of providing additional anatomical detail. Especially, 3D ICE system can monitor the esophageal position and the proximity to the esophagus⁴³. On the other hand, real-time CMR has the potential to detect occluded pulmonary vein with balloon, lesion formation, and potentially even collateral damage^{44, 45}. Moreover, real-time CMR may be able to detect gaps in a liner lesion set allowing them to be targeted right away⁴⁶. However, CMR-compatible devices needed to be implemented before this becomes a clinical reality.

Imaging after procedure

LGE-CMR has been used to estimate chronic lesion scar after radiofrequency ablation in the LA (Figure 4)⁴⁶. Real-time monitoring of tip-to-tissue contact force has improved clinical outcomes and decreased complications but insufficient tissue injury and ablation related edema formation are thought to be the main cause of reversible electrical conduction and arrhythmia recurrence^{47, 48}. Acute edema related to radiofrequency ablation resolves over the span of few weeks and higher contact force has been shown to be related to creation of larger edema^{49, 50} but different power source could make chronic scar with relatively smaller acute edema⁵¹. Catheter ablation of AF targeting the PVs rarely achieves permanent encircling of the PV with scar and this has shown to effect clinical outcomes^{47, 52}. Hence, more experimental and clinical studies are needed to develop the best means of lesion creation while minimizing the creation of reversible edema. Post ablation LGE-MRI can be

used to visualize ablation induced scar and identify gaps in lesion sets (Figure 4). This can be useful when planning redo ablations.

Summary

Cardiac imaging plays an important role in the assessment of anatomical structure and cardiac function. New imaging technology and techniques have been developed that provide more precise assessment of the underlying myocardial substrate and can be useful in predicting the risk of AF in patients with HF. Moreover, imaging modalities are able to identify preablation atrial fibrosis and scar formation following catheter ablation. Studies are needed to further validate the new techniques and define the usefulness of these additional imaging techniques but they hold immense promise in AF risk prediction, improving patient selection for ablation and finally improving ablation outcomes.

Disclosure statement

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Synopsis

Atrial fibrillation (AF) is the most common cardiac rhythm disorder and is associated with heart failure (HF). Cardiac imaging modalities play an important role in risk assessment and managing AF. In this article, we will review the risk assessment and the utilization of cardiac imaging to optimize treatment strategy in AF patients with HF. First, the clinical role of echocardiography, computed tomography, and cardiac magnetic resonance for risk stratification event is provided. Second, the value of imaging in catheter ablation is reviewed, including preoperative assessment, optimizing patient selection for ablation, utilization during the ablation procedure, and postoperative scar assessment.

Key Points

- Echocardiography is an useful tool in patients with suspected heart failure, in terms of availability, safety and cost.
- Computed tomography has the highest spatial resolution and provides detailed anatomy and functional information.
- Cardiac magnetic resonance can provide accurate anatomical and functional information and is unique in providing preoperative atrial tissue structural remodeling information and postoperative atrial scar assessment.

Figure 1.

Current Guideline flowchart for Management of AF Patients with HFAF = atrial fibrillation; HF = heart failure; HFrEF = heart failure with reduced ejection fraction; HFpEF = heart failure with preserved ejection fraction; ACC = American College of Cardiology; AHA = American Heart Association; ESC = European Society of Cardiology. Data from January CT, Wann LS, Alpert JS, Calkins H, Cigarroa JE, Cleveland JC, Jr., Conti JB, Ellinor PT, Ezekowitz MD, Field ME, Murray KT, Sacco RL, Stevenson WG, Tchou PJ, Tracy CM, Yancy CW, Members AATF: 2014 AHA/ACC/HRS guideline for the management of patients with atrial fibrillation: a report of the American College of Cardiology/American Heart Association Task Force on practice guidelines and the Heart Rhythm Society. *Circulation* 2014; 130:e199–267 and Kirchhof P, Benussi S, Kotecha D, Ahlsson A, Atar D, Casadei B, Castella M, Diener HC, Heidbuchel H, Hendriks J, Hindricks G, Manolis AS, Oldgren J, Popescu BA, Schotten U, Van Putte B, Vardas P: 2016 ESC Guidelines for the management of atrial fibrillation developed in collaboration with EACTS. *Eur Heart J* 2016; 37:2893–2962.

Figure 2. Example of abnormal intracardiac structure and four-dimensional CT imaging (A) Pseudo-Diverticulum locate in LA anterior wall (yellow arrow). (B) Low attenuation zone suspected LA thrombus is detected in LAA. (C) Right panel shows four-dimensional CT imaging with the ability to the LA function accurately. The two snap shots show the LA in diastole and systole. CT = computed tomography, LA = left atrium, LAA = left atrial appendage, RSPV = right superior pulmonary vein

Figure 3.

Use of MRI to predict esophageal position during ablation. Panel A shows an example of patient with a GAP of 10.6 mm having 14.8 mm of esophageal movement. Panel B shows an example of patient with a GAP of 1.2 mm having only 3.1 mm of esophageal movement. LA = left atrium, LGE-CMR = late gadolinium enhancement cardiac magnetic resonance imaging, LIPV = left inferior pulmonary vein, VB = vertebral body

Figure 4.

Examples of post-ablation LA scar imaging using LGE-CMR. Left panel (A-C) shows axial LGE-MRI views through the LA. The scar areas have higher image intensity. On the right panel are the three dimensional PA view (D) and Right Lateral (E) view of the LA showing scar along the pulmonary veins. In LGE-CMR axial views, the areas of enhancement are segmented (red arrow) and are shown as scar (red areas) in the 3D image. The gap between scar areas can be seen both in axial and 3D Right Lateral image (gap is marked with the yellow arrow).

Table 1.

Randomized controlled trial for catheter ablation of AF in Patients with HFrEF

Study	Multicenter	Publication Year	Sample Size	Age (years)	EF (%)	Persistent AF (%)	Mean number of procedures	Catheter Ablation group	Comparison group	Follow-up (months)	Primary Endpoint	sinus restoration	Results
PABA-CHF ²⁷	Yes	2008	81	60	27	51.0	1.2	PVI (41)	AV node ablation with biventricular pacing (40)	6	Composite of ejection fraction, 6-MW/Dand MLWHF score	71% without AAD	Catheter ablation was superior to AV nodal ablation and biventricular pacing
MacDonald ²⁸	No	2011	41	64	15.1	100	1.35	PVI ± linear ± CFAE (22)	Rate control (19)	6	LVEF measured by CMR	50%	No significant difference between groups
ARC-HF ²⁹	No	2013	52	64	22	100	1.23	PVI ± linear ± CFAE (26)	Rate control (26)	12	PeakVO ₂	88% without AAD	Improvement in peak VO ₂ in the catheter ablation group compared with rate control
CAMTAF ³⁰	No	2014	50	55	31.8	100	1.7	PVI ± linear ± CFAE (26)	Rate control (24)	12	Left ventricular ejection fraction at 6M	81% at 6M 73% at year	Improvement in left ventricular ejection fraction at 6 months in catheter ablation group
AATAC ³¹	Yes	2016	203	62	29	100	1.4	PVI ± posterior wall ± CFAE (102)	Amiodarone (101)	36	Freedom from AF	70%	Significant improvement in freedom from AF in the catheter ablation group
CAMERA-CMR ³²	Yes	2017	68	59	34	100	NA	PVI + posterior wall (34)	Rate control (34)	6	LVEF measured by CMR	100% using DCCV	Significant improvement in ejection fraction in catheter ablation group
CASTLE-AF ³³	Yes	2018	363	64	32.5	70.0	1.3	PVI ± linear ± CFAE (179)	Medical rate or rhythm control (184)	60	Death or heart failure hospitalizati on	63%	Significant improvement in composite endpoint of death and heart failure hospitalization in catheter ablation group