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Preprocedural Imaging for Patients with Atrial Fibrillation and Heart Failure

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Abstract

Various electrophysiological procedures and device implantation has been shown to improve morbidity and mortality in patients with atrial fibrillation (AF) and patients with heart failure (HF). Non-invasive cardiac imaging is used extensively in the pre-procedural patient selection and for procedural guidance. In this review, we will discuss the application of pre-procedural cardiac imaging in patients with AF prior to pulmonary vein and left atrial ablation as well as insertion of left atrial occluder device. We also discuss the role of non-invasive cardiac imaging in the selection of appropriate HF patients for device therapy as well as their use in guiding implantation of biventricular pacemaker for cardiac resynchronization therapy by assessing left ventricular ejection fraction, coronary venous anatomy, mechanical dyssynchrony and myocardial scar. We describe new research associated with pre-procedural imaging in these patient cohorts.

Keywords

Computed tomography; magnetic resonance imaging; echocardiography; atrial fibrillation; ablation; left atrium; pulmonary veins; heart failure; left ventricular ejection fraction; cardiac resynchronization therapy; dyssynchrony; Preprocedural imaging

Introduction

Cardiac imaging modalities, whether non-invasive or invasive, provide useful anatomical and functional information prior to electrophysiology procedures in patients with atrial fibrillation (AF) and heart failure (HF). Echocardiography is a well established imaging technique for the diagnosis and management of AF and HF patients. Recent advances in cardiac imaging with transthoracic (TTE) and transesophageal echocardiography (TEE), cardiac computed tomography (CT) and magnetic resonance imaging (MRI) have enabled these non-invasive imaging modalities to be increasingly used for 1) assessment of pulmonary venous, LA and LA appendage (LAA) anatomy in AF patients, and 2) quantitative and qualitative assessment of ventricular function, mechanical dyssynchrony, myocardial scar and coronary venous anatomy in the HF cohort (Fig. 1). This review addresses the use of established and more novel noninvasive cardiac imaging techniques used pre-procedurally in patients with AF and HF to facilitate various electrophysiology

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Disclosure

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procedures. The role, advantages, limitations and new research applications of these imaging modalities for the assessment of patients with AF and HF are also presented.

Imaging of pulmonary veins and left atrium prior to catheter ablation for atrial fibrillation

Radiofrequency catheter ablation with electro-isolation of the pulmonary veins (PV) is a treatment option in patients with symptomatic drug-refractory paroxysmal or persistent AF [1]. Ablation strategies have evolved over the past decade and TEE, CT and MRI are imaging techniques that can facilitate the delineation of PV and LA anatomy pre-procedurally. The choice of imaging modality is dependent on the local expertise and equipment available.

Pre-procedural cardiac imaging enables specific information to be obtained regarding the PV and LA prior to AF ablation: 1) the number of PV and branching pattern, 2) individual PV ostial measurements, 3) measurement of LA dimensions, 4) identification of LA appendage thrombus 5) identification of anatomic anomalies including anomalous pulmonary venous drainage and left persistent superior vena cava 6) demonstrate the anatomy of the interatrial septum which may help guide trans-septal puncture and 7) provide anatomic knowledge of structures such as the esophagus to minimize complications including atrioesophageal fistula caused by burns to the esophagus during ablation [2]. Pre-procedural CT and MRI datasets can also be co-registered with electroanatomic maps (EAM) prior to ablation [3–5] or overlaid directly onto live fluoroscopic images in the electrophysiology laboratory [6–7]. There remains controversy over the need for image integration with EAM. While most studies suggest that integration reduces procedural duration, recurrence of AF and radiation exposure from fluoroscopy [4–5, 8–9] one study does not [4]. CT image reconstruction overlaid onto fluoroscopy has been shown to shorten duration of PV isolation compared to conventional CT image integration with EAM [6–7]. Further studies are required to assess if pre-procedural CT/MRI image integration with EAM or fluoroscopy improves procedural and clinical outcomes.

Special consideration with respect to CT is the need for additional radiation exposure which has been reported to range between 4.6 mSv with non-ECG gating to 13.4 mSv with ECG-gated scans [10]. However newer CT scanner technology using single beat acquisition such as 320-detector row has yielded low mean radiation doses for PV imaging between 1.9–3.8 mSv [11]. In our experience, we achieved a very low median radiation dose of 1.4 mSv using a high-pitch dual source CT scan protocol [12]. Thus, the issue of increase radiation dose with pre-procedural CT may be obsolete in the future and should be weighed in with the reduction in radiation exposure from the fluoroscopic time saved. Table 1 outlines the strengths and limitations of pre-procedural imaging with TEE, CT and MRI in the assessment of patients with AF prior to ablation.

Pulmonary venous anatomy

While TEE can visualize each of the PV in separate views, it underestimates the ostial measurements of both left sided and right superior PV by 0.16–0.43 cm compared to CT [13]. The imaging modalities of choice for imaging the PV are cardiac CT [13] and MRI [14] due to their superior spatial resolution and ability to provide three-dimensional (3D) images that can also be co-registered with EAM. PV anatomy, including ostial branching pattern and dimensions are similar between CT and MRI [15]. As pulmonary venous anatomy is variable and accessory veins are not uncommon [16–17], inadequate visualization of all PV ostia may compromise procedural success. A left common PV ostium may result in the decision for circumferential ablation rather than segmental isolation as the

larger diameter common ostium may preclude the use of most commercially available circular catheters [18]. An additional middle PV with a thin rim of atrial tissue separating this vein from neighboring PVs may not allow stable positioning of the ablation catheter and undesirably result in applying radiofrequency ablation within the PV. Early branching is important as an ostial ablation near a side branch may be complicated by stenosis or occlusion [19].

Left atrial anatomy

Application of radiofrequency ablation lesions at various locations of the LA can prove challenging during ablation [20]. Such locations include the ridge of Marshall located between the LA appendage (LAA) and the left PV which is not adequately appreciated on EAM, as well as the ridges separating the right middle PV with its neighboring right superior and inferior PV. These anatomical ridges are visualized well with CT and MRI; the LAA ridge is <5mm and ridges surrounding the right middle PV superiorly and inferiorly are narrower than 2 mm [20]. The inability to achieve stable catheter positions at these locations may result in incomplete ablation lines and delivery of lesions within the PV, potentially resulting in PV stenosis or ablating too close to the LAA. Thus pre-procedural imaging of the LA with CT or MRI demonstrating narrow LA ridges may affect the ablation location and strategy. Aside from demonstrating LA anatomy, quantitative measurement of LA volume has clinical relevance. Although not routinely measured in clinical practice, CT derived LA volumes prior to AF ablation has been shown not only to predict AF recurrence but has incremental predictive power over LA diameter measured in a single dimension by echocardiography [21]. Recent experimental research has described the use of delayed-enhancement MRI following ablation to identify LA scar burden and regions of incomplete scar around the PV to help facilitate complete circumferential lesions for improved clinical outcome during repeat ablation procedures [22].

Left atrial appendage thrombus

Although TEE remains the gold standard for the definitive exclusion of LAA thrombus, the usefulness and limitations of CT and MRI to detect LAA thrombus have been recently assessed. LAA thrombus is suspected on CT by the presence of a low attenuation filling defect in the appendage after a contrast-enhanced scan [23–25]. Studies comparing CT with TEE to detect LAA thrombus in patients prior to AF ablation report excellent negative predictive value of 98% [23], though variable sensitivities between 29–100% [23, 26–27], specificities from 85–88% [26–27], and positive predictive values of 20–31% [23, 27]. Thus, if the LAA completely opacifies in early arterial phase, then the presence of LAA thrombus is extremely unlikely. If there is a filling defect during arterial phase imaging, then a non-contrast CT delayed scan can be performed immediately within 1 minute to differentiate between LAA thrombus (where the filling defect will persist) versus circulatory stasis (or slow flow where the filling defect will no longer be present) [25]. Due to its modest specificity, if LAA thrombus is suspected on CT, then confirmation with TEE is still necessary [28]. MRI has also been reported to have the ability to detect LAA thrombus as compared to TEE [29].

Variations in a patient's volume status, heart rate and rhythm during the interval between imaging and ablation may contribute to registration error between CT/MRI and EAM datasets. Intraprocedural 3D rotational x-ray angiography of the LA and PV with contrast injection in the pulmonary artery from a femoral venous approach has been investigated as an alternative experimental approach to address this issue. Small studies have shown this technique is feasible [30–34] however its invasive nature, additional radiation exposure (~8mSv), and need for special equipment may limit its use.

Interestingly, a recent publication of 333 AF patients found that pre-procedural imaging with CT (161 patients) or MRI (37 patients) prior to antral PV isolation did not improve time of the procedure, total radiofrequency application or maintenance of sinus rhythm at 22 months follow-up [35]. The authors concluded that with increased AF ablation experience these structures can be adequately assessed with intra-procedural catheter navigation. However, these results may not be relevant to patients who have other variant anatomy or to centers with limited ablation experience. Perhaps pre-imaging of the PV and LA anatomy may not be necessary in the future, but the current practice for most electrophysiologists is to use either CT or MRI to guide this procedure and imaging of the PV pre-procedurally remains an "appropriate" indication for CT and MRI [36].

Imaging prior to LA appendage occluder device implantation

Non-surgical percutaneous occlusion of the LAA may be an alternative strategy to reduce thromboembolic stroke risk in patients with non-rheumatic AF unable to tolerate oral anti-coagulation therapy. Human studies have shown that device implantation is feasible [37–38] and a multicenter, randomized trial demonstrated non-inferiority to chronic warfarin therapy in patients with CHADS2 score ≥ 1 [39]. However, no current LAA occluder device has received approval by the Food and Drug Administration nor are there current evidence-based clinical guidelines that recommend the use of the LAA closure devices for stroke prevention in patients with AF.

In the multicenter occluder device study [39–40], pre-procedural imaging with 2D TEE was used to identify patients with LA thrombus, atrial septal defects, patent foramen ovale, septal aneurysms, LV EF<30%, intracardiac thrombus, significant mitral stenosis, complex aortic atheroma with mobile plaque as these were exclusion criteria for device implantation. Pre-procedural 2D TEE was used to specifically assess LA and appendage anatomy including accessory lobes and delineate the maximal width and depth of the dominant lobe to facilitate device sizing. Fluoroscopy and if required, intracardiac echocardiography, were also used to facilitate the procedure. Prior to device release, TEE was used to verify adequate device positioning and stability. Repeat TEE was performed at 45 days, 6 and 12 months to interrogate peri-device flow and jet width for adequate device 'seal'. The use of pre-procedural CT and 3D TEE prior to device implantation in a small study has shown that measurements between these modalities are not interchangeable with 2D TEE measurements, and that LAA diameter by 2D TEE were smaller compared to multiplanar CT reconstructions [41]. As evidence on longer-term safety and efficacy of these devices call for the need of large, randomized controlled trials with adequate follow-up data before these devices will be used routinely, pre-procedural imaging will have an important role to guide device implantation.

Cardiac imaging prior to implantable devices for patients with heart failure

Patients with HF undergo implantation of cardiac devices to improve morbidity and mortality. Such cardiac devices include implantable cardiac defibrillators (ICD) in patients with reduced LV systolic function who are deemed high risk of sudden cardiac death and biventricular pacemaker for cardiac resynchronization therapy (CRT) in appropriately selected patients with symptomatic HF. Pre-procedural imaging plays an important part in selecting patients who will most likely to benefit from device therapy. Furthermore, there are various research methods for evaluating the most appropriate patient population for device implantation.

Assessment of left ventricular ejection fraction (LVEF)

Cardiac imaging plays an important role in the assessment of LV systolic function, where clinical management decisions are based on LV ejection fraction. The most current device therapy guidelines recommend ICD implantation for primary prevention of sudden cardiac death in patients with LVEF $\leq 35\%$ who have prior myocardial infarction >40 days or patients with non-ischemic dilated cardiomyopathy [42]. CRT is recommended as a Class I indication for symptomatic HF patients with prolonged QRS ≥ 0.12 second with LVEF $\leq 35\%$. Of the imaging modalities, cardiac MRI is considered the gold standard for measuring LVEF due to its high reproducibility [43]. Despite lower accuracy of echocardiography compared to cardiac MRI, it is a commonly used modality as it is widely available [44]. An improvement in the accuracy and reproducibility of LVEF assessment with real-time 3D echocardiography or contrast echocardiography when compared to 2D echocardiography has been shown in studies which used MRI as the reference standard [45–46]. Other imaging modalities such as cardiac CT and radionuclide scans are able to assess LVEF with acceptable accuracy, at the expense of radiation exposure [47–49].

Beyond LVEF Assessment for CRT in HF

Despite the benefits of CRT, a relatively high non-response rate of over 30% has been noted [50]. Better selection criteria for CRT beyond LVEF and QRS duration are necessary as implantation of these devices are invasive and associated with complications and high economic cost secondary to device and post-implantation management. Pre-CRT cardiac imaging can also be used to refine patient selection to identify subjects more likely to respond to CRT. Although still mainly for research purposes, there is evidence that cardiac imaging used to 1) image the coronary venous anatomy for guidance of LV lead placement, 2) assess for mechanical dyssynchrony, 3) evaluate the burden and location of myocardial scar, and 4) identifying of the site of latest activation free of transmural scar may improve outcomes (Table 2).

Imaging the Coronary Venous Anatomy prior to CRT

Pre-implantation knowledge of coronary venous anatomy with CT is an accepted indication for the use of cardiac CT [36]. This information may help facilitate CRT patient selection and optimization of LV lead positioning by providing anatomical information such as the coronary sinus (CS) location, angle, direction and ostial measurements, the anatomic characteristics of first and second order venous side branches and establish the presence of a Thebesian valve [51–53]. Successful fusion with high registration accuracy between pre-procedural coronary venous CT or MRI [54–55] datasets and fluoroscopy has been shown in a small proof-of-concept study to facilitate CRT implant success in 8 patients with previously failed implants [56]. Cardiac MRI 3D whole-heart images of myocardial scar can also be fused with fluoroscopic images to provide additional information for LV lead implantation to avoid regions of scar [56]. More prospective studies are needed to investigate the impact of non-invasive pre-CRT imaging of the coronary venous anatomy, whether alone or fused with invasive venography on the procedural success and duration, radiation exposure, use of contrast agents and clinical outcomes.

Mechanical dyssynchrony

There is currently no gold standard for the assessment of mechanical dyssynchrony. Multiple echocardiographic markers of mechanical interventricular and intraventricular dyssynchrony have been studied and their utility remains controversial [57]. The multi-center PROSPECT trial evaluated 12 echocardiographic parameters of mechanical dyssynchrony and found not only poor reproducibility but that these parameters were unable

to adequately differentiate CRT responders from non-responders [58]. More recent technique such as speckle tracking echocardiography, unlike tissue Doppler based techniques, are not angle dependent and assessment of circumferential and radial strain parameters are possible. Speckle tracking to assess for LV dyssynchrony appears promising to predict LVEF response and long term adverse cardiac events after CRT [59–60]. Another imaging echocardiographic method, real time 3-dimensional echocardiography (RT3DE) is viewed to have an advantage over 2-dimensional echocardiography as the contraction of the entire ventricle can be assessed in all directions during the cardiac cycle and predictive of CRT response [61–62]. However this technique tends to be limited by lower frame rate acquisition and the reliability on good image quality.

Cardiac CT, MRI and radionuclide imaging are alternative imaging methods for assessing mechanical dyssynchrony. Cardiac CT allows 3-dimensional acquisition of cardiac function without the limitation of the need for adequate acoustic windows with echocardiography, and hence potentially improves reproducibility for assessment of mechanical dyssynchrony. CT-based dyssynchrony index using time to maximal wall thickness [63] and time to minimum LV volume [64] was highly reproducible was compared to echocardiographic assessment of dyssynchrony. While promising as a single imaging modality for CRT with visualization of the coronary veins, dyssynchrony assessment, and myocardial scar [65], prospective studies are needed to validate the utility of CT derived dyssynchrony index with clinical CRT response. Various MRI sequences can be used to assess LV mechanical dyssynchrony [66]. Functional data from cine short axis stacks through the LV obtained with steady-state free precession sequences provides information on LV contraction at high spatial and temporal resolution. The standard deviation of the radial wall motion in the various myocardial segments can be use to derive the tissue synchronization index, which has been shown to predict long term major adverse cardiovascular events in 77 patients who underwent CRT [67]. The circumferential uniformity ratio estimate by MRI and is determined by measuring the regional systolic circumferential strain in 24 ventricular segments in a small study of 20 patients and was also shown to predict CRT response [68]. Gated myocardial perfusion single-photon emission computed tomography uses information on regional wall systolic thickening together with phase information to provide the time interval when a region of myocardial wall starts to contract. The phase histogram bandwidth and phase standard deviation correlates well with the delay in peak velocity between the earliest and latest activated LV segments as assessed by echocardiography [69–70].

Myocardial Scar detection

The presence of scar in the region of the tip of the LV pacing lead may contribute to CRT non-response. MRI studies have shown that non-responders to CRT have more extensive scar, with more transmural scar particularly in the posterior lateral wall [71–72]. Scar quantification with SPECT myocardial perfusion scan showed that patients with higher scar burden not only had a lack of functional improvement but also had reduced survival [73]. Quantifying the amount of myocardial contraction with speckle tracking echocardiography using radial strain was shown to be able to differentiate transmural from non-transmural scar as classified with MRI [74] and increased risk for all cause mortality if the LV lead targeted an area of scar [75]. Using delayed enhancement cardiac CT, the size and location of myocardial scar can be assessed with excellent correlation compared with delayed gadolinium on MRI in humans [76–77]. As data accumulates on the relationship between myocardial scar and CRT response, its clinical applicability may be useful for patient selection as well as guiding LV lead placement in CRT.

Guiding LV lead placement

Aside from using imaging techniques to identify patients who will benefit from CRT, its use in guiding biventricular pacemaker implantation was shown in a recent randomized study to improve clinical outcomes. This study used speckle tracking to guide LV lead position at the latest site of peak contraction which is free of scar (strain amplitude >10%) and resulted in higher number of responders at 6 months, with greater improvement in LV volume and EF (70% vs 55%, $P=0.03$), improvement in NYHA class (83% vs 65%) and a reduction in HF admissions [78]. More research will be needed to determine the clinical utility of pre-procedural imaging to guide optimize LV lead location.

Conclusions

Pre-procedural cardiac imaging of patients with AF and HF can provide not only important anatomical and functional information, but may play a role in facilitating patient selection, guiding procedural technique and improving clinical outcomes. Despite each non-invasive imaging modality having its advantages and limitations, the integration of pre-procedural cardiac imaging with electrophysiology procedures highlights their complementary role in the investigation and management of patients with AF and HF.

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Figure 1.

A) Transesophageal echocardiogram showing left atrial appendage thrombus in patient with AF, three-dimensional reconstruction of the pulmonary veins prior to AF ablation with B) MRI and C) CT, D) speckle tracking echocardiography demonstrating a septal to posterior wall delay in peak systolic strain of 224 msec suggesting the presence of mechanical dyssynchrony, E) Late-Gadolinium enhancement MRI demonstrating inferolateral scar in a patient with ischemic cardiomyopathy, F) CT demonstrating the coronary venous anatomy in a patient prior to CRT to guide LV lead placement. AF- atrial fibrillation, MRI-magnetic resonance imaging, CT- computed tomography, CRT- cardiac resynchronization therapy, LV-left ventricular.

Table 1

Role of pre-procedural imaging modalities in the assessment of patients with atrial fibrillation prior to radiofrequency catheter ablation

	TEE	CT	MRI
Identify PV anatomy	+	+++	+++
Perform PV ostial measurements	+	+++	+++
Measure LA dimensions	++	+++	+++
Detect LA and appendage thrombus	+++	++	+
Anatomical delineation of esophagus	N/A	++	++
EAM co-registration	N/A	+++	+++
Ionizing radiation	N/A	+++	N/A
Sedation required	+++	N/A	+
Contrast agent usage	+	+++	+++
Compatibility with pacemakers *	+++	+++	+
Short scan duration	+	+++	+
Portability of imaging modality	+++	N/A	N/A

TEE denotes transesophageal echocardiography; CT, computed tomography; and MRI, magnetic resonance imaging.

* There is some preliminary data on the safety of MRI in patients with cardiac devices [79–80].

Table 2

Role of various pre-procedural imaging modalities in the assessment of heart failure patients prior to cardiac resynchronization therapy

	Echocardiography	CT	MRI	SPECT
LV Ejection Fraction	+++	++	+++	+
Coronary Veins	N/A	+++	+	N/A
Myocardial Scar	++	++	+++	+++
Mechanical Dyssynchrony [*]	+	+	+	+

CT denotes computed tomography; MRI, magnetic resonance imaging; SPECT, single-photon emission computed tomography.

^{*} Research related.