Role of Echocardiography in Atrial Fibrillation Ablation

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Abstract

Radiofrequency catheter ablation is an increasingly adopted strategy for difficult-to-manage patients with atrial fibrillation. Echocardiography is the key imaging modality to assess left atrial structure and function. In this review, the role of echocardiography in atrial fibrillation ablation before, during and after ablation is discussed. Currently established roles of echocardiography in patient selection pre-ablation and peri-procedural guidance, as well as newer echocardiographic techniques including the assessment of atrial mechanics are reviewed in the context of atrial fibrillation ablation.

Introduction

Atrial fibrillation (AF) is a common arrhythmia associated with significant morbidity and mortality. In recent years, radiofrequency catheter ablation with the electrical isolation of the pulmonary veins is commonly performed for patients with paroxysmal and persistent AF who continue to be symptomatic despite at least one Class I or III antiarrhythmic medication. Restoration of sinus rhythm after AF ablation significantly improved symptoms, exercise capacity, quality of life and left ventricular (LV) function, even when concurrent heart disease and ventricular rate control had been adequate before ablation.

Multimodality imaging is often employed to assess patients undergoing ablation. However, echocardiography remains integral in the assessment of left atrial (LA) structure and function. This review discusses the role of echocardiography in AF ablation from pre-ablation, during and post-ablation. This includes the initial evaluation and patient selection, pre-procedural screening for LA and LA appendage (LAA) thrombus, direct visualization of anatomic landmarks during ablation, assessment of ablation complications, assessment of LA mechanics post-ablation and risk stratification for thromboembolism.

Pre-Ablation

Transthoracic echocardiography (TTE) is essential for the initial evaluation of patients with AF, in most cases, before AF ablation is even considered a treatment option. The overall management strategy of AF depends on a variety of clinical factors, including the type and duration of AF, severity of symptoms, patient age, associated cardiovascular disease and other concurrent medical conditions. TTE provides information on the etiologies and predisposing factors for the AF, effect on the ventricular function, as well as prognostic information on the risk of recurrence and thromboembolism.

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boembolic risk (Table 1).

Information on LV function impacts the choice of appropriate pharmacological agents for both rate- and rhythm-control strategies. Agents such as beta-blockers including sotalol, and nondihydropyridine calcium channel antagonists should be administered with caution in patients with severe LV dysfunction and heart failure. Impaired LV systolic function is also an independent echocardiographic predictor of stroke in patients with AF, even after adjusting for other clinical features.4

Impact of LA Size and LV Function on Patient Selection for AF Ablation

Accurate assessment of both LA size and LV function provides essential information for patient selection and is an important determinant of successful AF ablation.

LA Size

Marked LA dilation is associated with a lower success rate of maintaining sinus rhythm after AF ablation compared to patients with structurally normal hearts.5 As a result, the lack of LA enlargement is an important component of the current guideline recommendations for the use of AF ablation as an alternative to pharmacologic therapy in symptomatic patients.3,6 Hence, accurate measurement of LA size is crucial for the decision-making on suitability for AF ablation.

LA size measurement is routinely performed by TTE. LA anteroposterior dimension can be measured by M-mode or 2D echo in the parasternal long axis view. This method is convenient and has been widely adopted in routine clinical practice. However, LA volume measured by either the ellipsoid model or the Simpson’s method is a more reliable measure of true LA size than M-mode LA dimension and is the recommended method for the accurate assessment of LA size.8

To improve the accuracy of LA size measurement, 3-dimensional echocardiography (3DE), cardiac computed tomography (CT) and cardiac magnetic resonance imaging (CMR) have been studied. The 3DE measurements demonstrate favorable test-retest variability and good agreement with CMR.9-11 When these techniques are applied in the context of AF ablation, LA size measurements by 3DE,12-13 cardiac CT,14 and CMR15-16 also show

Table 1
The role of TTE and TEE in the Pre-Ablation Assessment of Patients with AF

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<thead>
<tr>
<th>Transthoracic Echocardiogram</th>
<th>Transesophageal Echocardiogram</th>
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<tr>
<td>Underlying causes of AF:</td>
<td>Exclusion of LA appendage thrombus:</td>
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<td>• Valvular heart disease</td>
<td>• Prior to cardioversion</td>
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<td>Effect of AF on the LV:</td>
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<td>• Tachycardia-induced cardiomyopathy</td>
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<td>• Rate control vs. rhythm control</td>
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<td>• Left atrial size</td>
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good correlation with subsequent procedural success. Among the newer techniques, 3DE shows the most promise of adoption in routine clinical practice as it is non-invasive, readily available, and can be added onto the routinely performed post-ablation 2DE examination. As will be discussed later, 3DE also offers the possibility of measuring LA volumes at different phases of the cardiac cycle, yielding information on LA phasic function. Nevertheless, it is worthwhile to note that LA size measurements made by 2DE tend to be lower than those of 3DE, cardiac CT, and CMR. The relative strengths and weaknesses of various imaging modalities in the valuation of LA size are outlined in Table 2.

**LV Function**

When AF ablation is first adopted, patients with normal LV systolic function are initially selected. However, there is increasing evidence that AF ablation benefits patients with impaired LV systolic function. Currently, task force consensus guidelines suggest that selected symptomatic patients with heart failure and/or reduced ejection fraction could be considered for catheter AF ablation. In the aforementioned studies, the average pre-ablation ejection fraction ranged from 33% to 41%. Several important observations could be made including the fact that catheter AF ablation is feasible without an increase in procedural complication and that the efficacy of the procedure in patients with impaired systolic function is lower than in those with normal systolic function with a higher recurrence rate. Nevertheless, AF ablation results in significant symptomatic relief, improvement in quality of life, as well as some recovery of cardiac function. Future studies are likely to further clarify the relative efficacy and clinical benefits of ablation in patients with significant LA dilation and LV systolic dysfunction.

**TEE and Exclusion of LA/LAA Thrombus**

The pathophysiology of AF is complex and is currently the gold standard investigation for excluding thrombus prior to elective cardioversion and AF ablation (Figure 1). The sensitivity and the specificity of TEE for detecting LA thrombi are 93-100% and 99-100% respectively. The finding of severe spontaneous echo contrast, which is seen as echo-
genic swirling blood flow, reflects red cell and clotting factor aggregation with slow moving blood within the atrium. This, by itself, is not an absolute contraindication to cardioversion or AF ablation, although it is associated with LA thrombus formation, a higher risk of thromboembolism, and increased cardiovascular mortality. 29

LA and LAA thrombus is an especially important issue for AF ablation because the procedure not only involves manipulation of multiple catheters inside the LA with the potential of dislodging in situ thrombus, but also leads to substantial areas of denuded LA endothelium that may become a nidus for thrombus formation in the days or weeks post-ablation. A recent study found a prevalence of LA thrombus and sludge of 0.6% and 1.5% respectively on routine pre-ablation TEE. The prevalence of spontaneous echo contrast was as high as 35%. In this population, the predictors of LA thrombus were found to be high CHADS 2 score, history of congestive heart failure, and left ventricular ejection fraction <35%. While it remains contentious whether TEE should be routinely performed in all patients because of the low incidence of thrombus, the recent task force consensus guidelines stated that patients with persistent AF who are in AF at the time of ablation should have a TEE performed to screen for LA/LAA thrombus, regardless of the adequacy of pre-ablation anticoagulation. 1

Since cardiac CT is commonly performed immediately before AF ablation to use the 3D dataset in image integration with real-time electroanatomic data during ablation, attempts have been made to use CT to screen for LA thrombus. Retrospective single centre trials have suggested that a negative CT has a high negative predictive value making it a potential alternative for excluding LAA thrombi before ablation. 33-35 This issue will need to be clarified in future studies.

### TEE and Pulmonary Venous Anatomy

The accurate imaging of LA and pulmonary venous (PV) anatomy is important for understanding the anatomic relationships between the PVs, LA and LAA. The most commonly seen pattern of PV anatomy is that of two separate right PVs and 2 separate left PVs. The right middle PV drains into the right superior PV before entering the LA. However, variations in PV anatomy are common. Supernumerary right PVs have an incidence of 18-29%. Common antrum of the left PVs results in a broad PV-LA junction and is found in 6-35% of patients. 42-44 Moreover, morphological remodeling of the PVs and LA can also be observed in patients with AF. Studies have found that PV ostia...
During Ablation

Use of ICE During Ablation

During AF ablation, intraoperative TEE dramatically improves the visualization of anatomic landmarks over that of fluoroscopy. However, it is limited by patient discomfort and more importantly, the need for airway management during a prolonged procedure. Advances in intracardiac echocardiography (ICE) performed by electrophysiologists have improved both the efficacy and safety of the procedure (Table 3).

Available ICE systems include those with mechanical single-element transducers and phased-array multi-element transducers. A mechanical transducer contains a rotational single-element and produces high quality images but only at shallow depths. To visualize LA structures, the transducer has to be inside the LA. Phased-array multi-element transducers image at frequencies from 5.5-10MHz, providing 2D images with a deeper penetration and allowing an RA-located ICE probe to image the LA without an additional transseptal puncture.

During an ablation procedure, ICE accurately identifies key anatomic locations, such as the fossa ovalis, LAA, valve apparatus, pulmonary veins and extracardiac structures. It facilitates transseptal puncture, which is often challenging in clinical scenarios, such as large septal aneurysm.

Cardiac CT and CMR are the gold standard investigations for accurate imaging of LA and PV anatomy. TEE is not the first-line investigation for this purpose mainly due to patient comfort, although TEE does excel in that it lacks radiation exposure and has a lower cost. Nevertheless, whenever TEE is performed pre-ablation for another reason, valuable information on PV anatomy and its variations could be gained, and all PVs should be interrogated in detail as baseline information. While some studies report that TEE can only visualize two-thirds of superior and inferior veins with experienced operators, the superior and inferior PVs can be identified in over 94% of cases. The identification of PV anatomical variations, such as common left PV antrum and supernumerary right PVs, is slightly more challenging compared to cardiac CT. In our experience, careful rotation of the probe with the veins in view should permit the visualization of most veins. Useful techniques include imaging the right PVs at 45-60° with a clockwise rotation of the transducer and imaging the left PVs at 110° with a counterclockwise transducer rotation.

Figure 2: Examples of variant PV anatomy shown on TEE. Separate ostium for the right middle and superior PV are noted in (a). Common ostium of the left superior and inferior pulmonary veins is noted in (b). Reproduced with permission from Gabriel and Klein.

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lipomatous atrial septal hypertrophy, double membrane septum, prior cardiac surgery distorting anatomy, and previous surgical or percutaneous closure of atrial septal defect or patent foramen ovale. It determines the exact position of the transseptal sheath by the tenting of the interatrial septum and confirms access to the LA by the injection of agitated saline. With ICE guidance, it is possible to aim for a transseptal puncture in the posterior region of the fossa ovalis. This is believed to be safer than the more anterior portions as the pulmonary veins are posterior structures. ICE provides real-time images of PV anatomy and is far more sensitive to small movements of the circular mapping and the ablation catheters than fluoroscopy alone. Tissue contact is traditionally monitored by stability of the ablation catheter on fluoroscopy and stability of the electrical recording. The detection of microbubbles during ablation with ICE indicates tissue superheating and has been used to optimize ablation catheter placement. This strategy has been used to prevent tissue damage and scar formation, reduce the risk of tissue superheating, optimize radiofrequency energy delivery, and increase the number of lesions with optimal contact and energy delivery. Recent development in open irrigation platforms has lessened the importance of ICE in this regard. However, recent research has investigated using ICE to monitor the relationship between the catheter tip and adjacent structures, such as the esophagus. This strategy may reduce the incidence of esophageal injury.

ICE is able to detect intra-procedural complications promptly, similar to intraoperative TEE; however, potential complications include cardiac perforation and tamponade, thrombus formation on the transseptal sheath and other catheters, as well as pulmonary vein stenosis (PVS), which may be predicted by an increase in PV flow velocity with Doppler measured during the procedure.

**Post-Ablation**

Patients are followed clinically with varying use of routine imaging studies post-ablation amongst institutions. A summary of the role of TTE and TEE in the post-ablation patients is outlined in Table 4. PVS is routinely screened for in some practices by cardiac CT, CMR, and/or TEE. TTE is also sometimes performed to document the degree of atrial remodeling and changes in LV function post-ablation.

**TEE and the Diagnosis of PVS**

Thermal injury to PV musculature results in PV stenosis. The incidence of post-ablation severe PV stenosis has been reported to be 3.4%. Symptoms of PV stenosis include shortness of breath, cough, hemoptysis, chest pain, and recurrent lung infections. With the evolution of techniques, the incidence of PV stenosis has declined due to the avoidance of delivering radiofrequency energy within the PV, together with the increasing use of ICE and complementary image integration systems with pre-ablation cardiac CT and real-time electroanatomical data.

While some institutions routinely screen for PVS post-ablation, others perform imaging tests when symptoms dictate them. It remains unclear whether early diagnosis and treatment of asymptomatic PVS provide long-term advantage, although asymptomatic PVS has the potential to cause progressive hypoplasia of the entire pulmonary vein proximal to the stenosis. Such pulmonary vascular occlusive damage may not be fully reversible and may lead to difficulties with subsequent percutaneous treatment should symptoms develop in the future.

The diagnosis of PVS is most commonly made by tomographic modalities such as cardiac CT or CMR, because they quantify the degree of PVS wi-
The excellent reproducibility and demonstrate the relationship of the stenosis to the rest of the PV anatomy so percutaneous treatment can be planned. TEE, on the other hand, plays a supplementary role in the diagnosis of PVS and offers both anatomical and functional information. PV stenosis severity is defined according to the percentage reduction in luminal diameter, with a >70% luminal diameter reduction commonly considered severe PVS. An absolute diameter of <7 mm may also be sufficient to diagnose significant PV stenosis on TEE. When comparing TEE and cardiac CT, two important aspects are notable. Firstly, PVS are elliptical in shape with a larger diameter in the cranio-caudal axis than the transaxial axis; this is not as readily recognized by TEE. Secondly, TEE has the tendency to systematically underestimate ostial diameters compared to CT. These aspects should be taken into account when serial studies across different modalities are compared.

The unique feature of TEE in the diagnosis of PVS is that it provides functional assessment of the PVs. The use of color and pulsed Doppler assessment of PV flow confirm the presence of hemodynamically significant stenosis by detecting turbulence and aliasing of the color Doppler signal as well as an increase in pulsed wave Doppler diastolic flow velocities (Figure 3). The optimal cutoff velocity for defining stenosis is currently unknown, although studies have shown that a peak diastolic velocity of >100 cm/s has a 86% sensitivity and 95% specificity for diagnosing PVS compared to the gold standard investigation of cardiac CT. 63 It is important to remember that such comparison may not be valid, as functional information from TEE is not equivalent to anatomical information from cardiac CT, and the two modalities may supply incremental value in selected cases. For instance, functional information may be important in assessing patients with equivocal symptoms and a moderate degree of stenosis. Information on the functional significance of stenosis may also be helpful over that of size alone in determining the necessity of intervention.

### Atrial Mechanics – Prediction of Recurrence

AF results in electrical and structural remodeling of the atrium that can be considered part of a rate-related atrial cardiomyopathy. The termination of arrhythmia may, as a result, lead to a degree of reverse remodeling of the atrial cardiomyopathy. The documentation of atrial reverse remodeling post-ablation may not routinely be performed in clinical practice, but studies have recently suggested a potential role in predicting recurrence post-ablation and stratifying thromboembolism risk.

Understanding atrial mechanics extends our current interest from simply measuring the maximum LA volume at end-ventricular systole to measuring LA phasic functions (Table 5). Analyzing events at various phases of the cardiac cycle can supply information on the dynamic LA reservoir (atrial filling), conduit (passive atrial emptying)
and contractile (active atrial contraction) functions. Although studies are sparse at the moment, it is likely that AF ablation has varying effects on the different components of LA phasic function.

Marsan et al. studied 57 patients with AF, of whom had paroxysmal AF. Atrial volumes were studied at various phases of the cardiac cycle to assess LA phasic functions. In the patients who maintained sinus rhythm at 3 months, there was a significant reduction in overall LA volume, with improvement in LA active contractile and reservoir functions. LA conduit function, or passive emptying, was relatively unchanged, highlighting that LA phasic function analysis can study the effect of AF ablation on the LA in detail. Such changes were not observed in studies performed immediately after AF ablation, but rather took several weeks to occur. In the group that reverted back to AF, the changes of atrial reverse remodeling were not observed, illustrating that changes in atrial mechanics post-ablation could be used to predict future AF recurrence. Other studies using 3D echocardiography or CMR have also demonstrated post-ablation atrial reverse remodeling. The magnitude of change of the various parameters is in the range of 10-20%. A lack of demonstrated atrial reverse remodeling has been associated with post-ablation recurrence.

In addition to measuring phasic volumes, LA mechanics could also be studied with Doppler echocardiography. Traditionally, the measurement of pulsed Doppler derived mitral A wave velocity and a’ from mitral annular tissue Doppler velocity gives some insight into LA contractile function. Studies have found that a’ decreases immediately after AF ablation but subsequently improves, suggesting that LA contractile function deteriorates immediately post-ablation but recovers later.

Recent research applies strain and strain rate imaging to study LA mechanics using either color tissue Doppler imaging techniques or 2-dimensional speckle tracking techniques. Using these techniques, changes in LA phasic functions pre- and post-ablation can be accurately quantified. Schneider et al. studied 118 patients with paroxysmal and persistent AF before and 3 months after AF ablation. Color tissue Doppler imaging measured the LA strain and strain rates at the reservoir, conduit and contractile phases of the atrial cardiac cycle, and was feasible in 97%. Changes in atrial myocardial properties post-ablation differed significantly between patients with paroxysmal and persistent AF. Recurrence is predicted by a lower post-ablation strain and strain rate during the LA reservoir phase, as well as a lower strain rate during the LA contractile phase. Such difference in atrial mechanics is not detected by conventional parameters of Doppler echocardiography, suggesting that strain and strain rate analysis appears more sensitive in investigating changes in LA mechanics after AF ablation. Studies have used 2-dimensional speckle tracking techniques to measure LA mechanics, although they have yet not been applied to the AF ablation population.
Atrial Mechanics – Thromboembolic Risk

The study of atrial mechanics may also be important for the prediction of thromboembolic risk. Currently, studies are sparse and the effect of changes in atrial mechanics post-ablation on thromboembolic risk is uncertain. Many patients may opt for AF ablation as an alternative to long-term anticoagulation with warfarin therapy. However, this strategy cannot be recommended at this stage because the impact of AF ablation on thromboembolic risk remains unknown. While some studies demonstrate an improvement in LA function using 3-dimensional echocardiographic measurements, other studies have shown that post-ablation LA reservoir and contractile functions remain significantly impaired, especially when compared to patients undergoing cardioversion and control subjects. Further studies are required both to understand the effect of AF ablation on LA mechanics and how the changes in LA mechanics impact on thromboembolic risk. Such changes are likely to differ between patients with paroxysmal vs. persistent AF, as well as with the number of prior AF ablations.

Current guideline recommendations for anticoagulation rely on pre-ablation risk factors. Post-ablation LA function changes have not been incorporated into the decision making process due to the lack of evidence. The guideline recommends that discontinuation of anticoagulation with warfarin therapy be avoided in patients with congestive heart failure, history of high blood pressure, age ≥75 years, diabetes, prior stroke or transient CHADS score ≥2. In those with a CHADS score of 1 post AF-ablation, either aspirin or warfarin is thought to be appropriate.

Conclusions

Echocardiography plays a central role in decision making for patients undergoing AF ablation—pre-ablation, during ablation and post-ablation. The role of echocardiography pre-ablation is now well established, in patient selection, screening of patients for LA/LAA thrombus prior to ablation, and the use of ICE in the guidance of catheter ablation. Emerging echocardiographic roles include the identification of variant pulmonary vein anatomy, diagnosis of PVS, as well as the use of data from atrial mechanics studies in documenting atrial reverse remodeling and in prognosticating for AF recurrence and future thromboembolic events. The role of echocardiography will continue to evolve with the introduction of new technologies and techniques.

**Table 5**

<table>
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<tr>
<th>LA phasic volumes</th>
<th>Potentially Useful Measures of LA Mechanics</th>
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<tr>
<td>LA maximum volume (end-ventricular systole)</td>
<td>Total LA emptying fraction (LA reservoir function)</td>
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<tr>
<td>LA pre-atrial contraction volume (start of atrial systole)</td>
<td>Passive LA emptying fraction (LA conduit function)</td>
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<tr>
<td>LA minimum volume (end-atrial systole)</td>
<td>Active LA emptying fraction (LA contractile function)</td>
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<td>Doppler echo</td>
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<td>SRearly negative(LA conduit function)</td>
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<td>SRLate negative(LA contractile function)</td>
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creasing use of AF ablation in AF management.

Acknowledgments

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Abbreviations

2DE: 2-dimensional Echocardiography
3DE: 3-dimensional Echocardiography
AF: Atrial Fibrillation
CMR: Cardiac Magnetic Resonance
CT: Computed Tomography
ICE: Intracardiac Echocardiography
LA: Left Atrium / Left Atrial
LAA: Left Atrial Appendage
LV: Left Ventricle / Left Ventricular
PV: Pulmonary Vein(s) / Pulmonary Venous
PVS: Pulmonary Vein Stenosis
TEE: Transesophageal Echocardiography
TTE: Transthoracic Echocardiography

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