Chapter 4

Multimodality Echocardiographic Assessment of Patients Undergoing Atrial Fibrillation Ablation

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Additional information is available at the end of the chapter

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Abstract

Atrial fibrillation (AF) is most common sustained arrhythmia in clinical practice. The new treatment standard in paroxysmal and persistent AF is the catheter ablation. Echocardiography plays a key role in risk stratification and management of patients with AF and is critical in the assessment of candidates for AF ablation, providing both anatomic and hemodynamic information. Echocardiography is crucial for patient selection, preprocedural left atrial appendage thrombus excluding, intraprocedural guidance, and detection and monitoring for early and late ablation related complications. Transthoracic echocardiography allows rapid and comprehensive assessment of cardiac anatomical structure and function. Transoesophageal echocardiography also provides accurate information about the presence of a thrombus in the atria and thromboembolic risk, making safe the ablation procedure by immediately detection of the complications related procedure. Intracardiac echocardiography has emerged as a popular and useful tool in the everyday practice of interventional electrophysiology, being very useful only during the ablation procedure. This paper presents the role of echocardiography in all these steps concerning AF ablation procedure, and also (1) delineates the role of echocardiographic techniques in guiding the procedure, (2) discusses the critical echocardiographic aspects of this procedure, and (3) underlines the strengths and limitations of various echocardiographic modalities.

Keywords: atrial fibrillation, ablation, transthoracic echocardiography, transoesophageal echocardiography, intracardiac echocardiography

1. Introduction

The most common sustained cardiac arrhythmia, nonvalvular atrial fibrillation (AF), has an increasing prevalence and incidence in association with increased age and medical comorbidities. Nonvalvular AF is defined as AF in the absence of prosthetic mechanical heart valves, or haemodynamically significant mitral stenosis (moderate or severe) [1]. Evaluation of patients with AF requires an assessment of cardiac structure and function by echocardiography. Such an assessment complements the clinical evaluation and helps decision-making regarding rhythm strategy (rhythm control vs. rate control), stroke risk stratification, and prognosis. Currently approved AF therapies are only partially effective and are associated with substantial morbidity and mortality. The new treatment standard in this arrhythmia, AF catheter ablation, requires a multidisciplinary team approach involving interventional cardiologists and imaging specialists. For AF ablation, there is a need to identify individualized mechanism-based ablation targets (defined as mapping), located especially in left atrium (LA). Achieving durable pulmonary vein isolation as first step in AF ablation therapy remains technically challenging. AF substrate ablation (by targeting LA myocardium attaint by fibrosis due to the LA structural remodelling), in addition to pulmonary vein isolation, may prevent AF recurrence if pulmonary veins reconnect or nonpulmonary vein triggers emerge. Intrinsic cardiac autonomic nerve activity precedes the onset of AF. Autonomic activity is mediated by discrete ganglionated plexi localized on the LA posterior epicardium. It promotes LA electrical remodelling. Targeting these ganglionated plexi is another method for AF ablation. New approaches to mapping and ablation may target regions of oscillating action potential duration (especially in the LA myocardium) that can cause wave breaks leading to AF [2]. Recently, European Association of Cardiovascular Imaging and the European Heart Rhythm Association published evidences available on the role of imaging techniques (including echocardiography) and their applications in patients with AF, and provided recommendations for their use in clinical practice [3]. Echocardiography is critical in the assessment of candidates for AF ablation, providing both anatomic and haemodynamic information; it offers the potential for improved safety of AF ablation. Echocardiography is very useful at each step of the procedure: before AF ablation (by patient selection and pre-procedural LA appendage thrombus exclusion), intraprocedural guidance, and after AF ablation for detection and monitoring for early and late ablation-related complications, and also atrial reverse remodelling occurrence after obtaining stable sinus rhythm.

2. Echocardiography before atrial fibrillation ablation

Transthoracic echocardiography (TTE) allows rapid and comprehensive assessment of cardiac anatomical structure and function. It plays a central role in each of identifying comorbidities and identification of suitable candidates for AF catheter ablation. Pulmonary vein flow monitoring using echocardiography has the potential to an increasing role in the evaluation of cardiac diastolic function directly related to LA remodelling. Transoesophageal echocardiography (TOE) also provides accurate information about the presence of a thrombus in the atria or LA appendage (which is an absolute contraindication for AF ablation) and thromboembolic risk. The novel technique of intracardiac echocardiography (ICE) has emerged as a popular and useful tool in AF ablation during the procedure.

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2.1. Echocardiography Assessment of Left Atrial Size, Anatomy and Function

LA dilatation (structural remodelling) can occur in a broad spectrum of cardiovascular diseases including hypertension, left ventricular dysfunction, mitral valve disease, and AF. In general, two major conditions are associated with LA dilatation: pressure overload and volume overload. TTE has an important role to diagnose all these diseases in patients with AF. The LA size has an incremental value of overconventional risk factors. However, LA size has also prognostic value for long-term outcome. The current guidelines on management of patients with AF recommend a standard two-dimensional (2D) TTE and Doppler echocardiogram, with assessment of LA *size and function*, in the clinical evaluation of all patients with AF (not only before AF ablation) [2].

LA size in addition to LA anatomy and function are the parameters mandatory to be assessed before deciding to include a patient for AF ablation procedure. The LA anterior-posterior diameter was one of the first standardized echocardiographic parameters for assessment of *LA* size. LA enlargement may result in an asymmetrical geometry of the LA. LA anterior-posterior diameter assessed in the parasternal long-axis view by 2D or M-mode echocardiography may underestimate LA size [4]. Anterior-posterior linear dimension should not be used as the sole measure of LA size [4]. Optimal assessment of LA size should include LA volume or LA area (preferably indexed) measurements [4]. LA dimensions can be assessed in the apical four- and two-chamber views. LA dimensions should be measured at end-ventricular systole, at maximal LA size. Each view must be optimized in order to avoid: an underestimation of LA size by foreshortening of the major length of the LA, inaccurate assumption of the mitral annulus boundary, loss of lateral resolution of the LA wall in the apical view, or dropout of the interatrial septum or anterior wall [4]. LA area is easy to assess and closer to LA size than anterior-posterior diameter. Various methods for the assessment of LA volume with 2D echocardiography are available, including the cubical method, area-length method, ellipsoid method, and modified Simpson's rule [4]. Because it is theoretically more accurate than the area-length method, the biplane disk summation technique, which incorporates fewer geometric assumptions, should be the preferred method to measure LA volume in clinical practice. For LA volume assessment, the same views as LA area are indicated (**Figure 1**). In

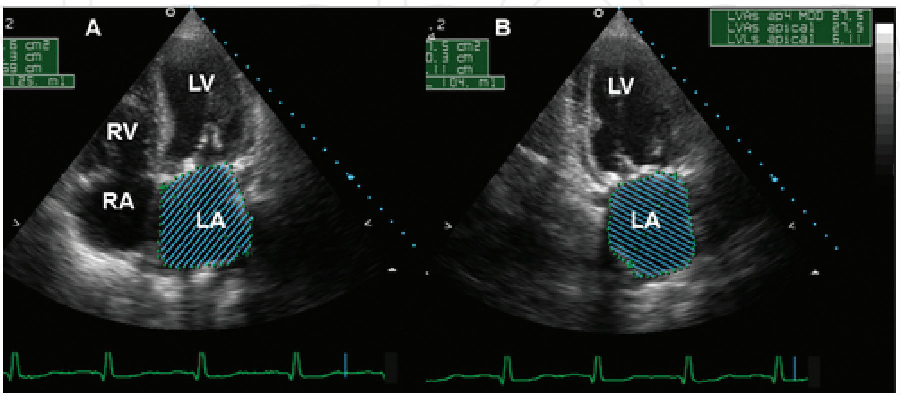

Figure 1. Biplane left atrial volume measurement by disk summation method in apical 4-chamber (A) and apical 2-chamber (B) views of bidimensional transthoracic echocardiography. LA: left atrium, LV: left ventricle, RA: right atrium, RV: right ventricle.

addition, the same precautions must to be respected. LA appendage and pulmonary veins should be avoided to be included as LA cavity. LA long diameter is recommended to be considered the shorter value of this length assessed in the two views specified above. The measurement of LA length is considered appropriate if the difference between the two values (in apical two- and four-chamber views) is not higher than 5 mm.

Alternatively, LA volume can be calculated using the disk summation technique by adding the volume of a stack of cylinders and area calculated by orthogonal minor and major transverse axes assuming an oval shape.

LA volume enables accurate assessment of the asymmetric structural remodelling of the LA and is a more robust predictor of cardiovascular events than linear or area measurements. However, the cornerstone of LA volume assessment is geometric assumptions about LA shape (as an ellipsoid shape).

The upper normal limit for 2D echocardiographic LA volume is 34 mL/m^2 for both genders. Single-plane apical four-chamber indexed LA volumes are typically 1–2 mL/m^2 smaller than apical two-chamber volumes. Apical four- and two-chamber linear measurements and nonindexed LA area and volume measurements are not recommended for routine clinical use [4].

In conclusion, TTE is the recommended approach for assessing LA size [4]. LA size should be measured at end-ventricular systole, at maximal LA size, with precautions to not underestimate or overestimate LA dimensions [4]. TOE slightly underestimates LA size; it provides good correlation with TTE. Although TOE permits good views on the LA and the LA appendage, it should not be used to assess LA size [4].

Recently has been demonstrated the feasibility of three-dimensional (3D) TTE for the assessment of LA volumes [5]. 3D echocardiography has the advantage that no geometrical assumption about LA shape has to be made and it seems to be more accurate when compared to 2D measurements. In addition, this echocardiographic method has a lower intraobserver and interobserver variability as compared to 2D echocardiography [5]. However, there still remain some technical limitations: The spatial and temporal resolution is low, depends on adequate image quality, and requires patient's cooperation; in addition, there are limited data on normal values [4].

LA size and volumes throughout the cardiac cycle can be acquired more precise with magnetic resonance image or computer tomography. Because the longitudinal axes of the left ventricle and LA frequently lie in different planes, dedicated acquisitions of the LA from the apical approach should be obtained for optimal LA volume measurements. However, these imaging methods are more expensive, sometimes with limited accessibility and more invasive (X-ray irradiation for computer tomography and potential kidney complications for both image techniques).

ICE is only used during AF catheter ablation procedure [6]. Therefore, no standardized measurements of LA size or volume are available. Although ICE is limited by the monoplane character and the lack of standardized measurements of LA size, it is a valuable tool for guidance ablation procedure.

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The assessment of *LA anatomy* is important in the setting of catheter ablation procedures for AF [6]. Because of the complex anatomy of the LA and the variability in pulmonary vein anatomy, a detailed roadmap is mandatory to be known before the ablation procedure. The various imaging modalities that are available for assessment of LA and pulmonary vein anatomy in catheter ablation procedures include multislice computed tomography, magnetic resonance imaging, ICE, and electroanatomical mapping systems. Patients referred for AF ablation often have highly variable pulmonary vein anatomy, which could influence the procedure technique [6]. Four discrete pulmonary veins are present in the minority of patients with paroxysmal AF undergoing pulmonary vein isolation [6]. Anatomical variations include a single insertion or common antrum of the ipsilateral pulmonary veins, and an additional pulmonary vein. Assessment of LA and pulmonary vein anatomy by cardiac magnetic resonance or computed tomography before AF ablation is mandatory before the procedure. Pulmonary vein anatomy may in part explain the variable outcome to electrical isolation in patients with paroxysmal AF, although there is still debate concerning the best ablation strategy and the optimal lesion set. This information might aid in planning procedural strategies, and reducing unexpected procedural complications in AF ablation [6]. Among echocardiographic methods, only ICE (not TTE and TOE) has the capacity to assess a detailed pulmonary vein anatomy and morphology [7–9]. The interest in LA anatomy increases with AF ablation techniques developing [7–9]. New image integration systems have become available for AF catheter ablation procedures [8].

In patients in sinus rhythm LA has three important functions: the reservoir, the conduit, and the booster pump function. The change in the *LA function* in different phases can be evaluated noninvasively by echocardiography, utilizing not only usual methods including transmitral flow and changes in LA area and volume.

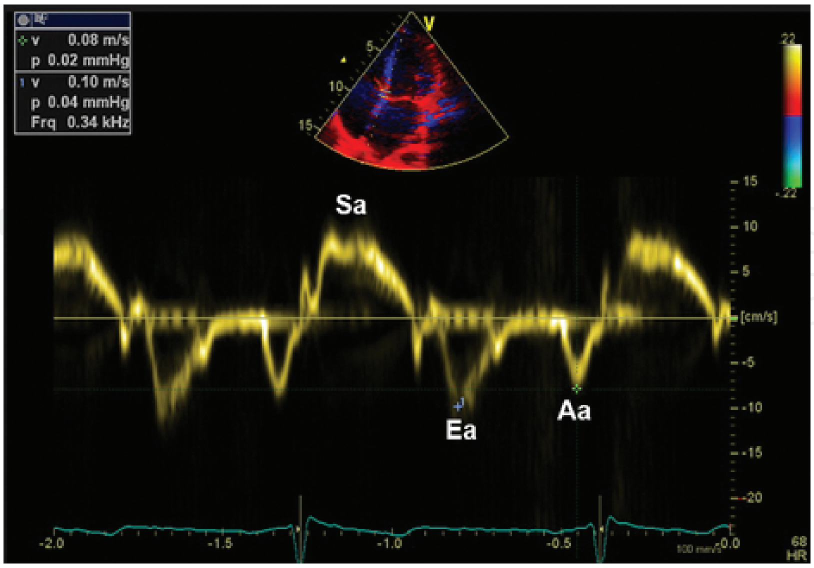

Figure 2. Tissue Doppler Imaging study (at the level of basal segment of septal interventricular wall) in apical four-chamber view of transmitral inflow in a patient with paroxysmal atrial fibrillation during sinus rhythm. Sa represents systolic myocardial velocity of left ventricle; Ea represents early diastolic filling myocardial velocity of left ventricle; Aa represents late diastolic filling myocardial velocity of left ventricle.

Pulsed-wave Doppler permits the assessment of late diastolic filling wave (A) on transmitral inflow pattern as marker of LA mechanical function. Both peak velocity and time-velocity integral of the mitral A wave could be used. However, in AF patients A wave is absent, so cannot be used for LA mechanical function assessment [5].

New echocardiographic techniques, such as Tissue Doppler Imaging (TDI) and speckle tracking (strain and strain rate) imaging, allow noninvasive measurement of regional function of the myocardium (including LA). TDI allows the quantification of the low-velocity, high-amplitude, long-axis intrinsic myocardial velocities in both systole and diastole, and provides a relatively load-independent measure of both left ventricle systolic and diastolic function (**Figure 2**).

The similar parameter of peak A velocity measured by TDI (Aa) is a myocardial velocity (not flow velocity) and could be also used as an atrial function parameter. It correlates with other parameters of atrial function as atrial fraction and atrial ejection force. In addition, it seems that Aa velocity assessed by TDI correlates with LA fractional area and volume change [5].

However, regional LA function is not routinely assessed, and therefore, no standardized parameters for regional LA functions are yet available [5]. A strong limitation for current using of this parameter is LA walls, which are thin and therefore difficult to be measured during wall moving. Improvement of LA regional function as marker of atrial electromechanical remodelling is an important outcome in patients that underwent AF catheter ablation.

Total electromechanical activity of the atria could be calculated by the interval between the onsets of the P-wave on the electrocardiogram to the end of the Aa wave on the TDI. However, TDI evaluation of regional LA function is the angle dependent. Therefore, careful adjustment of the beam and gain settings should be made to avoid aliasing and to allow reliable measurement of tissue velocities of the LA.

Another brand new technique, namely speckle tracking, is based on myocardial deformation assessment. Strain and strain rate are the two parameters that measure myocardial tissue velocity gradient by speckle tracking. This technique has some major advantages comparing with TDI: It is independent of wall movements and could differentiate between active and passive motion [5].

All TDI-derived parameters of the LA, including tissue velocities, strain and strain rate, were significantly reduced in patients with AF. Using TDI and/or strain imaging techniques, the decreased compliance of LA walls, the impairment of the reservoir and conduit function of LA, and the loss of the booster pump function in patients with AF were found.

After catheter ablation of AF, decreasing of these parameters means a possible criterion of do not interrupt the antiarrhythmic and anticoagulation treatment even in sinus rhythm due to the AF recurrences [5].

All changes in left ventricle diastolic function reflect on pulmonary venous flow morphology assessed by pulsed-wave Doppler [5]. In patients with AF due to LA pressure and functions (mainly the reservoir function), the following changes are possible: The wave of atrial reverse flow is absent due to the active LA mechanical function disappearance; peak velocity of systolic flow decreases and is related to the LA appendage dysfunction and thromboembolic risk; peak diastolic velocity higher than peak systolic velocity; an early systolic reverse flow is present [5]. In patients with AF catheter ablation pulmonary venous flow monitoring is important to assess LA mechanical function recovering. Preserved reservoir function of LA during AF is predictive of satisfactory recovery of mechanical function after pulmonary vein isolation [4, 5].

Pulmonary venous diastolic deceleration time is very useful to predict diastolic left ventricle filling pressure, as estimated by pulmonary capillary wedged pressure in AF [9]. This parameter is easy to be assessed after pulmonary venous flow registration by pulsed-wave Doppler. It is defined as duration between peak diastolic velocity and the upper deceleration slope extrapolated to the baseline.

According to the current guidelines, all these measurements should be taken on 5–10 cardiac cycles during a heart rate of 60–80 beats/min.

It seems that pulmonary venous deceleration time correlates better with pulmonary capillary wedged pressure than transmitral deceleration time in patients with AF [10]. Pulmonary venous deceleration time ≤150 ms could predict pulmonary capillary wedged pressure ≥18 mm Hg with 100% sensitivity and 96% specificity in patients with AF [10].

Patients with larger LA size, reduced LA function, and increased LA fibrosis (as marker of advanced electrical and structural remodelling) content are more likely to experience AF recurrences after ablation. The new echocardiography techniques have an emerging role in assessment of atrial fibrosis in patients with AF [7]. The appropriate selection of patients is mandatory for better outcomes in AF ablation; less fibrosis (that means less structural remodelling) seems to translate in better outcomes. Until now, there are not known imaging techniques able to predict AF ablation rate success tailored to each patient undergoing this treatment. However, there are some useful clinical tools (risk scores such as CHADS2, CHA2DS2-VASc, or APPLE scores) to identify patients with low, intermediate, or high risk of AF recurrence after AF ablation. However, echocardiography is very useful to detect and monitor LA reverse remodelling and improvement in atrial or ventricular function after AF ablation.

Atrial cardiomyopathies may provide the basis for the development of atrial fibrillation. The molecular alterations may also contribute to the occurrence of atrial thrombi. Thus, the concept of thrombogenic endocardial remodelling was introduced. In the future, echocardiography might be useful in this new type of atrial remodelling assessment.

2.2. Echocardiography Assessment of Left Atrial or Left Atrial Appendage Thrombus

The presence of LA appendage or LA thrombi is an absolute contraindication for AF ablation. Therefore, echocardiography assessment of thrombi presence is mandatory before AF ablation procedure. 2D TTE has a low sensitivity for detection of thrombi in LA and especially LA appendage. 2D or 3D TOE provides excellent visualization of posterior cardiac structures because of the anatomic relationship of these structures to the oesophagus. TOE is one of the modality of choice for detecting LA or LAA thrombi (**Figure 3A**).

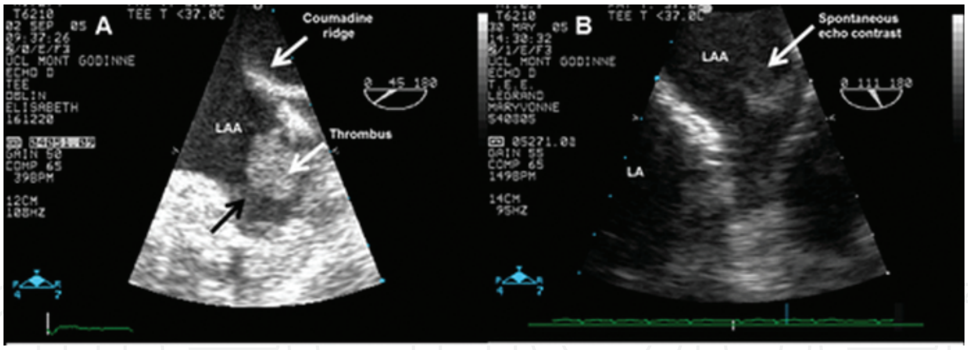

Figure 3. Two-dimensional transesophageal echocardiogram, midoesophageal view, allowing the identification of a left atrial appendage thrombus (A); zoom of the left atrial appendage illustrating the presence of a dense spontaneous echo contrast with swirling movements in the left atrial appendage (B).

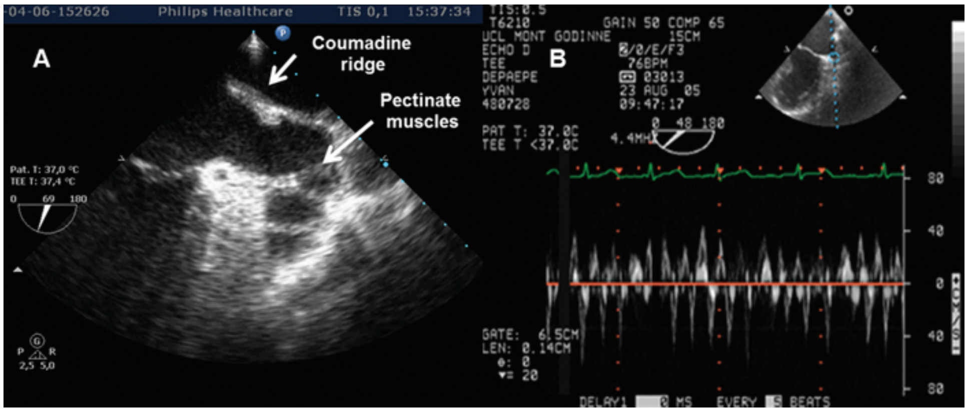

Figure 4. (A) Two-dimensional transesophageal echocardiogram, midoesophageal view, shows left atrial appendage with muscular ridge, namely coumadin ridge and pectinate muscles which could be misinterpreted as clots. (B) Pulsed-wave Doppler of the left atrial appendage demonstrates the decreased emptying and filling velocities in patients with atrial fibrillation.

It can detect thrombi with a high degree of sensitivity and specificity varying from 93% to 100% [5]. LA appendage has a very complex anatomy with variable shape, size, and orientation, with the possibility of several lobes and branches; therefore, thrombi assessment can be challenging. The muscular ridges and pectinate muscles (**Figure 4A**) must be carefully observed, because they can be misinterpreted as clots. Also ICE is very useful during AF ablation procedure to make the difference between muscular ridges and pectinate muscles (**Figure 5**). However, 3D TOE could make a better distinction between the pectinate muscles and thrombi, comparing with 2D TOE [11]. In addition, TOE is helpful in assessment of LA appendage velocities by pulsed-wave Doppler (**Figure 4B**). Usually, in patients in sinus rhythm without history of AF the average LA appendage filling velocity is 40–50 cm/s and correlates well with the LA appendage contraction velocity; the average LA appendage contraction velocity is 50–60 cm/s. Low LA appendage emptying flow velocities (defined as <20 cm/s) in AF correlate strongly with the presence of spontaneous echo contrast and thrombus formation. For patients with AF, TOE risk factors for thromboembolism associated with high risk of stroke

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include at least one of the following factors: LA appendage thrombus, severe spontaneous echo contrast, low flow velocities at LA appendage ostium, and complex aortic plaques [3].

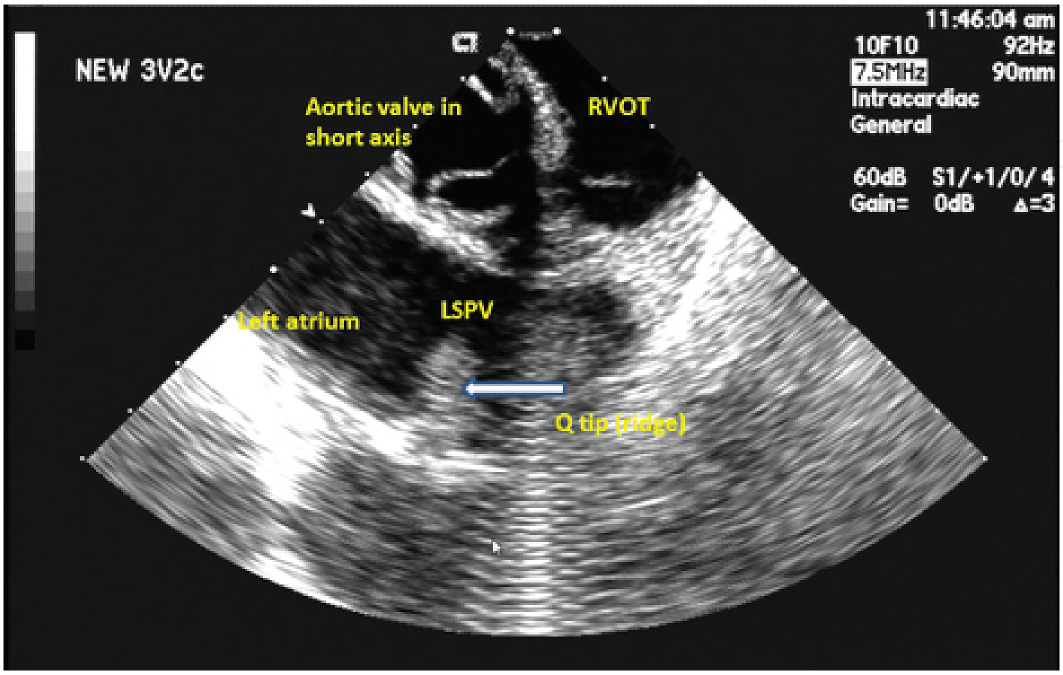

Figure 5. Intracardiac echocardiography shows very clearly anatomic structures during ablation procedure. This image was offered by courtesy of the editor. RVOT: right ventricle outflow tract; LSPV: left superior pulmonary vein.

Thrombus identification is also challenging even if the appendage is visualized adequately. In the absence of formed thrombi, a dense spontaneous echo contrast (**Figure 3B**) has been demonstrated to be strong a predictor of thromboembolism. Spontaneous echo contrast can be classified into four groups (1 to 4+), depending on the intensity, location, and presence of the swirling movement [12]. It seems that patients under anticoagulation and with thromboembolic risk scores (CHADS2 and CHA2DS2-VASc) <2 have a negative predictive value approaches to 100%; therefore, TOE before catheter ablation of AF might be avoided [13].

Sometimes it is difficult to distinguish small thrombi from artefacts, including prominent trabecular structures, duplication artefacts, and adipose tissue within the transverse sinus. It is necessary to attempt to differentiate any suspicious abnormalities from thrombus in multiple views. The mechanical function of LA appendage is best assessed with TOE utilizing pulsed-wave Doppler measurement of LA appendage emptying and filling velocities.

In addition to LA appendage Doppler assessment, measuring LA appendage area and ejection fraction (evaluated through vector velocity imaging), TDI, and 3D TOE are less validated and less frequently performed parameters associated with cerebrovascular events and the formation of LA appendage thrombus [11]. Pre-procedural multislice computed tomography may also identify the presence of thrombi in the LA appendage, but the gold standard is TOE [11]; in addition to the anatomy of the LA and pulmonary veins, it also provides detailed information on surrounding structures, such as the oesophagus and coronary arteries.

3. Echocardiography-Guided Ablation of Atrial Fibrillation

According to the new theories of AF physiopathology, some ablation strategies were elaborated; however, none is known as golden standard of this therapy. Depending on ablation technique, LA anatomy and pulmonary vein morphology are of essential importance to be well known during the ablation procedure. The veno-atrial junctions and anatomical structures of the LA, such as Coumadin ridge or the ridge between the left superior pulmonary vein and LA appendage, are critical for a safe and successful procedure.

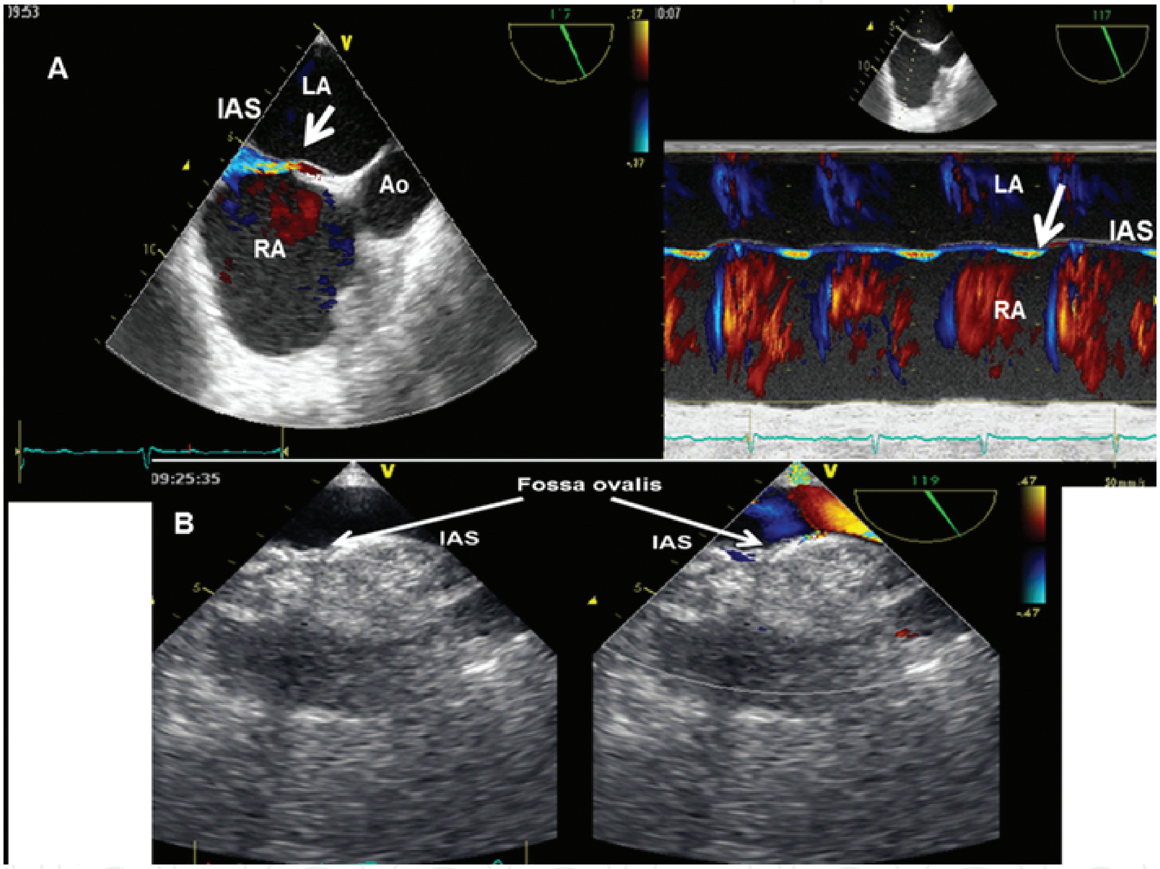

Figure 6. Two-dimensional transesophageal echocardiogram, midoesophageal view, shows (A) interatrial septum with left-right shunt in colour Doppler through patent foramen oval and (B) lipomatous interatrial septum. Ao: aorta; IAS: interatrial septum; LA: left atrium; RA: right atrium.

For pulmonary vein isolation or LA substrate ablation, it is mandatory to puncture the interatrial septum to gain left atrial posterior wall and pulmonary veins. If the patient has a patent foramen oval (**Figure 6A**), some operators say that transseptal puncture could be avoided. However, this is arguable, because accessibility to LA to gain pulmonary veins is difficult through a patent foramen oval. During TOE, a microbubble test under Valsalva manoeuvre could unmask a patent foramen oval. Rarely, TTE in subxiphoid view could identify the presence of a patent foramen oval. However, TOE has better sensibility to diagnose patent foramen oval before AF ablation. In patients with the lipomatous hypertrophy of the interatrial septum (**Figure 6B**), transseptal puncture could be difficult, without echocardiographic guidance.

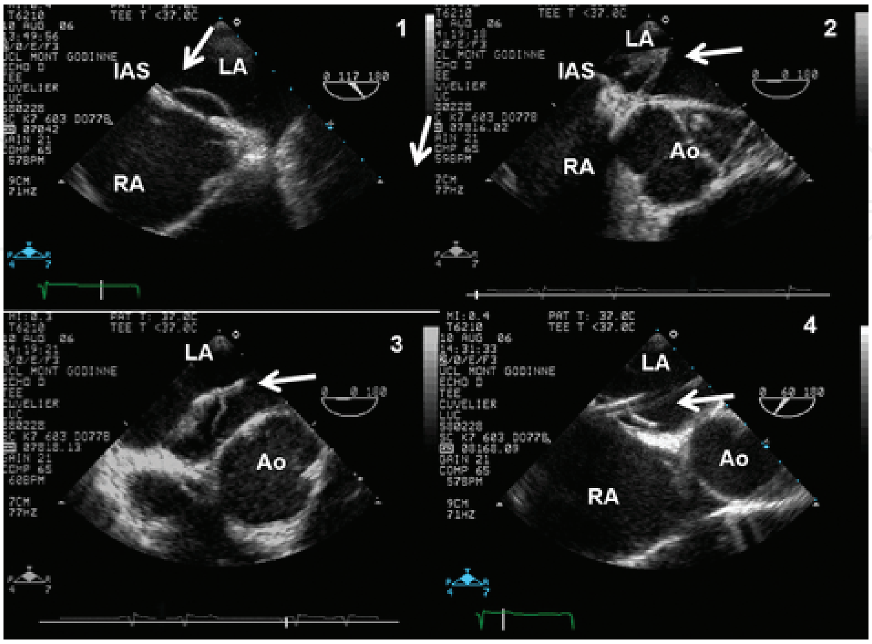

Figure 7. Transseptal puncture guided by bidimensional TOE shows direct visualization of the transseptal catheter and its relationship to the fossa ovalis and the ascending aorta. Ao: aorta; IAS: interatrial septum; LA: left atrium; RA: right atrium.

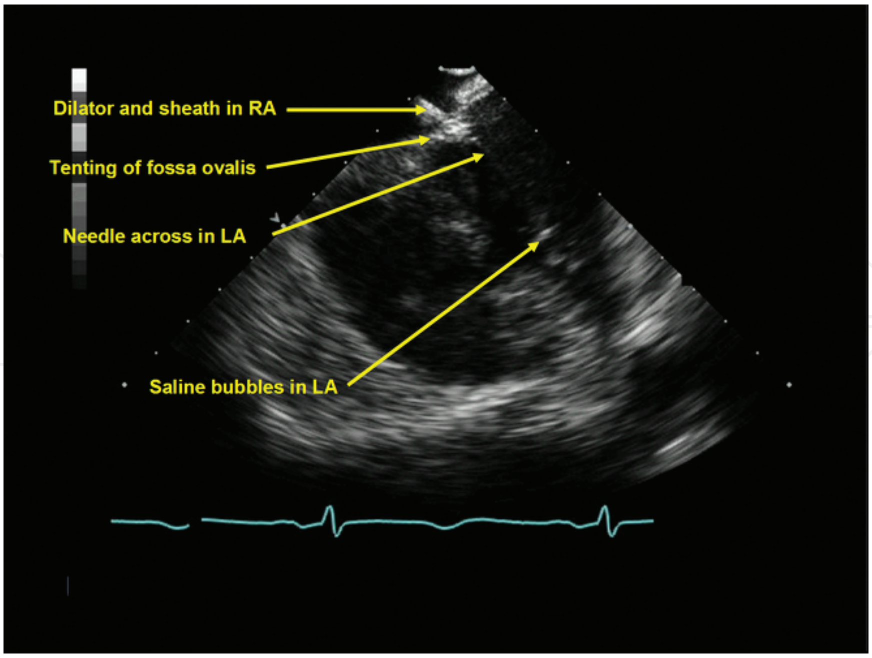

Figure 8. Uses of ICE for transseptal puncture guidance. LA: left atrium; RA: right atrium. This image was offered by courtesy of the editor.

Transseptal puncture allows procedural access to the LA. Anatomic structures are not directly visualized during transseptal puncture by fluoroscopic guidance. TTE and especially TOE may be helpful in performing this procedure by allowing direct visualization of the transseptal catheter and its relationship to the fossa ovalis. Anatomic variability in the position and orientation of the fossa ovalis and its surrounding structures may be challenging to even those interventional cardiologists with significant transseptal experience. However, echocardiography imaging offers increased safety to the operator, by avoiding the puncture of the intrapericardial aorta, a serious complication of transseptal puncture. In addition, radiation minimizes the fluoroscopy time required for the procedure, being very important during the learning curve. It was shown that TOE is of great value in performing transseptal punctures in AF ablation procedures. TTE can delineate the aorta and interatrial septum, and the characteristic bulging (or tenting) of the fossa ovalis and saline contrast echocardiography with TTE may help confirm needle position in the right atrium before puncture and in the LA after puncture (**Figure 7**). Anatomical variations in interatrial septum such as aneurismal septum, double-membrane septum, patent foramen oval, and others make this process complicated. Because TTE does not always offer sufficient imaging resolution, TOE and more recently ICE are preferably (**Figure 8**).

ICE could be useful only during the ablation procedure. It enables visualization of anatomical particularities of LA, being mostly important in transseptal puncture guidance and circular Lasso catheter positioning [14]. ICE enables to visualize the tenting of the interatrial septum due to the transseptal sheath tip during the puncture. It is important to be correctly placed in the posterior region of the fossa ovalis to avoid potential life-threatening complications such as aortic root perforation or LA lateral wall penetrating. For an appropriate mapping and ablation lesions, a good placement of Lasso catheter at the pulmonary vein antrum is mandatory. It could avoid important complications such as acute thrombus formation or early or late pulmonary vein stenosis by power, impedance, and temperature monitoring during energy delivery. Impedance increasing could be proceeding by microbubbles due to tissue superheating. ICE enables directly visualization of these microbubbles. In this case, immediate interruption of lesion creation is recommended to prevent severe complications such as cardiac tamponade by LA perforation, oesophageal injury or pulmonary vein stenosis. ICE is a useful tool also for the placement of mapping/ablation catheter according to anatomic landmarks and morphologic lesion changes monitoring for a safety and efficacy AF ablation procedure [7]. ICE has becoming a gold standard in complex AF ablation procedures by replacing fluoroscopy technique [14].

There has been a revival in the use of transseptal catheterization due to the increased use of radiofrequency ablation in the LA. Utilization of ICE in conjunction with fluoroscopy allows the electrophysiologist to clearly identify the interatrial septum and adjacent structures. ICE provides excellent views of the fossa ovalis and of the transseptal apparatus [7]. Life-threatening complications following inadvertent puncture of anatomic structures can be avoided under direct visualization. For electrophysiologist is important a direct visualization of the Brockenbrough needle and the Mullins sheath during the transseptal puncture. Sheath position in the LA could be verified by saline microbubbles or intravenous contrast injection.

The location of the Marshall vein, relevant in AF ablation, can also be identified from imaging of the "Q-tip" ridge, seen between the LA appendage and left pulmonary veins [7].

During AF ablation procedure, the mapping is followed by energy applications and lesion creation. Atrial myocardium suffers some alterations after energy application such as thickening, dimpling, and hyper-echogenicity. ICE enables identification of all myocardium sites transformed during ablation. The characteristics of lesions could be controlled by monitoring and titrating of energy parameters (temperature, impedance, and power). In addition, ICE allows identification of triggers sites such ligament of Marshall and to treat by applications under direct visualization. The applications on LA posterior wall could translate into fistula between anterior wall of the oesophagus and LA, a lethal complication of an extensive AF ablation procedure. Therefore, ICE is very useful during the procedure to titrate energy parameters to avoid this. In conclusion, ICE is used only during the ablation procedure; it allows better results of the procedure and lower risk of complications [15].

All echocardiography methods, TTE, TOE, or ICE, have the ability to detect early and avoid potential lethal complications during AF ablation [15]. Appropriate anticoagulation could prevent spontaneously thrombus formation and embolization during the procedure. Immediate detecting of thrombus by ICE allows prompting removal of catheters to avoid embolic complications.

Microbubbles visualization is most useful for prompting discontinuation of energy delivery when microbubbles are seen. Early detection of a pericardial effusion before cardiac tamponade (preferable before signs of haemodynamic compromise) and catheter-based treatment of the effusion are two facilitations allowed by TTE, TOE, or ICE. Pulmonary vein stenosis is a serious complication that can be detected early by visual tissue swelling and assessing severity with peak velocity measurements and colour flow parameters or pulsed-wave Doppler imaging, available with phased-array imaging [14].

During ablation procedure, ICE can accurately visualize LA anatomy and related structures and may guide transseptal catheterization and it is helpful in monitoring potential complications during catheter ablation procedures. In addition, it allows to establish a clear-cut relationship between the catheter tip and underlying tissue and to visualize the lesion formation; it can be performed with minimal additional patient risk and discomfort, without additional sedation or general anaesthesia; it does not need prolonged oesophageal intubation, accompanying patient discomfort, or the risk for aspiration. ICE offers imaging that is comparable with or superior to TOE and is an alternative to TOE in selected patients with absolute contraindications to TOE (oesophagectomy). This technique is quite safe with a negligible rate of complications and good patient tolerance. It allows improvement in success rate and decrease in complication when compared to fluoroscopic approach. ICE has been shown to improve patient comfort, shorten both procedure and fluoroscopy times, and offer comparable cost with TEE-guided interventions [5].

Comparing with TOE, ICE has some advantages: clearer image, reduced irradiation, and shorter duration of the procedure [16]. It has also some disadvantages such as: the shaft is thick without the possibility to have ports for pressure, therapeutic devices, and guide wires; the phased-array catheters are cost-ineffective (single use, higher costs); ICE offers only monoplane image views being difficult to obtain some sections as for TOE [10]. In addition, there are not still standard views for ICE as for other echocardiographic imaging modality such as TTE or TOE. In addition, in the literature there are described some potential risks of vascular lesion, cardiac perforation, arrhythmias, thromboembolism, and cutaneous nerve palsy [5]. However, it is expected to be used widely in clinical practice and even to become the standard for the transseptal catheterization.

4. Echocardiography after Atrial Fibrillation Ablation

Echocardiography is very useful after AF ablation for detection and monitoring for early and late related complications, and also for LA reverse remodelling assessment in patients with stable sinus rhythm.

Pulmonary veins flow monitoring is used to detect early pulmonary vein stenosis after AF ablation, which could occur in 1% to 3% of current series [17]. TOE allows the suspicion of a significant PV stenosis (**Figure 9**) by a combination of elevated peak pulmonary vein velocity (≥110 cm/s) with turbulence and little flow variation [17]. Although TOE has been used, it does not usually provide adequate assessment.

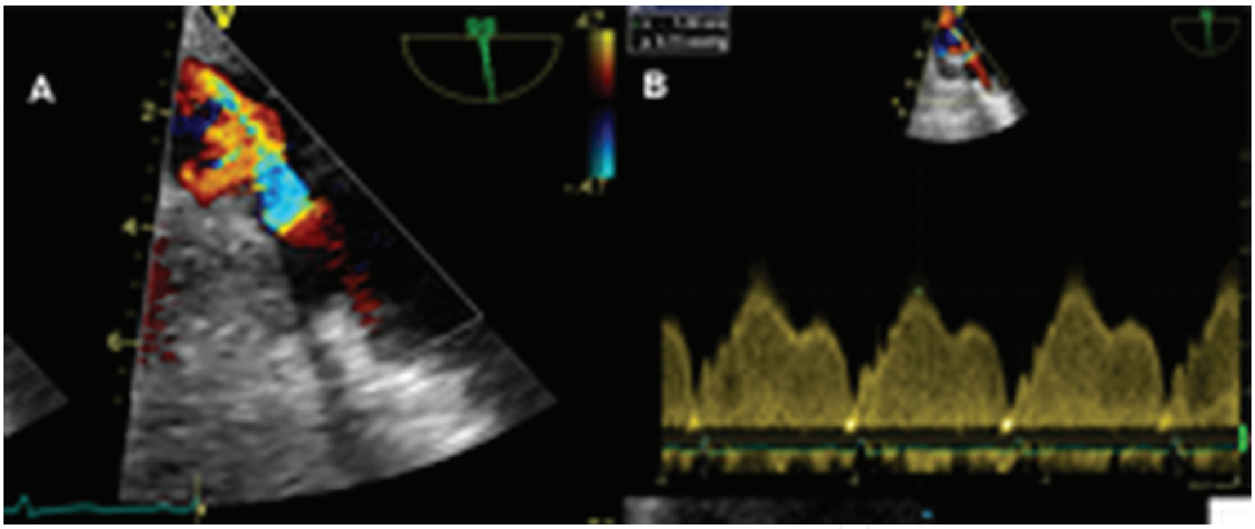

Figure 9. (A) Colour Doppler mode by transoesophageal echocardiography at the level of left superior pulmonary vein identify a significant pulmonary vein stenosis. (B) Pulsed-wave Doppler of left superior pulmonary vein inflow confirms haemodynamically significant stenosis. LA: left atrium, AO: aorta, LSPV: left superior pulmonary vein.

However, TTE or TOE are limited by its inability to image deeply into all four pulmonary veins and are less useful in establishing the extent and location of pulmonary vein stenosis. Diagnostic tests of value include magnetic resonance angiography and computed tomography. Progression of stenosis is unpredictable and may be rapid. Recurrent restenosis after angioplasty and stenting, as therapeutic solution of this complication, may occur in 30–50% of patients with pulmonary veins stenosis [17]. Follow-up of these patients typically involves computed tomography imaging to document restenosis.

Pulmonary vein stenosis could occur late after AF ablation. TOE could raise the suspicion by detection of high pulmonary vein velocities. Follow-up of these patients typically involves computed tomography or magnetic resonance imaging to document stenosis.

TOE and ICE allow early identification of complications related with procedure including damage to intracardiac structures, thrombus formation, pulmonary vein stenosis, and pericardial effusion during catheter ablation of AF.

A TOE performed 3–6 months after AF ablation can also evaluate thromboembolic risk and need for long-term anticoagulation, as echocardiographic risk factors may be present even if restoration of sinus rhythm is successful.

Catheter ablation has been demonstrated to be successful in the restoration of sinus rhythm and is performed in an increasing number of patients with symptomatic drug-refractory paroxysmal and persistent AF. It has been demonstrated that restoration and maintenance of sinus rhythm after catheter ablation is associated with a decrease in LA volumes (reverse structural LA remodelling), with subsequent improvement of LA function [5]. Using the new tissue Doppler-derived parameters, it was shown that in parallel with the improvement in LA function, both left ventricle systolic and diastolic function improved in the patients who maintained sinus rhythm [5]. In addition to LA reverse remodelling, even the area of the pulmonary venous ostia may decrease after successful catheter ablation procedures [5]. Post-procedural imaging to evaluate the extent of reverse LA remodelling after catheter ablation is critical to appropriate decisions regarding ongoing anti-arrhythmic therapy and long-term anticoagulation.

Conversion of AF and atrial flutter to sinus rhythm could result in a transient mechanical dysfunction of LA and LA appendage, termed atrial stunning [17]. Atrial stunning has been reported including after radiofrequency ablation. This phenomenon is well recognized with peak A velocity of transmitral inflow (by a very low value or absence) as well as TDI or strain imaging. Atrial stunning is at maximum immediately after procedure and improves progressively with a complete resolution within a few minutes to 4–6 weeks depending on the duration of the preceding AF, atrial size, and structural heart disease [18]. This suggests that a dissociation of electrical and mechanical recovery occurs after successful restoration of sinus rhythm, with a delay in gradual improvement of atrial mechanical function.

Stiff LA syndrome, defined as pulmonary hypertension with LA diastolic dysfunction, has regained attention in patients who had undergone catheter ablation for AF, especially after multiple ablation procedures [19]. This syndrome is a rare but potentially significant complication of AF ablation. Severe LA scarring, LA ≤45 mm, diabetes mellitus, obstructive sleep apnoea, and high LA pressure are clinical variables that predict the development of this syndrome [19]. The main echocardiographic findings include pulmonary hypertension in the absence of pulmonary vein stenosis or LA pressure tracings in the absence of mitral regurgitation. Pulmonary vein diastolic flow velocity (assessed by TTE or TOE) and E/Ea (by TTE using pulse wave Doppler and TDI) can be used as a noninvasive parameter predicting high

LA pressure peak (during sinus rhythm) in patients with AF [19]. Elevated LA pressure was closely associated with electroanatomical remodelling of the LA and was an independent predictor for recurrence after AF ablation [20, 21].

5. Conclusion

Multimodality echocardiography is needed at each step of AF ablation procedure. LA size, morphology, and function together with other cardiac parameters are mandatory for patient selection. 2D TTE allows rapid and comprehensive assessment of cardiac anatomical structure and function. 2D or 3D TOE provides accurate information about preprocedural LA appendage thrombus in the atria and thromboembolic risk and is very useful for intraprocedural guidance. The novel technique of ICE has emerged also as a popular and useful tool in the guidance of AF ablation procedure. TTE or TOE is need for early and late ablation-related complications detection and monitoring. In the future, echocardiography might be useful in thrombogenic endocardial remodelling assessment, a novel concept in atrial cardiomyopathies such as atrial fibrillation.

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