INTRODUCTION

Atrial fibrillation (AF) is the most common arrhythmia managed in clinical practice. Its incidence remains relatively low until around the seventh decade of life, but thereafter, the incidence increases exponentially. The overall prevalence of AF ranges between 1–2% in the general population. However, its prevalence is expected to double in the next 50 years because of the prolongation of life [1-3]. AF has been shown to be an independent predictor of cardiovascular and all-cause mortalities that primarily occur as a result of two complications: stroke and heart failure [4-10].

Aging, hypertension, body mass index, structural heart disease, heart failure, and pulmonary disease are recognized clinical risk factors for the development of AF [11]. Advances in cardiovascular imaging, including echocardiography, cardiac computed tomography (CT), and cardiac magnetic resonance imaging (MRI), have provided novel insights into the pathogenesis, prediction, and natural history of AF. Moreover, cardiovascular imaging has become an integral part of the pre-procedural assessment, procedural management, and follow-up of patients undergoing catheter-based ablation. We believe that knowledge and proper use of these cardiovascular imaging modalities will enhance the successful treatment and management of patients with AF.

Key words: Atrial fibrillation · Catheter ablation · Echocardiography · Multidetector computed tomography · Magnetic resonance Imaging.

The Role of Multimodality Cardiac Imaging in the Management of Patients with Atrial Fibrillation

Jung Im Jung
Department of Radiology, Seoul St. Mary’s Hospital, College of Medicine, The Catholic University of Korea, Seoul, Korea

Atrial fibrillation (AF) is the most common arrhythmia and is an independent risk factor for stroke, heart failure, and death. The prevalence of AF is expected to increase in the future due to increasing life expectancy. In this review, we describe and evaluate the utility of advanced cardiovascular imaging modalities, including echocardiography, cardiac computed tomography, and cardiac magnetic resonance imaging, to provide novel insights into the pathogenesis, prediction, and natural history of AF. Moreover, cardiovascular imaging has become an integral part of the pre-procedural assessment, procedural management, and follow-up of patients undergoing catheter-based ablation. We believe that knowledge and proper use of these cardiovascular imaging modalities will enhance the successful treatment and management of patients with AF.

PATHOGENESIS AND CLINICAL OVERVIEW OF ATRIAL FIBRILLATION

AF is classified into paroxysmal (converting spontaneously to sinus rhythm within 7 days), persistent (>7 days), longstanding persistent (>6 months), and permanent forms, in which no further attempts are made to restore sinus rhythm [16]. AF is initially paroxysmal and progresses to the persistent and permanent types. Annually, 5–15% of paroxysmal AF cases are thought to progress to persistent AF [17,18].

Herein, we review current evidence pertaining to the utility of advanced imaging modalities in AF.
main theories have been suggested regarding maintenance of AF. The first is multiwavelet reentry, which states that nonhierarchical wavelets give rise to fibrillatory conduction. The second is the localized source model, in which macroorganization in the form of spiral wave reentry (rotors) or focal sources causes secondary disorganization either inside or outside the PVs. PV isolation with catheter-based ablation is applied to block the trigger as the AF initiator as well as the AF-maintaining driver, while

Fig. 1. Atrial fibrillation likely results from trigger initiation and maintenance. (A) Triggers [red asterisk for pulmonary vein (PV) origin, and green stars for non-PV origin] are PV and non-PV in origin, with substrates in the form of fiber angles and ganglionated plexi enabling the formation of localized sources in the form of rotors. (B) The proposed mechanism for the maintenance of atrial fibrillation. Multiple wavelet reentry, with nonhierarchical wavelets giving rise to fibrillatory conduction of the atrium as widely distributed substrates. Focal drivers either inside or outside of the PVs, and rotor sources, or spiral wave reentry giving rise to localized sources, stable gradients of activation, and fibrillatory conduction in the rest of the atrium.

Fig. 2. Integration of an electroanatomic map and CT image. (A) Before left atrial (LA) ablation, CT images of the LA are obtained. (B) During the LA ablation procedure, the electroanatomic map is obtained using a mapping catheter. (C) Subsequently, the two images are merged with landmark registration and aligned. (D) After accurate registration of the two images, the catheter ablation procedure is performed under the guidance of the integrated images.
the MAZE operation is carried out to block multiwavelet reentry (Fig. 1) [22].

AF treatment first involves the evaluation of associated diseases; thereafter, anticoagulant therapy is started after the diagnosis of AF. Consequently, rate and rhythm control are also evaluated. Catheter-based ablation is considered if medical rhythm control fails. In case of refractory or medication-intolerant AF, catheter-based ablation is recommended as class IA according to the 2014 ACC/AHA/HRS guidelines [23].

The energy sources used for catheter-based ablation are radiofrequency, cryoenergy, and microwaves. Radiofrequency is the most popular type, and cryoenergy is the most recently introduced. The efficacy and safety of radiofrequency and cryoenergy are similar [24], with an equivalent one-year freedom from AF but shorter fluoroscopy times [25] and greater reproducibility with cryoballoon ablation [26].

Fig. 3. Anatomic variants of the pulmonary veins. (A) The right middle pulmonary vein (supernumerary right pulmonary vein) directly drains into the left atrium (arrows). The endoscopic view clearly visualizes the three orifices of the right superior pulmonary vein (RS), the right middle pulmonary vein (RM), and the right inferior pulmonary vein (RI). (B) The common ostium of the left pulmonary vein. The left superior (LS) and inferior (LI) pulmonary veins join to form a common trunk that drains into the left atrium. The endoscopic view shows the common trunk. (C) Right top pulmonary vein (arrows). An anomalous pulmonary vein arising from the roof of the left atrium and draining a superior part of the right upper lobe.
IMAGING ASSISTANCE FOR ATRIAL FIBRILLATION

Advanced cardiovascular imaging modalities have become an integral part of the preprocedural assessment, procedural management, and follow-up of patients undergoing catheter-based ablation and cardiac device implantation.

What assistance should we provide before left atrial ablation?

PVs are the most frequent foci of ectopic beats, and they initiate paroxysmal AF. Therefore, PV isolation, by removing the connection between the PV and the LA, is known to terminate AF [21]. To aid with PV isolation, the integration of electroanatomic mapping and anatomical imaging has been introduced. Among the several image integration systems, electroanatomic mapping and CT/MRI are the most commonly used [12,27]. Fig. 2 provides a simple illustration of the integration of electroanatomic mapping and CT imaging.

Preprocedural CT/MRI can also provide valuable information regarding the anatomy of the PV and LA, as well as the presence of contraindications for LA ablation, such as a thrombus or extreme LA dilatation [13,15].

Anatomy of the pulmonary vein

Before LA ablation, the anatomic variants, ostial diameter, and branching pattern of the PV are evaluated to prevent post-procedural complications, such as PV stenosis, and also to predict outcomes [15,28-30]. This is because PV diameter increases according to the progression of AF, with the largest diameters being seen in persistent AF [28].

PVs normally contain four branches that drain into the LA; the right superior PV, the right inferior PV, the left superior PV, and the left inferior PV. Anatomic variants of the PV are common and vary in frequency according to report. The most common variant is a right middle PV (supernumerary right PV), which has an incidence of 19–29%, followed by the common ostium of the left PV, right top PV (vertical PV), and common ostium of the right PV [31]. The right top PV is an anomalous PV arising from the roof of the LA in proximity to the right superior PV, presum-

Fig. 4. Endoscopic view is helpful to determine the pulmonary vein ostium. It is difficult to determine whether the right middle pulmonary vein (arrows) is separately drained or conjoined with the right superior pulmonary vein (RS) on multiplanar reformatted images (A) and volume-rendered images (B). The endoscopic view (C) reveals two orifices of the right superior and inferior pulmonary veins, which suggests that the right middle pulmonary vein is conjoined with the RS before left atrium drainage. RI: right inferior pulmonary vein.
ably draining a posterior segment of the right upper lobe (Fig. 3) [32]. A small ostial diameter less than 1 cm, a right top PV, and an early branching pattern within 1 cm of PV bifurcation or within 5 mm from the ostium of the main PV are factors that lead to stenosis after catheter ablation [28]. Cardiac CT and cardiac magnetic resonance (CMR) clearly demonstrate PVs. PV venography and transesophageal echocardiography (TEE) underestimate the diameter of the PV [15,28]. The ostial diameter of the PV changes according to the cardiac cycle, decreasing by around 32.5% of the ostial size during atrial systole [33]. The ostial diameter and distance from the ostium to the first branch can be measured on multiplanar reformatted and volume-rendered images. However, it is often difficult to identify the ostium. Therefore, an endoscopic view is helpful in identifying the precise draining ostium, irrespective of whether these drain separately or in a conjoint manner (Fig. 4).

PV anatomy is a powerful predictor of AF recurrence after LA ablation in cases of paroxysmal AF. McLellan et al. [34] reported that the left common PV or right middle PV was protective against AF recurrence.

Left atrial volume, left atrial thrombus, and left atrial anatomic variants

LA volume is a strong and independent predictor of AF recurrence after ablation [11,13,15]. Traditionally, LA dimensions and volumes are measured using echocardiography; its longitudinal diameter is 4.5±1.4 cm, and its transverse diameter is 4.0±1.2 cm (Fig. 5A) [35]. LA volume is traditionally calculated using the area-length and biplane Simpson’s method with two-dimensional (2D) echocardiography (Fig. 5B), but it is inherently inaccurate due to several geometric assumptions [30]. LA volume measured using echocardiography is smaller than that measured using cardiac CT by approximately 30–40 mL (25–30% of the total volume) [36]. The recently introduced real-time, three-dimensional (3D) echocardiography may overcome the limitation of 2D echocardiography [37].

LA volume measurement using cardiac CT is accurate and reproducible and is also a more independent predictor of AF rec-

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**Fig. 5.** Left atrium volume measurements with echocardiography (A and B) and cardiac CT (C).

**Fig. 6.** Flow stasis mimicking a thrombus in the left atrial auricle on CT. Cardiac CT (A) shows a low-density filling defect in the left atrial appendage (arrow). Transesophageal echocardiography (B) shows no thrombus (arrow). The filling defect in the left atrial appendage on CT is considered a flow stasis.
occurrence after ablation despite the increased risk of radiation exposure. Parikh et al. [38] revealed that a LA volume $\geq 117 \text{ mL}$ obtained through cardiac CT was associated with high odds of AF recurrence, and a LA volume $>130 \text{ mL}$ was associated with a $>90\%$ failure rate after adjustment for persistent AF. When LA volume is measured using CMR with cine images, similar findings to cardiac CT (LA volume $\geq 112 \text{ mL}$ had 80% sensitivity, 70% specificity, and area under the curve, 0.75) have been noted [39]. Automated quantification of LA volume using cardiac CT is a feasible, accurate, and fast technique, with low interobserver variability (Fig. 5C) [40].

LA thrombus is a contraindication for catheter-based LA ablation and is a common cause of stroke. TEE is a diagnostic standard for LA thrombus. However, for a proper diagnosis, TEE requires sedation and technical expertise. Cardiac CT is a very sensitive modality for detecting intracardiac structures, including thrombi. However, cardiac CT shows low sensitivity and only a modest specificity because of the circulatory stasis of the LA appendage (LAA). Therefore, if a LAA thrombus is suspected on CT, then confirmation with TEE is still necessary (Fig. 6) [41].

To overcome circulatory artifacts, two methods have been introduced: two-phase cardiac CT and dual-enhanced cardiac CT. Two-phase cardiac CT involves two scans: early phase imaging to evaluate the coronary arteries and the intracardiac thrombus and late-phase imaging to differentiate thrombi from circulatory stasis. It shows excellent sensitivity (100%) and specificity (98%). However, additional radiation exposure is a limitation of this technique [42]. Dual-enhanced cardiac CT involves double injection of the contrast agent, and the scan is performed only once in the late phase, 180 s after administering the first contrast bolus. The overall sensitivity and specificity of CT for the detection of thrombi and circulatory stasis in the LAA are 96% and 100%, respectively. However, the need for additional contrast administration is its limitation [43]. Hur et al. [44] also reported that dual-energy CT allows the differentiation of thrombi from spontaneous echo contrast in patients with stroke; hence, it is a highly sensitive modality for detecting LAA thrombi.

CMR is another noninvasive modality for identifying thrombi, but limited data are available regarding its use for evaluating the LAA [30]. On the basis of their study, Ohyama et al. [45] reported that CMR correctly identified all 16 patients with thrombi on TEE, but also produced three false-positive results among 50 patients (negative predictive value, 100%; positive predictive value, 84%), with an overall agreement of $K=0.88$. However, identification of spontaneous echo contrast was suboptimal.

In our practice, we frequently encountered the LA diverticulum or accessory LAA, which is quite common with a prevalence of 36% in patients with AF. However, the prevalence of the LA diverticulum or accessory LAA in patients with AF is not higher than that in patients without AF. The most frequent lo-

**Fig. 7.** The left atrium diverticulum (A) and accessory left atrial appendage (B). The difference between the diverticulum and accessory left atrial appendage (B, arrow) is the presence of trabeculation. These structures are located at the superior anterior wall of the left atrium close to the common ablation site.
Fig. 8. Pulmonary vein stenosis after radiofrequency ablation (RFA). Cardiac CT following RFA shows occlusion of the left superior pulmonary vein (A) and narrowing of the other pulmonary veins (B and C) (arrows). The before (left) and after (right) volume-rendered images clearly show pulmonary vein stenosis (D). Lung perfusion (E) reveals multifocal perfusion defects due to pulmonary vein occlusion and stenosis.
cation of the LA diverticulum or accessory LAA is the superior anterior wall of the LA, close to the common ablation site [46]. Identification of the presence and location of the LA diverticulum or accessory LAA is important (Fig. 7).

**What assistance should we provide after catheter-based left atrial ablation?**

The incidence of complications after LA ablation varies across institutions. Serious complications occur in up to 6% of the patients. PV stenosis is the most common complication, occurring in up to 19% of the patients, and most patients are asymptomatic. Symptomatic PV stenosis is less frequent at 1% (Fig. 8) [47,48]. Severe pericardial effusion or cardiac tamponade and esophageal injury can also occur [49]. Those complications are evaluated using CT or MRI.

Because the esophagus closely contacts the posterior LA wall and left-side PV, esophageal injury can occur during LA ablation and can be critical. Atrioesophageal fistula is a rare complication in such cases, and it can be fatal. Moreover, there is a latent period between this fatal complication and the causal procedure. The diagnostic triad of atrioesophageal fistula includes fever, neurologic symptoms, and a recent history of LA ablation. The investigation of choice is chest CT, and TEE must be avoided. Treatment with urgent surgery is mandatory, but the outcome is generally poor (Fig. 9) [50].

If the esophagus is too close to the ablation line and there is no fat pad between the esophagus and the LA, the procedure should be performed very carefully. However, predicting esophageal injury is difficult because the esophagus is motile during the procedure [51,52].

**What further assistance should we provide in the treatment of atrial fibrillation?**

AF is related to cardiovascular disease and stroke. Advances in cardiovascular imaging have helped identify those risks and guide new treatment modalities like LAA occlusion. CMRI can be used to evaluate LA fibrosis, localize the AF trigger, and predict the recurrence of AF after catheter-based ablation.

**Cardiovascular disease**

Valvular heart disease, coronary artery disease (CAD), hypertension, and congestive heart failure are recognized risk factors for the development of AF. Novel echocardiographic techniques are used for evaluating the risk factors associated with cardiovascular disease.

Cardiac CT can be used for evaluating CAD, but its usage has been debated. Because of the poor quality of cardiac CT images acquired in patients with AF, the detection of CAD in patients with arrhythmias is considered inappropriate according to the 2010 appropriate use criteria for cardiac CT [53]. However, recent advances in cardiac CT have enabled the acquisition of useful coronary images in patients with AF. On the basis of their systematic review and meta-analysis of diagnostic accuracy and radiation dose, Vorre and Abdulla [54] reported that the diagnostic accuracy of CT coronary angiography in AF was good (sensitivity, 94%; specificity, 91%; positive predictive value, 79%; and negative predictive value, 97.5%) even though the radiation dose was significantly higher in patients with AF than in those with sinus rhythm, with a mean difference of 4.03 mSv. However, Schuetz et al. [55] opposed that result. They pointed out that the diagnostic performance of CT coronary angiography is overestimated because, although non-diagnostic test results are commonly encountered, they are infrequently and variably reported (Fig. 10). In addition to full coverage of the heart, an improvement in the temporal resolution of CT coronary angiography may enable the evaluation of CAD in patients with AF.

Fig. 9. The atrioesophageal fistula after radiofrequency ablation. A 70-year-old man presented with fever, chills, and decreased mentality. He had received radiofrequency ablation due to recurrent atrial fibrillation 12 days before admission. Brain MRI with diffusion image reveals multifocal embolic infarction (A). Chest CT shows air bubbles in the left atrium (arrow), suggesting an atrioesophageal fistula (B). Although an emergency operation was performed, the patient died.
Fig. 10. Controversial findings in the diagnosis of coronary artery disease with CT coronary angiography in a patient with atrial fibrillation. CT coronary angiography in a 62-year-old woman with atrial fibrillation shows severe stair-step artifacts due to irregular heartbeats (A). Note the stenosis in the middle left anterior descending artery, distal left circumflex artery, and middle right coronary artery (mRCA) (B, C, and D; white arrows). However, another stenosis in the mRCA (D, black arrow) was overlooked during the initial interpretation but was confirmed on coronary angiography (E, arrows). This lesion might have been missed because of overlapping artifacts.
Left atrial appendage morphology and percutaneous left atrial appendage closure

The LAA has variable shapes and number of lobes, and is often an area of thrombus formation (Fig. 11). Di Biase et al. [56] evaluated the relationship between LAA morphology and the risk of stroke. They identified four different types of LAAs: 1) cactus (30%), 2) chicken wing (48%), 3) windsock (19%), and 4) cauliflower (3%). The LAA with chicken wing morphology portended a lower risk of embolism, while LAA with cauliflower morphology portended the highest risk of embolism. The ex-

![Fig. 11. Different types of left atrial appendages. Cactus (A), chicken wing (B), windsock (C), and cauliflower (D). The left atrial appendage is rarely absent (E). Endoscopic view (F) shows a blind pouch with a small remnant pit (arrow) at the left atrial appendage site.](image-url)
tent of LAA trabeculations and smaller LAA orifice diameters are associated with prevalent stroke [57]. However, the impact of these different morphologies on the procedural outcome following LAA closure remains controversial [58]. Subsequent studies focused on determining the thromboembolic risk after AF catheter ablation have failed to replicate these results or have even contradicted this observation [59,60].

Recently, percutaneous LAA closure has been introduced for patients with difficult-to-treat AF or intolerance to warfarin therapy [58]. Randomized studies using the LAA occluder device (Watchman left atrial appendage system for embolic PROTECTION in patients with Atrial Fibrillation, PROTECT-AF trial) have confirmed the non-inferiority of LAA occlusion compared with oral warfarin therapy with regard to the primary composite endpoint of stroke, cardiovascular or unexplained death, and all-cause death [61-63]. In the randomized PREVAIL (Evaluation of the Watchman Left Atrial Appendage Closure Device in Patients with Atrial Fibrillation versus Long-term Warfarin Therapy) trial, which was a continuation of the PROTECT-AF trial, LAA occlusion was non-inferiority to warfarin therapy for ischemic stroke prevention or systemic embolism >7 days after the procedure. Although non-inferiority was not achieved for the overall efficacy, the event rates were low and numerically comparable in two treatment arms (device implantation vs. chronic warfarin therapy) [64]. The European guideline for the management of AF now recommends that percutaneous LAA closure may be considered in patients with a high risk of stroke having contraindications for long-term oral anticoagulation therapy (class-IIb indication: level of evidence, B) [65].

Currently, three devices [Amplatzer Cardiac Plug (St. Jude Medical, Inc., St. Paul, MN, USA), the Watchman device (Boston Scientific, Natick, MA, USA) and the flexible LAA occlusion device Coherex WaveCrest (Coherex Medical, Inc., Salt Lake City, UT, USA)] are available for percutaneous implantation within the LAA, together with a suture-based technology (LARIAT suture device, SentreHEART, Inc., Redwood City, CA, USA) to occlude the LAA.

Before an LAA closure procedure, various imaging modalities are used for preprocedural planning. 2D and 3D transthoracic echocardiography are used to evaluate LA dimensions and volumes as well as LV function. Moreover, these techniques are used to exclude contraindications for LAA closure or significant valve disease requiring surgery, as well as to exclude patients with LV thrombus or a mechanical heart valve who require chronic anticoagulation. Preprocedural TEE is the main imaging modality used to exclude thrombi in the LA and LAA.

Cardiac CT is an emerging tool for guidance in percutaneous LAA closure; it allows for complete volumetric evaluation of the LAA and has good spatial orientation relative to important neighboring structures, including the mitral valve and PVs [66,67]. The ostial perimeter of the LAA measured by cardiac CT is the most reproducible parameter for sizing an LAA occluder, rather than the measurement of LAA maximum diameter [68,69]. The use of CT imaging is also not limited to preprocedural planning; it could also be used to assess device position, complete occlusion of the LAA, and device-related complications such as thrombosis and para-device leak (Fig. 12) [70].

CMR is an alternative noninvasive method. However, it has several limitations, including low spatial resolution, prolonged examination time, dependence on the ability to perform adequate breath holds, and limited scope for use in patients with implanted pacemakers or defibrillators. Nevertheless, it has the advantages of no radiation exposure and no need for administration of iodinated contrast agents, as required in cardiac CT [58].

Left atrial fibrosis and left atrial function
LA fibrosis leads to the development of AF. CMR is the method of choice for detecting LA fibrosis. Oakes et al. [71] reported that the extent of delayed enhancement of LA is associated with the clinical type of AF, procedural outcome, and AF recurrence.

![Fig. 12. Percutaneous left atrial appendage occlusion. (A) Left atrial appendage diameter is measured at the ostium and also at a depth of 10 mm from the ostium via transesophageal echocardiography at 120°. (B) Cardiac CT provides the ostial perimeter. (C) Cardiac CT after Amplatzer cardiac plug insertion shows a thrombus in the left atrial appendage. Note the small para-device leak in the inferior aspect (arrow).](image-url)
after ablation. In the multicenter Delayed-enhancement MRI Determinant of Successful Radiofrequency Catheter Ablation of Atrial Fibrillation trial in which 329 patients prospectively underwent late gadolinium-enhanced (LGE) CMR within 30 days prior to AF catheter ablation, the authors categorized patients into four groups according to the extent of preablation enhancement: stage 1 (atrial fibrosis burden <10%), stage 2 (10–20%), stage 3 (20–30%), and stage 4 (> 30%). The cumulative incidence of AF recurrence at day 47 after ablation was 15% for stage 1, 36% for stage 2, 46% for stage 3, and 69% for stage 4. These results suggest that the degree of LA fibrosis quantified using LGE CMR might be used to stratify the recurrence risk and, therefore, personalize the therapeutic strategy for each patient [72].

Fig. 13. Cardiac magnetic resonance imaging (MRI) with late gadolinium enhancement (LGE) demonstrates atrial fibrosis (AF) after catheter ablation. A 54-year-old man was admitted because of recurrent AF. Cardiac MRI with LGE shows incomplete isolation of the right superior pulmonary vein (arrows) (A and B), which correlated well with the voltage map (C). Repeat catheter ablation was performed to isolate the right superior pulmonary vein (D, arrow) according to the LGE findings (Figure courtesy of Sung Ho Hwang, Korea University Anam Hospital).
While the presence of a significant LA fibrosis/scar before ablation is associated with worse outcomes, the presence of a scar after AF ablation is associated with higher odds of freedom from AF recurrence at the 3-month follow-up [73]. If PV ostia are completely encircled by a scar, the recurrence of AF is low (Fig. 13) [74]. However, this is difficult to achieve, with only 7% of the patients having complete scarring of all veins in one study [75].

Although LGE CMR is a promising method for detecting LA scars, its findings are difficult to generalize because identifying a thin-walled atrium is challenging with LGE CMR owing to its low spatial resolution. Recently, a high-resolution LGE CMR sequence, the 3D respiratory-navigated sequence, has been introduced and allows for isotropic spatial resolution [73]. However, this method is still technically challenging and has a long post-processing time. Moreover, LGE imaging does not seem to provide accurate information regarding the location of PV reconnection sites in patients undergoing repeat ablation for AF [76]. Hunter et al. [77] recently concluded that LGE CMR is not yet sufficiently accurate to reliably assess the post-ablation lesion distribution.

Many researchers are also interested in LA function. Park et al. [78] reported that different components of the LA have different functions. The LA can be divided into three different parts according to their embryological origin: anterior, posterior including PV, and LAA. In patients with persistent AF, the posterior compartment shows a markedly decreased ejection fraction and paradoxical movement. This pattern might indicate that LA structural remodeling is often accompanied by a change in LA function with a progressive increase in interstitial fibrosis [70]. Recently, Hirose et al. [79] reported that the LA booster pump function was a much better predictor of new-onset AF than was LA dimension or LA volume. Therefore, a reduction in LA booster pump function might be a manifestation of LA mechanical remodeling that leads to the development of new-onset AF and could progress to the complete loss of booster function in patients with permanent AF.

**Epicardial adipose tissue and atrial fibrillation**

Research conducted during the past few decades has provided increasing evidence of the relationships between epicardial adipose tissue and coronary atherosclerosis, cardiovascular outcomes, and heart disease, such as AF [80,81]. The mechanism underlying this relationship has not been reliably identified, but the metabolic properties of epicardial fat seem to play a role. Obesity is increasingly being recognized as a risk factor for AF [80,82-84]. Researchers have intensely investigated the AF burden in obese patients and whether the levels of localized cardiac ectopic fat in obesity are more predictive of cardiovascular disease than traditional measures [70]. Several imaging modalities, such as echocardiography, cardiac CT, and CMR, can be used to quantify epicardial adipose tissue. Cardiac CT is the preferred measurement modality because of its high spatial resolution and true volume coverage of the heart (Fig. 14) [81,85].

**CONCLUSION**

The AF burden has been increasing as the population ages. Innovations and advances in noninvasive cardiovascular imaging have helped guide therapeutic procedures in patients with AF. Although echocardiography is a basic diagnostic tool, it is a valuable resource in the treatment and management of AF, especially when used in combination with cardiac CT and MRI, which are emerging diagnostic tools for AF. Knowledge and proper use of these tools will enhance the success of treatment and enable appropriate management of patients with AF.

**Conflicts of Interest**

The author declare that they has no conflict of interest.
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