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EDITORIAL

MDCT in the diagnostic algorithm in patients with symptomatic atrial fibrillation

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Abstract

Atrial fibrillation (AF) is the most common supraventricular arrhythmia and a major cause of morbidity. Arrhythmogenic foci originating within the pulmonary veins (PVs) are an important cause of both paroxysmal and persistent AF. A variety of endovascular and surgical techniques have been used to electrically isolate the PV from the left atrium. Pulmonary venography for localization of the PV ostium can be difficult to perform during the ablation procedure. While the anatomy of the PV is patient-specific, non-invasive imaging techniques may provide useful diagnostic information prior to the intended intervention. In this context, multidetector computed tomography (MDCT) visualization of the left atrial and PV anatomy prior to left atrial ablation and PV isolation is becoming increasingly important. MDCT imaging provides pre-procedural information on the left atrial anatomy, including atrial size and venous attachments, and it may identify potential post-procedural complications, such as pulmonary vein stenosis or cardiac perforations. Here, we review the relevant literature and present the current "state-of-the-art" of left atrial anatomy, PV ostia as well as the clinical aspects of refractory AF with MDCT imaging protocols and procedural aspects of PV ablation.

Key words: Atrial fibrillation; Multidetector computed tomography; Pulmonary veins; Pulmonary vein ablation

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INTRODUCTION

Radiofrequency catheter ablation (RFCA) is a potentially curative treatment modality for atrial fibrillation (AF) originating in the pulmonary veins (PVs)[1]. RFCA for AF can be employed to either eliminate ectopic pulmonary venous foci or electrically isolate the PVs[2-4]. For precise application of radiofrequency lesions, accurate visualization and knowledge about the individual pulmonary vein (PV) anat-

omy is necessary. For this purpose, the value of different imaging techniques to guide RFCA procedures is increasingly recognized. However, there is still considerable debate about the ideal diagnostic imaging tool for PV isolation[5-7].

Real-time acquisition of anatomic information on left atrial and PV anatomy can be obtained by intracardiac echocardiography (ICE)[8,9]. Advantages of this imaging technique include the possibility to obtain *in vivo* information of left atrial anatomy including the PVs in relation to the position of the ablation catheter. Furthermore, ICE facilitates a save transseptal puncture, and allows monitoring for acute complications, e.g. pericardial effusion.

Alternatively, for the acquisition of anatomic information of PV anatomy before RFCA, three-dimensional (3-D) imaging techniques such as multidetector computed tomography (MDCT), cardiac MRI (CMR) and cardiac C-arm computed tomography have been applied[5,6]. MDCT has been proven to provide accurate and detailed information on PV anatomy[7]. CMR imaging has been applied to detect anomalous insertion of PVs and to evaluate PV stenosis after RFCA[10-12]. The advantage of CMR imaging is the lack of ionizing radiation exposure. Nevertheless, there are several relative contraindications of CMR. Thus, MR imaging can not generally be performed in patients with claustrophobia or pacemakers, or in patients who cannot tolerate the considerably longer imaging times of MR imaging.

Accordingly, the purpose of our review was to evaluate the current role of MDCT to provide a "road map" for subsequent RFCA (Figure 1).

ATRIAL FIBRILLATION

AF usually starts as a paroxysmal arrhythmia, with approximately 60% of patients converting spontaneously to sinus rhythm (SR). Approximately 40% of patients develop persistent AF requiring medical or electrical intervention to restore SR[13]. Up to 50% of patients develop recurrent AF within the first year of onset[13,14]. Patients with AF have a mortality rate twice that of control subjects and are exposed to considerable morbidity, such as stroke[13,14]. The leading symptoms associated with AF are palpitations, reduced exercise capacity and exertional dyspnoea, and are related to the rapid and irregular ventricular rate.

The major complication of AF is the formation of atrial thrombi with the risk of systemic embolization, placing these patients at considerable risk for stroke. The electrocardiographic characteristics of AF are an undulating baseline EKG with absent P waves, an atrial rate of 300-600 beats per minute, and an irregular ventricular response. Paroxysmal AF is usually found in the absence of structural heart disease. Over the years it may progress to persistent AF if substantial atrial remodelling has occurred. AF is considered persistent if it lasts for more than 7 d or if it requires cardioversion for termination. Atrial fibrillation is usually treated first with antiarrhythmic drugs. However, the use of these drugs is limited by relatively low efficacy and by the potential for proarrhythmic side effects[13]. Cardioversion has a high initial success rate for treatment of AF, especially in patients with a recent onset, but it is associated with a recurrence rate of 60% at 6 mo after treatment[14]. Thus, both pharmacologic therapy and cardioversion have demonstrated only limited success in preserving SR during long-term follow-up[14].

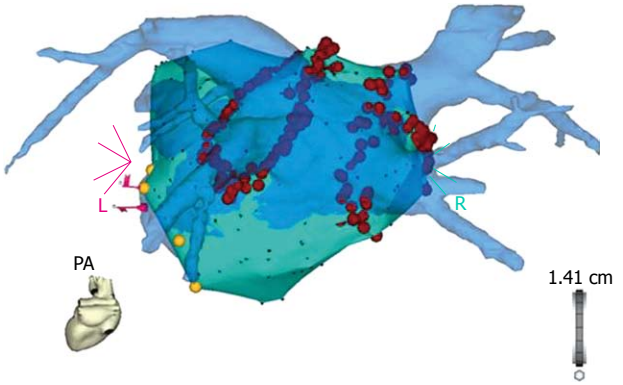

Figure 1 The blue 3D anatomical shell of the left atrium and the pulmonary veins, as acquired by pre-procedural computed tomography, is merged with the grey anatomical shell that was constructed with electro-anatomical mapping during the procedure (CARTO merge). Note the red ablation tags which mark the circumferential ablation lesions around the pulmonary vein ostia.

RELATION BETWEEN LEFT ATRIAL, PULMONARY VENOUS ANATOMY AND ATRIAL FIBRILLATION

It has been known for some time that the muscular sleeves of the distal PV are a frequent source for ectopic foci[1], with the left superior PV accounting for half of the ectopic foci initiating AF[5,6,14]. In these patients, the myocardium of the left atrium appears to extend a variable distance into the distal PV, and this is the region of interest which appears to be the origin of the ectopic discharges[14,15]. Thus, the treatment of AF is now focusing on the interruption of the conduction pathways by wide circumferential ablation around the PV ostia[16-18] (Figure 1). RFCA consists of placing a catheter with an ablation electrode at its tip into the left atrium, *via* percutaneous femoral vein access. This special catheter is forwarded through the inferior vena cava and into the right atrium under fluoroscopic monitoring. Subsequently, the catheter is advanced into the left atrium *via* a transseptal puncture. The ablation procedure itself, even in the most experienced hands, is tedious and usually lasts several hours[4].

IMAGING BEFORE RFCA

In RFCA, a significant portion of the procedural fluoroscopy time is spent imaging the PV anatomy if no other imaging technique is utilized[2-4]. Fluoroscopic imaging of the PV anatomy is achieved either by retrograde application of contrast material into the distal PVs or indirectly by positioning a circular mapping catheter within the PV. Difficulty may arise, however, in establishing all the

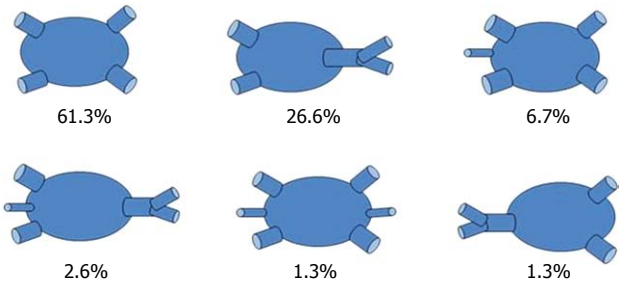

Figure 2 Variants of the left atrium and pulmonary vein-anatomy.

necessary anatomic information if only fluoroscopy is used. ICE is useful, and does not increase the radiation burden, but the echocardiographic transducer has a small field of view and this may be inadequate for visualizing the relationships between the left atrial wall and distal PV, especially when the left atrium is dilated[14]. Furthermore, ICE probes are expensive and require an invasive access[14]. Successful RFCA outcome is not only defined by elimination of AF but also by minimizing complications, and both require a precise understanding of the complex atrio-pulmonary venous anatomy. Unfortunately, the classical anatomy is found in only 70% of cases[14]. The remaining 30% of individuals have pulmonary venous anatomic variants; thus, imaging provides an important "road map" for the electrophysiologist (Figure 2). Successful pre-interventional imaging includes identification of the number, location and angulations of the PVs. In addition, exclusion of atrial or atrial appendage thrombi is mandatory, because their presence is a contraindication for the ablation procedure.

ANATOMIC CONSIDERATIONS

By application of MDCT imaging, the PV ostium needs to be identified at its juncture with the left atrium (Figure 1). The location, length and number of veins also need to be identified (Figure 2). Today, electro-anatomic mapping systems (e.g. CARTO, Biosense Webster; NavX SJM,) are utilized for real-time anatomical reconstruction of the left atrium (LA) in many centres. The technology and the technique have also been described in detail earlier[19,20]. The operator manually places the catheter tip in stable endocardial contact at multiple (at least 50) locations throughout the LA. A three-dimensional virtual shell of the mapped chamber is created by software interpolation over the coordinates of multiple endocardial points, and its volume is automatically reconstructed and "merged" with previously acquired images, e.g. a CT image of the LA (Figure 1).

Radiologists commonly divide PVs into segments, with a segment defined as the vein from the ostium to its first branch point. An ostial branch is defined as a venous branch within 5 mm of the atriopulmonary venous junction. The intervenous carina is identified as the portion of the atrial wall interposed between separate ipsilateral PVs[15]. Classically, there are four PVs with separate ostia into the left atrium. However, accessory PV can be present. A common or conjoined vein occurs when superior and inferior veins join proximal to the left atrium, resulting in a single atriopulmonary venous orifice on the involved side. In contrast, supernumerary or accessory PVs are additional veins with independent atriopulmonary venous junctions separate from the superior and inferior PVs. Conjoined veins occur more commonly on the left side, which is the side more frequently targeted for ablation[15]. Conjoined veins typically have a broad, atriopulmonary venous junction. Accessory veins occur more frequently on the right side. In this case, separate drainage of the right middle lobe or superior segment of the right lower lobe are the most frequent[15]. Accessory veins are named for the respective pulmonary lobe or segment that they drain, and these sometimes cross pulmonary lobar fissures before emptying into the left atrium. Accessory veins typically have a narrower atriopulmonary venous junction than the superior and inferior PV. Anomalous pulmonary venous drainage occurs when all or part of the PV drain into a structure other than the left atrium. If no PV drains into the left atrium, there is total anomalous PV return. Partial anomalous PV return occurs when at least one PV drains into the left atrium.

CIRCUMFERENTIAL PULMONARY VEIN ABLATION

Circumferential pulmonary vein ablation (CPVA) is the standard procedure performed in many centres (Figure 1). The procedure is in general performed by manual catheters or remotely by soft magnetic catheters[16-18]. CPVA consists of large circumferential lesion lines to ensure a point-by-point tailored distal disconnection of all PVs (Figure 1). Accumulating data from larger studies indicate that among patients with paroxysmal or persistent AF without enlarged atria, CPVA alone is associated with an excellent outcome. Additional atrial ablation lesions may be required to achieve stable sinus rhythm in patients with long-lasting, persistent, or permanent AF and enlarged atria[16-21].

COMPLICATIONS AFTER ABLATION

Complications during or immediately after the ablation procedure include pericardial effusion and embolic events in 1%-4% of patients[14,22]. The radiologist may encounter these complications on chest radiographs or head CT scans after the procedure. Pulmonary dysfunction and bleeding resulting from anticoagulation may also occur[23-25]. Circumferential PV isolation rarely causes symptomatic PV stenosis[25]. Scharf *et al*[26] showed that 3% of patients have stenosis of up to 65% luminal diameter narrowing but remain asymptomatic. They also showed that some patients have PV dilatation after CPVA. Severe PV stenosis (Figure 3) is described in 11% of patients[22,23] and has been reported to cause pulmonary veno-occlusive disease in three patients[24,26]. Clinically, symptomatic PV stenosis may present with dyspnoea on exertion or manifest

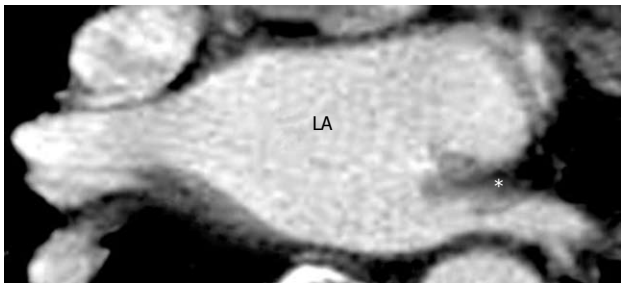

Figure 3 Axial multidetector computed tomography image of the area around a pulmonary vein stenosis (*) into the left inferior pulmonary vein in a 66-year-old male patient with dyspnea and chest discomfort 3 mo after pulmonary vein ablation. LA: Left atrium.

as focal pulmonary oedema on chest radiographs or CT scans or as PV luminal narrowing on CT images. Ablation is performed at or within 5 mm of PV ostia to reduce the risk of PV stenosis. Ablation inside the PV increases the risk of stenosis and increases the difficulty in treating stenosis. Stenosis after ablation (Figure 3) is not predicted by the initial PV size or total duration of radiofrequency energy application delivered to the vein, but instead by catheter position. The more distal the catheter from the ostium, the greater the degree of narrowing created[27]. The left inferior PV is most susceptible to the development of narrowing because of the more medial and posterior location of its ostia, therefore, projecting inside the cardiac silhouette on standard imaging and fluoroscopy. As a consequence, more energy may be delivered inside the vein distal to the ostium. CT before the procedure is helpful to clearly identify the position of the left inferior pulmonary vein ostium. Pulmonary vein stenosis may also be associated with pulmonary vein thrombosis[24]. Thrombus formation has been reported to occur from 1 d to 3 mo after RFCA, with an embolism rate of 2% despite adequate anticoagulation therapy. Therefore, patients receive anticoagulation during the procedure and post-operatively for approximately 1 mo[22]. Chest radiographs may show evidence of focal pulmonary oedema distal to the occluded vein. Recently, the optimal method for diagnosis of PV stenosis was not established[28]. In an analysis by Stavrakis *et al*[28] they came to the conclusion that in comparison with CT or MRI, TEE has a high sensitivity and specificity in detecting PV stenosis. Given its wide availability and favourable side effect profile, their data suggest that TEE is a very useful tool for the diagnosis of PV stenosis after catheter ablation of AF[28]. CT angiography or MR angiography can be used to diagnose PV occlusion noninvasively. Infarction may result in wedge-shaped parenchymal consolidation. CT may also show interlobular septal thickening and ground-glass opacity as a result of localized pulmonary venous hypertension. Reactive regional mediastinal lymph node enlargement may also occur as a result of mediastinal inflammation and fibrosis from thermal injury[29,30]. Furthermore, a detailed list of the different complications related to RFCA in AF reported with their relative incidence is shown in Table 1.

Table 1 Complications related to radiofrequency ablation in atrial fibrillation

Complication type (relative incidence)
Pulmonary veins
Pulmonary vein stenosis (1.5%-42.4%)
Pulmonary vein thrombosis
Pulmonary vein dissection
Lungs and pleura
Pulmonary hypertension (11%)
Pneumothorax (0.02%)
Hemothorax (1.3%)
Heart and pericardium
Pericarditis (3%-4.8%)
Hemopericardium, cardiac tamponade (1%-1.3%)
ST-T wave changes (3%)
Coronary artery spasm
Valvular damage (0.01%)
Other
Stroke (0.28%)
Transient ischemic attack (0.66%)
Pain or discomfort during radiofrequency energy delivery
Systemic thromboembolism (cerebral, retinal, or peripheral) (1.4%-2.6%)
Permanent diaphragmatic paralysis (0.11%)
Hematoma at puncture site (13%)
Cutaneous radiation damage
Arteriovenous fistula (1%)
Indirect
Aspiration-induced pneumonia
Sepsis (0.01%)

MULTIDETECTOR-ROW CT PROTOCOL

Contrast medium-enhanced spiral CT of the PVs ideally should be performed with a MDCT scanner and with the patient in sustained deep inspiration. Collimation of 1.5-2.5 mm is appropriate for demonstration of all PVs on axial or reformatted sections. Acquisition should begin 20 s after intravenous injection of 100 mL of 30% iodine-based contrast medium at a flow rate of 3 mL/s. A bolus test or bolus monitoring with triggering may be used to reduce the amount of contrast medium needed. Three-dimensional or multiplanar reformations are useful for analysis of the atrial-venous junction. ECG gating is not mandatory. With gated examinations, 1.25-mm collimation, 500-ms scans triggered at 50%-70% R–R interval are preferred. For non-gated examinations, images can be acquired at a collimation of 2.5 mm and a 25-cm field of view. If heart rates are rapid, drug therapy may be indicated to decrease heart rates to below 93 beats per minute to facilitate ECG gating[31-33].

The images commonly encompass an area from the top of the aortic arch through the apex during a single breath-hold. Once generated, the data are transferred to a workstation for post-processing with lung and soft-tissue algorithm displays.

POST-PROCESSING

From the source images it is usually possible to identify the

primary PV, along with any associated anatomic variants, including pulmonary lobe or segmental accessory vessels. The anteroposterior diameters of the PV ostia are routinely measured. On the initial source images, it is important that the left atrium and left atrial appendage are also scrutinized for thrombi. Both epicardial and endocardial reconstructed views of the left atrium and distal PV are obtained, including surface-rendered views of the left atrium. It is also important that the reconstructed views include the entire left atrium and the distal 2 cm of the PVs, but exclude the remainder of the heart, pulmonary arteries, aorta and superior and inferior venae cavae. Sufficient views are needed to clearly depict atrial size, shape and the number and angulation of PVs, as well as the location of any ostial branches. Shaded-surface displays (SSDs) are often preferred, in order to calculate left atrial volumes and atrial dimensions. In a study by Schroeder *et al*[34] and Marom *et al*[35], it was shown that 71% of 142 patients had two ostia on the right side and 28% (56 patients) had three to five. Also, 2% (three patients) had a single right ostium. For the left side, 86% of 173 patients had two ostia and 14% had a single ostium. Individuals with an accessory ostium for the right middle lobe tended to have a higher frequency of atrial arrhythmias[34,35]. Endocardial views are needed to show the anatomy from an intra-atrial perspective and ostial measurements and the distance between ostia are important to document[15] (Figure 1). Accurate measurements are necessary, since different-sized electrodes are used for different ostial diameters. Measurements are also needed to provide baseline dimensions in the case of post-RFCA stenosis.

CMR IMAGING

Several studies demonstrated that AF is associated with electrical, contractile, and structural remodelling (SMR) in the left atrium (LA) which contributes to the persistence and sustainability of AF[1-4]. It has also been shown that the final result of this remodelling process is loss of atrial myocytes and increased collagen content, and hence fibrosis of the LA wall[36]. Delayed enhancement MRI (DE-MRI) using gadolinium contrast has been demonstrated to localize and quantify the degree of SRM and fibrosis associated with AF in the LA. Basically, DE-MRI has also been shown to be useful in localizing and quantifying scar tissue in the LA following radiofrequency ablation (RFA)[37]. Furthermore, the PV antral region can be visualized to assess circumferential PV scarring resulting from RFA lesions/ablation. In addition, the amount of scarring to the LA after catheter ablation can be quantified as a proportion of the total left atrial volume. Recently, methods for merging MR anatomical data with electrophysiological anatomic data have been introduced, motivated by the possibility that a more accurate depiction of anatomy might improve the speed, effectiveness and success rate of the ablation procedure, and to reduce procedure time[38].

CONCLUSION

The electric isolation of PVs by the application of radiofrequency energy at the veno-atrial junction is a novel technique for the treatment of paroxysmal AF. As AF is the most common cardiac arrhythmia, an increasing number of ablation procedures are performed at many centres. 3-D reformatted MDCT images of the left atrium and distal PVs provide the necessary anatomic information, including the number, location and angulation of PVs and their ostial branches. Thus, MDCT imaging can serve as a "road map" for the interventional cardiologist, as well as providing a diagnostic baseline for possible later complications, if these should occur.

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