Contrast Use in CTA Applications

CT of the pulmonary veins and left atrium

By providing a detailed map of cardiac structure and morphology, multislice CT guides complex invasive procedures for the treatment of atrial fibrillation and cardiomyopathy.

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Multislice computed tomography (CT) is often performed to assess cardiac structure and morphology. In this role, it assists in the planning of complex invasive procedures—eg, pulmonary vein isolation in patients with atrial fibrillation, and biventricular pacemaker implantation in patients with cardiomyopathy.

This article will review the common triggers for atrial fibrillation, the role of pulmonary vein isolation in controlling this arrhythmia, and the importance of cardiac CT in identifying the pulmonary veins and branches, documenting their dimensions, and creating a structural map for use during radiofrequency catheter ablation. It will also discuss the role of cardiac CT in planning for the implantation of biventricular pacemakers in patients with cardiomyopathy.

This article will review the common triggers for atrial fibrillation, the role of pulmonary vein isolation in controlling this arrhythmia, and the importance of cardiac CT in identifying the pulmonary veins and branches, documenting their dimensions, and creating a structural map for use during radiofrequency catheter ablation. It will also discuss the role of cardiac CT in planning for the implantation of biventricular pacemakers in patients with cardiomyopathy. By localizing and characterizing the coronary sinus and lateral veins, CT assists the electrophysiologist in selecting the site for pacemaker lead insertion, speeds the procedure, and reduces radiation exposure to the patient.

Atrial fibrillation

Atrial fibrillation is among the most common of cardiac arrhythmias. Approximately 2.5 million people in the United States have atrial fibrillation. Its prevalence increases with age, doubling every 10 years after age 60. By age 65, approximately 5% of people have atrial fibrillation, a condition that independently increases the risk of cardiac events in those with coronary artery disease.

In patients with atrial fibrillation, the heart rate depends on the speed of conduction across the atrioventricular (AV) node and can range from 30 to 300 bpm. Cardiologists have long debated whether it is more important to control the heart rate or the heart rhythm. Recent data suggest that either approach is acceptable for asymptomatic patients. For very symptomatic patients, however, rhythm control may be the only acceptable option.2

There are several common triggers for atrial fibrillation. Many patients develop this arrhythmia after cardiothoracic surgery. In such cases, treatment with beta-blockers may be sufficient, as the atrial fibrillation often reverts to normal sinus rhythm on its own. Patients with high autonomic tone can also go in and out of atrial fibrillation. Atrial fibrillation can develop spontaneously in patients with valvular heart disease, particularly mitral valve stenosis or regurgitation. In such patients, treatment must focus on the underlying valvular heart disease.

High blood pressure can cause atrial fibrillation by increasing left ventricular wall tension, which impedes ventricular inflow and causes the left atrium to enlarge. Similarly, hypertrophic cardiomyopathy and aortic stenosis can lead to the development of atrial fibrillation.

The distal pulmonary veins are a frequent source of ectopic foci that lead to the development of atrial fibrillation. In fact, the left superior pulmonary vein alone accounts for 50% of all such ectopic beats.1 Successful isolation of electrical activity in the distal pulmonary veins can eliminate atrial fibrillation in half of patients.

Today, many centers are performing pulmonary vein isolation in patients with atrial fibrillation. Catheter ablation for atrial fibrillation is an invasive procedure that requires the use of multiple catheters, right-to-left transseptal puncture, localization of the target pulmonary veins, and ablation around the ostium. For radiofrequency catheter ablation to be successful, it is essential that the electrophysiologist have a good map that characterizes the structure of the pulmonary veins in detail.

CT of the pulmonary veins

Multislice CT is playing a major role in preprocedural evaluation for several reasons. First, noninvasive imaging is most acceptable to patients and referring physicians. Second, tomographic techniques are superior to ultrasound and even to invasive methods for depicting atrial and pulmonary venous anatomy (Figure 1).

A 2003 study by Schwartzman et al1 examined the role of multislice CT in the evaluation and characterization of the
left atrium and distal pulmonary veins in 70 patients with atrial fibrillation and in 47 without. The study showed that multislice CT provides detailed and accurate anatomic information about the left atrium and pulmonary veins. Left atrial and pulmonary venous dimensions were significantly larger in patients who had atrial fibrillation when compared with those who did not, and in those with persistent atrial fibrillation when compared with those with paroxysmal atrial fibrillation. There were no major differences between the 2 groups in morphological details, however.

These findings are intuitive: From our clinical experience, we know that a patient with an enlarged atrium is very likely to develop atrial fibrillation, and that the larger the atrial size, the more likely the patient will stay in atrial fibrillation.

Another report by Wood et al compared imaging modalities commonly used in the evaluation of the pulmonary veins in 24 patients with atrial fibrillation, including multislice CT, intracardiac echocardiography, invasive venography, and semi-invasive transesophageal echocardiography. The authors found that CT is far more accurate than other imaging modalities for defining the number of pulmonary veins, a very important characteristic that increases the likelihood of isolating the source of ectopic foci. The increased accuracy of cardiac CT in assessing anatomical structure derives in large part from the ability to retrospectively reconstruct the image of the heart based on the recorded electrocardiogram during the scan to minimize the image artifact due to cardiac motion and to carefully evaluate images with no limitation on the viewing angle.

A more recent report by Jongbloed et al confirmed these findings. In a head-to-head comparison study of multislice CT and intracardiac echo in 42 patients with atrial fibrillation, including multislice CT, intracardiac echocardiography, invasive venography, and semi-invasive transesophageal echocardiography. The authors found that CT is far more accurate than other imaging modalities for defining the number of pulmonary veins, a very important characteristic that increases the likelihood of isolating the source of ectopic foci. The increased accuracy of cardiac CT in assessing anatomical structure derives in large part from the ability to retrospectively reconstruct the image of the heart based on the recorded electrocardiogram during the scan to minimize the image artifact due to cardiac motion and to carefully evaluate images with no limitation on the viewing angle.

A more recent report by Jongbloed et al confirmed these findings. In a head-to-head comparison study of multislice CT and intracardiac echo in 42 patients with atrial fibrillation, CT had a much higher sensitivity for detecting not only the total number of pulmonary veins, but also additional anomalies that are commonly associated with the development of atrial fibrillation. In addition, intracardiac echocardiography tended to underestimate ostial size. The authors concluded that 3-dimensional (3D) imaging techniques, particularly multislice CT, are superior to 2-dimensional (2D) techniques for detecting pulmonary venous branches and visualizing the oval shape of the pulmonary vein ostium.

The primary goals of pulmonary vein mapping by multislice CT are identification of the anatomy of the pulmonary veins and documentation of the ostial
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FIGURE 3. A left atrial appendage thrombus, which could dislodge and cause a pulmonary embolism, precludes radiofrequency catheter ablation of atrial fibrillation. Multiplanar reconstructed images are shown.

Table 1. Cardiac CT scanning protocol

<table>
<thead>
<tr>
<th>Scanning parameters</th>
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<tbody>
<tr>
<td>Scanner</td>
<td>64-slice</td>
</tr>
<tr>
<td>Detector</td>
<td>0.6 mm</td>
</tr>
<tr>
<td>collimation</td>
<td>0.6 mm</td>
</tr>
<tr>
<td>Rotation time</td>
<td>0.33 sec</td>
</tr>
<tr>
<td>kV</td>
<td>120</td>
</tr>
<tr>
<td>mAs</td>
<td></td>
</tr>
<tr>
<td>Test bolus</td>
<td>40</td>
</tr>
<tr>
<td>CTA</td>
<td>850</td>
</tr>
<tr>
<td>Pitch</td>
<td></td>
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<tr>
<td>Test bolus</td>
<td>0</td>
</tr>
<tr>
<td>CTA</td>
<td>0.2 mm</td>
</tr>
<tr>
<td>Scan range</td>
<td>Carina to base of the heart</td>
</tr>
<tr>
<td>Scan time</td>
<td>12–15 sec</td>
</tr>
<tr>
<td>Dose modulation</td>
<td></td>
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<tr>
<td>Retrospective</td>
<td></td>
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<tr>
<td>ECG gating interval</td>
<td></td>
</tr>
<tr>
<td>Contrast administration</td>
<td></td>
</tr>
<tr>
<td>Contrast agent</td>
<td>Low osmolar</td>
</tr>
<tr>
<td>Concentration</td>
<td>320 mg I/mL</td>
</tr>
<tr>
<td>Volume</td>
<td></td>
</tr>
<tr>
<td>Test bolus</td>
<td>10 mL</td>
</tr>
<tr>
<td>CTA</td>
<td>80 mL</td>
</tr>
<tr>
<td>Injection rate</td>
<td>4–5 mL/sec</td>
</tr>
<tr>
<td>Saline chaser</td>
<td>50 mL at same flow rate</td>
</tr>
<tr>
<td>Image acquisition timing:</td>
<td></td>
</tr>
<tr>
<td>Peak aortic enhancement (entire coronary circulation, including bypass grafts)</td>
<td></td>
</tr>
<tr>
<td>Peak aortic enhancement plus 3–4 seconds (native coronary arteries only)</td>
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CT data can also be used in the electrophysiology laboratory to guide the ablation procedure, through fusion of volume-rendered CT images and electrophysiology maps. DICOM data from the CT scanner can be uploaded to the electrophysiology console and images can be fused using image integration software developed by BioSense Webster, Inc. (Diamond Bar, CA). This enables radiofrequency ablation to be guided by a more realistic structural representation of the left atrium and the pulmonary veins.

The complications of radiofrequency ablation for atrial fibrillation are numerous, and some are quite dangerous. Pulmonary vein stenosis, for example, is the result of fibrosis and aggressive proliferation of the smooth muscle cells and fibroblasts. It has been reported to occur in 1.5% to 42.4% of patients. Pulmonary hypertension and pulmonary venous infarct are also serious complications of radiofrequency ablation. Imaging is crucial in the follow-up evaluation of patients who develop symptoms, such as shortness of breath, after pulmonary vein ablation.

Biventricular pacing

CT assessment of cardiac structure and morphology play an important role in the treatment not only of patients with atrial fibrillation but also of those with heart failure and cardiomyopathy. A study by Cazeau et al showed that atrioventricular pacing, or cardiac resynchronization therapy (CRT), significantly improved exercise tolerance and quality of life in patients with New York Heart Association Class III and Class IV heart failure, a left ventricular ejection fraction <35%, intraventricular conduction delay (QRS duration >150 msec), and a left ventricular end-diastolic volume >60 mm.

Without a good imaging map, electrophysiologists may find it difficult to cannulate the coronary sinus and to locate the lateral vein where the pacemaker lead is inserted. Venous anatomy varies a great deal from one person to another. Approximately 10% of people do not have a suitable vein along the lateral left ventricle for the placement of the biventricular pacemaker lead.
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A good imaging evaluation prior to placement of the pacemaker leads will save a great deal of time, enabling the electrophysiologist to select the lateral, high lateral, anterolateral, or posterior veins much more precisely and efficiently, while avoiding the great cardiac vein and left ventricular apex, which are usually not suitable for lead placement. Thus, it will also reduce radiation exposure to the patient during the placement of the pacemaker.

Scanning protocol

The scanning protocol for evaluation of the pulmonary veins is the same as that for coronary CT angiography (CTA). With no special tailoring, the protocol produces excellent imaging results.

We routinely give patients an atrioventricular nodal blocking agent (eg, 5 to 30 mg of intravenous metoprolol immediately before the scan, or 50 to 100 mg of oral metoprolol 1 hour before the scan) to slow the heart rate and to regularize the R-R interval as much as possible. If the cardiac rhythm is characterized by a combination of long and short cycles, it may be very difficult to achieve acceptable image quality during retrospective reconstruction. Similar to coronary CTA, we typically use image data obtained from the retrospective reconstruction at 60% of the R-R interval.

We perform a high-resolution scan using a 64-slice scanner and the following settings (Table 1). Our detector collimation is 0.6 mm. For the test bolus, we use 120 kV, 40 mAs, a 2-second cycle time, and a pitch of 0 mm. For CTA, we use 120 kV,
This information gives electrophysiologists a preprocedural point of reference. Weeks or months after the procedure, we may do a follow-up CT examination and remeasure the pulmonary vein ostium, particularly in patients who develop symptoms suggestive of pulmonary vein stenosis.

**CT versus MR**

Magnetic resonance (MR) is an alternative to CT for cardiac imaging. It is useful to compare the advantages and disadvantages of these 2 imaging modalities. If radiation exposure is a substantial concern, MR is the better choice. Both modalities yield excellent image quality. CT is much faster than MR in image acquisition. CT necessitates the use of iodinated contrast medium and, therefore, has the potential for contrast toxicity, whereas MR does not. Therefore, in patients with renal insufficiency, MR may be the better choice. Generally, if the serum creatinine level is 1.4 to 1.6 mg/dL, we perform CT using an isosmolar contrast agent, iodixanol (320 mgI/mL), to reduce the risk of renal toxicity. If the serum creatinine level is >1.6 mg/dL, we prefer to evaluate the patient with MR.

CT is far more widely available than MR, especially given that 16- or even 4-slice scanners can be used to evaluate pulmonary vein anatomy. Claustrophobia is much less a problem with CT than with MR. CT can be used to examine patients with metallic implants, whereas MR cannot. This is an increasingly important consideration, as many patients with cardiomyopathy are treated with some type of implantable device.

Atrial fibrillation used to be an absolute contraindication to CT, but today it is not a major problem, assuming the R-R interval is controllable with medication. Finally, it is desirable to evaluate the status of the coronary arteries in many patients prior to pulmonary vein isolation or implantation of a biventricular pacemaker. From this perspective, CT is far superior to MR. Therefore, although the choice between CT and MR depends on the overall clinical picture, multislice CT wins out most of the time.

**Postprocessing**

Many electrophysiologists request a “flythrough” endoscopic view of the pulmonary veins. We create this view by applying virtual endoscopy software to the CTA data.

Usually, however, 3D volume renderings are sufficient. In order to provide specific atrial and pulmonary venous measurements, it is often necessary to isolate the left atrium and associated pulmonary veins from the initial 3D image (Figure 4). On some workstations, this can be done very quickly and easily. A region-growing tool selects the left atrium and pulmonary veins, and with a push of a button, the workstation extracts the entire anatomical structure.

We can then quickly do a double-oblique measurement of the diameter of the pulmonary vein ostium (Figure 5).
enough information. So, ideally, you’re trying to get the R-R interval regularized as much as possible. That’s something that you have to do.

So this is not something you just do after a patient walks in. Most of the time, these are patients I see on consultation. I do an EKG, look at the EKG, and then I’ll work with the patient. Sometimes it will take me several days to get the R-R interval acceptable, so that it doesn’t have so much variability. We use a combination of beta-blockers, calcium-channel blockers, and digoxin to get the EKG to look OK, as I said. You don’t want to do a useless study, so I’d rather spend a bit more time to get all of the information. If the rate is too fast and too irregular, you might as well just do MR.

ACHENBACH: Do you then not choose EKG-correlated tube current modulation? Do you trigger to systole? In my imagination, if you have atrial fibrillation, the diastolic state can be different depending on how long diastole is or if systole is more constant.

POON: The pulmonary vein is not that crucial, but if you want to get the coronary information, then you might have to just take the ECG pulsing off. Then you have a better chance of capturing the coronary, and some important information can be gathered. If you just do the pulmonary vein, I don’t think it’s that much of a problem. Most of the time, 60% or using the absolute millisecond will be adequate to get you enough information about the anatomical structure in the accessory vein. You might not be able to measure very precisely, but based on my own experience, it’s usually good enough for the EP team.

ACHENBACH: What kind of image display do your EP colleagues want? Do they want the 3D image? Do they want to sit down at the workstation?

POON: Dr. White might want to comment on the Cleveland Clinic, since they do a lot. Based on my own experience from the Mt. Sinai group with a couple of the local EP teams, they want the 3D volume-rendered image so they can see the dorsal view of the left atrium. They also like to know the measurement, which I provide them on the 3D volume rendering, even though the measurements were done on MPR. Then I give them a CD of the DICOM data so that they can upload it onto the BioSense. That’s usually what I do.

ACHENBACH: Measurement as far as length measurement?

POON: You get a long and short access, because the pulmonary vein is sort of oval-shaped, so we give them the 2 measurements.

RICHARD D. WHITE, MD: Our EP people used to ask for the same thing, but now they tell me they don’t really care about the diameter anymore. We put a 3D workstation in the EP labs and then they do their own endoscopic view, which is cute. I don’t understand why they like them, but they do. So we provide them with quick information of whether there is anything to worry about, such as clot.

But, as I mentioned in my talk, we need to do some work there. We’re still sending too many patients to transesophageal echocardiography because we’re really getting quite fooled by smoke. We don’t really have the luxury of manipulating the patient chemically. We might do 25 pulmonary vein cases in a day, and it might be a little difficult to administer heart rate or rhythm control to all. So we don’t do anything special.

J. JEFFREY CARR, MD, MSCE: I’ve actually worked with our private-practice cardiologists and our in-house cardiologists on this. What we do now is a rotation in the horizontal plane in the posterior view. Then we do a cranio-caudal rotation. I think that if you do 2 movie clips of those rotations between those 2 views, the electrophysiologist can see how the branches move in and out. In those endoscopic views, I have a hard time being oriented. I have no idea how they orient the tip of the catheter doing that, but they may be useful in planning where to plan the RF ablation.

But one of the nice things is that the pulmonary veins are relatively immobile and the gating is not as critical as it is, for example, for the coronary arteries. However, don’t forget to analyze the coronary arteries on these studies. My EP colleagues love me when I call and I say, “This guy has a high-grade stenosis in his LAD.” Because they’ll take him over to the cath lab, fix the obstructive coronary artery disease, and that can sometimes resolve their atrial fibrillation right there. That saves them a whole day in the EP lab. So it is important to look at the coronary arteries as well.

WHITE: We do that too.

POON: Most patients in that age group are very likely to have concomitant coronary artery disease, but they don’t necessarily know that. So they have to do some kind of noninvasive nuclear assessment, but if you can give that piece of information, it just makes their lives so much easier.

JILL E. JACOBS, MD: Are you routinely doing follow-ups on your patients postablation? If so, when are you doing them?

POON: Not routinely. We do them only by referral. The EP staff usually sees the patients on follow-up, and they indicate if there are some symptoms that are suggestive of a problem. Then they will send them to us, since we already have the baseline image.

WHITE: We used to do 1-month, 3-month, and 12-month follow-up in the early days. But now that the ablation technique is better, the incidence of stenosis has decreased dramatically. So they do a 3-month follow-up. If that’s negative, we’re done. If it shows any signs, they’ll bring the patient back at roughly 1 year just to be sure that things have not progressed, because you can’t rely on symptoms. By the time the patients have symptoms, they have a 70% stenosis somewhere, so it would be on the late side.

POON: Right now the isolation is not so much focal. It’s doing entire areas. So maybe that’s the reason the endoscopic view is useful, so they can see where they draw the circle and can encompass all of the pulmonary vein at once.

WHITE: I just want them to be happy. They do it themselves, and I don’t know what they’re looking for. But if they are happy, I’m happy.
CARR: I will tell you, on the EP workstation that both of our labs use, one of the key areas is that ridge between the atrial appendages. It’s technically difficult. It’s easy for the RF ablation catheter to slip on either side of that. So having the CT data coregistered with that saves them a tremendous amount of time.

The other tip that I learned from talking to them is that they generally have a catheter in the coronary sinus as well. So, on our 3D volumes, in addition to doing the left atriums, we’ll put the coronary sinus in the volume, so that it actually appears and tracks with the coronary sinus catheter. It’s really interesting. You can see the coronary sinus and the left atrium, and they use that to triangulate when they rotate the different planes.

FISHMAN: I have another question related to your technique in terms of your comment about using gadolinium on some of the patients if they have borderline renal function. Why the choice of gadolinium and not, let’s say, an isosmolar agent? Or at what level do you make that decision to use gadolinium?

POON: Actually that’s Dr. White’s technique. I need to learn from him how to do this. I’ve never used gadolinium. I will go with isosmolar first. For the pulmonary vein, if the renal function is so compromised, I’ll just go with MR. I think MR is easy enough to do for pulmonary-vein isolation. So if renal function is a problem, do it in MR.

FISHMAN: Just going around, are there some magic numbers that people use in their practice for what you would consider renal compromise?

POON: I use 1.6 for the serum creatinine. I don’t know about everybody else.

ACHENBACH: It’s 1.5 at our place.

JACOBS: It’s 1.5 at ours also. We’ll reduce the contrast dose.

WHITE: 1.5.

MARILYN J. SIEGEL, MD: 1.5 to 1.8.

FISHMAN: We use 1.7 to 1.8.

CARR: We use 1.7 to 1.8, depending. Of course, if patients have concomitant risk factors, if they’re diabetic or have congestive heart failure, then we’re more conservative. But it also depends on how much renal data you have on the individual. If you have just one serum creatinine level, versus years of notes, that will influence this decision as well.

FISHMAN: Particularly in cardiac patients, we tend to be a little bit more lenient with the lower numbers. Anything borderline on serum creatinine, particularly in diabetic patients, we tend to go that direction as well.

POON: If it’s around 1.6, we start to give Mucomyst and preparation. So we do it, but those patients need to be prepped.

JACOBS: One of the nice things about these new CT scanners is that you can get away with a smaller intravenous contrast dose in patients.

CARR: I also want to mention the importance of hydration, if we know someone has borderline creatinine. Most of the data supports the fact that you can get a significant protective effect if you hydrate someone with IV hydration.

FISHMAN: Right. At Hopkins, it seems that lately everyone is also interested in also giving bicarb. There seems to be a very big push to do that on the borderline patients, if there is time. There’s no downside to that. There’s that one very good article that had great results. But surely hydration is critical. As Jill mentioned, the biggest thing in terms of contrast and nephrotoxicity sometimes is sheer volume. It’s so nice with 64-slice CT, depending on how you do it, to use just 60 to 90 mL of contrast total. With the low dose, it’s just not going to be that much of an issue. Thanks very much.