3D CTA Mapping for Electrophysiological Procedures

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Introduction

Traditionally, cardiac angiography has been the standard used to assess internal cardiac structures and to define the cardiac anatomy. Angiography, in conjunction with electrophysiological procedures (EP), has been used for many decades to correlate anatomy with the electrical physiology of the heart. This invasive and time-consuming technology is not only unable to visualize three-dimensional structures in detail, but is also limited for pre-EP planning. With advances in electrophysiology techniques, including availability of pulmonary vein and left atrial catheter ablation procedures for the treatment of atrial fibrillation, advanced knowledge of the three dimensional anatomy of the left atrium and pulmonary veins is important. The new generation of multi-slice CT scanners, with superior resolution, fast acquisition, and advanced image processing capability make it possible to display the cardiac structures with more clarity. This chapter will use clinical cases to illustrate the use of multi-slice CT technology (MSCT or CTA) for guiding electrophysiological applications.

II. Roles of MSCT for Pulmonary Vein Ablation Procedures:

1. Pre-Ablation planning:
   - Assessment of Pulmonary veins (PV)
   - Evaluation of left atrium & its appendage
   - Interatrial septum anatomy
2. Post-Ablation Follow-up:
   - Diagnosis of post ablation complications
   - Left atrial changes post procedure
3. Cardiac Resynchronization Therapy (CRT) in heart failure with Bi-Ventricular pacemaker insertion:
   - Coronary sinus venous anatomy for left ventricular pacing lead insertion
   - Post MI scar detection prior to coronary sinus vein lead implant
   - Phrenic nerve location prior to CS lead placement

III. Classification & Terminology

1. Pulmonary vein (PV) anatomy and variations:

In the human heart, there are usually four pulmonary veins (PVs) that drain oxygenated blood from the lungs. There are two PVs from each lung draining into the left atrium. Each lobe of the lung is drained by one pulmonary venous trunk i.e., three in the right lung, and two in the left. The right middle and the superior lobar veins are usually joined, so that two veins, superior and inferior, leave each lung.

The following normal variations can occur:

A. The three right lobar veins may remain separate (19-23 %) (1, 2).

B. The two left PVs may form a single trunk (2.4-25%) (1, 2).

C. Occasionally, the two left PVs, each draining a lobe, may be augmented by an accessory lobar vein from each lobe, and these may unite to form a third left PV.

2. Nomenclature for variations of pulmonary venous drainage:

A. Ostial branch: A pulmonary venous branch joining within 5 mm of the atriovenous junction.

B. Saddle: The region of tissue interposed between separate, ipsilateral veins or between branches of the same vein.

C. Common vein: Coalescense of superior and inferior veins proximal to the junction of the LA body.

D. Supernumerary vein: An additional (neither superior nor inferior) vein, having an independent atriovenous junction (3).

IV. MSCT Techniques:

1. Acquisition

Image acquisition was performed using the Siemens Sensation with 16-slice system. 80 cc of Iodinated non-ionic contrast was injected in the antecubital vein at a rate of 4 cc/s. Craniocaudal scanning (from aortic arch to the base of the heart) was performed using simultaneous acquisition of 16 sections with a collimated slice thickness of 0.75 mm. Helical pitch was 0.75 mm/ 0.5 sec, rotation time was ~3 ms (depending on the patient's heart rate), and tube voltage was 120 kV at 550 mA. Scanning was performed during breath holding after a delay of about 15-30 sec. The delay is dependent on the patient's cardiac output, and hence is determined by giving a test bolus of dye prior to scanning. Retrospective electrocardiographic gating was performed to minimize mis-registration from cardiac motion artifacts. Data acquisition was completed in about 22 seconds. Data reconstruction was performed on the Aquarius Workstation from TeraRecon, Inc.

2. Processing & Measurements:

Post-processing reconstructions are the key to display, assess, and measure PVs. It is important to use an advanced tool, like the Aquarius Workstation, to perform image reconstructions. These processes are usually performed in the following order:

A. 3D reconstruction & Overview (Figure 1 and 2):

Three-dimensional CT images are reconstructed to overview the overall structures of left atrium and PVs as shown in Figure 1. The left atrium can be examined to assess the size and the presence or absence of thrombus in the left atrium.

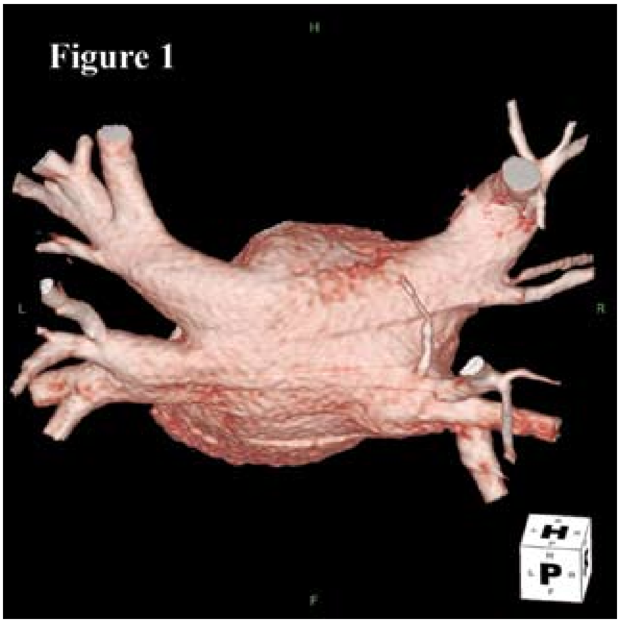

Figure 1: Posterior 3-Dimensional View of the left atrium and the four pulmonary veins.

An example of a thrombus in the left atrium appendage is shown in Figure 2. The result was confirmed by trans-esophageal echocardiogram (TEE).

Figure 2 Trans-esophageal echocardiogram (TEE) of left atrial appendage (Image on the left) confirms the presence of Thrombus noted on the two-dimensional contrast filled left atrial appendage as seen by CTA.

B. Alignment (Figure 3):

Multiplanar reformatting in three different orthogonal planes (transverse or axial, sagittal, and coronal views) is used to identify the axis of the PV lumens. An imaginary line is drawn parallel to the centerline of the PV in two orthogonal planes for preparation of measurements. Using this technique, a picture of the ostium of the PV is obtained as shown in Figure 3. In this example, the right inferior PV is identified. The alignments of the right PV are done for its long axis (coronal and axial views) and short axis (sagittal view).

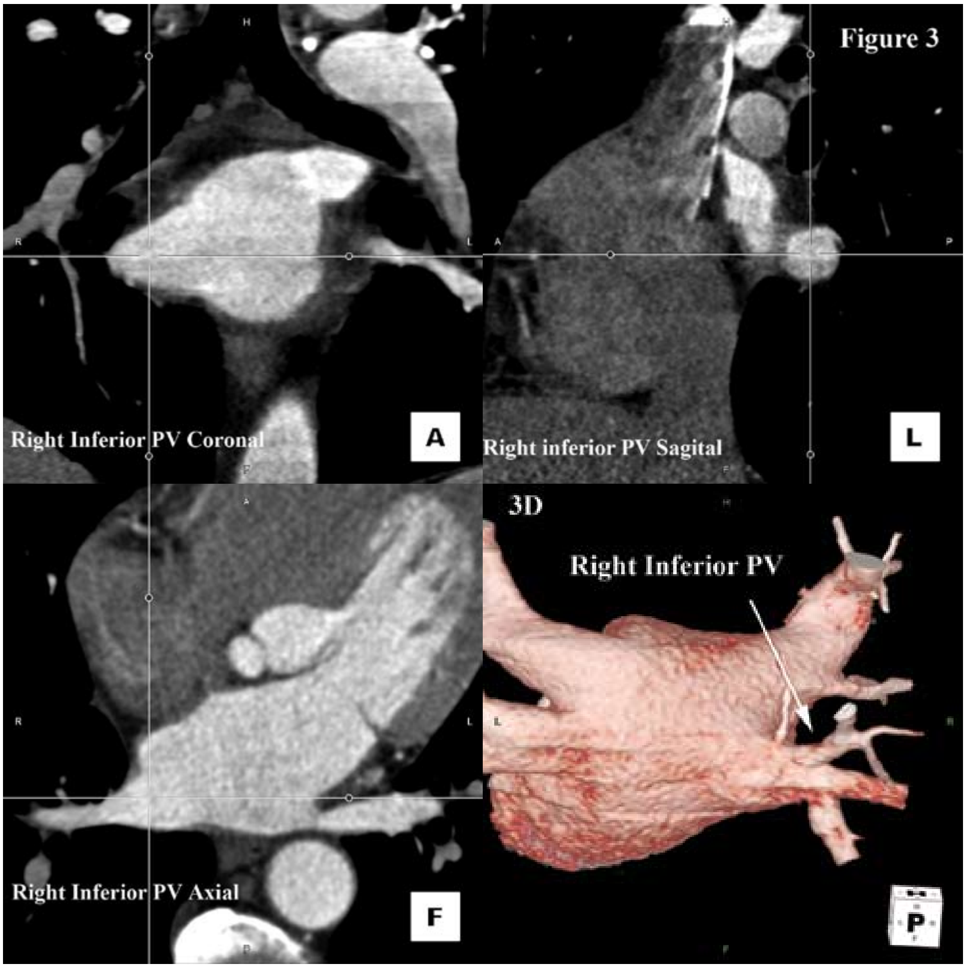

Figure 3 Upper left: An imaginary line is drawn parallel to the Right Inferior Pulmonary Vein (RIPV) in the Coronal plane. Bottom left: An imaginary line is drawn parallel to the RIPV in the axial plane. Top Right: Alignment of the RIPV in the Sagittal plane, based on the previous two images. Bottom Right: 3-Dimensional view of the left atrium from the posterior aspect of the heart showing the RIPV.

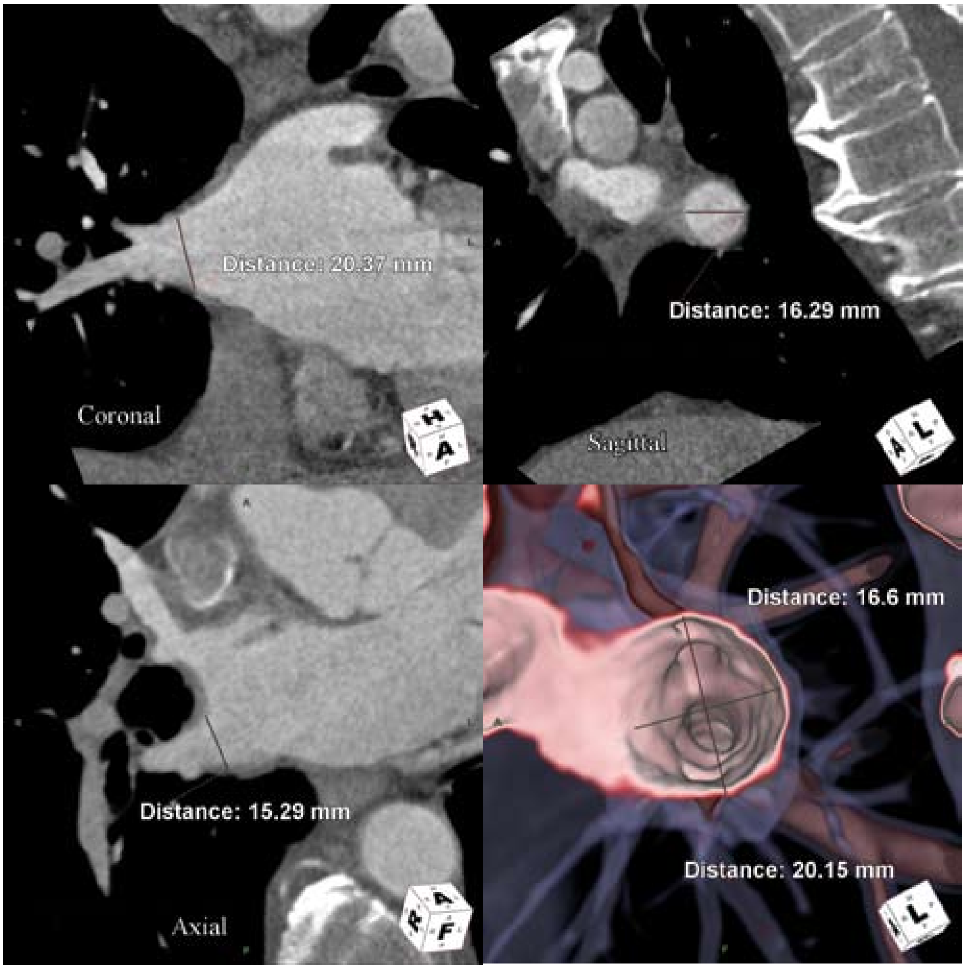

Figure 4: Upper left: Ostial diameter of the Right Inferior pulmonary vein (RIPV) in the Coronal plane. Bottom left: Ostial diameter of the RIPV in the Axial plane. Top Right: Ostial diameter of the RIPV in the Sagittal plane. Bottom Right: 3-Dimensional navigation view of RIPV allows measurement of ostial diameter. Of note, all these views measure ostial diameter at the same attachment point of the RIPV to the left atrium.

C. Measurements and Reassurance from 3D navigation view (Figure 4):

The 3D navigation view provides the actual inside structure to the electrophysiologist, similar to intracardiac echocardiography (ICE) or angioscope. It can demonstrate the internal diameter of PV at the same plane as the two dimensional images illustrated as Figure 3. The measurement is 16 x 20 mm for the internal diameter, similar to the measurements from three different orthogonal planes described above in Figure 3.

D. Fusion imaging for PV ablation: CTA and CARTO (Figure 5 and 6):

A 3D electroanatomic and non-fluoroscopic system (CARTO, Biosense Webster) is used to map the origins of the PVs during ablation for atrial fibrillation. By using this technique, a three dimensional image of the left atrium and PVs is created to guide ablation. Images from CT angiogram can be superimposed on the electroanatomical imaging created with the CARTO system. This allows verification of the origin of PVs and helps precisely guide the ablation catheter to the different areas of interest (pulmonary veins ostium and atrium). This technique significantly decreases the procedure time and the fluoroscopy time, which is important for the patient and the electrophysiologist.

Figure 5 illustrates the cardiac chambers and the vessels in different colors. The cardiac images have been modified by the electroanatomical CARTO system.

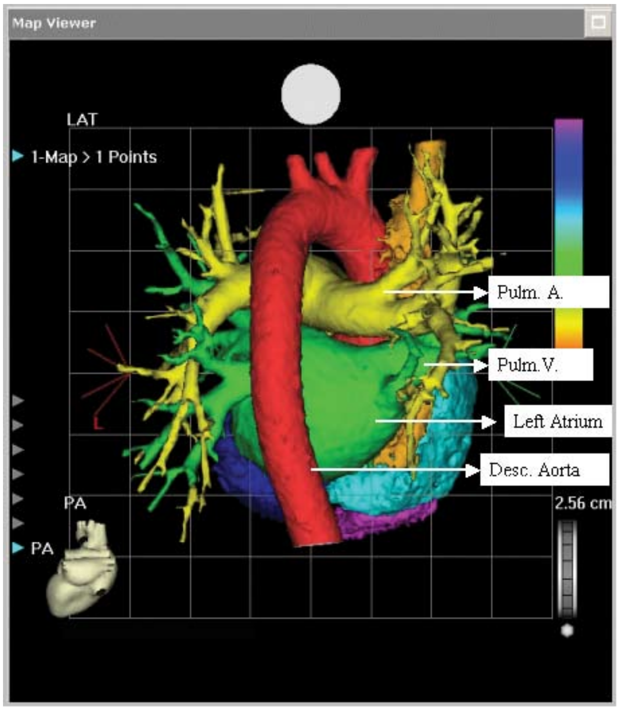

Figure 5: Posterior color view of the heart chamber and the vessels, as seen by CTA and modified on the electroanatomic CARTO mapping system (Biosense Webster), demonstrating the relationship of left atrium and pulmonary veins to other posterior structures.

Subsequently, the CTA imaging, superimposed with the 3D electroanatomical CARTO reconstruction of the left atrium and the pulmonary veins is used to manipulate the ablation catheter inside the LA chamber. The relationship of the left atrium and PVs to the descending aorta can also be easily visualized. In addition, the esophagus and its relationship with the LA and PVs can also be used to avoid esophageal injury during the ablation. In this particular example the esophagus has been deleted.

Figure 6 illustrates the 3 D CT angiogram of the left atrium and PVs, superimposed with the electroanatomical CARTO imaging (CARTO Merge, Biosense Webster). Fig A shows a posterior view of the LA and PVs. Fig B shows an “open” view of the left superior PV seen from inside the LA chamber. In both views, the ablation points are documented as dark purple dots. The electrophysiologist can precisely locate the ablation points in the left atrium from this 3 D view (Figure 6a and 6b). In this patient, the left PV has a common ostium and the lesions were deployed in the PV atrium.

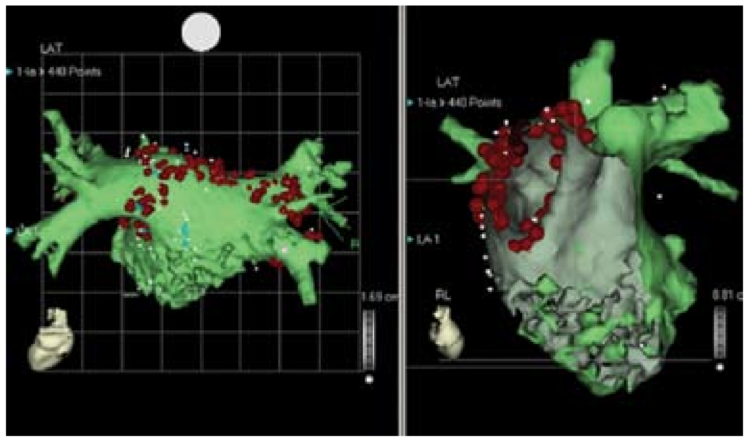

Figure 6: Posterior (6 a) and right lateral "open" view (6 b) of the left atrium and PVs as seen by the CTA imaging superimposed on the electroanatomic CARTO mapping system (Biosense Webster). The dark dots indicate the ablation points around the pulmonary vein ostium and PV atrium.

3. Reporting & Interpretation:

Based on the processing and assessment mentioned above, the following statements need to be included into the reports:

1. Pre-Ablation:
   - Left atrial size and morphology
   - Esophageal and aorta relationship with LA and PVs walls
   - PVs number, size and location
   - Presence of LA thrombi or other tumors (i.e. myxoma, etc)
   - Mitral valve disease
   - Interatrial septum anomalies

2. Post-Ablation:
   - Differential diagnosis of pulmonary vein stenosis
   - Left atrial and pulmonary vein thrombosis
   - Left atrial size and assessment of LA re-modeling
   - Atrio-esophageal fistula
   - Post pulmonary vein ablation piloric spasm with gastric dilatation

V. Cases & Discussions

The following 3 cases illustrate some common CTA findings for EP procedures, especially for PV ablation. Acquisition of images, processing, and assessment follows the format described above.

CASE 1

History:

The patient is a female, aged 63. She has a history of paroxysmal atrial fibrillation and is referred for PV ablation. Multi-slice CT angiogram is performed using the techniques mentioned above. Imaging technique and interpretation are as per the standard protocols.

CTA Findings:

The right PV has two branches with right superior and right inferior PVs. The left PV has a common ostium, as shown in Figure 4 using 3D CTA mapping. This PV divides into the left upper and the left lower branches.

Clinical Significance:

The left inferior PV is relatively smaller in diameter. Placing a lesion inside or close to the PV ostium must be avoided because this vein may be more prone to stenosis. In addition, the right superior PV has a large diameter. This vein may need more radiofrequency energy applications and higher power to effectively isolate this large vein.

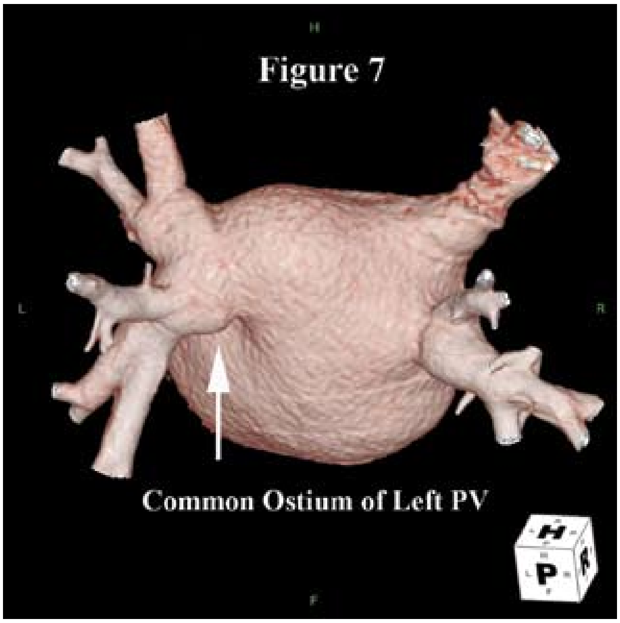

Figure 7 A 3D posterior view of left atrium demonstrating a common ostium of the left pulmonary veins.

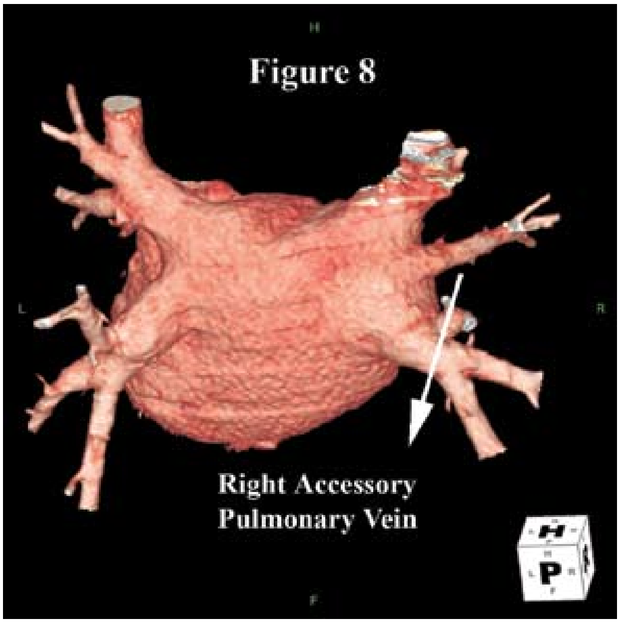

Figure 8 A 3D reconstruction image of the posterior left atrium demonstrating the right accessory PV.

CASE 2

History:

The patient is a male, aged 50. He suffers from persistent atrial fibrillation, fatigue, and pre-syncopal episodes, and is referred for PV ablation following failure of anti-arrhythmic drug treatment. Prior to the procedure, a multi-slice CT angiogram is performed.

CTA Findings:

Figure 8 shows the 3 D reconstruction images of left atrium and PVs. This confirms that the right PV has three branches with right superior (1.9 x 1.4 cm), right inferior (1.6 x 1.4 cm) and an extra accessory branch, right middle (0.9 x 0.9 cm) PVs.

Clinical Significance:

The CTA finding of an accessory mid right PV branch is very important. This finding helps the operator to avoid missing the mid vein as the right inferior PV and isolate this small vein only, instead of the large right inferior PV.

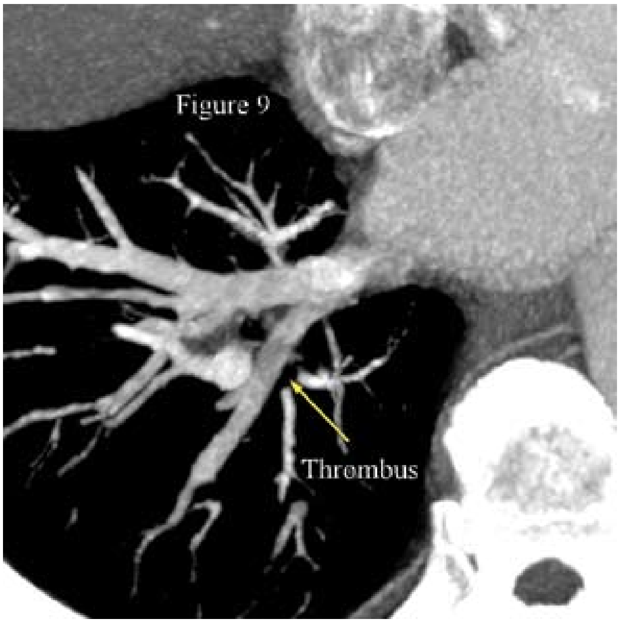

Figure 9 A 2DAxial View shows thrombus in a contrast filled secondary branch of right inferior pulmonary vein.

CASE 3

History:

The patient is a male, aged 55. He had a history of medically refractory paroxysmal atrial fibrillation and underwent intra-cardiac echocardiography guided PV ablation procedure. Two months after the procedure, he complained of cough with blood-tinged sputum. He was initially diagnosed with bronchitis/pneumonia and treated with antibiotics.

CTA Findings:

A MSCT scan was performed to rule out PV stenosis. MSCT of the PVs is shown in Figure 6. A primary branch of the right inferior PV is occluded by a small thrombus or PV branch stenosis.

Clinical Significance:

PV stenosis is a potential complication of PV

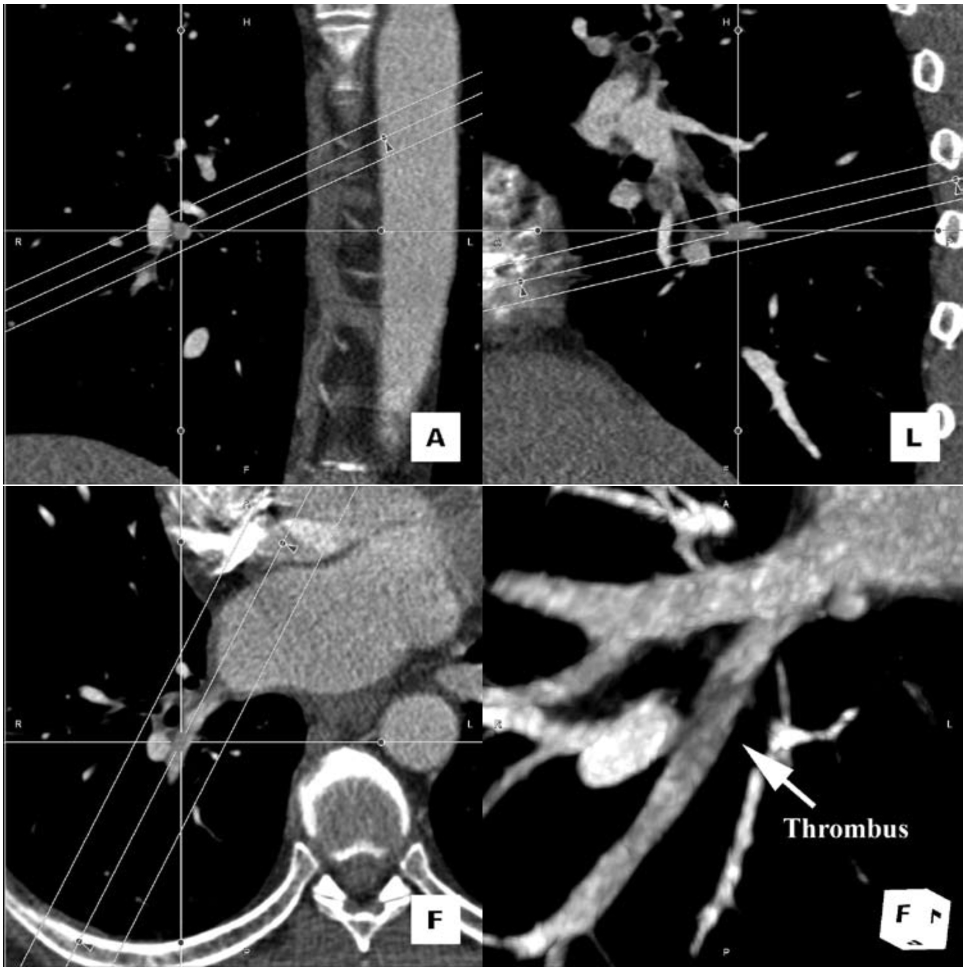

Figure 10 Multiplanar reformatting in three different orthogonal planes

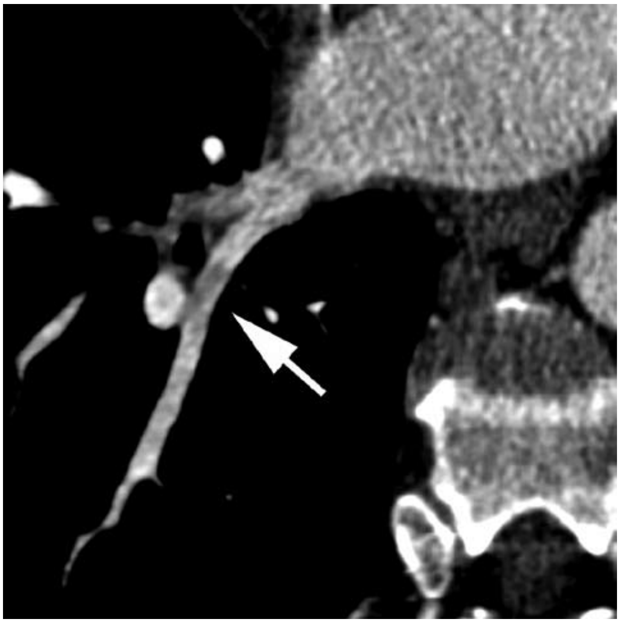

Figure 11 CPR through secondary branch of right inferior pulmonary vein. Thrombus can be easily identified.

isolation (PVI). The complications include intimal thickening, thrombus formation, endocardial contraction, and proliferation of elastic laminae (4). This can occur in up to 5% of patients undergoing PVI as reported in one large series (5). Patients could be asymptomatic or can have dyspnea, cough, or hemoptysis, mimicking other commonly occurring respiratory disorders. MSCT is the modality of choice to evaluate for PV stenosis or thrombosis.

PV stenosis is judged by digital measurements of luminal diameters on adjacent segments as well as by comparison with previous films, when available. Stenosis is considered mild if luminal narrowing is less than 50%, moderate between 50-70%, or severe if > 70% (5).

VI. References

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