

# How I Read CT Coronary Angiography using the Aquarius Workstation

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## Introduction

**D**irect visualization of the epicardial coronary arteries is necessary to confirm the presence and focal severity of coronary luminal disease. For the past 50 years, invasive coronary arteriography has been the clinical reference standard for defining coronary artery disease. However, in many patients with known or suspected luminal coronary disease, a convenient, non-invasive, safe, and reliable means to perform coronary arteriography can offer a significant benefit.

Non-invasive arteriography of the epicardial coronary system has recently matured with the latest generation of multi-detector CT scanners (MDCT). 32 to 64 slice MDCT scanners have recently demonstrated excellent sensitivity and specificity for defining obstructive coronary artery disease, as compared with direct invasive coronary arteriography. In addition, these methods now afford the potential to look for the so-called “soft plaque” that may be the harbinger of future coronary events even in the absence of true obstructive disease. These machines are now capable of performing CT coronary arteriography (CTCA) using low intravenous contrast volumes (50-100 cc) with imaging completed in less than 10 seconds. However, the issues of success are not so dependent

on the actual image acquisition, but in the interpretation by the imaging specialist. At that point, a rapid method to “navigate” through the large “volumetric” CT dataset involves knowing how to best visualize the various epicardial segments and having a standardized method of review.

The subject of the following discussion is “How I read CTCA”, once the images from a variety of CT scanners and other methods are transferred to the workstation. The choice of a visualization workstation is one of the most important decisions to be made by physicians working with CTCA. The major concern is that the reading/interpretation platform must provide for rapid review of the huge 2-D and 3-D volume datasets and convenient structuring of the final report. The processor must also have the ability to perform advanced image manipulation, and the potential to review dynamic imaging sequences for determining cardiac dimensions and volumes (such as with left ventricular size and global/regional function). Finally, the workstation should have a universal operating system so that further image processing (e.g. for formal presentations and research papers), image storage and communication (e.g. via a server or the PACS system), and report generation and dis-

tribution to referring physicians can be done easily and seamlessly. I use the TeraRecon Aquarius Workstation for these and other cardiac and non-cardiac image processing purposes.

The following discussion outlines the “work path” of how I approach CTCA of the native coronary arteries.

## Method

### *Before You Begin:*

All of us have a routine for reading any imaging method and CTCA is no exception. MDCT does not have the spatial resolution of direct angiography (measured in hundredths of millimeters); however the latest generation of MDCT can provide superb sub-millimeter spatial resolution with nearly cubic or “isotropic” voxel (volume element) size nominally (less than 0.5 mm x 0.5 mm x 0.5 mm). This affords nearly an infinite number of viewing planes using CTCA, providing actually an advantage over conventional and direct angiography.

However, the goal of CTCA is to have the “look and feel” of standard invasive angiography (albeit with the ability to look not only at the lumen, but at the arterial mural surfaces). The interpretation should proceed along established guidelines and in a systematic fashion. I recommend using the standardized American Heart Association 15-segment model (please refer to Figure 1).

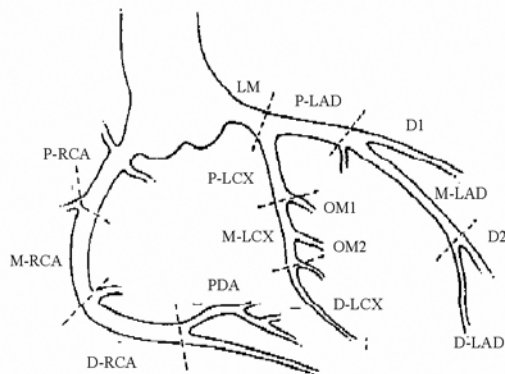


Figure 1 American Heart Association's 15-segment coronary artery anatomy denotation.

I start reading the left main (LM) and then go down the left anterior descending (LAD). Once I review the LAD, I return to the LM and proceed down the left circumflex (LCX) and its branches. Finally, I return to the right coronary artery (RCA) ostium, and proceed distally to the most inferior segments.

## Navigating the “Globe” of the Native Coronary Anatomy

Figure 2 shows the presentation of the standard coronary artery anatomy superimposed on the globe of the world. Within that framework, the heart can be thought of as a small “globe.” Navigation from one anatomic site to another can be thought of as traversing between longitudes and latitudes. This helps us to define, follow, or pursue visual trajectories of the arterial segments.

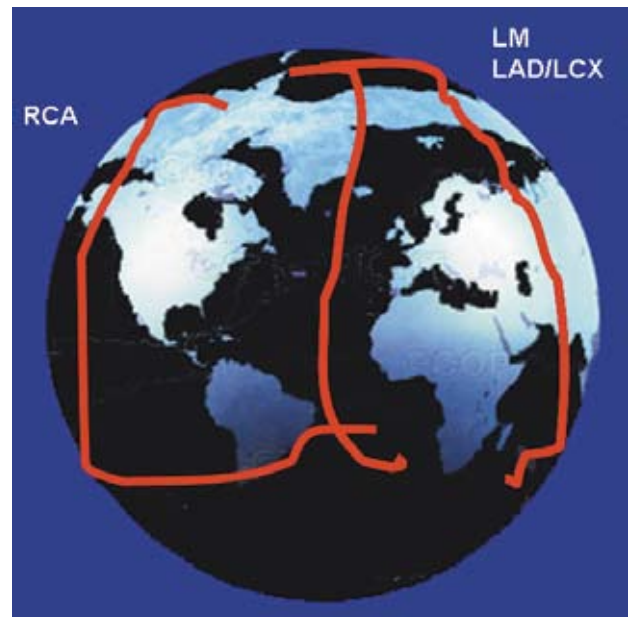


Figure 2 General major epicardial coronary artery anatomy on a globe.

Using the Aquarius Workstation, this navigation is relatively straightforward.

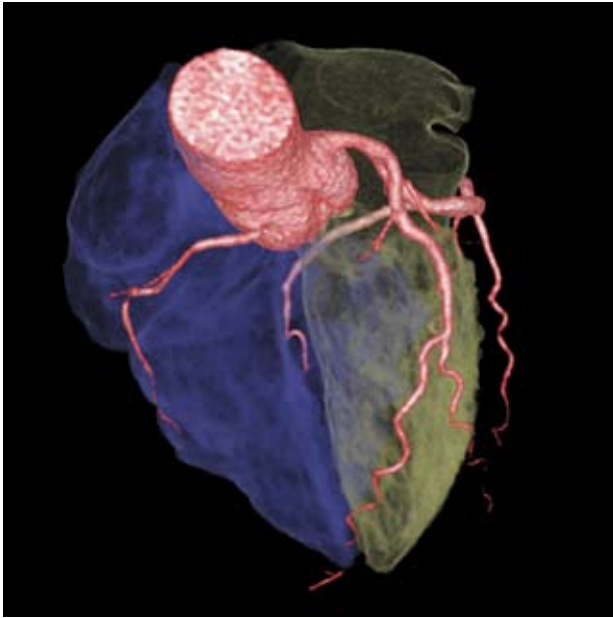


Figure 3 3D volume rendering of heart.

### Image Displays:

The ability to have cubic voxel shapes extends the potential array of image display from standard 2-dimensional images to a variety of 3-dimensional representations, but allowing for preservation of linear dimensions. Although there are a number of presentations that can be accomplished, I use (almost exclusively) the MIP (maximum intensity projection) and the VRT (volume rendering technique). The Aquarius Workstation allows me to alternate between both presentation types in a rapid and convenient manner while viewing a coronary segment or a larger portion of the cardiac anatomy.

The VRT method allows for a general 3-D view of the anatomy under concern. Pre-designed density ranges are provided as “templates” on the Workstation for almost any particular section of the anatomy. MIP images can be “thin” or “thick”, but they basically represent a “sliding slab” view through any region. Specific coronary segments can then be brought into view during navigation, while other segments fade over the “horizon” (using a globe analogy). The maximum value encountered by each ray can be encoded in a 2-dimensional projection display and generates a MIP image. MIP gray scale thus reflects relative x-ray attenuation. The absence of a thresholding step, as is the case for VRT, ensures that no information is lost and subtle variations in attenuation can be appre-

ciated. This has tremendous importance in the differentiation of calcified atheromata versus intraluminal contrast. An interactive tool, MIP can provide valuable information about the condition of a vessel by enabling the reading physician to present the CTCA data in an appropriate context. MIP does not encode depth relationships in a single projection image. To avoid this problem, I use both MIP and VRT.

### Internal Mammary Arteries

I begin my review of the native coronary arteries by first constructing global views of the whole heart including the chest wall. Although there is software available to “remove” the thoracic wall and bony structures prior to initial 3-D viewing, I want to look at the chest wall and examine the internal mammary arteries. CTCA provides incredible imaging of these areas that would otherwise require direct injection methods. Although I am not going into the details of the use of CTCA for bypass graft evaluation, this step is very important in defining spatial relationships between the chest wall, the heart, and any internal mammary bypass grafts for any potential future surgical interactions requiring sternotomy. An example of normal right and left internal mammary arteries (using MIP and VRT) methods is shown in Figure 5.

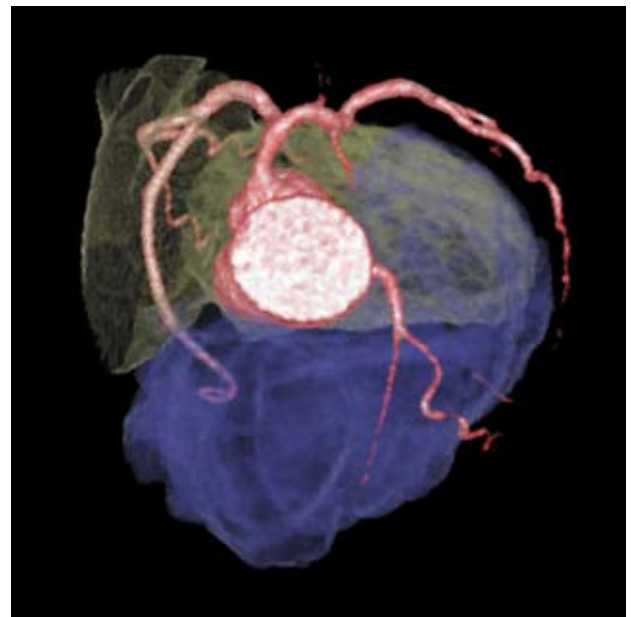


Figure 4 3D volume rendering of heart.

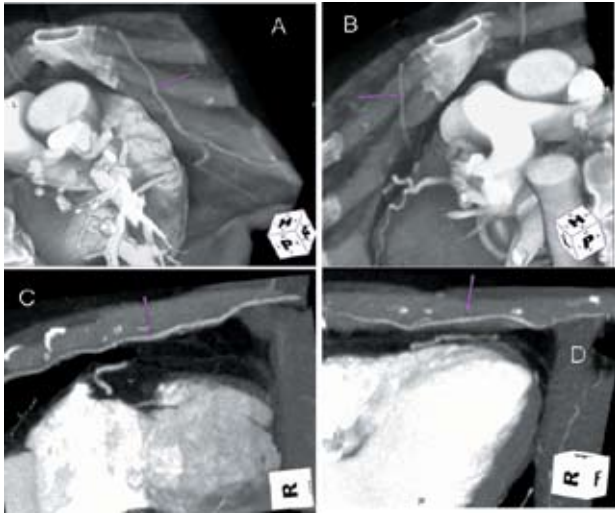


Figure 5 Images of normal internal mammary artery anatomy. A – VRT of right internal mammary artery; B – VRT of left internal mammary artery; C – MIP of right internal mammary artery; D – MIP of left internal mammary artery.

### Coronary Venous System

Intravenous contrast administration for CTCA implies that coronary venous anatomy will also be opacified and, as the course of the veins is often parallel to the arteries, there can be some confusion or interference with anatomic interpretation. Figure 6 shows standard coronary artery venous anatomy and should be kept in mind while performing review and analysis. Specific areas that commonly may confound some studies and their interpretation will be noted below.

### Left Main (LM) Artery

Careful review of the LM artery is a major concern of all coronary imaging studies. By imaging both the lumen and any adjacent calcified and non-calcified plaque in the vessel wall or projecting into the lumen, CTCA provides an advantage to imaging the

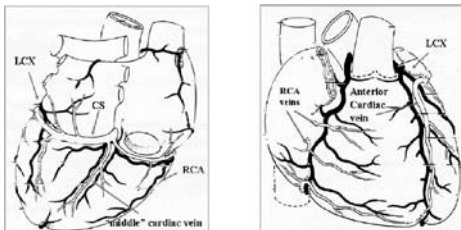


Figure 6 General coronary venous anatomy.

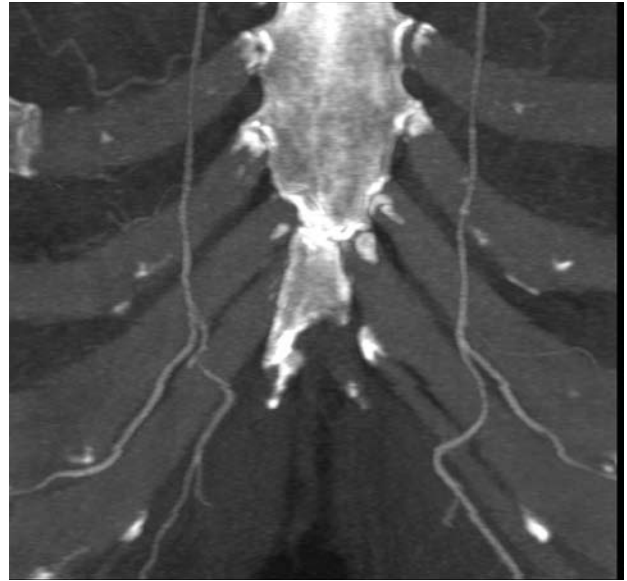


Figure 7 Maximum intensity projection of internal mammary arteries.

LM that otherwise might be compromised using selective catheter-based approaches. I prefer using MIP imaging for this region. Selective images of the LM are shown in Figure 8.

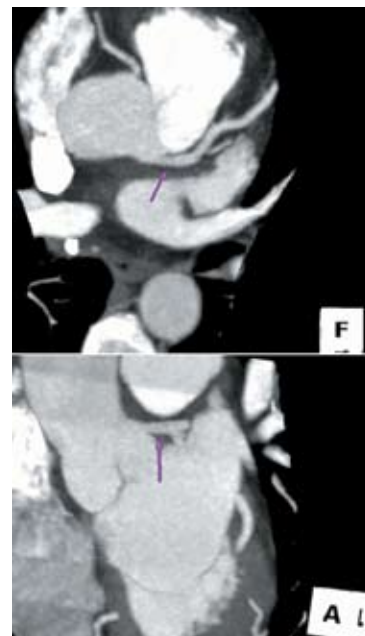


Figure 8 MIP images of the LM (left main coronary artery). Top – LM (arrow) in standard transaxial (superior) view; Bottom – LM (arrow) as viewed from an anterior view.

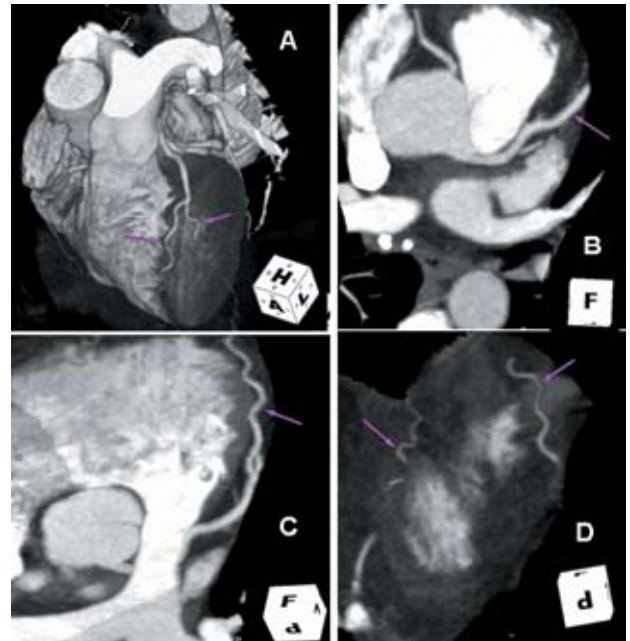
## Left Anterior Descending (LAD) Artery

Defining the entire LAD artery and at least the most proximate branch segments is relatively straightforward using CTCA. The anterior cardiac vein, which runs roughly parallel to the LAD and is made opaque using intravenous contrast enhancement, can easily be separated in most instances (refer to Figure 4). VRT imaging of the proximal, mid, and distal segments is very helpful in defining the “road map” of the LAD and in defining areas that should be more carefully reviewed by segmental MIP images. In my experience, a normal looking VRT image almost assures a normal coronary lumen on more detailed MIP inspection. However, the opposite is not necessarily true. In particular, VRT imaging is still unable to fully define maximum and minimum CT densities. Thus, although the VRT survey can help you quickly determine if a given CTCA study is “normal”, areas of interest may still appear relatively normal in MIP images. Relying solely on VRT images can result in visual “overestimation” of actual luminal stenosis severity.

“Navigating” down the LAD using MIP involves setting up a standard superior view and then, using the Aquarius Workstation, moving the mouse in the general direction of the adjacent segment. As the segment becomes visible over the “horizon”, moving the center of the viewing position to the center of that segment facilitates rapid navigation along the unique global positioning of the LAD (or for that matter any other coronary) segment. Figure 9 provides various views of a normal LAD.

## Left Circumflex (LCX) Artery

My original Mayo Clinic laboratory began performing CTCA over a decade ago using the older EBT technology and had good success. However, one area that caused considerable frustration was imaging of the proximal LCX. There were two structures that initially confounded our 3-D imaging efforts - the anterior cardiac vein as it passes across the proximal LCX on its way to the coronary sinus, and the left atrial appendage, which in some views obscures the initial LCX segments, including in some instances the first obtuse marginal artery (OM1). There is no question that the move to thinner and thinner CT slices (e-Speed EBT and MDCT) has improved visu-



*Figure 9 Images of the LAD (left anterior descending). A – VRT anterior image showing the LAD (left arrow) and first diagonal (D1) branch (right arrow); B – MIP view from superior angle of proximal LAD (arrow); C – MIP view from a superior angle of the proximal and mid-LAD (arrow); D – MIP view from an inferior angle of the distal LAD (right arrow), note the position of a portion of the posterior descending artery (PDA, left arrow).*

alization of this often-small vessel – but this is only part of the solution. Some current workstations do not allow sufficient navigation to facilitate “unveiling” of the anterior cardiac vein/coronary sinus and left arterial appendage. Some analyses require digitally “removing” some of these structures before formal analysis of the LCX images can commence.

Using the Aquarius Workstation and the navigational tools as noted above, review of the LCX is as straightforward as that of the LAD. I begin with the most proximal segments and then proceed distally. Although in the majority of cases the LCX is the non-dominant vessel, I always fully review the LCX as it courses around the posterior cardiac surface to make sure that it is not the dominant or the co-dominant vessel with the right coronary artery (RCA). A combination of VRT and thick and thin MIP images is best to define the spatial relationships. Figures 10 and 11 show a LCX study in a patient who is “left” dominant. The image of the RCA shown in Figure 8 in which that vessel is small and the posterior descending artery (PDA) comes off the LCX.

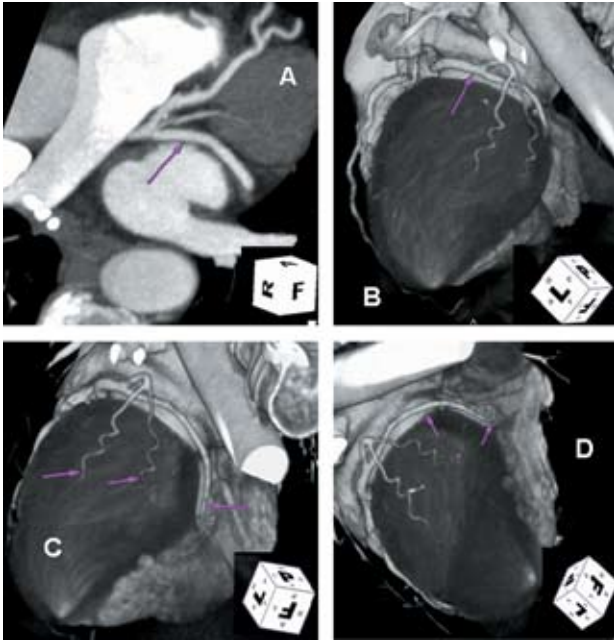


Figure 10 Images of the LCX (left circumflex). A – MIP image of the proximal LCX from a superior view; B – VRT image of the proximal LCX from an anterior view; C – VRT image of two marginal branches of the LCX (arrows) and the mid-LCX from a shallow lateral view; D – VRT image of the distal LCX from a lateral view.

### Right Coronary Artery (RCA)

Excellent views of the RCA ostium are possible with CTCA and may be better than the standard catheter-based direct angiography for subtle lesions, especially “soft plaque.” The RCA can either be dominant or not. Figure 12 shows a non-dominant RCA. The RCA has a unique anatomy in that often imaging the entire proximal, mid, and distal segments can be captured not only by VRT, but also in a MIP image very reminiscent of what is done in the catheterization laboratory.

Figure 13 shows such images in a patient who is “right” dominant. The PDA and posterior lateral (PL) branches, if patent, are almost always seen on late model EBT and the latest MDCT scanners. The “nemesis” for imaging the PDA (analogous to the anterior cardiac vein/coronary sinus for the LCX) is the middle cardiac vein. This vessel follows and sometimes circles portions of the PDA. However, by following the vessel navigation carefully from one tomographic plane to the next, this vein can be easily traced to the coronary sinus.

Figure 13 - Images of a dominant right coronary artery (RCA). A – VRT image from the proximal and mid RCA segments from an anterior view; B – thick section MIP of the entire RCA showing the proximal segment, mid-segment, distal segment, and PDA (arrows); C – MIP image of the distal RCA from an inferior view (arrow shows PDA); D – VRT image of the distal RCA and the PDA (bottom arrow) from an inferior view, note the distal LAD (top arrow)

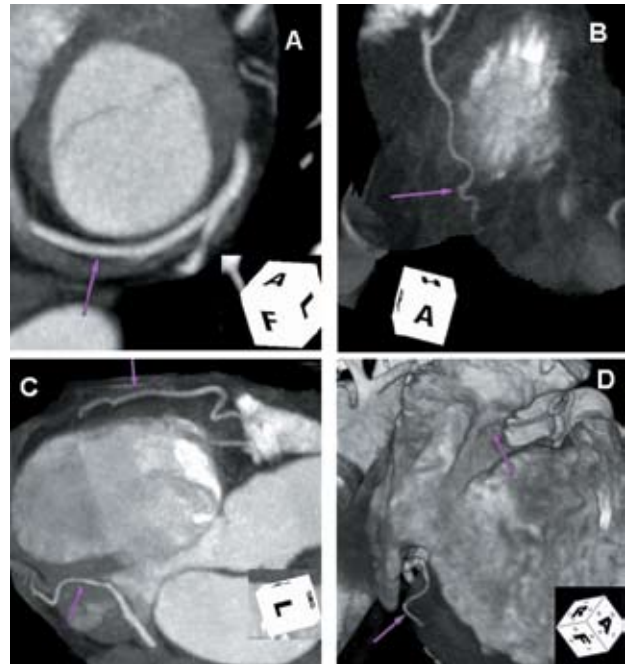


Figure 11 Images of the LCX in a patient with “left” coronary dominance. A – MIP image from an inferior angle of the distal LCX (arrow); B – MIP image of the posterior descending artery (PDA, arrow) from an inferior/anterior view; C – Thin section VRT image of the distal, dominant LCX (bottom arrow) demonstrating in the same lateral plane, the non-dominant right coronary artery (RCA, top arrow); D – VRT image from an anterior view showing the distal LCX giving off the PDA (lower arrow) and the small non-dominant RCA.

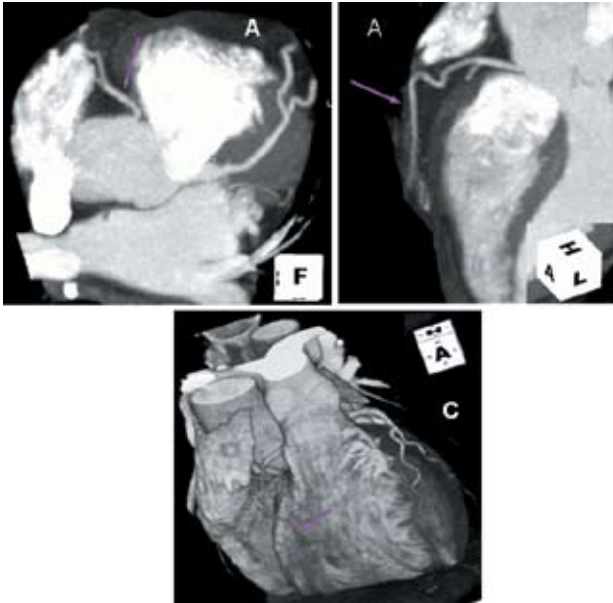


Figure 12 Images of a non-dominant right coronary artery (RCA). A – MIP image of the ostium of RCA (arrow) from a superior view; B – MIP image of the RCA from an anterior view demonstrating the proximal and mid segments; C – MIP image of the RCA from an anterior view.

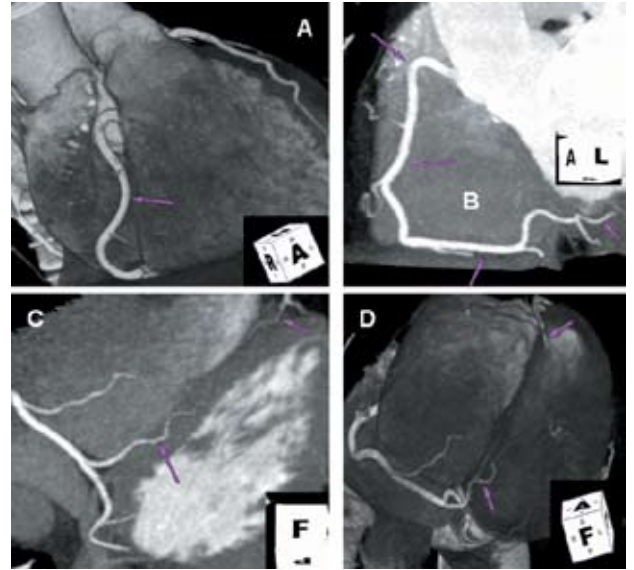


Figure 13 Images of a dominant right coronary artery (RCA). A – VRT image from the proximal and mid RCA segments from an anterior view; B – thick section MIP of the entire RCA showing the proximal segment, mid-segment, distal segment, and PDA (arrows); C – MIP image of the distal RCA from an inferior view (arrow shows PDA); D – VRT image of the distal RCA and the PDA (bottom arrow) from an inferior view, note the distal LAD (top arrow).

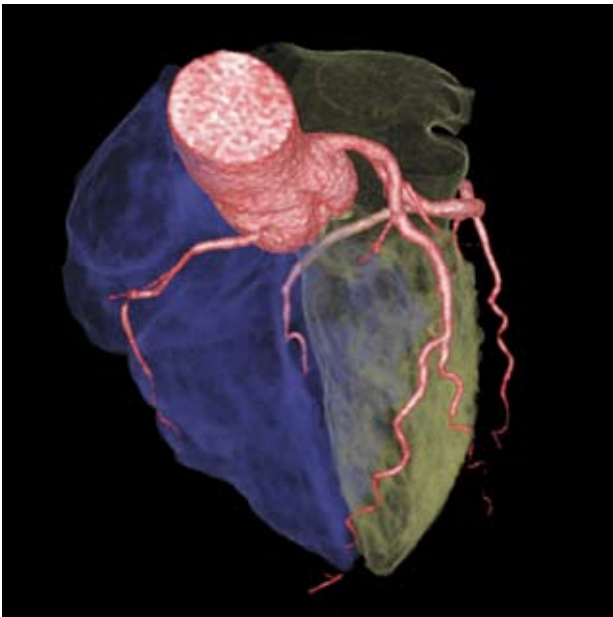


Figure 3 3D volume rendering of heart.

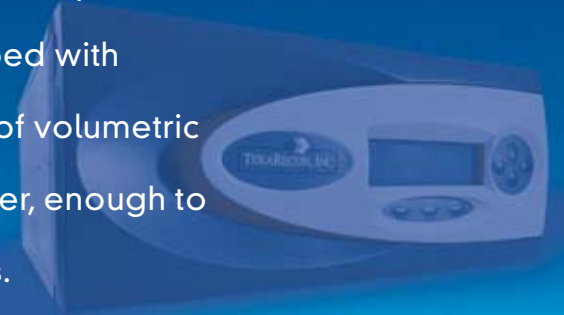
## Conclusion

Current MDCT technology provides superb imaging of the coronary artery mural and luminal anatomy providing diagnostic imaging for stenoses and hard and soft plaque. However, the first step is to know the arterial and venous anatomy, have a set plan for interpretation, and understand the anatomic pitfalls that can influence proper interpretation of CTCA. This article attempts to help you with these initial steps into diagnostic non-invasive coronary arteriography using CT and the applications of imaging using the Aquarius Workstation.

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