Methodology for CCTA Image Acquisition

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Abstract

Cardiovascular computed tomographic angiography (CCTA) can assess cardiovascular pathology through visualization of gross anatomic abnormalities, characterization of tissue attenuation, and cardiac functional analysis. As cardiac structures are in constant motion, special attention to the methodology of image acquisition is essential to capturing high quality images during the most quiescent stage of cardiac and coronary artery motion. Successful imaging requires an understanding of the interplay of multiple motions, including the complexities of cardiac motion, motion related to variation in heart rate and rhythm, potential respiratory motion, potential patient movement, table motion, gantry rotation, and timing and movement of the intravenous contrast bolus through the structures of interest (Fig. 7.1).

Optimization of image acquisition is achieved through localization of target structures, timing of scanning for capture of images during the segment of the R-R interval with relatively slow cardiac motion, and injection of contrast media to enhance opacification of structures throughout all slice levels. These techniques help to avoid or minimize motion artifacts and suboptimal opacification of structures of interest, which would make subsequent image reconstruction and diagnostic analysis a challenge. Imaging methodology must also focus on minimizing the exposure to radiation and the amount of intravenous contrast. This chapter will focus on methods essential to acquisition of diagnostic images for the assessment of cardiovascular pathology.

Keywords

Cardiac computed tomography • Image Acquisition • Methodology • Non-invasive angiography • Radiation • Contrast • Calcium scoring • Scan protocols

Introduction

Cardiovascular computed tomographic angiography (CCTA) can assess cardiovascular pathology through visualization of gross anatomic abnormalities, characterization of tissue attenuation, and cardiac functional analysis. As cardiac structures are in constant motion, special attention to the methodology of image acquisition is essential to capturing high quality images during the most quiescent stage of cardiac and coronary artery motion. Successful imaging requires an understanding of the interplay of multiple motions, including the complexities of cardiac motion, motion related

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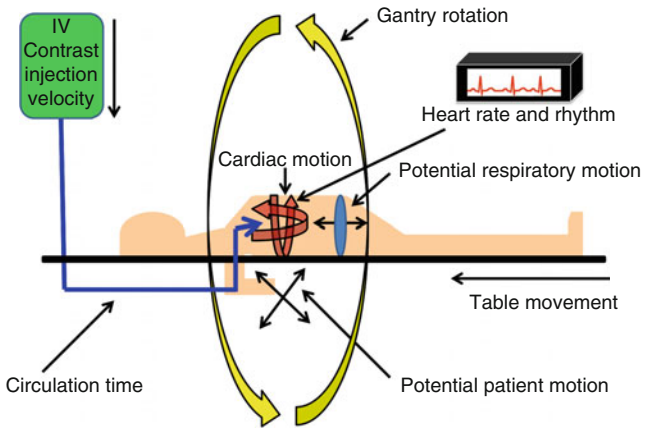

Fig. 7.1 Schematic demonstrating multiple motion factors which must be accounted for during imaging, including the complexities of cardiac motion, motion related to variation in heart rate and rhythm, potential respiratory motion, potential patient movement, table motion, gantry rotation, and the movement of the intravenous contrast bolus to the structures of interest

to variation in heart rate and rhythm, potential respiratory motion, potential patient movement, table motion, gantry rotation, and timing and movement of the intravenous contrast bolus through the structures of interest (Fig. 7.1).

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Image Acquisition Concepts

The ability to visualize the coronary vasculature is due to advances in spatial and temporal resolution of scanning technology. There are multiple factors that affect spatial and temporal resolution, many of which are interdependent. The goal of image acquisition is to visualize the target structures in their entirety while limiting the field of view to exclude additional structures, as a larger field of view will increase radiation exposure and may diminish image quality. The field of view defines the imaging boundaries important to ensuring visualization of structures of interest. As the 512 by 512 voxel matrix is assigned to a particular field of view, a smaller field of view leads to greater spatial resolution. For example, if a field of view is set at 20 cm, the voxel size is 20 cm divided by 512 voxels, or 0.4 mm. If the field of view is set a 50 cm to include evaluation of axilla, breast and lungs, the voxel size is approximately 1 mm, or 2.5 fold worse resolution. Structures are delineated by their attenuation, as measured in Hounsfield units (HU), named after Sir Godfrey Hounsfield, the inventor of computed tomography. Each voxel is assigned a unit of attenuation based on a scale, with the attenuation values of different substances represented by a different HU value [1]. Representative HU values include: air −1000, fat −50 to −100, water 0, muscle 10–40, contrast 80–300, calcium 130–1500.

Scanner

Conceptually, multidetector computed tomography (MDCT) systems work using similar principles, but vary in regard to specific components and features. A MDCT system has an x-ray tube/collimator and detector/collimator housed in a gantry capable of extremely rapid rotation. The x-ray tube provides radiation energy quantified through tube current (mAs) and tube voltage (kVP). Multidetector scanners have multiple rows of detectors arranged in a variety of arrays with the goal of covering a specified volume during each gantry rotation. Advances in detector number and arrangement have lead to increases in the volume of coverage per rotation, with imaging of the entire heart now achievable within one cardiac cycle [2].

The relationship between table movement, gantry rotation speed and beam collimation defines the degree volume coverage per rotation, as well as the degree of overlap between rotations. The concept of "pitch" quantifies this relationship, as pitch relates to coverage obtained by the x-ray beam, through beam width and table movement, during one rotation of the gantry. The pitch therefore defines the amount of overlap of the acquired data and the speed at which the study is complete. Overlapping images allow for oversampling, permitting multisector image reconstruction, but also lead to greater radiation exposure. With a pitch value of less than 1, there is overlap between volumes of coverage. The definition of pitch has evolved with advancement of scanner technologies, and various equations have been proposed depending on the specific type of scanner [3]. Using conventional ECG-gated helical data acquisition, the pitch values for coronary CT angiography are typically considerably less than 1 (e.g., 0.22), which indicates that the table is advanced by much less than one detector row width during one rotation of the scanner. Thus, the same region within the heart is exposed during several consecutive rotations, which increases radiation dose. Newer systems enable thinner slice thickness and collimation, allowing for an even lower pitch resulting in more images, thinner

reconstruction intervals, and better visualization of the coronary anatomy. Systems which provide enough Z axis coverage for whole heart imaging in one gantry rotation eliminate the variable of pitch, by allowing for imaging without table movement [2]. In contrast, the latest generation dual-source CT technology permits ECG-triggered helical scanning at very high pitch values. By inter-weaving data measured from two detector systems separated by approximately 90°, pitch can be increased up to 3.4 [4]. Helical scanning with such high pitch values reduces the amount of redundant data collected, thus substantially decreasing radiation exposure. This dual-source CT configuration allows prospectively ECG-triggered high-pitch helical scan mode, first introduced in 2009. With single-source CT systems, this pitch is limited to a maximum value of 1.5 for gapless data acquisition in the z-axis. At higher pitch values, data gaps occur, which may result in image artifacts and errors in image reconstruction. However, with second-generation dual-source CT, the second tube/detector system is used to fill the data gaps; accordingly, the pitch can be increased to values above 3. This results in very short CT data acquisition and radiation exposure times.

ECG Triggering

ECG triggering is essential to minimize the effects of cardiac motion on image acquisition. Cardiac and coronary motion during a single cardiac cycle is extremely complex and can be analyzed in the context of the X, Y, and Z axis planes. Left ventricular contraction and relaxation are the main source of cardiac motion. Multiple types of cardiac motion have been noted including: inward or outward motion of the endocardium with systole and diastole; rotation; torsion or wringing; translocation; and "accordion-like" base to apex motion [3]. There is greater X-Y direction motion at the mid-portion of the left ventricle and greater Z direction motion at the base of the heart [5]. Left ventricular endocardial maximal motion speed has been reported at 41–100 mm/s [6, 7].

Specific motion issues also relate to individual coronary arteries. Since the right coronary artery is further from the center of the left ventricle than the left coronary artery, this artery exhibits faster motion, especially in its mid-section [8]. Atrial systole and diastole are important factors causing motion of the right coronary artery and the left circumflex coronary artery [9]. The right coronary artery has 50 mm/s motion speed by angiography [10]. The left main and proximal portion of left anterior descending coronary artery have greater Z plane motion, and therefore Z axis motion can induce left main motion abnormalities [5, 7].

Given the imaging challenges caused by cardiac motion, appropriate collimation size and acquisition speed are factors important to minimizing CCTA motion artifact. Since the acquisition speed is insufficient to completely freeze heart motion, cardiac triggering is essential in order to capture and process images at times of minimal cardiac and coronary artery motion speed to avoid blurring of images.

Based on ventricular and atrial contraction and relaxation, there are six phases in a cardiac cycle (R-R interval). These include: isovolumic contraction time, ejection time, isovolumic relaxation time, left ventricular rapid filling, diastasis, and atrial contraction time. During ventricular systole, the motion of right coronary artery and left circumflex mid-segment are in an anterior and inner direction, which reverses in diastole. At end isovolemic contraction and relaxation, the motion speed is close zero, but the time interval for imaging is very short.

There are three relatively low speed motion segments: isovolumic contraction, isovolumic relaxation, and diastasis. The isovolumic contraction time (after the R wave) and relaxation time (after the T wave) are approximately 50–140 ms. Diastasis is the other slower motion segment, but the length is more variable following heart rate changes. In patient with heart rates of greater than 100–110 bpm, diastasis is minimal [11]. The diastasis segment is the optimal scan time in patient with a lower heart rate, and is the most common time period for assessment in patients with regular and controlled heart rates.

With image acquisition, an ECG signal is simultaneously recorded with the raw data set. Two ECG gating techniques are used for CCTA imaging, retrospective and prospective triggering. With retrospective ECG gating, images are acquired throughout the cardiac cycle (Figs. 7.2 and 7.3) [12]. The strength of this approach is that images can be reconstructed using the most optimal timing for each coronary artery or arterial segment after image acquisition has occurred. Additionally, acquisition of images throughout the cardiac cycle allows for volumetric assessment of cardiac function. The major drawback of this approach is that radiation exposure is significantly greater than with a prospective ECG gated approach. Retrospective gating with current tube modulation leads to a significant decrease in radiation by decreasing radiation exposure during the systolic phase of the cardiac cycle [13].

With prospective triggering, images are obtained at a set percentage of the R-R interval. The advantage of this technique is the limitation to radiation exposure [14]. The disadvantage relates to the limited dataset obtained. If the images obtained demonstrate significant motion artifact, there are no other images to reconstruct. Given the variability of heart rate with arrhythmias, prospective gating can be problematic with significant atrial or ventricular ectopy or atrial fibrillation.

In regard to variability of heart rate or rhythm, any change in heart rate or rhythm can alter chamber size, and therefore change of the spatial location of target structure in axial or

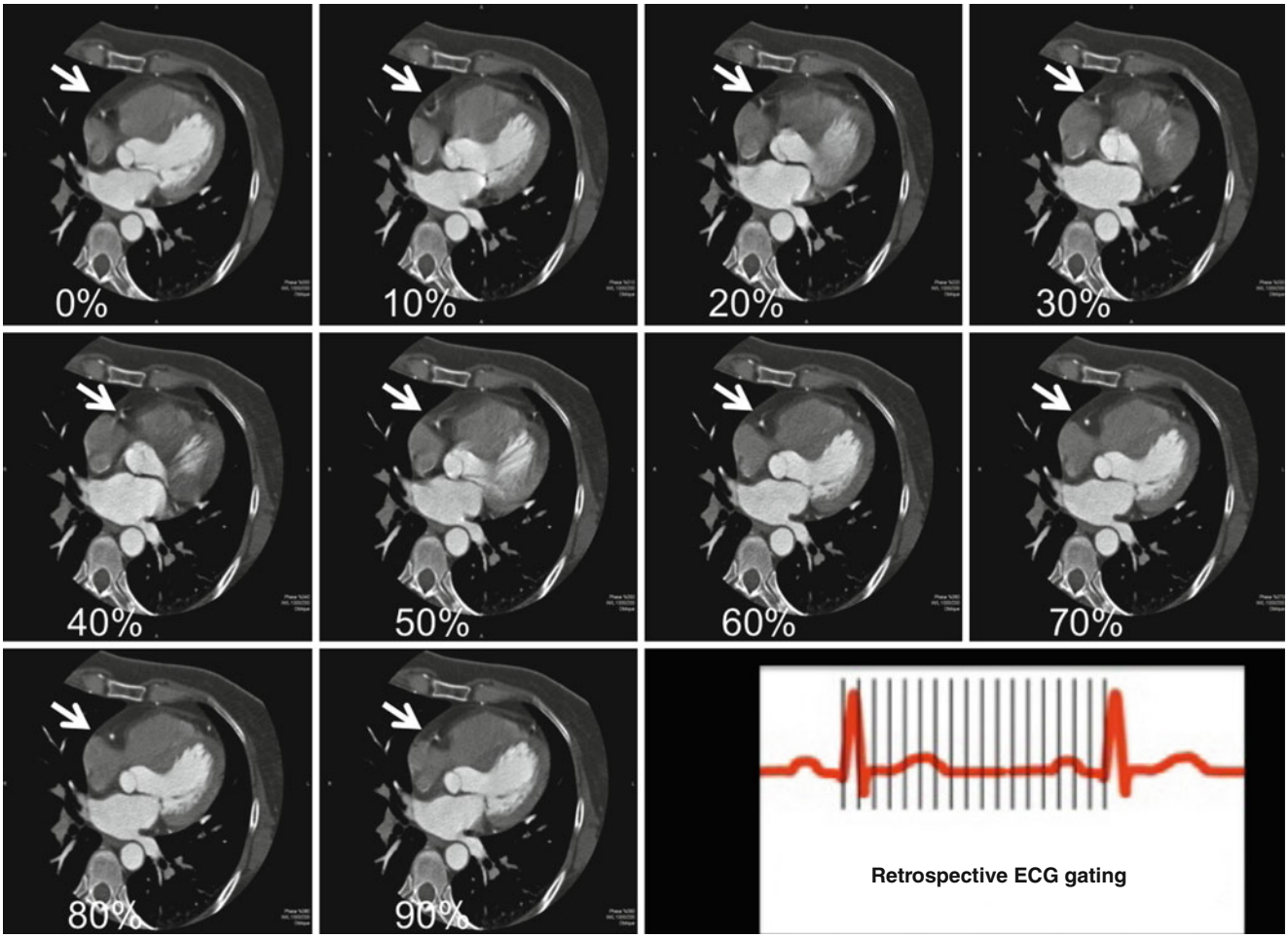

Fig. 7.2 Demonstration of motion of the right coronary artery at serial decile percentages of the R-R interval during retrospective gating. The most optimal R-R percentage is 70 %, as blurring of the right coronary artery is seen at other phases. The *arrow* depicts the right coronary artery, which should be a round structure, but with motion, appears as a 'cashew-nut' shape

3-D images, even if the individual axial image is not blurred. All patients have some variability in heart rate, even those without atrial or ventricular ectopy. Scanning protocols exist which can withhold imaging during short R-R intervals during image acquisition [15]. Post processing analysis includes editing and deletion of images from ectopic beats and analysis of mid-diastolic phases of the R-R interval with an absolute rather than relative time from the preceding R wave when the R-R interval is variable.

Heart rate control is essential for image optimization. Premedication with beta blockers, or calcium channel blockers when beta blockers are contra-indicated, is used to achieve sinus rates of 60 beats/min using most standard MDCT systems. With dual source MDCT systems, imaging can be performed with heart rates in a higher range (although radiation doses will still go up with faster heart rates, so good justification for beta blockade with this system still exists) [16, 17].

High quality images on CCTA depend on a low and steady heart rate (below 70 bpm, and preferably below 60 bpm in most cases), as a consistently wide diastolic time interval is needed with techniques such as ECG-based tube current modulation, prospectively ECG-triggered axial scanning, and prospectively ECG-triggered high-pitch helical scanning. Without adequate patient preparation (generally, beta-blocker drugs), it is rare that this goal is achieved. Calcium channel blockers with good chronotropic effects (verapamil, diltiazem) can be used as an alternative, or in conjunction with, beta blockade in patients with high resting heart rates undergoing CCTA.

Nitroglycerin is given sublingually prior to scanning to maximally dilate coronary arteries. Since there may be catecholamine stimulation with breath hold, the sound of the scanner, nitroglycerin administration, and the sensation of contrast administration, a resting sinus rate that appears to be controlled without medications prior to scanning may still increase during scanning. Special attention to monitoring of heart rate and blood pressure is important, as in some circumstances patients may not be able to tolerate medications for heart rate control and dilation of coronary arteries.

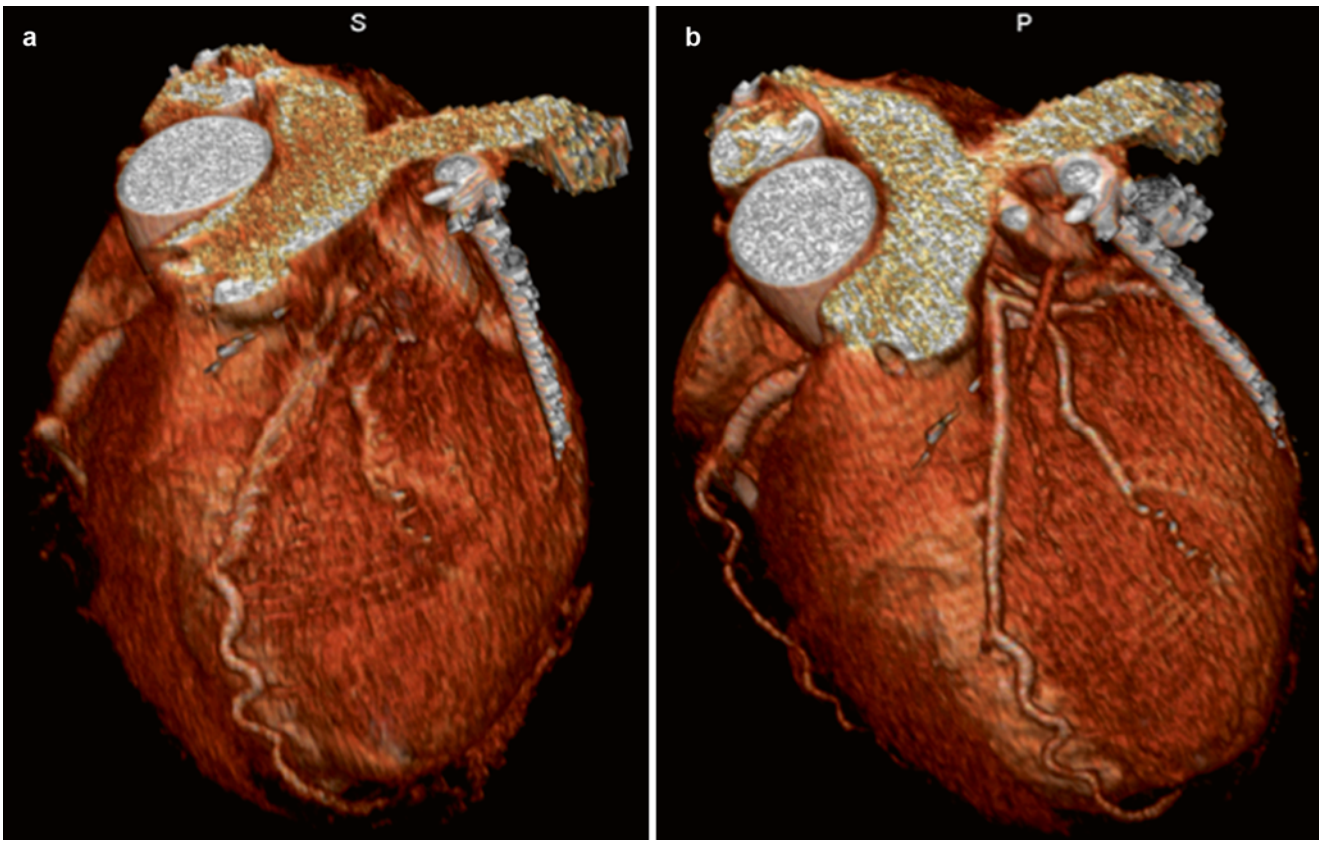

Fig. 7.3 3-D reconstructions of the LAD at different phases of the R-R interval, demonstrating reconstruction at a suboptimal phase and an optimal phase for artery visualization. (**a**) Reconstruction at 30 % of the R-R interval. (**b**) Reconstruction at 70 % of the R-R interval

Breath hold is essential to limit motion of structures due to respiration during image acquisition. Breath hold times have decreased significantly with advances in technology and allow for cardiac imaging to be completed during a single breath hold. There is some controversy as to the optimal phase of respiration for breath hold. Regardless of the phase chosen in an individual lab, it is important to practice breath hold commands and exercises prior to the scan. The technologist, by assessing whether breath holding was optimal during the scout film, calcium score and/or contrast timing run, can further educate the patient prior to the CTA scan acquisition. As an end-inspiratory breath hold will move thoracic structures more caudally than an end-expiratory breath hold, consistent breath hold instructions need to be given for preview images and actual scans, and critical for the CTA for diagnostic images.

Contrast Media Injection

The aim of contrast media injection is to enhance the contrast differentiation between target structure and surrounding tissues, by increasing the CT Hounsfield Units (CT HU) of the interest structure. Ideally, an injection protocol will achieve optimal enhancement with uniformity of contrast enhancement at all slice levels using as small a dose of contrast medium as possible. Important factors to consider in regard to contrast media injection are circulation time and injection methodology.

Assessment of the circulation time is important to timing the acquisition of images, and is defined as the time from contrast injection to the optimal enhancement of target structures. This sequence typically consists of repetitively imaging a single slice using a low radiation serial scanning of the same slice to obtain the peak enhancement time through time density curve analysis (Figs. 7.4 and 7.5). With CCTA, scans are obtained at the level of the takeoff of the left main coronary artery or descending aorta, to create a time–density curve to assess the time to peak opacification. The measured transit time is then used as the delay time from the start of the contrast injection to imaging start for the CCTA. It is important to use the same injection rate for the circulation time as for the subsequent CCTA study.

Another contrast timing method utilizes an automatic bolus-triggering technique. With this method, angiography imaging is automatically activated when the CT HU reaches a pre-specified HU value [18]. Circulation times vary based on the cardiac output. Patients with low output states having increased times and high output states with decreased times. Many factors influence circulation time, including venous

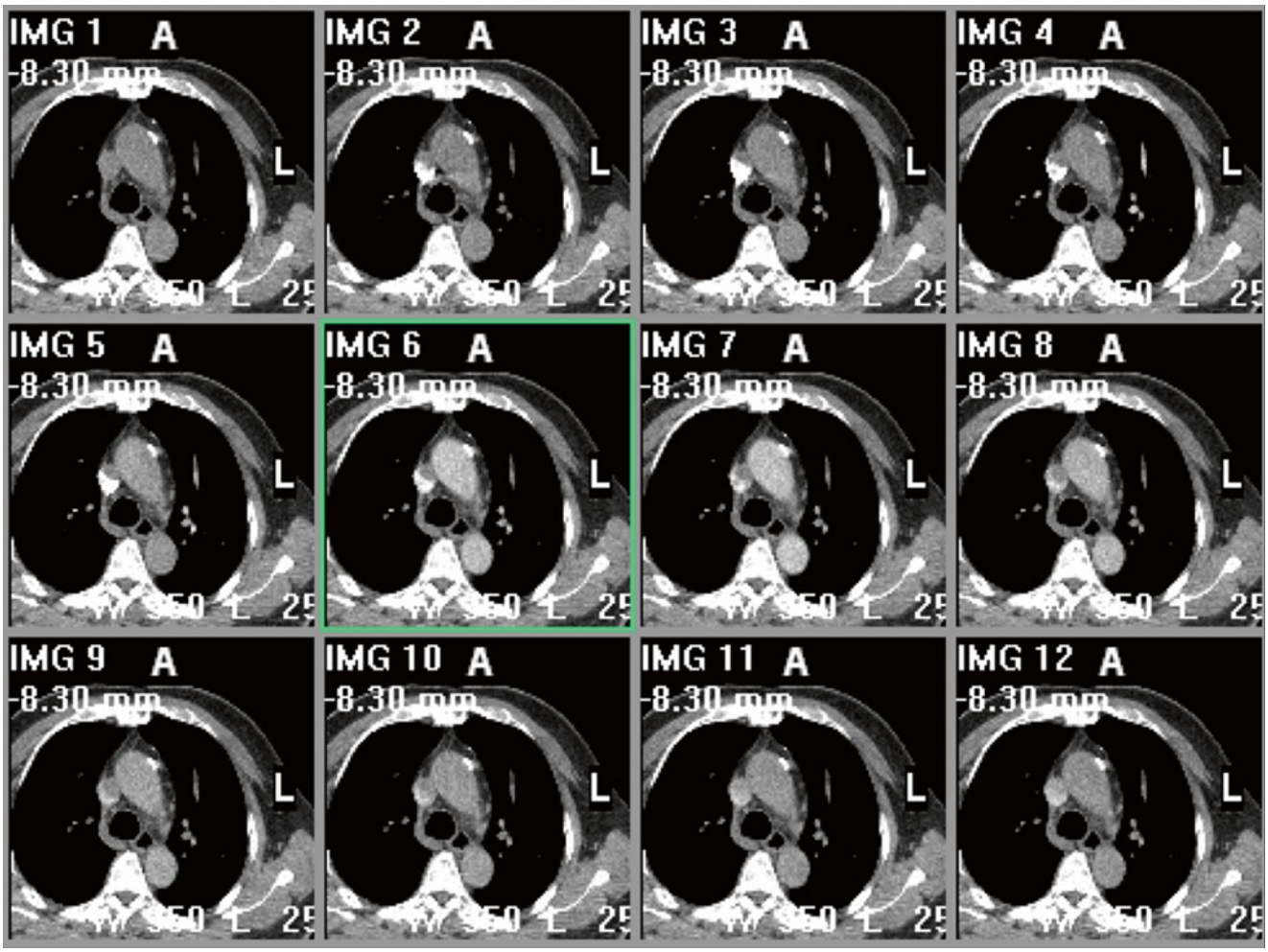

Fig. 7.4 Serial axial images of the target slice demonstrating opacification for determination of the circulation time

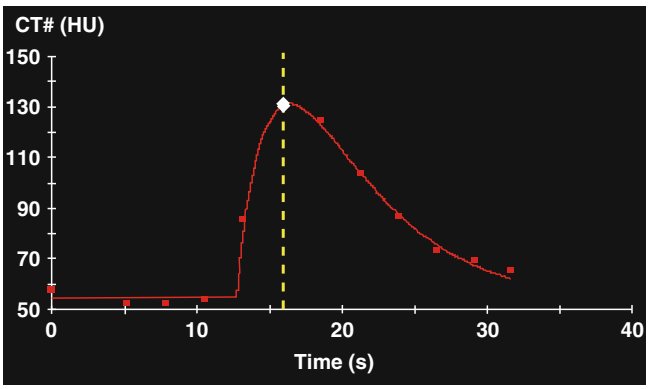

Fig. 7.5 Graph of CT Hounsfield Units versus time, demonstrating the time to maximal opacification of the region of interest

anatomy, cardiac output, and underlying cardiac and valvular function and therefore must be individually determined.

Low osmolar nonionic contrast media contrast medium is usually administered via an 20-gauge needle in the antecubital vein. Optimal enhancement depends on the contrast media dose and injection rate. The goal is to maintain the same level of vascular enhancement throughout image acquisition. The dose of contrast media is dependent on multiple factors, such as patient size, scan time, and desired enhancement level (CT HU). Multiphase contrast injectors with preset volumes and injection velocities are used to maintain uniformity of contrast enhancement throughout the study. A first injection stage with a high velocity, often 5 ml/s, is followed by saline injection to flush the remaining contrast out of the intravenous line and antecubital vein using a multiphase injector. The use of a saline bolus after contrast injection moves the residual contrast in the intravenous tubing and arm veins into the heart and coronary vasculature. The timing of the saline bolus is important, as in some studies clearance of the venous circulation and right heart structures can help with visualization of arterial structures, while in other studies, these structures are important to analysis. A middle phase with diluted contrast can also be utilized for some opacification of right heart and venous structures.

Specific injection protocols may be necessary for certain specialized indications including congenital heart disease. Since image quality on CT is based upon contrast to noise ratios (CNR), maintaining good contrast opacification is important. In larger patients or more obese subjects, the noise will be greater, so to ensure good image quality, faster rates of contrast injection are preferable to maintain the CNR. Thus, for patients who are very obese, increasing the rate of contrast to 6 ml/s is often necessary. A larger IV access may be necessary to ensure good flow at higher injection rates.

Preview, Calcium, and Contrast Scans

CCTA is performed in the following sequence: planar scout images, a non-contrast coronary artery calcium scan, a timing scan for assessment of the circulation time, and a contrast scan. Planar scout images are obtained in order to define the most cranial and caudal scanning levels (Z-axis) of the structures of interest. The scout images are obtained in anteroposterior and lateral views and aligned to the patient by a laser system. The scan volume is selected with the structures of interest placed within the center of the scanning volume. Important landmarks can be identified including the left atrial appendage, which is usually the most cranial structure of the heart, and the ventricular apex, which is the most caudal structure. Although the carina had served as a marker to localize the most cranial aspect of the heart, the distance from carina to left main coronary artery is extremely variable [19]. Also, the left anterior descending coronary artery can course cranial to the left main coronary artery (Fig. 7.6). For coronary artery imaging, scanning 10 mm cranial to the left main coronary artery and 10 mm caudal to the apex is subsequently performed with CCTA. In patients with coronary artery bypass grafts, the starting point is the top of the aortic arch or 10 mm higher than the surgical metal clips. The mid level of the right pulmonary artery can also be used as the beginning of the scan level, if it can be defined in preview images.

After the scout images, a calcium scan is performed (Fig. 7.7). This is a high resolution non-contrast cardiac-gated study which provides important prognostic information regarding future cardiovascular risk. For the calcium scan, the 2-D axial images are analyzed with the identification of calcium either using manual or automated methods, with quantification of calcium score based on identification of HU units with an attenuation of at least 130 HU in the areas of identified calcium. There are two major methods of quantifying coronary artery calcium, the Agatston score and volumetric analysis. The Agatston score is based on the plaque number, and plaque area times a coefficient based on the peak HU units in the plaque [20]. Calcium volume score describes a volumetric analysis of calcium with calculation based on volumetric reconstruction and is more reproducible on serial study [21]. The calcium score is a marker of plaque burden and is an independent risk factor for coronary artery disease beyond traditional risk factors [22, 23].

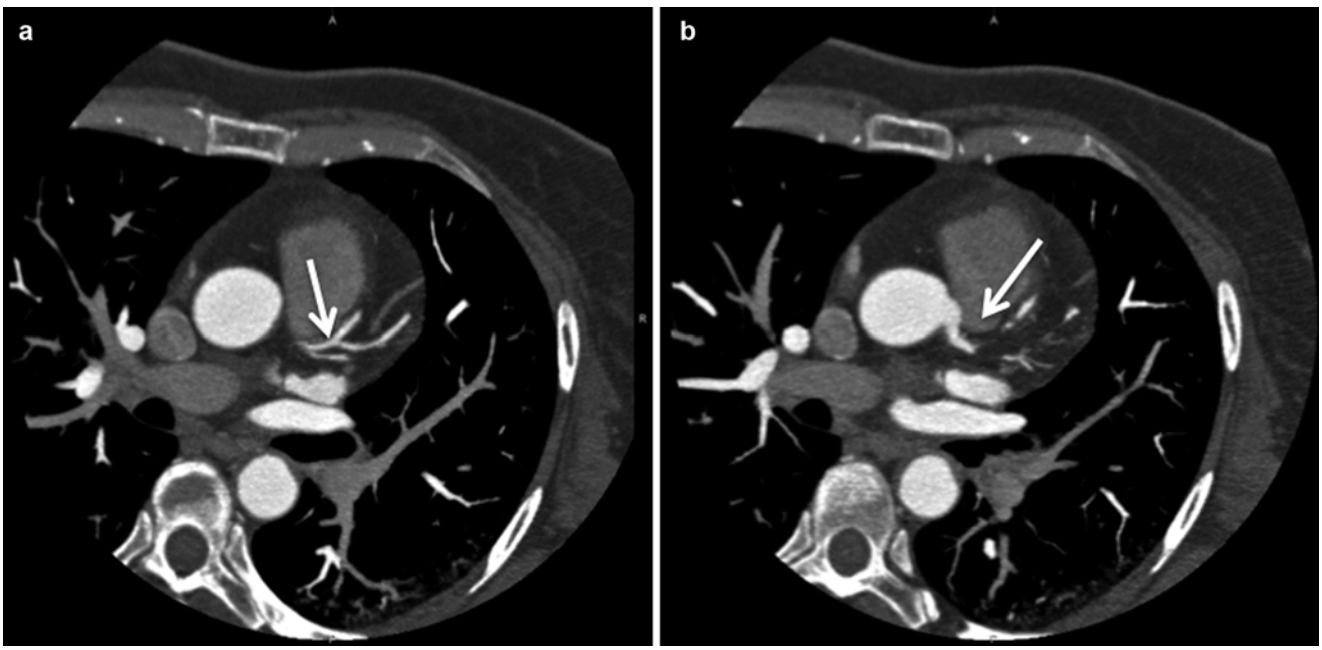

Fig. 7.6 Axial views (cranial to caudal) showing the left anterior descending artery coursing cranial to the takeoff off the left main coronary artery. If the cranial limit of the field of view were at the level of the left main, the left anterior descending could be out of the imaging field. (**a**) The cranial slice, showing the left anterior descending (*arrow*). (**b**) A more caudal slice, demonstrating the left main artery (*arrow*) is visualized inferiorly to the left anterior descending artery

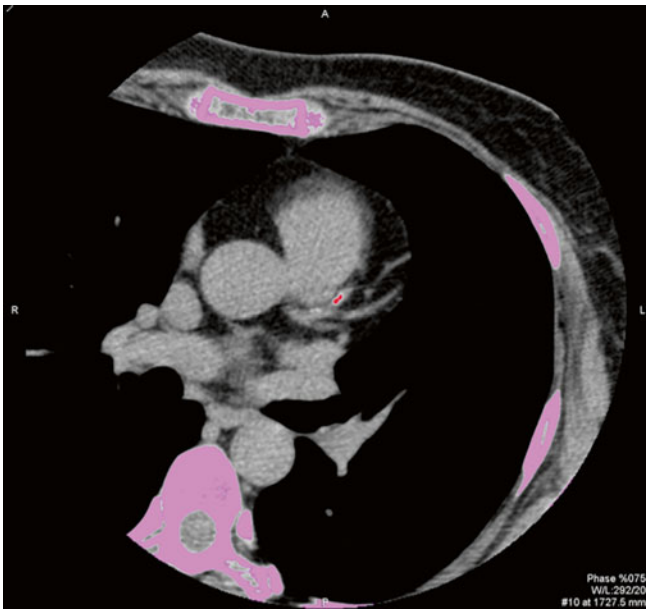

Fig. 7.7 Coronary artery calcium score axial image showing a calcification of the left anterior descending coronary artery

The calcium scan is useful to the planning, performance, and interpretation of the CCTA. Assessment of the images can be used to ensure that there is complete coverage of the coronary anatomy in the image set prior to contrast angiography, as well as to determine the minimum volume to be covered to minimize radiation exposure [24]. The degree of coronary calcification may prohibit the accurate assessment of coronary artery stenoses.

The calcium score as well as the calcium distribution should be assessed prior to the performance of the CCTA to determine whether the contrast study should be performed. Different imaging centers use various cutoffs for the performance of CCTA in the setting of a significantly elevated calcium score, with some center using >500 or >1000. It is important though to have an understanding of the specific goal of an individual study, as depending on the question asked and the location of calcium, some studies may still be performed in settings of an elevated calcium score. For example, in cases where the location and patency of coronary artery bypass grafts are the clinical questions, calcium in the native coronary arteries may still not necessarily prohibit the study from being performed. In addition to traditional cardiac risk factors, knowledge of the calcium score is helpful in assessing the pretest probability of coronary artery disease when interpreting the contrast angiography images.

After performance of the calcium scan, a contrast angiography study is performed, requiring the administration of iodinated contrast timed to enhance the structures of interest. This may vary by the type of study, with some studies performed specifically for assessment of coronary artery anatomy, while others are performed for additional assessment of thoracic vasculature, such as in the case of congenital heart disease.

Relation of Image Acquisition to Image Analysis

Image reconstruction is dependent on image acquisition, as the reconstructed images are only as good as the acquired data. The raw datasets are imported to workstations with software allowing the analysis of images in multiple 2-D and 3-D formats. Prior to reconstruction, the 2-D axial dataset must be reviewed to ensure that the structures of interest were scanned in their entirety and that there is uniformity of contrast throughout the study. A decrease in contrast in the distal vessels can appear as stenoses. Adequate and uniform enhancement of the distal aorta can be helpful in ensuring that distal coronary arteries have been adequately opacified.

Interpretation of CT coronary angiography requires reconstruction and analysis of multiple 2-D and 3-D analyses so that findings can be confirmed on multiple views and artifacts related to image acquisition can be identified. Image reconstruction allows a 3-D understanding of cardiovascular anatomy from large vessel to small vessel. The serial axial 2-D images are reconstructed into a 3-D data cube with subsequent use of software to edit out and analyze cardiovascular structure. Workstation software has dramatically reduced the time for image editing and reconstruction. Systematic reconstruction, serial automated editing, and analysis of this data cube allows one to glean information important to characterization of the structure and relationship between structures essential to clinical diagnosis and planning and facilitation of cardiovascular procedures. These reconstructions include: assessment of thoracic structures in relation to skeletal structures, relation of large vessel vasculature and structures, cardiac chambers, valves, and coronary vasculature (Fig. 7.8).

Reconstruction of coronary artery anatomy requires assessment of the phase of the cardiac cycle during which an artery or arterial segment is most quiescent. Retrospectively gated axial images can be reconstructed at different diastolic phases of the cardiac cycle and assessed for the most optimal images regarding minimizing cardiac motion (Figs. 7.2 and 7.3). As the optimal phase of the cardiac cycle may vary by artery and arterial segment, different arteries or segments may need to be analyzed using multiple modalities. Once the correct phase or phases have been chosen, 2-D images can be rapidly formatted in axial, sagittal, and coronal planes.

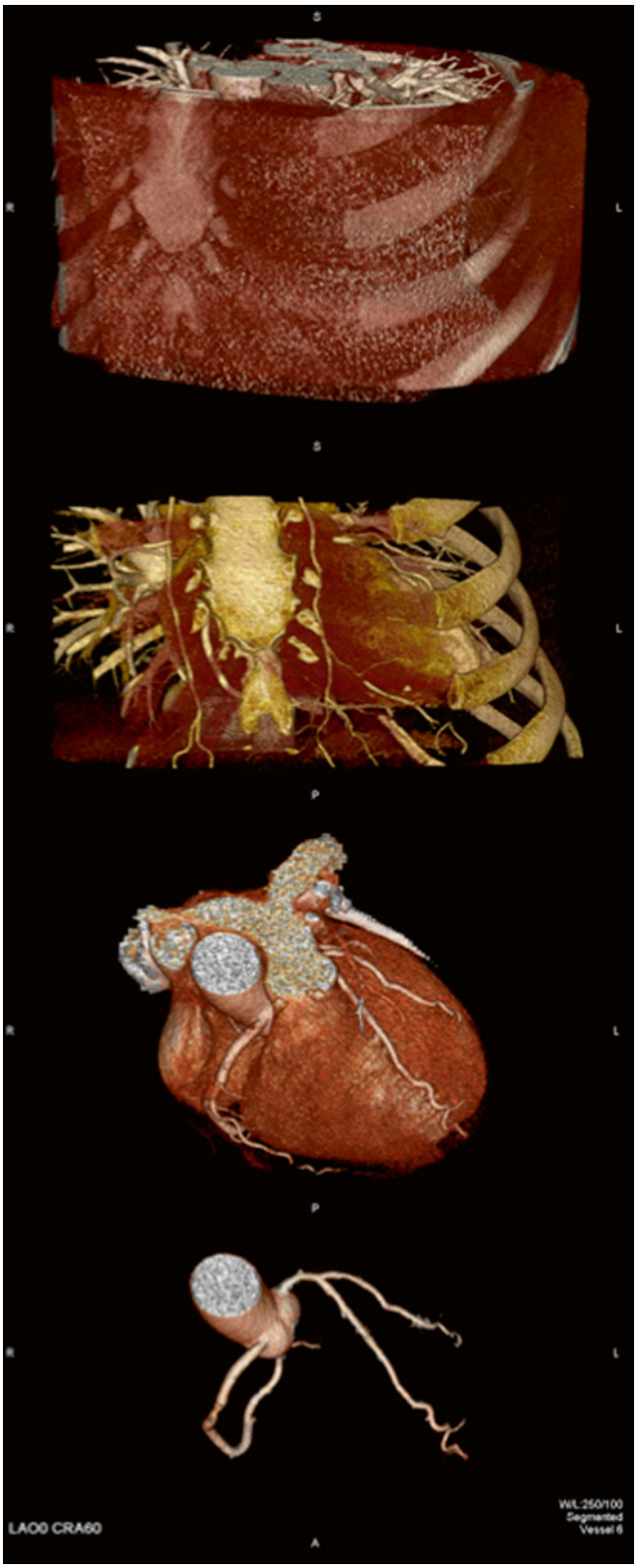

Fig. 7.8 Reconstructions of thoracic structures in relation to skeletal structures, relation of large vessel vasculature and structures, cardiac chambers, valves, and coronary vasculature

Subsequent analysis is performed primarily from axial images with additional analysis with multiple modalities of image reconstruction (Fig. 7.9a–g). Functional analysis for retrospectively gated scans can be formatted and assessed in standard echo views (Fig. 7.10).

Although the 3-D reconstructed images are both aesthetic and intuitive regarding orientation, it is essential to recognize that the process of reconstruction has limitations. It is essential to remember that the 2-D views provide an entire dataset whereas the 3-D techniques lead to loss of data and potential artifacts that adversely affect interpretation of images. Given the limitations of reconstruction techniques, it is essential to continually reference back to the 2-D images and view potential findings using multiple types of reconstructions before making a diagnosis.

There are many factors related to image acquisition that may affect image reconstruction and analysis. With volume rendering, pixels are assigned HU depending on their attenuation. With automated editing, pixels below a certain HU cutoff (lower threshold 80–100 HU) are edited out. Volume rendering and editing software allows creation of 3-D image with structures removed to adequately visualize structures of interest, but involves potential loss of data through over-editing of structures. If over-edited, the coronary arteries can appear as though stenoses are present.

Construction of 3-D images from 2-D image sets with cardiac respiratory or patient motion between slices can lead to artifactually discontinuous arterial segments that could be misinterpreted as stenoses. Lack of uniformity of contrast enhancement on serial slices may also result in the artifactual appearance of stenoses. If only viewed on 3-D images, myocardial bridging can be misinterpreted as obstructive coronary artery disease. Misalignment artifacts (formed from movement between the large acquisitions of the 64–160 detector arrays or collimation), can also form regions of pseudo-stenosis. Misalignment artifacts have been previously known as mis-registration, stair step, collimation or a multitude of prior names. The Society of Cardiovascular Computed Tomography has developed a nomenclature document to standardize these names [25].

Partial volume effects may limit reconstruction and analysis. The goal of scanning is to acquire isotropic data, where the spatial resolution is equal in the X, Y, and Z axes, allowing for accurate images with multiplane reconstructions [26]. As spatial resolution in the Z axis may not be truly isotropic, some volume averaging of data may occur. Therefore, volumes averaging may occur with only a portion of the depth of the image being represented as present throughout the dataset.

Calcified plaques may also limit reconstruction and analysis of images. The purpose of contrast enhanced studies

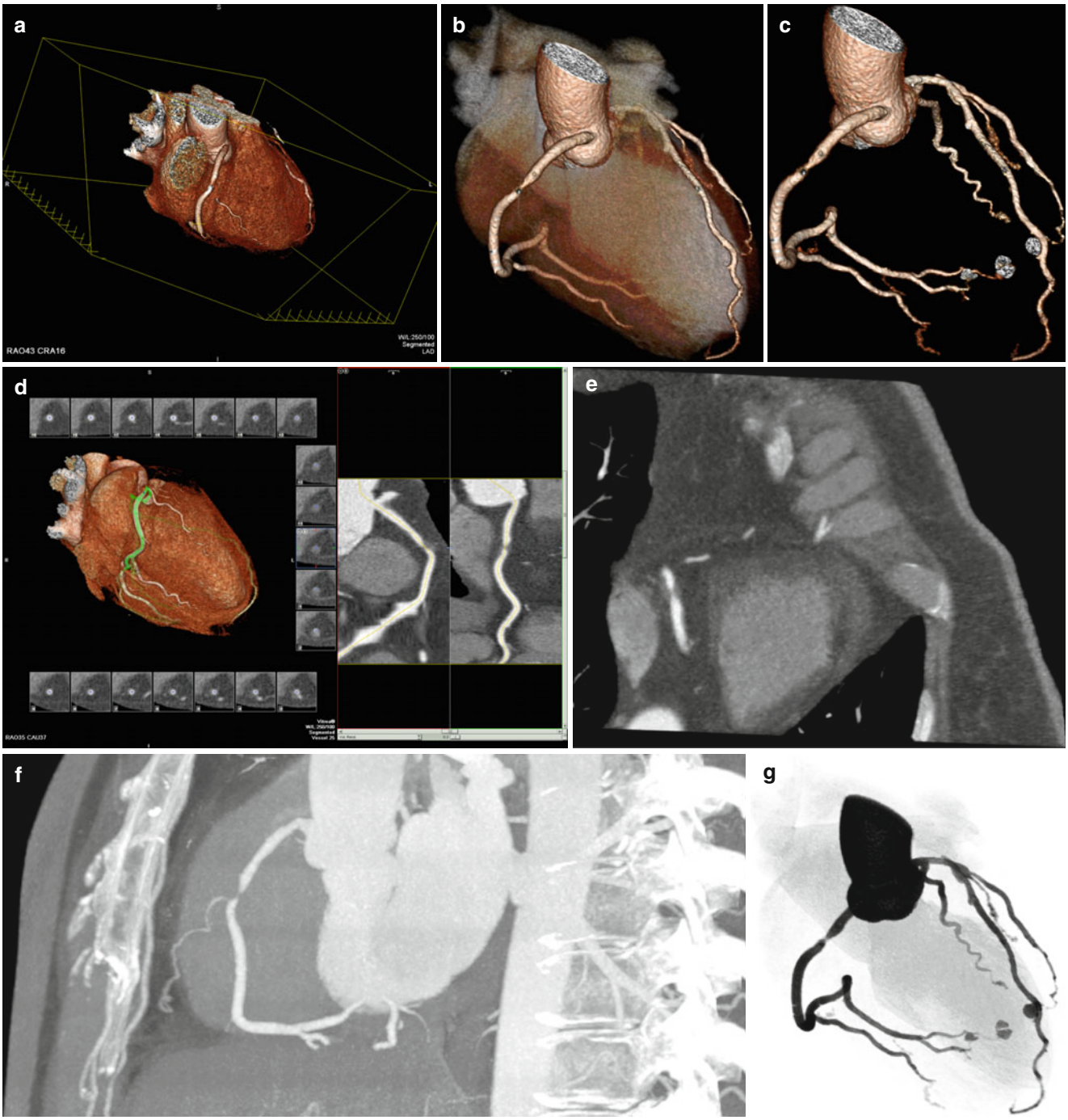

Fig. 7.9 A significant right coronary artery non-calcified stenosis is shown using multiple reconstruction modalities. Multiple CCTA angiography views are demonstrated including; (**a**) 3-D volume rendered view of the heart and coronary arteries; (**b**) 3-D volume rendered view of the heart and coronary arteries; (**c**) 3-D volume rendered view of only the coronary arteries; (**d**) Curved multiplanar reformatted view; (**e**) Double oblique reformat; (**f**) Sagittal view with a thick maximum intensity projection; (**g**) Cardiac catheterization angiography emulation

is to increase contrast between coronary vessel lumen and surrounding tissues. Greater lumen enhancement (represented by increased CT HU) will create greater contrast between the vessel lumen and non-calcified vessel wall, which is especially important for visualization of small vessels. Luminal enhancement though, will decrease the contrast between enhanced vessel lumen and calcified plaques. This can make assessment of the coronary arterial wall challenging for assessment of different tissue components of the plaque wall.

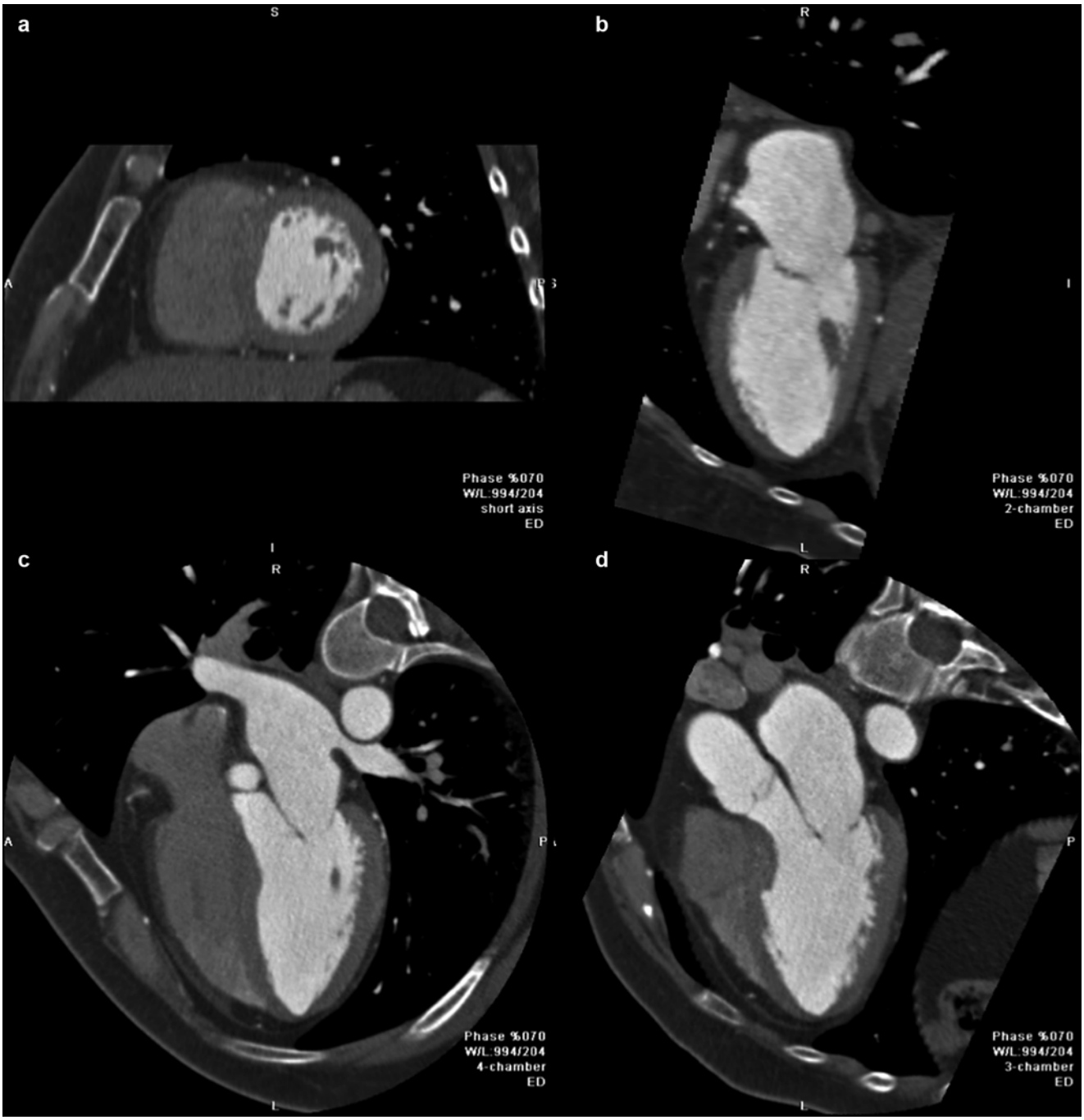

Fig. 7.10 Functional views in standard echo planes. (**a**) Short axis view; (**b**) 2 chamber view; Panel; (**c**) 4 chamber view; (**d**) 3 chamber view

Other reconstruction and viewing modalites can are useful for analysis of images that are problematic due to issues related to image acquisition [27]. Maximal intensity projections demonstrate the maximal density point at each point in a 3-D volume. Conceptually, this provides the ability to move through the 3-D data cube with a thick slab focused on the maximum intensity of the images in the slab. The modality provides for assessment of small and distal vessels and is helpful for differentiating calcium, contrast, and metal in the coronary arteries and avoids issues of volume averaging of structures. As editing is not involved with this modality, there will be overlap of structures as one moves through the dataset.

Multiplanar curved reformatting allows for in plane analysis of an individual vessel (Fig. 7.11) [28]. A reconstruction is performed orthogonal to vessel centerline

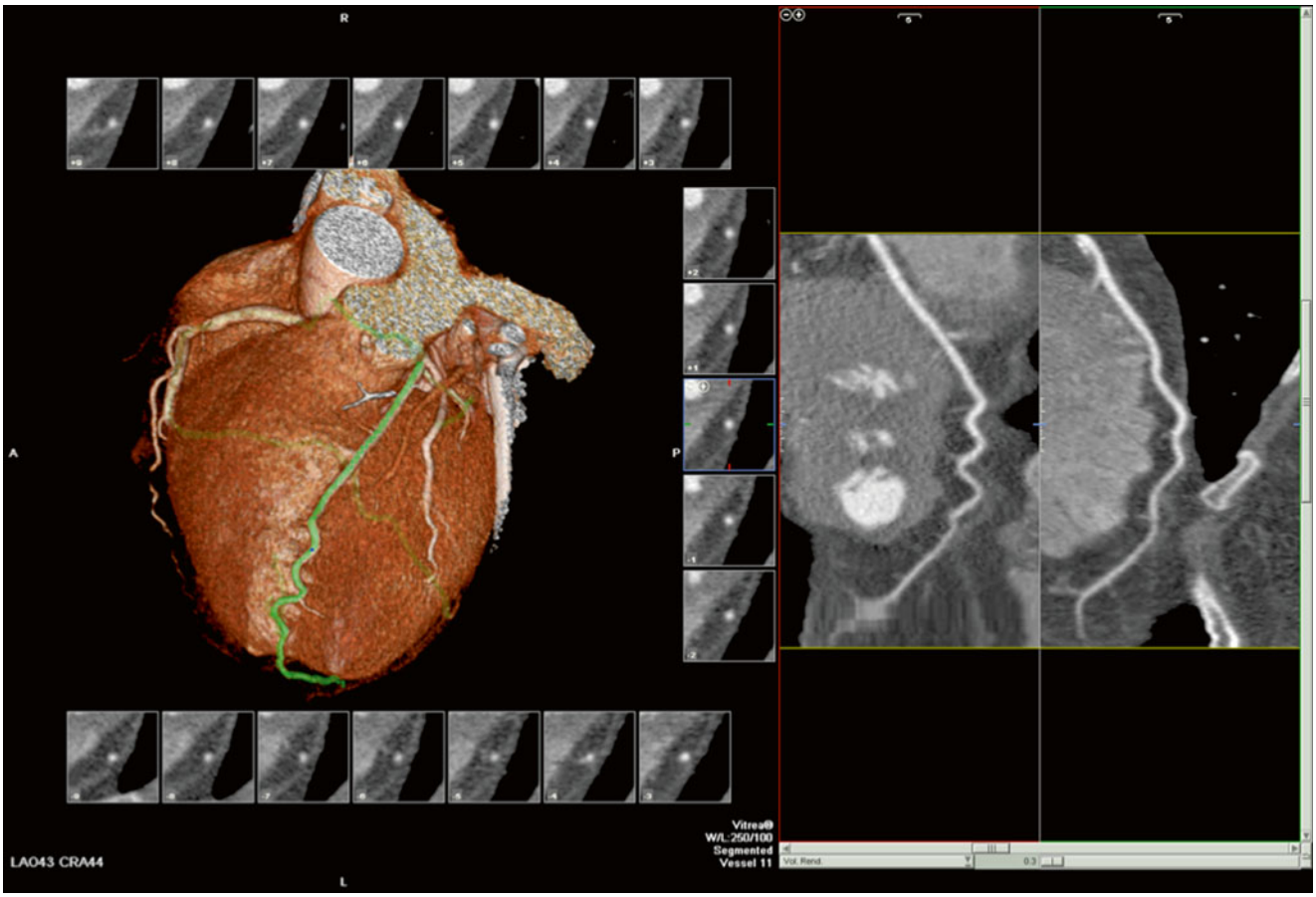

Fig. 7.11 Curved multiplanar reformation of the left anterior descending coronary artery, allowing in plane analysis of the vessel

and does not require editing. Vessels can be analyzed in a 360° rotation allowing for assessment of eccentricity of plaque in relation to the vessel lumen. The technique requires accurate vessel tracking and determination of the centerline of the vessel. Interactive display methods may provide greater diagnostic accuracy than pre-rendered images [27]. Virtual endoscopic views, which provide a perspective from inside a vessel or chamber have been developed, but are very dependent on filtering and smoothing techniques. Fluoroscopic views are helpful for assessment of metallic structures such as pacemaker leads.

The evolution of CT scanners and workstations allow for rapid acquisition and reconstructions of images for the characterization of cardiovascular disease processes. CCTA imaging poses challenges due to the complex motion of the heart, variation in heart rate and rhythm, and tissue characteristics of cardiovascular structures. An understanding of these factors and meticulous attention to triggering techniques, contrast injection methods, and preview methods can lead to images visualizing anatomy and function critical to the diagnosis and treatment of patients with cardiovascular disease.

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