Cardiac CT Angiography: Protocols, Applications, and Limitations

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KEYWORDS

• Cardiac computed tomography • Coronary CT anatomy
• CT angiography • Calcium scoring • Coronary stent

Coronary artery disease (CAD) affects 17.6 million Americans and remains the most common cause of mortality, with 425,425 deaths in 2006.[1] The traditional management of patients presenting with acute chest pain involves history and physical, electrocardiography (ECG), and cardiac biomarkers. Imaging modalities including chest radiography and fluoroscopy, coronary angiography and cardiac catheterization, echocardiography, and nuclear medicine are routinely used to assess and diagnose cardiac disease. However, the emergence of multidetector computed tomography (MDCT), with robust spatial and temporal resolution as well as decreased image acquisition time, has enabled accurate visualization of the coronary tree and cardiac structures. For example, noncontrast material–enhanced assessment of coronary artery atherosclerotic plaques (CT calcium scoring) is used for cardiac risk stratification in asymptomatic patients and monitoring of medical (statin) therapy. In addition, contrast material–enhanced CT coronary angiography has become established as a valuable method for several clinical applications, including evaluation of coronary artery stenosis, coronary artery anomalies, coronary artery bypass patency, coronary artery stent patency, assessment of myocardial viability, pulmonary vein anatomy prior to ablation, and preoperative planning. The versatility and availability of MDCT has contributed to the increasing use of cardiac CT as an alternative technique in noninvasive diagnostic cardiac imaging.

CARDIAC CT EVOLUTION

Cardiac CT scanning was introduced in the 1980s with electron-beam CT (EBCT) to quantify coronary artery calcium (CAC). The EBCT scanner lacked moving mechanical parts and used a rotating electron beam to produce x-rays. With no rotating components, image acquisition time was relatively short and temporal resolution was enhanced for better depiction of the coronary arteries, which are subject to motion artifact. However, EBCT had limited spatial resolution and commercial availability, and was supplanted by the development of newer and more versatile MDCT technologies. MDCT scanners with ECG synchronization have the ability to assess not only coronary artery calcification but also coronary artery stenosis and cardiac function, as well as to analyze atherosclerotic plaque.[2–5] The diagnostic accuracy of MDCT in CAD significantly improved with each subsequent scanner generation, as demonstrated with the emergence of 64-slice and, more recently, dual-source 256-slice and

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320-slice CT scanners. The now commonplace 64-detector-row MDCT scanner can complete coronary artery acquisition within 5 to 8 seconds with a spatial resolution of 0.5 to 0.6 mm and temporal resolution of 50 to 150 milliseconds,[6] whereas newer-generation MDCT scanners with extended z-axis coverage and faster gantry speeds reduce susceptibility to arrhythmia.[2,7,8] This review provides an overview of cardiac CT and highlights some of the indications for this rapidly evolving technology (**Table 1**).

MDCT Protocol

Many imaging protocols are in use for MDCT evaluation of coronary arteries. Image quality depends on optimizing various patient and scanner parameters for better temporal and spatial resolution. To obtain diagnostic-quality MDCT images and reduce motion artifacts, the heart rate should be maintained at 65 beats per minute or less. This pace is usually achieved with the administration of β-blockers prior to image acquisition. Patients with contraindications to β-blockers can be given calcium-channel blockers. Sublingual nitroglycerin, a coronary vasodilator, can be administered to optimize imaging. Once optimal heart rate is achieved, the patient is positioned in the scanner, and attached to ECG leads and an intravenous contrast injector. In prospective ECG gating, the x-ray beam is turned on during a select phase of the R-R cycle and turned off during the rest of the cycle; this is also referred to as a step-and-shoot nonhelical acquisition, as the table does not move during image acquisition. In retrospective ECG gating, the x-ray beam is turned on throughout the R-R interval and images are acquired continuously with table motion. The main advantage of prospective triggering is the lower radiation dose compared with retrospective ECG gating. To reduce radiation exposure for retrospective gating, tube current modulation is developed using higher tube current during the most important part of the R-R interval with lower tube current in the remaining cycle. Retrospective ECG gating, typically using the 60% to 80% phases of the R-R interval, enables the acquisition of multiple time points to optimize coronary artery imaging. Volume data sets from retrospective ECG gating can also be used to evaluate cardiac function. Cardiac anatomy is best imaged during the diastolic rest phase of the cardiac cycle when the coronary arteries are least prone to cardiac motion. A nonionic iodine contrast agent is administered through an appropriately sized cannula inserted into an antecubital vein. A preliminary topogram is acquired to ensure appropriate alignment as well as to enable the patient to practice breath-holds. Scanning is timed with the arrival of contrast in the ascending aorta, and can be adjusted using a region of interest placed in the aorta or left ventricle and then set to a predefined signal threshold of 100 to 150 Hounsfield units (HU). Alternatively, a test bolus of a small amount of contrast can be injected, followed by a saline flush to determine transit time. Based on the clinical indication, a calcium scoring image is often obtained first. Scans are usually performed in the craniocaudal direction and extend from the carina to below the cardiac apex (**Fig. 1**A). In patients with coronary artery bypass grafts (CABG), the scan range is shifted superiorly to include the origins of the subclavian or internal mammary grafts (see **Fig. 1**B). Images are acquired with a single breath-hold during mid-inspiration to reduce heterogeneity of contrast in the right atrium. The total time in the scanner including setup and image acquisition is generally less than 15 minutes. Axial cardiac images are typically acquired in a limited field of view (FOV) to allow for better resolution in evaluating cardiac disease (**Fig. 2**). A wider FOV can be secondarily reconstructed to encompass the entire thorax. Images are further reconstructed using curved planar reformation, maximum intensity projection, and volume-rendering techniques (**Fig. 3**). Additional dose-reduction strategies can be achieved with iterative reconstruction techniques, with the potential for improved image quality relative to filtered back-projection techniques.

Table 1
Technical parameters in currently available cardiac CT

Resolution/Coverage	64-Slice (Multiple Vendors)	256-Slice (Philips)	320-Slice (Toshiba)	Dual-Source with 128 × 2-Slice (Siemens)
Temporal resolution (ms)	165–200	135	175	75
Spatial resolution (mm)	0.5–0.625	0.625	0.5	0.6
z-Axis coverage (mm)	32–40	80	160	38.4

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