Cardiac computed tomography

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Abstract

Recent developments in computed tomography (CT) technology permit imaging of the coronary arteries. Non-enhanced CT is used to perform coronary artery calcium scoring, which is useful to stratify the risk of future coronary events but does not allow assessment of stenosis. Contrast-enhanced CT enables angiographic evaluation of the coronary artery lumen. The high negative predictive value of coronary CT angiography (CTA) makes it a useful test to rule out the presence of significant coronary stenoses, especially in those patients with an intermediate pre-test likelihood of coronary artery disease. Coronary CTA also has potential to aid triage of patients with acute chest pain in the emergency department. Coronary artery bypass grafts can be assessed reliably using CT. Intracoronary stents are difficult to image due to artefacts caused by metal, often precluding detection of in-stent restenosis. There is emerging evidence supporting the ability of CT to characterize atherosclerotic plaque, potentially allowing identification of those plaques at most risk of rupture. Myocardial perfusion imaging using cardiac CT is also the subject of current investigation.

Keywords Calcium scoring; cardiac; computed tomography; coronary angiography

Cardiac computed tomography (CT) is now established as an important non-invasive tool for the diagnosis and monitoring of heart disease, and has become a routine test in clinical practice following the introduction of the National Institute for Health and Care Excellence (NICE) chest pain guidelines. Recent technological improvements in CT have led to improved spatial and temporal resolution, and have made it possible accurately to characterize the coronary tree with improved image quality. Radiation dose reduction has been an important area of development in recent years, with methods available to reduce patient radiation dose below that of conventional diagnostic angiography.

Technical considerations

The primary technical challenge for CT is to overcome the effects of continuous cardiac motion. High spatial resolution (ability to distinguish between adjacent structures) and fast temporal resolution (time needed to acquire one image) are therefore both prerequisites for imaging the complex anatomy of the coronary arteries.

Stepwise evolution in helical CT technology (from 4 to 8, 16, 64, 128, 256 and 320 slices) has allowed progressively more data to be acquired simultaneously per rotation of the gantry around the patient, thereby increasing the speed at which an area such as the heart can be scanned. The minimal requirement for state-of-the-art coronary CT angiography (CTA) is a 16-slice scanner, although 64-slice scanners are recommended. When coupled with thinner slice collimation and faster tube rotation (improving spatial and temporal resolution, respectively), multi-slice CT is now an accurate and reliable technique for imaging the coronary arteries.[1,2] It is now possible to image the entire coronary circulation within a single heartbeat, thus minimizing cardiac motion artefact. With dual source CT, this is achieved by the use of two perpendicularly oriented X-ray tubes and detectors, allowing the same data to be acquired in just over a quarter gantry rotation as opposed to the standard half gantry (180 degrees) rotation.[3]

Performing a scan

Patient preparation

Coronary imaging is most likely to be successful if the patient has a slow and regular heart rate. It is usual to aim for a heart rate of <65 beats/min. This may require administration of a short-acting beta-blocker (e.g. metoprolol) or calcium channel blocker (e.g. diltiazem). Some centres advocate use of sublingual nitrate immediately before scanning to dilate the coronary arteries. Patients must also be able to hold their breath for 5–20 seconds during the scan.

ECG-gating

Most CT scanners currently used in clinical settings take from 0.33 to 5 seconds to cover the heart. Images of the coronary arteries are usually reconstructed from data obtained from multiple heartbeats. Since the coronary arteries typically show the least motion in diastole, images are usually reconstructed from diastolic data. Thus, it is necessary to monitor the cardiac cycle by simultaneously recording an electrocardiogram (ECG) during scanning. Images can either be acquired prospectively in diastole alone (prospective ECG-triggering) or obtained throughout the entire heart cycle and reconstructed later at the desired phase (retrospective ECG-gating). The latter approach is more versatile as it allows reconstructions at different phases during image analysis. However, the radiation dose is greater with retrospective gating than with prospective gating.

Study protocol

The series of images obtained for a cardiac CT examination is dependent on the clinical indication. At our centre, a routine study evaluating the coronary arteries is conducted in two stages: a non-enhanced scan covering only the heart is obtained, for coronary calcium scoring, after which a contrast bolus is delivered for coronary angiography. Between 80 and 120 ml of contrast media is injected at a rate of 4–5 ml/s via a 20 G cannula into an antecubital vein, followed by a 40–50 ml saline chaser bolus to wash out contrast from the right ventricle. The start of the scan is timed to coincide with the arrival of adequate contrast in the ascending aorta. The scan range is usually from just below the carina to the diaphragmatic surface of the heart. Variations are made to this protocol depending on the clinical circumstance, particularly in the setting of congenital heart disease or previous

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surgery when the area scanned may vary and the calcium score is omitted.[4]

Data-processing techniques

The reconstruction of data from all cardiac phases may generate 2000–3000 individual axial images. Analysis and interpretation of these large datasets can be a time-consuming process. Since the coronary arteries may be oriented at any angle to the axial plane, multiplanar reformations and other post-processing techniques are used to supplement the axial CT images (Figure 1). Three-dimensional reconstructions, although visually impressive, are rarely useful for assessment of coronary artery stenoses.

Indications and contraindications for cardiac CT

Currently accepted indications and contraindications for cardiac CT are listed in Tables 1 and 2. The major indications are discussed further below.

Calcium scoring

Coronary artery calcification occurs almost exclusively in the context of advanced atherosclerotic disease, and coronary calcium can be considered a surrogate marker for subclinical coronary atherosclerosis. Non-enhanced low-dose CT allows detection and quantification of coronary calcium. The Agatston score, which is a product of plaque area and peak plaque density for each individual plaque, is the most widely used measure. An Agatston score of 1–10 is considered minimal, 11–100 low, 101–400 moderate and >400 high. The relationship between the amount of coronary artery calcium and the risk of future cardiovascular events has been established. However, the coronary calcium load detected by CT does not correlate well with the degree or haemodynamic significance of individual coronary artery stenosis.[5]

Coronary CT angiography

A recent systematic review of 28 studies showed that the new generation scanners (i.e. 64-slice or higher) had a high patient sensitivity and specificity of 98% and 82%, respectively, for the detection of haemodynamically significant (>50% luminal narrowing) stenoses.[6] Overall, CTA has a high negative predictive value (96–100%) and so is able to exclude the presence of important coronary artery stenosis.[7] Therefore, the benefit of coronary CTA is likely to be greatest for symptomatic patients who are at intermediate risk of coronary artery disease after initial risk stratification, including those with equivocal stress-test results (Figure 2). For such patients, a negative CTA (i.e. no or low-grade stenosis) can prevent the need for invasive coronary angiography. Patients with a high pre-test probability of coronary stenoses should be referred directly for cardiac catheterization, with the option of performing immediate percutaneous coronary intervention, so routine CTA would afford no clinical benefit in this high-risk group. CTA may be considered in low-risk patients who are unable to exercise or where the ECG is uninterpretable. There is no evidence to justify screening asymptomatic individuals.[8]

Prognostic value of CTA

The presence and severity of atherosclerotic disease on CTA is an indicator of future cardiac events, with the presence of one or more significant coronary stenosis being associated with an annualized cardiovascular event rate of just under 12%.[9] A large systematic review (CONFIRM) revealed that an increasing burden of non-obstructive CAD (as well as obstructive CAD) is associated with an increased rate of further adverse cardiovascular events. As a non-invasive test CTA is therefore useful in being able to demonstrate milder degrees of non-obstructive CAD (<50% stenosis).[10]

CTA for patients with acute chest pain in the emergency department

The current European guidelines recommend that CTA should be considered as an alternative to ICA for patients with suspected acute coronary syndrome, with a low to intermediate likelihood of CAD. As a quick imaging procedure, the value of CTA in the emergency department (ED) is undergoing widespread evaluation. Recent studies have shown that CTA performed in the ED can reduce length of hospital stay and costs, and may therefore play an increasing role in the future.[11]

Combined imaging of the coronary arteries, ascending aorta, and pulmonary arteries to assess for the presence of coronary artery disease, thoracic aortic dissection and pulmonary embolism (PE) can be performed in a single CT examination. Compared with standard coronary CTA, this 'triple rule-out' protocol requires an extension of the field-of-view and a prolonged administration of intravenous contrast (over 20–25 seconds) to ensure adequate contrast enhancement of both the thoracic aortic and pulmonary vasculature. This technique has been shown to be as accurate as standard CTA for detecting CAD, and could potentially improve the triage and management of patients with acute chest pain. Given the low prevalence of PE and aortic dissection in a recent systematic review of this technique, as well as the increased radiation and contrast exposure, its routine application requires further evaluation.[12]

Plaque characterization

Whereas conventional coronary angiography visualizes only the arterial lumen, CT has the potential to characterize atherosclerotic plaque and its composition. The ability to differentiate between calcified, partly calcified or non-calcified plaque may be of prognostic value, as it is thought that calcified plaque is generally associated with stability whereas non-calcified plaque has a greater tendency to rupture, leading to acute coronary syndromes. Additional plaque characteristics on CT that are associated with increased plaque vulnerability include 'spotty' calcification, low attenuation plaque and positive remodelling, whereby the arterial segment expands to compensate for luminal narrowing caused by plaque. Accurate classification of non-calcified plaque type by CTA is difficult, owing to a wide overlap in density measurements as well as the confounding effects of contrast within the adjacent vessel lumen and reconstruction parameters. However, a plaque CT density of less than 30 is thought to be associated with a higher risk of rupture.[13]

Bypass graft and stent assessment

CT angiography has been advocated for follow-up after surgical or catheter-based myocardial revascularization. Patency of bypass grafts is indicated by contrast opacification within the vessel. Saphenous vein grafts are generally easier to assess than