Cardiac computed tomography

Patrick MT Wong

Simon PG Padley

Abstract

Advances in computed tomography (CT) technology now allow definitive 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 coronary angiography (CTCA) enables angiographic evaluation of both the coronary artery lumen and wall. The high negative predictive accuracy of CTCA makes it a useful test to rule out the presence of significant coronary stenoses, especially in patients with an intermediate pre-test likelihood of coronary artery disease. CTCA also has potential to aid the triage of patients with acute chest pain in the emergency department. CTCA can determine the approximate degree of stenosis as well as detect high-risk plaque characteristics. Coronary artery bypass grafts can be assessed reliably using CT. Intracoronary stent evaluation is possible because of advances in temporal resolution. Myocardial perfusion imaging using cardiac CT is the subject of current investigation.

Keywords Calcium scoring; cardiac; computed tomography; coronary angiography; MRCP

Key points

- Computed tomography coronary angiography (CTCA) has a high negative predictive accuracy and is a useful rule-out test for coronary artery disease
- CTCA has a moderate to high positive predictive accuracy and may necessitate further investigations to quantify coronary artery disease
- CTCA is used as a first-line diagnostic test for stable angina (typical and atypical) as well as non-anginal chest pain with changes on ECG suggestive of recent or prior myocardial ischaemia
- Calcium scoring is a useful predictor of lifetime risk of myocardial ischaemia
- CTCA is useful for follow-up of coronary artery bypass grafts, evaluation of coronary artery stents and evaluation of suspected coronary artery anomalies

Introduction

Computed tomography cardiac angiography (CTCA) is an important and rapidly growing non-invasive tool for the diagnosis and monitoring of heart disease; it has become a routine test in clinical practice following the updated 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 made it possible accurately to characterize the coronary tree, with improved image quality. Reduction in radiation dose has been an important development in recent years, with methods available to reduce the patient's radiation dose well 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 prerequisites for imaging the complex anatomy of the coronary arteries.

Stepwise evolution in helical CT technology (currently up to 320 slices) has allowed progressively more data to be acquired simultaneously per rotation of the gantry around the patient; this increases the speed at which an area such as the heart can be scanned (particularly important in atrial fibrillation). The minimal requirement for state-of-the-art coronary CTCA 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), multislice CT is now an accurate and reliable technique for imaging the coronary arteries. It is now possible to image the entire coronary circulation within a single heartbeat, minimizing cardiac motion artefact. With dual-source CT, this is achieved by using two perpendicularly oriented X-ray tubes and detectors, allowing the same data to be acquired in just over a quarter of a gantry rotation as opposed to the standard half-gantry (180°) rotation.

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 <60 beats per minute. This usually requires intravenous administration of a short-acting β-adrenoceptor blocker such as metoprolol. Most centres advocate use of sublingual nitrate immediately before scanning to dilate the coronary arteries. Patients must also be able to hold their breath for 5–10 seconds during the scan.

Electrocardiogram (ECG) gating

Most CT scanners currently used in clinical settings take 0.33–5.0 seconds to cover the heart. Images of the coronary arteries are usually reconstructed from data obtained from multiple heartbeats.

Patrick MT Wong *MBBS FRANZCR is Radiology Fellow at Royal Brompton Hospital, London, UK and Monash Medical Centre, Melbourne, Australia. Competing interests: none declared.*

Simon PG Padley *FRCP FRCR is a Consultant Radiologist at the Royal Brompton Hospital, London, UK. Competing interests: none declared.*

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Because the coronary arteries typically show the least motion in diastole, images are usually reconstructed from diastolic data. It is thus necessary to monitor the cardiac cycle by simultaneously recording an ECG during scanning. Images can either be acquired prospectively in diastole alone (prospective ECG triggering) or obtained through all or part of the 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 than prospective gating.

Study protocol

The series of images obtained for a cardiac CT examination depends on the clinical indication. At our centre, a routine study evaluating the coronary arteries is usually conducted in two stages: a standardized non-enhanced scan covering only the heart, for coronary calcium scoring, and afterwards delivery of a contrast bolus for coronary angiography. Between 60 and 100 ml of contrast media is injected at a rate of 4–5 ml/second via an 18G or 20G cannula into the right antecubital vein, followed by a 40–50 ml sodium chloride chaser bolus to wash contrast out of 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 clinical circumstances, particularly with of younger patients, and patients with congenital heart disease, previous surgery or stent insertion, when the area scanned can vary and the calcium score is omitted.

Data-processing techniques

The reconstruction of data from all cardiac phases can generate anywhere from 300 to 3000 individual axial images. Analysis and interpretation of these large datasets can be time-consuming. Because the coronary arteries can be oriented at any angle to the axial plane, curved multi-planar 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 disease (CAD).

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 most widely used measure is the Agatston score, which is a product of plaque area and peak plaque density for each individual plaque. 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 an individual coronary artery stenosis. When a calcium score is performed in isolation, it is used as a predictor of lifetime risk of events. When used in conjunction with a post-contrast CTCA, it can show the presence of calcified plaque that might be obscured by the high-attenuation intra-arterial contrast column.

Computed tomography cardiac 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.[1] Overall, CTCA has a high negative predictive value (96–100%) so is able to exclude the presence of coronary atheroma.[2] Therefore, the benefit of coronary CTCA is likely to be greatest for symptomatic patients who are at intermediate risk of CAD after initial risk stratification.

Although CTCA was initially recommended as a first-line test for intermediate-risk chest pain, the 2016 revision of the CG95 NICE guidelines recommending CTCA has abandoned pre-test probability modelling because of the clinical difficulties related to identifying cardiac chest pain. Instead 64-slice (or above) CTCA is recommended as the first-line investigation in all patients with atypical or typical angina symptoms and those who are asymptomatic with ECG changes suggestive of ischaemia.[3] This guideline is based primarily on the diagnostic accuracy and cost-effectiveness of this strategy.

Prognostic value of CTCA

The presence and severity of atherosclerotic disease on CTCA is an indicator of future cardiac events, with the presence of one or more significant coronary stenoses being associated with an annualized cardiovascular event rate of just under 12%. A large systematic review (CONFIRM – Coronary CT Angiography Evaluation for Clinical Outcomes: An International Multicenter Registry) revealed that an increasing burden of non-obstructive (as well as obstructive) CAD is associated with an increased rate of further adverse cardiovascular events. As a non-invasive test, CTCA is therefore useful in being able to demonstrate milder degrees of non-obstructive CAD (<50% stenosis).[4]

CTCA for patients with acute chest pain in the emergency department

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

Combined imaging of the coronary arteries, ascending aorta and pulmonary arteries to assess for the presence of CAD, thoracic aortic dissection and pulmonary embolism can be performed in a single CT examination. Compared with standard

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