X-ray computed tomography of the heart

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Introduction: Cardiac imaging is an emerging application of multidetector computed tomography (MDCT). This review summarizes the current capabilities, possible applications, limitations and developments of cardiac CT.

Sources of data: Relevant publications in peer reviewed literature and national and international guidelines are used to discuss important issues in cardiac CT imaging.

Areas of agreement and controversy: There is broad consensus that coronary CT angiography is indicated in patients with an intermediate pre-test probability of coronary artery disease (CAD) when other non-invasive tests have been equivocal. In this context, CT can reliably exclude significant CAD. Cardiac CT also has an established role in the evaluation of bypass grafts and suspected coronary anomalies. Radiation exposure from CT procedures remains a concern, although techniques are now available to reduce the X-ray dosage without significantly compromising the image quality. However, with the current level of knowledge, the cardiac CT examinations are not justified to screen for CAD in asymptomatic individuals. Neither is it considered appropriate in patients with a high pre-test probability of CAD, for whom invasive catheter coronary angiography is usually of more benefit.

Growing points and areas timely for developing research: The ability to reconstruct the volumetric cardiac CT data set opens up avenues for advanced physiological analyses of the heart. For example, if CT myocardial perfusion assessment becomes a reality, there is potential to revolutionize the practice of MDCT imaging. Research is also ongoing to investigate whether cardiac CT has a role in the appropriate triage of patients with chest pain in the emergency department.

Keywords: multidetector computed tomography/coronary angiography/cardiac

Introduction

X-ray computed tomography (CT) has undergone rapid development during recent years, driven in part by the desire to provide reliable and accurate visualization of the heart and especially the coronary arteries. 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 temporal resolution (time needed to acquire one image) are therefore prerequisites for imaging the complex anatomy of the coronary arteries.1
Invasive coronary angiography is currently the clinical ‘gold standard’ for assessing coronary artery stenoses. This modality has high spatial and temporal resolution and offers the option of performing percutaneous coronary intervention on the same occasion. However, many conventional coronary angiographic examinations disclose only non-obstructive disease and do not lead to revascularization therapy. Therefore, in order to prevent patients undergoing unnecessary invasive investigations, a robust non-invasive test for the detection and grading of coronary artery disease (CAD) would be of benefit. Advances in multidetector computed tomography (MDCT) technology have led to improvements in spatial and temporal resolution, as well as reduction in radiation exposure times, making it the most promising technique for non-invasive imaging of the coronary arteries (Fig. 1). Furthermore, the ability to assess cardiac structures at all phases of the cardiac cycle enables advanced functional assessment.

This review article will provide a summary of the current capabilities of cardiac CT. It will also explore future applications and discuss the limitations of the technique.

**Historical perspective**

Clinically viable X-ray CT was invented by Sir Godfrey Hounsfield in 1972. He shared the 1979 Nobel Prize for Medicine with Allan Cormack, and in his acceptance speech stated that ‘...a further promising field may be the detection of the coronary arteries’.3

![Volume rendered image of the heart.](image)
Early CT scanners used ‘stop and shoot’ modes of operation that required a long scan time and acquired a series of images with repeated breath holds. The advent of slip ring technology in 1991 enabled spiral acquisition of CT images in a shorter scan time, resulting in a single volumetric data set in one breath hold. Whilst helical CT improved the quality of CT images, this technology was still limited by relatively long breath-holding requirements.4

The introduction of MDCT further improved scanning speed. The use of multiple rows of detectors allowed for simultaneous registration of multiple channels of information with each gantry rotation. Successive generations of MDCT scanners have rapidly developed since the initial dual-slice technology—from 4 to 8, 16, 32, 40, 64, 128, 256 and now 320-slice detectors currently in use. The consequent reduction in scan times renders imaging less susceptible to cardiac dysrhythmias and reduces beat-to-beat variability (Table 1).5

The first dual-source MDCT was launched in 2005.6 This has two pairs of X-ray sources and multislice detectors mounted at approximately 90° to each other, resulting in faster scanning and a temporal resolution of 83 ms.

Electron beam tomography is a specific form of CT that has been used in calcium scoring of coronary arteries. Electromagnetic steering of the electron beam can be completed much faster than the mechanical rotation of MDCT, providing very high temporal resolution, although spatial resolution is poor.7 MDCT can now perform accurate calcium scoring and is more widely available than electron beam CT, which will not be discussed further here.

**Table 1:** Comparison of spatial and temporal resolution.

<table>
<thead>
<tr>
<th></th>
<th>Spatial resolution (mm)</th>
<th>Temporal resolution (ms)</th>
<th>Scan time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Invasive angiography</td>
<td>0.2</td>
<td>5–20</td>
<td>—</td>
</tr>
<tr>
<td>Electron beam CT</td>
<td>&gt;0.6</td>
<td>33–100</td>
<td>~40</td>
</tr>
<tr>
<td>16-slice CT</td>
<td>0.5</td>
<td>200</td>
<td>~20</td>
</tr>
<tr>
<td>64-slice CT</td>
<td>0.4</td>
<td>165</td>
<td>~10</td>
</tr>
<tr>
<td>256-slice CT</td>
<td>0.6</td>
<td>34</td>
<td>~5–8</td>
</tr>
<tr>
<td>Dual-source (2 × 64-slice CT)</td>
<td>0.4</td>
<td>83</td>
<td>~2–4</td>
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</table>

**Technical aspects**

**Spatial resolution**

The coronary arteries are complex structures with small luminal diameters, measuring from 4 to 5 mm in the left main stem to 1 mm in the distal left anterior descending artery.
Sub-millimetre spatial resolution with isotropic imaging (i.e. equal resolution in all three planes) is desirable to delineate sub-millimetre coronary artery branches. In order to differentiate a 10–20% stenosis, isotropic spatial resolution of 0.3 mm is considered necessary.8

The spatial resolution of a CT scanner is dependent on the size of the three-dimensional pixels (or voxels) which make up the image observed on the monitor. Each voxel displays a shade of grey depending on the average attenuation of the tissue within it. If a voxel within a coronary artery contains both high attenuation structures (e.g. calcified plaque, displayed as white) and low attenuation structures (e.g. fatty plaque, displayed as dark grey), then the whole of the voxel will be displayed as average density and useful information is lost. This artefact is known as ‘partial voluming’ in CT. The smaller the voxel size, the less partial volume effects will be seen, and spatial resolution will be better. Voxel size is dependent on the resolution of the X-ray sensors and the focal spot size, rather than the number of simultaneously acquired slices.4

**Temporal resolution**

The coronary arteries are imaged during continuous cardiac motion. Reducing motion artefacts requires image acquisition when the heart is relatively stationary, typically during late diastole. The temporal resolution of a CT scanner is determined by the speed of rotation of the gantry around the patient. As images may be accurately reconstructed using data from a 180° rotation rather than the full 360° rotation, the temporal resolution is equal to half the gantry rotation speed. The rotation speed of the gantry has been increased over recent years to 250 ms per rotation, although as the speed increases mechanical forces become extreme and engineering solutions increasingly challenged.

Ideally, a temporal resolution of <50 ms is needed for coronary CT angiography (CTA) to cover all heart rates. With new reconstruction algorithms and dual source scanners, temporal resolution of 65 ms is achievable with motion-free imaging up to 100 bpm.9

**ECG gating**

Motion artefacts caused by cardiac pulsation can be minimized by reconstructing images taken over consecutive cardiac cycles at time points when cardiac motion is least, usually in late diastole (65–85% of the R–R interval). The heart phases can be determined by a simultaneously recorded ECG. The most commonly used ECG
synchronization techniques for cardiac CT scanning are prospective ECG triggering and retrospective ECG gating. In prospective gating, the scan is triggered at a specified point along the R–R interval (the phase of ventricular depolarization), then stops after a certain period and resumes again at a similar time during the next cycle. This technique has the potential to limit radiation dose as scanning only occurs during the chosen phase rather than the entire cardiac cycle. However, prospective gating is greatly dependent on a regular heart rate, and misregistration of data may occur in the presence of a single ectopic beat or other dysrhythmia. Image quality will also suffer if the time delay selected is suboptimal.

In retrospective gating, data are acquired continuously throughout the cardiac cycle, allowing images to be later reconstructed at an appropriate percentage of the R–R interval. The actual phase required can vary for each coronary artery and several different phase reconstructions may be used to obtain optimal images of all vessels. Retrospective ECG gating is therefore the method of choice for evaluating contrast-enhanced images of the coronary arteries.

Performing a scan

Patient preparation

A low heart rate during the scan has been shown to substantially improve the image quality. It is usual to aim for a heart rate of <65 beats/min. If the patient’s inherent rate is >65 beats/min, oral or intravenous beta-blockers can be administered as clinically feasible. Patients intolerant of beta-blockers can be given a calcium channel antagonist. Some centres also advocate administration of sublingual nitrates immediately before scanning to dilate the coronary arteries.

Intravenous contrast delivery

An initial study without contrast is obtained if coronary artery calcium scoring is indicated. For optimal opacification of the coronary arteries, it is recommended that a high concentration contrast agent (300–400 mg iodine/ml) is injected at a high flow rate (4–5 ml/s) followed by a 40–50 ml saline chaser bolus to washout contrast from the right ventricle. This protocol aims to deliver 2 g of iodine per second for the duration of the acquisition. Contrast flux may be reduced or increased depending on the patient size. The start of the scan needs to coincide with the arrival of contrast in the ascending aorta. This can be
achieved either by automatic triggering using a bolus-tracking technique, or manual timing after measuring the contrast agent transit period in a separate step using a test bolus of contrast. Typically, between 80 and 120 ml of contrast agent is injected for a high-resolution volume acquisition, and the patient needs to perform a breath hold of 5–20 s (depending on the scanner generation and dimensions of the heart).\textsuperscript{15}

\textit{Radiation dose}

Radiation doses in MDCT coronary angiography depends on a number of fixed and adjustable factors and published doses range from 1 to 15 mSv. More modern scanners are now very much at the lower end of this range, with doses similar to simple diagnostic invasive coronary angiography. The radiation exposure is higher when using retrospective ECG gating, compared with prospective imaging, because of the continuous X-ray exposure and overlapping data acquisition. Radiation dose for retrospectively ECG-gated imaging of the heart can be considerably minimized by means of automated exposure control and ECG-gated tube current modulation during the phases of maximal cardiac movement, when the data are likely to be less useful. Depending on the heart rate, ECG-gated dose modulation techniques can achieve an 80–96% drop in the tube current, resulting in a radiation dose reduction from approximately 10 to 1 mSv for MDCT coronary angiography. However, this method is only applicable in patients with steady heart rates and in whom the diastolic phase can be predicted with some certainty, in order to ensure that diagnostic image quality is not compromised.\textsuperscript{16,17}

\textit{Post-processing techniques}

The reconstruction of data from all cardiac phases may generate 2000–3000 individual axial images. Slice thickness is typically selected between 0.5 and 1.0 mm, and reconstructed sections are spaced so that consecutive images overlap by approximately 50%. Analysis and interpretation of these large data sets can therefore be a time-consuming process. Data evaluation is usually performed on dedicated workstations. The coronary arteries are initially assessed using the raw axial images as these are often useful to provide an overview and identify areas requiring further analysis. Additional interactive assessment using multiplanar reformations (MPRs), curved MPRs and maximum-intensity projections have been shown to increase reporting
sensitivity and accuracy (Fig. 2). Three-dimensional volume rendered reconstructions can be visually impressive, although are rarely helpful in evaluating the data. Four-dimensional functional analysis of wall motion and dynamic cardiac cine loops can be performed using a retrospectively gated data set. Most software enables quantification of coronary calcification, plaque composition and left ventricular ejection fraction. Wide field-of-view images are also reviewed as they may reveal unsuspected extra-cardiac pathology.

Clinical applications

In 2006, the American College of Cardiology/American Heart Association (ACC/AHA) published a position statement on the use of cardiac CT. Their recommendations are summarized in Table 2. The various clinical applications of cardiac CT are now discussed, although it should be noted that the appropriateness of CT is still uncertain in some instances.

Coronary artery calcium scoring

Coronary artery calcification occurs almost exclusively in the context of atherosclerotic disease, usually at an advanced stage of arterial remodelling. Therefore, coronary calcium may be considered a surrogate marker for subclinical coronary atherosclerotic plaque. Coronary

Fig. 2 Curved planar reformat of the left anterior descending artery showing scattered mixed density plaque.
calcification progresses over time, increasing by 15–25% per year, although the rate of progression may be slowed or stopped with lipid-lowering therapy.\textsuperscript{21}

MDCT reliably detects arterial calcification and allows semi-automated quantification of coronary calcium load. The Agatston calcium score is the most widely employed semi-quantitative measure used in MDCT. In general, a score of 1–10 is considered minimal, 11–100 low, 101–400 moderate and >400 high. Several prospective and retrospective studies have shown that coronary calcium detection accurately predicts risk for future cardiovascular events.\textsuperscript{22,23} However, whilst the relationship between the amount of coronary artery calcium and the likelihood of significant CAD has been established, the coronary calcium load detected by MDCT does not correlate well with the degree or haemodynamic significance of coronary artery stenoses. Furthermore, the presence of coronary calcium is not closely associated with the propensity of an individual atherosclerotic plaque to rupture; calcification being neither a sign of plaque stability nor instability.\textsuperscript{1} Nevertheless, most large professional bodies, including the European Society of Cardiology and the ACC/AHA,\textsuperscript{24,25} now recognize that coronary calcium detection using MDCT is a useful additional tool to improve risk stratification in asymptomatic subjects with intermediate pre-test probability for future coronary events based on traditional risk factors (risk of hard events at 10 years, 6–20%).\textsuperscript{26} However, further research is required to assess whether calcium detection is cost-effective

### Table 2: Appropriate indications for cardiac CT.

<table>
<thead>
<tr>
<th>CT coronary angiography</th>
<th>Structure and function: evaluation of intra- and extra-cardiac structures</th>
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<tbody>
<tr>
<td>Evaluation of chest pain syndromes</td>
<td>Assessment of cardiac masses in patients with technically limited images from echocardiography or CMR.</td>
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<tr>
<td>Intermediate pre-test probability of CAD, ECG uninterpretable or unable to exercise.</td>
<td>Evaluation of pericardial conditions in patients with technically limited images from echocardiography or CMR.</td>
</tr>
<tr>
<td>Uninterpretable or equivocal stress test (exercise, perfusion or stress echo).</td>
<td>Evaluation of pulmonary vein anatomy before invasive radiofrequency ablation for atrial fibrillation.</td>
</tr>
<tr>
<td>Evaluation of acute chest pain</td>
<td>Non-invasive coronary vein mapping before placement of biventricular pacemaker.</td>
</tr>
<tr>
<td>Intermediate pre-test probability of CAD, no ECG changes and serial enzymes negative.</td>
<td>Non-invasive coronary arterial mapping, including internal mammary artery before repeat cardiac surgical revascularization.</td>
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</table>

Cardiac CT

Structure and function: morphology

Assessment of complex congenital heart disease, including anomalies of coronary circulation, great vessels, and cardiac chambers and valves.

Evaluation of coronary arteries in patients with new-onset heart failure to assess aetiology.

Evaluation of chest pain syndromes

Intermediate pre-test probability of CAD, ECG uninterpretable or unable to exercise.

Uninterpretable or equivocal stress test (exercise, perfusion or stress echo).

Evaluation of acute chest pain

Intermediate pre-test probability of CAD, no ECG changes and serial enzymes negative.

Structure and function: morphology

Assessment of complex congenital heart disease, including anomalies of coronary circulation, great vessels, and cardiac chambers and valves.

Evaluation of coronary arteries in patients with new-onset heart failure to assess aetiology.
in comparison with other diagnostic modalities for the assessment of subclinical atherosclerosis. Large prospective trials are currently in progress to assess the prognostic value and risk stratification of calcium scoring.27

Coronary CTA

Several investigators have examined MDCT as an alternative or adjunct diagnostic modality to cardiac catheterization in the diagnosis of CAD. Studies have shown sensitivities of up to 97% and specificities as high as 94% for the detection of haemodynamically relevant coronary artery stenoses (>50% luminal diameter reduction) using 16-slice and 64-slice CT. The positive predictive value of MDCT using 64-slice MDCT is relatively modest only at 80–85%.28,29 However, the negative predictive value of MDCT in evaluating the coronary artery stenosis approaches 100%. Whilst this may reflect the relatively low prevalence of coronary stenoses in most studies, it suggests that CT can reliably rule out the presence of significant coronary artery stenoses. The high negative predictive value makes coronary CTA useful in symptomatic patients who are considered for invasive angiography but have a low-to-intermediate pre-test probability of CAD. The recently published ROMICAT (Rule Out Myocardial Infarction using Computer Assisted Tomography) trial, designed to determine the usefulness of coronary CTA in patients with acute chest pain, showed that coronary CTA ruled out CAD in 50% of 368 patients with acute chest pain and a low-to-intermediate likelihood of acute coronary syndromes.30 Patients whose clinical presentation suggests a high likelihood of having a stenosis remain more likely to benefit from invasive angiography, which provides the option of immediate intervention. The literature does not currently support the application of coronary CTA as a ‘screening’ test for asymptomatic individuals.

‘Triple rule-out’ coronary CTA is a relatively new technique that provides non-invasive visualization of coronary arteries with simultaneous evaluation of the pulmonary arteries, thoracic aorta and other intra-thoracic structures that might explain signs and symptoms that overlap with an acute coronary syndrome (ACS).

Compared with coronary CTA alone, this protocol requires extension of the field of view and a prolonged administration of contrast material to ensure adequate visualization of the pulmonary and thoracic aortic vasculature. Takakuwa and Halpern31 showed that in 200 emergency department patients evaluated with ‘triple rule-out’ CT, 76% of patients with symptoms mimicking cardiac disease were not caused by ACS. Eleven per cent of patients had a non-cardiac cause of their
symptoms, which included some life-threatening diagnoses such as pulmonary embolism and aortic dissection. With regard to CAD, 5% of patients had severe disease and 6% had moderate disease that was recognized using CT. These results demonstrate that ‘triple rule-out’ CT has the potential to help appropriately triage patients in the emergency department.

Plaque imaging

A potential important advantage of MDCT coronary angiography compared with conventional coronary angiography is the ability to distinguish between different types of atherosclerotic plaque. Although still under development, this may identify patients at elevated risk of future coronary events. Schroeder et al. demonstrated significantly different mean densities of 419 ± 194, 91 ± 21 and 14 ± 26 Hounsfield units for calcified, mixed and soft plaques, respectively. Soft plaque can be further stratified into fibrous and lipid-rich plaque. Calcified plaque is associated with plaque stability, whereas non-calcified plaque may be more unstable and prone to rupture leading to an acute coronary syndrome or myocardial infarction. MDCT accurately detects calcified or mixed plaques with sensitivities and specificities above 90%, but is less accurate for the detection of non-calcified plaque with sensitivities and specificities ranging from 60 to 85%. Furthermore, there is only moderate agreement with intravascular ultrasound and the reproducibility is poor. Therefore, the clinical application of coronary CTA for risk stratification based on plaque characterization is as yet not supported by scientific evidence.

Bypass grafts

Recent studies have shown that CT imaging permits the assessment of bypass grafts, the anastomotic site and the native arteries. Invasive coronary angiography can often be technically challenging in such patients. Venous bypass grafts are generally easier to visualize than the coronary arteries with CTA, being less mobile and larger than the native coronary vessels. Internal mammary artery grafts can be more difficult to image owing to artefacts related to surgical clips placed alongside the bypass grafts (Fig. 3). Several studies performed using 16- and 64-slice MDCT have shown that occlusion of bypass grafts and stenoses in the body of the grafts can be detected with high accuracy. However, native coronary arteries can often become heavily calcified following bypass surgery making interpretation of
stenoses difficult. This limits the clinical usefulness of coronary CTA in patients who develop chest pain after bypass surgery, as it usually will be necessary to assess the status of both the bypass grafts and the native coronary arteries.\textsuperscript{37} Nevertheless, MDCT can be useful to identify the position of bypass grafts relative to the sternum when planning re-do bypass surgery.\textsuperscript{38}

\textbf{Coronary stents}

Stent imaging is possible with newer generations of cardiac CT, but remains challenging due to the small size and high-density of stent material with resulting artefacts that can obscure the lumen. Assessibility of stents is therefore dependent on several factors, including the stent type and material, stent dimensions (particularly the diameter) and the vessel in which the stent has been implanted. Stent

\begin{figure}
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\includegraphics[width=\textwidth]{image.png}
\caption{Volume rendered image demonstrating course of internal mammary artery graft (arrowheads) and saphenous vein grafts (arrows).}
\end{figure}
patency is indicated by the enhancement of the lumen within the stent. In-stent restenosis is not reliably imaged with CT, although the diagnosis can be suggested when the lumen does not appear to completely enhance. A study performed with 64-slice CT in a group of 51 patients showed that in-stent restenosis was correctly detected by CT in five of six cases, with a sensitivity of 83% and specificity of 100%. However, at present, numbers are too small to provide conclusive evidence to support the role of CT for routine follow-up of patients after coronary stent implantation.

Non-angiographic clinical applications

Functional assessment

The retrospectively gated cardiac MDCT data set can be used to derive left and right ventricular function. Since images can be reconstructed at multiple phases of the cardiac cycle, determination of both end-diastolic and end-systolic volumes using semi-automated software allows accurate calculation of stroke volume, ejection fraction and cardiac output. Cine loops can be created to demonstrate regional wall motion. Studies have found good correlation between MDCT and cine cardiovascular magnetic resonance (CMR) imaging for the assessment of the above-mentioned parameters. However, due to the relatively high radiation dose, MDCT is currently not recommended for the evaluation of cardiac function alone.

Myocardial assessment

Based on CMR techniques, contrast-enhanced CT can help visualize infarcted myocardium during first-pass and late perfusion imaging. Infarcts show quantitative, and usually qualitative, reduction in attenuation relative to normal adjacent tissue on arterial phase (<30 s) and delayed (5–10 min) images. The infarcted area can also demonstrate hyperenhancement on the delayed images, which is usually due to contrast accumulation in the extravascular space and scarred myocardium. Preliminary studies assessing myocardial enhancement and infarct size early after acute myocardial infarction have shown good correlation between MDCT and CMR, although the latter modality does not use ionizing radiation. Nevertheless, myocardial perfusion imaging at CT can be considered for imaging of infarct size in patients with contraindications to CMR imaging. A recent study evaluating a novel cardiac CT protocol combining adenosine-induced stress and rest myocardial...
 perfusion imaging with coronary CTA identified stress-induced myocardial perfusion defects with diagnostic accuracy comparable to nuclear perfusion imaging (SPECT). Importantly, information on coronary stenoses and myocardial perfusion were available in this study with an average radiation exposure that was similar to SPECT.44

**Congenital heart disease and anomalous coronary arteries**

Whilst echocardiography and CMR imaging remain the techniques of choice for the assessment of patient with complex congenital heart disease, MDCT is now emerging as a viable alternative to CMR in those patients who are unable (e.g. those with pacemakers) or unwilling to undergo it.45 Although blood-flow information is not available, a cardiac MDCT data set allows assessment of most other aspects of a CMR study (Fig. 4). Traditional indications, such as CT pulmonary angiography for evaluation of pulmonary hypertension, can therefore

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**Fig. 4** Delineating position of Blalock-Taussig shunt (arrowhead) connecting the right subclavian artery and the pulmonary artery in a patient with congenital heart disease (image courtesy of Dr Michael Rubens).
be combined with broader assessment of cardiac anatomy and function.

MDCT coronary angiography can also be used to identify the course of anomalous coronary arteries. Although most of these aberrant vessels are not clinically important, anomalous coronary arteries that traverse between the aorta and pulmonary trunk (so-called ‘malignant’ variants), or via a prolonged intramuscular course (‘myocardial bridging’), may result in vessel impingement and ischaemic symptoms.

**Defining pulmonary vein anatomy**

Cardiac CT is being routinely employed to facilitate certain electrophysiological procedures, such as atrial fibrillation ablation. A three-dimensional CT image of the atria can be superimposed on the electroanatomical map, improving the ability to localize the pulmonary veins and hence reduce fluoroscopy times (Fig. 5).

**Evaluating structural lesions**

Cardiac masses, pericardial lesions and complications of cardiac surgery can be assessed using MDCT in patients with technically limited images on echocardiography or CMR.

![Fig. 5 Pulmonary venous anatomy by cardiac CT.](image-url)
Limitations

Despite significant advances in CT technology, important limitations of the technique should be recognized. As well as method-related (e.g. radiation dose, contrast load) and patient-related limitations (e.g. cardiac dysrhythmia, contraindications to contrast), cardiac CT is a purely anatomical imaging modality and cannot assess the haemodynamic relevance of a lesion.¹

A further drawback of coronary CTA has been the failure to assess vessels or segments due to suboptimal visualization, reported in up to 12% of segments on 64-slice CT.²⁸ Causes of non-diagnostic images include motion, heavy calcification and image noise. Motion can lead to blurring of the contours of the coronary vessels. Severe calcifications may obscure the coronary artery lumen because of partial volume effects (‘blooming artefact’) and lead to false-positive results. In addition, as opposed to invasive coronary angiography, there is no option to perform immediate intervention.

Recent technical developments

CT has gone through rapid improvement during the last few years. Scanners with more detector rows allow a greater volume to be covered in one rotation of the scanner, significantly reducing breath-hold time and amount of contrast. The latest 320-slice scanners increase coverage and decrease overall scan time. However, higher temporal resolution is still required to overcome motion artefact. Dual-source CT (DSCT) offers substantial improvements in temporal resolution. These scanners have two sets of X-ray tubes and detectors, which are mounted onto the gantry at approximately 90° to each other. Therefore, the X-ray tube and detectors will only need to complete one-quarter of a complete rotation around the patient rather than the 180° of rotation required for a single tube system. Using half-scan reconstruction algorithms, this produces faster scanning and temporal resolution of 83 ms. This technology has potential to visualize the coronary tree with high image quality even at heart rates >75 beats/min.

It is also possible to produce two different energies of X-ray using a dual source system. Therefore a single area of interest can be scanned using dual-source X-rays of different voltages (kV). As tissues interact differently with the two different X-ray energies, this technology can improve tissue differentiation. In cardiac imaging, it has the potential to ‘remove’ calcification, thus permitting a clearer view of the lumen.
Therefore, technological advances on a number of fronts are likely to improve the accuracy and reliability of CT for assessing CAD and, if the expected reductions in radiation dose are achieved, the spectrum of accepted clinical indications will expand.

Summary

CT has advanced rapidly during the past years. Current MDCT technology with sub-millimetre slice collimation and high temporal resolution permits reliable and accurate visualization of the coronary arteries. Adequate patient selection and preparation are essential for obtaining diagnostic CT examinations. Available data suggest that the high negative predictive value of CT can rule out the presence of haemodynamically significant CAD in some patient subgroups.

There is also growing evidence that coronary CTA may improve the management of those patients presenting with acute chest pain who have a low pre-test likelihood of CAD. Although questions remain about radiation dose, newer scanners with DSCT can significantly reduce radiation dose. The spectrum of clinically validated indications for cardiac CT is expanding, and in the future the technique should have an established place within the diagnostic armamentarium.

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