CT myocardial perfusion imaging

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Introduction
Computed tomography (CT) is capable of comprehensively assessing the heart in order to provide information on anatomy, function, perfusion and viability. CT coronary angiography can assess both the coronary artery lumen and the characteristics of atherosclerotic plaques. CT myocardial perfusion imaging can provide additional information compared to CT coronary angiography by highlighting areas of myocardial hypo-perfusion and potential ischaemia. This article provides a brief overview of CT myocardial perfusion imaging protocols, current evidence and examples of its clinical uses.

CT myocardial perfusion imaging protocols
CT myocardial perfusion imaging involves the acquisition of electrocardiogram-gated contrast enhanced CT images of the heart during rest and stress. Although CT myocardial perfusion imaging can be performed using a 64 row multi-detector scanner, it is not recommended. Wide volume or dual source scanners are recommended in order to reduce radiation dose and potential artifacts.

The ‘rest’ CT component of the protocol provides information on the coronary arteries and the resting myocardium. This is performed as per standard protocols for contrast enhanced electrocardiogram-gated CT coronary angiography, the discussion of which is outside the scope of this article. Rate limiting medication such as beta-blockers may be required to optimise heart rate as per standard CT coronary angiography protocols. Sublingual glyceryl trinitrate may also be given prior to rest CT coronary angiography to optimise the visualisation of the coronary arteries. Rest imaging can be performed first, in order to decide whether stress imaging is required (figure 1), or rest imaging can be performed after stress imaging, once the effect of the stress agent has worn off.

Although exercise stress could be used, the most frequent method is pharmacological stress with an infusion of adenosine (140mg/kg/minute for three minutes). Prior to an adenosine infusion it is essential that patients abstain from caffeine for at least 12 hours as caffeine is a competitive inhibitor of the adenosine receptor. Dipyridamole and newer bolus agents such as regadenoson have also been used. An adequate response is indicated by a change in heart rate, blood pressure or symptoms. As with all non-invasive stress tests, occasional physiological ‘non-responders’ may not develop the required stress response from pharmacological agents, resulting in a false negative stress test.

Two protocols are currently in use for the acquisition of stress CT images, namely the ‘snap-shot’ and the ‘dynamic’ protocols. For both protocols the scan range can be reduced to cover only the left ventricle, in order to minimise radiation dose.

The snap-shot protocol acquires a small number of images at, or just after, the peak of myocardial contrast enhancement (figure 2). This is also known as the static or single phase CT myocardial perfusion protocol. Perfusion defects are identified as an area of reduced attenuation density compared to normal adjacent or resting myocardium. These can be assessed visually using greyscale or colour images, or semi-quantitatively using ratios such as the transmural myocardial perfusion ratio (the ratio of the endocardial to epicardial attenuation density).

The dynamic protocol involves the acquisition of multiple images during the wash-in and wash-out of contrast (figure 2). This protocol is less reliant on contrast timing and, in addition, mathematical models can be used to calculate myocardial blood flow from these data sets. Images are acquired more frequently during the wash-in of contrast in order to improve the accuracy of myocardial blood flow calculations. However, the acquisition of multiple images does lead to an increased radiation dose.

Interpreting CT myocardial perfusion images
Rest and stress images are re-orientated into the short axis view of the left ventricle for analysis. Ischaemia is identified as an area of the myocardium with reduced contrast enhancement during stress imaging that normalises during rest imaging. Ischaemia is initially apparent in the subendocardial region and the resolution of CT allows the assessment of these small perfusion defects. More severe perfusion defects can affect the full thickness of the myocardium. An irreversible area of myocardial hypo-perfusion present on both rest and stress imaging indicates infarction. Care must be taken not to misinterpret areas of beam hardening artefact, motion artefact or the normal reduced perfusion in the fibrous valvular region of the left ventricle. Perfusion defects are described according to the 17-segment model, similar to other non-invasive myocardial perfusion imaging modalities such as MRI or SPECT.

When is CT myocardial perfusion useful?
CT coronary angiography has an excellent negative predictive value for the identification of significant coronary artery stenosis. However, areas of high attenuation such as dense coronary artery calcification or coronary artery stents can lead to overestimation of the degree of stenosis due to beam hardening or blooming artifacts. CT myocardial perfusion imaging can be useful to assess such indeterminate lesions. Several studies have shown that CT myocardial perfusion imaging can be additive to CT coronary angiography and improve diagnostic accuracy. In addition, the use of information on ischaemia may enable more appropriate use of coronary revascularisation compared to management guided by coronary artery stenosis severity alone. For example the FAME study showed that outcomes were improved when coronary revascularisation was guided by assessment of fractional flow reserve.

CT myocardial perfusion imaging has been validated in animal models and human studies as compared to other non-invasive and invasive methods to assess myocardial perfusion such as SPECT, MRI, PET, invasive coronary angiography and fractional flow reserve. The largest study of CT myocardial perfusion to date, the CORE320 study, assessed 381 patients with snap-shot CT myocardial perfusion imaging as compared to invasive coronary angiography and SPECT. They identified sensitivity, specificity, positive predictive and negative predictive value of combined CT coronary angiography and CT myocardial perfusion imaging as compared to combined invasive coronary angiography and SPECT of 80%, 74%, 65% and 80% respectively. A recent meta-analysis of 12 CT myocardial perfusion imaging studies in which showed that snap-shot CT myocardial perfusion imaging had a sensitivity and specificity of 82% and 78% for the identification of invasive coronary artery stenosis of greater than 70% on a per vessel basis. Dynamic CT myocardial perfusion imaging had a sensitivity and specificity of 77% and 89% as compared to stress SPECT.
Radiation dose

The radiation dose of CT myocardial perfusion imaging varies depending on the protocol used and the heart rate of the patient. For snap-shot imaging using a wide volume detector and iterative reconstruction, the radiation dose is between 5 and 9mSv for the rest and stress protocol. For dynamic CT myocardial perfusion imaging the radiation dose is higher, in the region of 10 to 15mSv.

Example cases

Case 1: An example of CT myocardial perfusion imaging that is additive to CT coronary angiography (Figure 3).

This previously healthy male presented with new onset chest pain. CT coronary angiography identified heavily calcified coronary arteries. Blooming artifact in the coronary arteries made assessment of the severity of stenosis using CT coronary angiography alone difficult. Assessment of the resting myocardium was normal. However, adenosine stress snap-shot CT myocardial perfusion imaging identified perfusion defects in the left anterior descending and left circumflex artery territories.

Case 2: An example of CT myocardial perfusion to guide revascularisation treatment (Figure 4).

This male with known coronary artery disease presented with worsening symptoms of angina. CT coronary angiography identified heavily calcified atherosclerotic plaque in all three coronary arteries that may have been the cause of his symptoms. However, adenosine stress snap-shot CT myocardial perfusion imaging identified that only the circumflex lesion was causing ischaemia. A perfusion defect was seen in the left circumflex artery territory during stress imaging that resolved on rest imaging. This meant that targeted revascularisation of the left circumflex artery could be performed.

Conclusion

CT myocardial perfusion imaging can be performed as a rapid and low radiation dose technique in the assessment of coronary artery disease. The additional information provided by CT myocardial perfusion imaging can be used to guide management decisions, and is additive to CT coronary angiography. The technique is now validated in both animal and human studies with a good diagnostic accuracy as compared to several gold standard assessments. Improvements in software and hardware will mean that the radiation dose of both snap-shot and dynamic CT perfusion techniques will reduce further. However, where this and other techniques assessing perfusion should be positioned in the patient care pathway is still debated, and further work will be required on a larger scale to assess issues of cost effectiveness.

References


![Figure 1](image1.png)

Figure 1
A CT protocol for rest then stress myocardial perfusion imaging.

![Figure 2](image2.png)

Figure 2
A comparison of snap-shot and dynamic CT myocardial perfusion imaging protocols. The graph shows the change in attenuation density during the wash-in and wash-out of contrast in the left ventricle. The snap-shot protocol acquires a small number of images at, or just after, the peak of contrast enhancement. The dynamic protocol acquires multiple images during the wash-in and wash-out of contrast. The increased frequency of imaging during the wash-in of contrast aids the accuracy of the mathematical models used to calculate myocardial blood flow.
Figure 3
Case 1: An example of CT myocardial perfusion imaging that is additive to CT coronary angiography. Short axis images of the left ventricle at the level of the base, mid portion and apex are shown for (A) rest and (B) stress imaging with arrows identifying perfusion defects. Associated curved planar reformations of the (C) coronary arteries.

Figure 4
Case 2: An example of CT myocardial perfusion to guide revascularisation treatment. (A) A three-dimensional reconstruction showing the coronary arteries and myocardium. The myocardium is color-coded based on the attenuation density during stress imaging with white/yellow/orange/red showing normal perfusion and purple showing an area of reduced perfusion. (B) The left circumflex lesion that was the cause of the perfusion defect seen on stress imaging.