

# Myocardial Perfusion Imaging with Computed Tomography: Can It Be Used in Clinical Practice?

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Coronary computed tomography (CT) angiography has recently been implemented as a noninvasive imaging modality for the assessment of coronary artery anatomy. This was made feasible through the development of recent generation CT scanners, especially those with 64 detector rows or greater, which achieve adequate temporal and spatial resolution to accurately image coronary artery plaque and stenoses.<sup>1</sup> Apart from coronary anatomy, CT angiography can also assess ventricular systolic function, both global and regional, and myocardial perfusion.<sup>2</sup>

Although a knowledge of coronary anatomy is mandatory in many cases in order to choose a management strategy, the detection of myocardial ischemia is of paramount importance both for prognosis and for management.<sup>3</sup> The lack of reversible perfusion defects on myocardial scintigraphy or the lack of segmental wall motion abnormalities on stress echocardiography are indicators of a benign prognosis in patients with chest pain or with known coronary artery disease, and these findings dictate a conservative treatment strategy in most cases. The anatomic severity of a stenosis does not always correlate with the presence or extent of myocardial ischemia, especially in moderate degree stenosis.<sup>4</sup> There has been evidence that the combined knowledge of coronary anat-

omy and myocardial perfusion confers additive information in terms of prognosis,<sup>5</sup> and both are used in influencing the treatment strategy.

Several methods are currently used for the assessment of myocardial perfusion: the ECG exercise stress test was the only available method for decades, before imaging methods were developed to detect inducible myocardial ischemia with greatly improved diagnostic accuracy. Myocardial scintigraphy perfusion imaging was the first of these tools to be developed, but it was quickly followed by exercise and dobutamine stress echocardiography, positron emission tomography, and more recently, stress perfusion magnetic resonance imaging.<sup>6</sup> More complex tools include perfusion stress echocardiography with vasodilatory agents, such as adenosine or dipyridamole. Finally, the evaluation of the functional severity of a stenosis can also be performed invasively via the measurement of fractional flow reserve with the use of a pressure wire during coronary artery catheterization.<sup>7</sup> It was not until recently, however, that cardiac CT was introduced for the study of coronary anatomy and left ventricular perfusion.

## Description of the technique

The assessment of myocardial ischemia during stress with computed tomogra-

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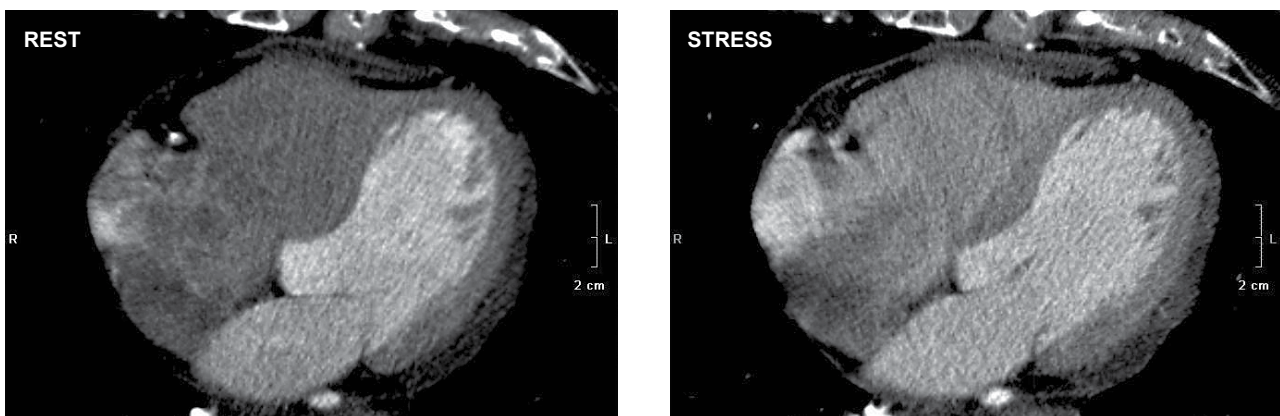
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phy is based on the comparison of myocardial enhancement during infusion of a vasodilator agent, such as adenosine, to myocardial enhancement during rest. This concept is similar to myocardial perfusion imaging with scintigraphy during pharmacological stress with dipyridamole or adenosine. In brief, two separate scans with iodinated contrast are performed, one at rest and one during continuous infusion of adenosine, or with the use of other vasodilator agents, such as dipyridamole or regadenoson. The rest scan is the same scan performed to assess coronary anatomy, and is used for both coronary anatomy and rest perfusion; beta-blocking agents and sublingual nitrates are administered as indicated. The stress scan is performed at least 15-20 minutes after the initial scan in order to allow sufficient time for contrast to wash out of the myocardium, and to eliminate the effect of nitrates used in the first scan. It should be noted that this protocol has not been standardized yet, and some centers prefer to perform the stress scan first and the rest scan afterwards; both approaches have advantages and disadvantages. Rest and stress perfusion images are reconstructed at various slice thickness and compared with each other; a negative study shows normal enhancement in all myocardial segments in both scans (Figure 1). If a perfusion defect is observed on both sets of images, this would be considered an irreversible perfusion defect, denoting an infarct zone (Figure 2); if a perfusion defect is observed only on the stress images, this would be considered a reversible perfusion defect, denoting ischemia during stress (Figure 3). Hence, the terminology is similar to that used in myocardial perfusion scintigraphy.

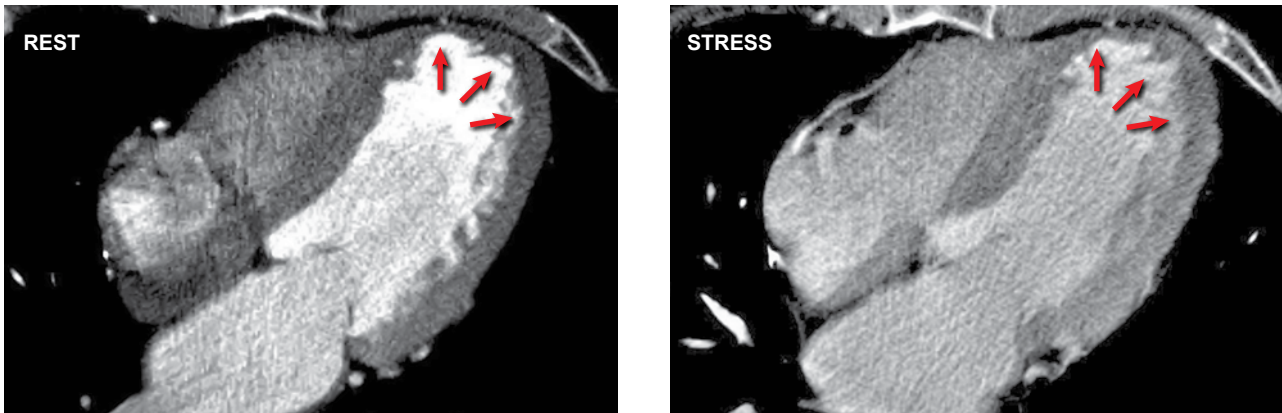
## Diagnostic performance

There are several studies examining the diagnostic accuracy of CT perfusion; the majority of them are small and single-center and they have compared CT perfusion with different noninvasive and invasive modalities of assessing myocardial perfusion or coronary anatomy, mostly with single-photon emission computed tomography (SPECT) and quantitative coronary angiography (QCA). The first study was conducted by George et al<sup>8</sup> and published in 2009. This study enrolled patients with abnormal SPECT and assessed the ability of combined coronary CT angiography and CT perfusion performed with 64-slice or 256-slice CT scanners to detect coronary stenoses causing myocardial ischemia. In this preliminary study, CT performed quite well, with sensitivity, specificity, positive predictive value and negative predictive value of 86%, 92%, 92%, and 85%, respectively, in the per-patient analysis. In another study by Blankstein et al,<sup>9</sup> patients at high risk of coronary artery disease were studied with dual-source CT, SPECT, and invasive coronary angiography. Using invasive coronary angiography as reference standard, CT perfusion showed a diagnostic accuracy equal to SPECT in the per-patient analyses, but was superior to SPECT in the per-vessel analyses.

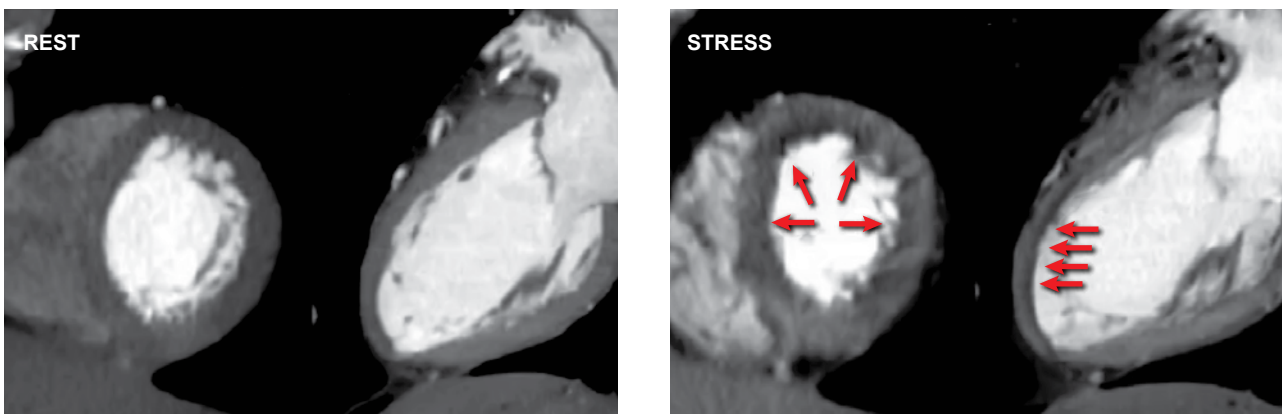
These first two studies were followed by several others that compared CT perfusion with SPECT, QCA, or even stress perfusion magnetic resonance imaging; the initial promising results were reproduced in all of the following studies.<sup>10-13</sup> Recently, the diagnostic accuracy of CT perfusion was assessed using fractional flow reserve as reference standard; the



**Figure 1.** Normal rest and stress scan. There is no perfusion defect in either rest or stress images.



**Figure 2.** Remote myocardial infarction with no peri-infarct ischemia. Note the fixed perfusion defect (arrows) present in both rest and stress images.



**Figure 3.** Reversible non-transmural ischemia in the mid- to distal-anterior, anteroseptal, and anterolateral walls (arrows). From Ko BS, et al. Computed tomography stress myocardial perfusion imaging in patients considered for revascularization: a comparison with fractional flow reserve. *Eur Heart J.* 2012; 33(1): 67-77. Reproduced by permission of Oxford University Press.

addition of CT perfusion to coronary CT angiography increased the diagnostic accuracy of CT, with sensitivity and specificity both 95% when analyzed on a per-patient basis.<sup>14</sup>

**Contrast administration – radiation exposure**

The major drawback of CT perfusion is the need for an extra scan compared to single coronary CT angiography; this results in double contrast administration and higher radiation exposure. In terms of contrast administration, the whole study can be accomplished in most cases with no more than 120 to 140 mL of contrast, which in patients with normal renal function would not be a matter of concern. Radiation exposure is of possible concern with certain scanners, and if radiation dose reduction protocols are not followed the total radiation dose can be very high. However, vari-

ous dose reduction methods can be employed such as prospective triggering (step-and-shoot method), provided low heart rates are achieved with adequate beta-blockage, and low tube current voltage. These may result in radiation doses comparable to or lower than those in nuclear studies. Newer generation scanners, capable of covering the whole heart in just one cardiac cycle, have drastically lowered radiation exposure; when a 320-slice scanner was used in a CT perfusion study the effective radiation dose for the stress scan was  $5.3 \pm 2.2$  mSv,<sup>14</sup> while with a high-pitch 128-slice dual-source scanner the effective radiation dose for the stress scan in selected non-obese patients with low heart rates was as low as  $0.93 \pm 0.18$  mSv.<sup>13</sup>

**Current era and future directions**

It appears that computed CT perfusion is an effective

noninvasive imaging tool for the comprehensive assessment of coronary artery disease. In a “one-shop-stop” fashion it can provide both anatomical and physiological information about coronary artery anatomy and the functional severity of detected stenoses. CT angiography can be utilized to assess both the lumen of the vessels and the plaque composition in the arterial wall, while CT perfusion can determine the physiological significance of a stenosis and its ability to cause myocardial ischemia during stress. The technique is in its primordial stage of development, and for the time being it is used only for research purposes, although it may not be far from clinical application. There are several issues that remain to be addressed; the protocol should be standardized, both in terms of image acquisition and reconstruction and in terms of image interpretation.<sup>15</sup> More data on its diagnostic accuracy and prognostic information are needed; one should always compare this new method with other well-established noninvasive ones, such as nuclear imaging techniques and stress echocardiography. Finally, the adoption of radiation exposure reduction technologies and techniques is a prerequisite for the widespread adoption of CT perfusion in clinical practice.<sup>16</sup>

### Acknowledgement

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