
CT Evaluation of the Myocardial Blood Supply: Ultra-Low Radiation Dose CT Techniques

Beyond Structure and Function: CT Imaging of Myocardial Perfusion and Viability

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Abstract

An ECG triggered high pitch (3.2) spiral CT scan acquired 8-16 seconds after the administration of contrast media and achievement of 100 HU in the ascending aorta best displays the difference in enhancement between ischemic/infarcted and remote myocardium. If this CT scan is been performed under pharmacological stress and repeated at rest, reversible ischemia may be distinguished against infarcted myocardium. In our experience, regadenoson is superior to adenosine to provoke stress induced ischemia. The rest scan with beta blockage may be performed before the stress scan to avoid image distortion by motion artifacts when diagnosing the coronary arteries. This scan protocol is associated with much less radiation compared to dynamic CTA. The total amount of radiation for a stress and rest scan is in the range of 2 mSv and may be sufficient to diagnose clinically relevant myocardial ischemia. However, this approach does not allow for quantitative assessment of myocardial blood flow and is therefore not suited to follow for changes in myocardial perfusion under treatment.

Cardiac CT primarily reveals coronary atherosclerosis. However, the degree to which coronary atherosclerosis impairs myocardial blood flow is uncertain (Rocha-Filho et al. 2010). For instance, in patients with bypass grafts or stents in the coronary arteries, coronary CT lacks the ability to predict sufficient blood flow to the myocardium particularly if the patient is under exercise.

Recently, CT has begun to offer the ability to determine myocardial blood flow at rest and exercise through perfusion imaging (Blankstein et al. 2009). Quantitative assessment of the myocardial blood flow requires repetitive scanning of the myocardium while the contrast media passes through it. This technique, described in the prior chapter, however, has three major drawbacks. First, even under optimal conditions the radiation exposure is high, compared to a regular coronary

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CT examination. Second, this dynamic image acquisition requires breath holding for 30–40 s. For many patients holding their breath for such a long period of time is quite challenging. Third, the scan range depends on the detector width. At least 7–8 cm is needed to cover the entire myocardium in the z-direction. Alternatively, with a smaller detector width, the table needs to alternate between two positions every-other or every-second heartbeat to increase z-coverage (Bamberg et al. 2010). However, this approach results in a reduced temporal resolution and is susceptible to extrasystole and arrhythmia.

The maximum enhancement difference between ischemic and normal myocardium may be seen only during a short period of time while the contrast medium is passing through the myocardium; therefore, the myocardium is acquired only during this particular time frame. This results in significantly reduced radiation exposure when compared with conventional CT perfusion imaging. Although the difference in enhancement between ischemic and normal myocardium may be measured in Hounsfield units, single time-point acquisition does not allow for quantitative assessment of the myocardial blood flow (Blankstein et al. 2009). The information revealed from a single acquisition scan of the myocardium is comparable to the myocardial blood volume imaging derived for a perfusion study.

Reviewing CT perfusion time-density curves reveals that maximum differences in contrast enhancement between ischemic and nonischemic myocardium during stress may be expected about 8–16 s after contrast enhancement of the ascending aorta exceeds 100 HU. This time point may of course depend on a variety of physiological parameters, particularly cardiac output. Optimization and visualization of ischemic versus normal myocardium require provocation by a stress agent, such as adenosine. Adenosine, a vasodilator, improves blood flow in remote myocardium supplied by unaffected coronary vessels. However, in diseased coronary arteries, adenosine will cause a steal phenomenon, detouring the blood and contrast. As a result, blood and contrast flow may be further reduced in myocardial territories that are supplied by coronary arteries with significantly impaired blood flow caused by high-grade stenoses (Blankstein et al. 2009). Adenosine is administered intravenously at an amount of 140 mcg/kg/min for 3 min until the investigation is initiated. A second intravenous line is then required for the administration of the contrast media. The vasodilative effect is terminated immediately upon discontinuation of adenosine injection. Regadenoson is a selective A_{2A} receptor agonist and acts as an alternative for adenosine. The selective receptor binding properties of Regadenoson seem to improve the visualization of ischemic versus remote myocardium. The safety profile of Regadenoson allows administration even in patients with chronic obstructive pulmonary disease. Patel et al. reported that



Fig. 1 Seventy-three-year-old female patient with coronary artery disease treated with several bypass grafts. CT scan revealed an occluded graft to the right coronary artery (*arrowhead*), a patent graft to the left anterior descending coronary artery (*arrow*) but an inconsistent course of the peripheral original vessel (*star*)

prospectively triggered stress CT perfusion with Regadenoson may allow detection of myocardial perfusion deficits even if radiation exposure is substantially reduced (Patel et al. 2011). As of this writing, the use of Regadenoson has not been reported in the scientific literature for the single scan acquisition of myocardium perfusion imaging as it is described here.

Initial attempts to image the myocardial blood volume were performed with retrospective ECG gating technique. Comparing the detection of coronary artery stenoses greater than 50 % by CT blood volume imaging to cardiac catheter, Blankstein et al. reported a sensitivity and specificity of 67 and 83 %, respectively (Blankstein et al. 2009). Moreover, Rocha-Filho et al. reported additional incremental sensitivity (83–91 %) and specificity (71–91 %) for CT blood volume imaging over CT angiography of the coronary arteries for the detection of significant stenoses (Rocha-Filho et al. 2010). However, the radiation exposure with the technique used as reported in these two papers was in the range of 10 mSv.

Prospective ECG triggered scan acquisition is far more radiation dose efficient when compared with retrospective ECG gating technique. Depending on the detector width, this technique allows covering the myocardium within 2–3 heartbeats. However, when using CT systems with a detector width not covering the entire heart, different areas of the myocardium are scanned at different time points

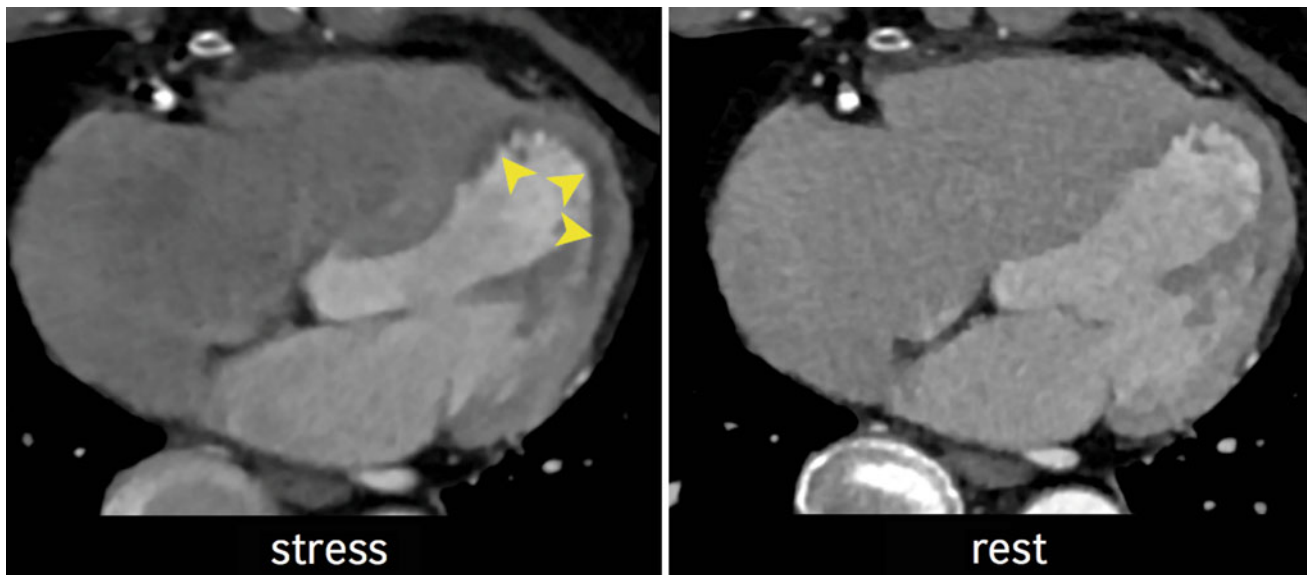


Fig. 2 The CT scan at stress with Regadenoson reveals an area of hypo-attenuation in the sub-endocardial region of the apex (*arrowheads*) that is substantially less pronounced in the scan performed at rest

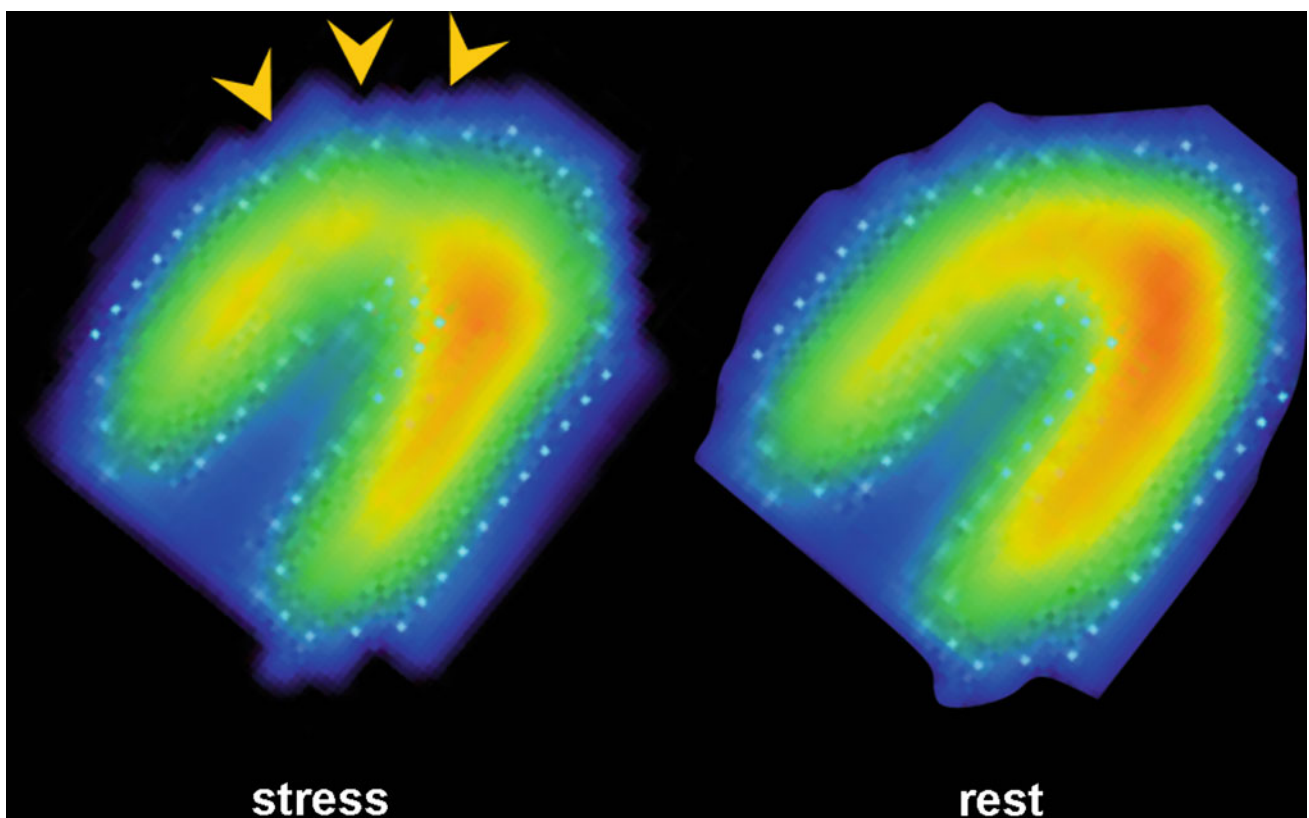


Fig. 3 Corresponding to CTP, SPECT reveals a stress-induced myocardial hypoperfusion in the left ventricular apex (*arrowheads*)

during the passage of contrast medium resulting in differences in myocardial contrast enhancement that may possibly mimic areas of myocardial hypoperfusion. The most

effective way to image the myocardium with low radiation exposure is the use of a prospectively ECG triggered high pitch spiral mode with second-generation dual-source CT.

In the high pitch spiral mode, the effective table feed is approximately 48 cm/s. With the typical scan range for the myocardium being 8–10 cm, this range may be acquired within a single heartbeat in roughly 200 ms. The radiation exposure for this protocol may be in the range of 1 mSv. As of this writing, only one paper is available on the use of this technique for myocardial blood volume imaging. Feuchtner et al. reported incremental additional overall accuracy (84–95 %) for the detection of high-grade stenosis with high pitch perfusion imaging over coronary CT angiography (Feuchtner et al. 2011).

If single scan acquisition for the assessment of ischemic myocardium is to be used, it is mandatory to compare the scan at stress with the scan at rest. Ischemic myocardium may be identified by reduced enhancement compared to remote myocardium at stress and equalized enhancement at rest. Alternatively, myocardial infarction may not enhance under any condition. Preferably, the scan at stress is performed during the contraction of the myocardium in the systole, while the scan at rest is performed in the diastolic phase to allow visualization of the coronary arteries within the same acquisition. A contrast volume of 60 ml is injected with a flow of at least 5 ml/s to achieve sufficient enhancement of the myocardium (Feuchtner et al. 2011).

The order in which these two scans, rest and stress, should be performed is unclear. Option one is to perform the stress scan first and then proceed with the rest scan. Here, the advantage is that ischemic myocardium may not be pre-enhanced by a prior contrast application. Discontinuation of adenosine may allow for immediate continuation with the rest scan. Regadenoson has several advantages over adenosine. It is more efficient and selective and may also be used in patients with COPD (Thomas et al. 2008). However, the vasodilative effect of Regadenoson persists for 15–20 min. Therefore, when using Regadenoson instead of adenosine, either the time interval between the stress and rest scans should be at least 15 min or intravenous administration of theophylline should be used to terminate the effect of Regadenoson.

The rest scan may alternatively be performed prior to the stress scan. It is logical to begin with the rest scan, because such an acquisition permits assessment of the coronary arteries. In case coronary artery disease of indeterminate value is discovered, the stress investigation with Regadenoson may be performed right after. As one important consideration, animal studies have shown that beta blocker, typically given to reduce the patient's heart rate during the

rest scan in order to improve visualization of the coronary arteries, can interfere, to a minor degree, with Regadenoson if it is given immediately afterward (Zhao et al. 2012). The effect of myocardial pre-enhancement by the rest scan would appear to be insignificant due to the small amount of contrast media given, especially if there is a period of several minutes between rest and stress imaging.

Myocardial ischemia, which typically occurs in the sub-endocardium, may be detected by comparing the images acquired at rest and stress. If the perfusion deficit is exclusively detected during the acquisition performed at stress or a major difference is observed between the scans at rest and stress, the area of the myocardium is likely been affected by reversible ischemia (Figs. 1–3). Conversely, if the hypo-attenuated myocardium is seen in both phases, stress and rest, it likely corresponds to a myocardial infarction scar. As of this writing, the clinical value of CT low dose blood volume image acquisition has yet to be established.

References

- Bamberg F, Klotz E, Flohr T et al (2010) Dynamic myocardial stress perfusion imaging using fast dual-source CT with alternating table positions: initial experience. *Eur Radiol* 20:1168–1173
- Blankstein R, Shturman LD, Rogers IS et al (2009) Adenosine-induced stress myocardial perfusion imaging using dual-source cardiac computed tomography. *J Am Coll Cardiol* 54:1072–1084
- Feuchtner G, Goetti R, Plass A et al (2011) Adenosine stress high-pitch 128-slice dual-source myocardial computed tomography perfusion for imaging of reversible myocardial ischemia: comparison with magnetic resonance imaging. *Circ Cardiovasc Imaging* 4:540–549
- Patel AR, Lodato JA, Chandra S et al (2011) Detection of myocardial perfusion abnormalities using ultra-low radiation dose regadenoson stress multidetector computed tomography. *J Cardiovasc Comput Tomogr* 5:247–254
- Rocha-Filho JA, Blankstein R, Shturman LD et al (2010) Incremental value of adenosine-induced stress myocardial perfusion imaging with dual-source CT at cardiac CT angiography. *Radiol* 254:410–419
- Thomas GS, Tammelin BR, Schiffman GL et al (2008) Safety of regadenoson, a selective adenosine A_{2A} agonist, in patients with chronic obstructive pulmonary disease: a randomized, double-blind, placebo-controlled trial (RegCOPD trial). *J Nucl Cardiol Off Publ Am Soc Nucl Cardiol* 15:319–328
- Zhao G, Zhang S, Shryock JC et al (2012) Selective action of metoprolol to attenuate regadenoson-induced tachycardia in conscious dogs. *J Nucl Cardiol Off Publ Am Soc Nucl Cardiol* 19:109–117