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Technical prerequisites and imaging protocols for dynamic and dual energy myocardial perfusion imaging

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ABSTRACT

Coronary CT angiography (CCTA) is an established imaging technique used for the non-invasive morphological assessment of coronary artery disease. As in invasive coronary angiography, CCTA anatomical assessment of coronary stenosis does not adequately predict hemodynamic relevance. However, recent technical improvements provide the possibility of CT myocardial perfusion imaging (CTMPI). Two distinct CT techniques are currently available for myocardial perfusion assessment: static CT myocardial perfusion imaging (sCTMPI), with single- or dual-energy modality, and dynamic CT myocardial perfusion imaging (dCTMPI). The combination of CCTA morphological assessment and CTMPI functional evaluation holds promise for achieving a comprehensive assessment of coronary artery anatomy and myocardial perfusion using a single image modality.

1. Introduction

Coronary CT angiography (CCTA) is an imaging technique providing non-invasive, morphological assessment of the coronary arteries which can accurately depict coronary anatomy and the atherosclerotic plaque burden. A growing body of evidence has validated CCTA as the non-invasive imaging technique with the highest sensitivity and specificity for the detection of coronary artery disease (CAD), with a pooled sensitivity and specificity of 98% and 89%, respectively [1–3] (Fig. 1).

Nevertheless, CCTA is burdened by several limitations when evaluating the hemodynamic significance of flow-limiting stenosis, an issue also found with invasive coronary angiography (ICA). The FAME and COURAGE trials [4,5], two major investigations validating the impact of functional tests in coronary revascularization, have shown that purely anatomical tests do not adequately predict the hemodynamic relevance of coronary stenosis and thus revascularization should be guided by functional assessments of myocardial perfusion.

Therefore, there are increasing efforts toward determining the functional relevance of lesions using CCTA in order to combine both comprehensive anatomical and functional assessment of CAD using a single modality. Recent technological advancements in CT myocardial perfusion imagine offer the possibility to directly detect the presence of perfusion defects in the myocardium following the administration of pharmacological stressors.

CT myocardial perfusion imaging (CTMPI) uses the distribution of iodinated contrast material in the myocardium as a surrogate for myocardial blood flow, identifying perfusion defects as hypoattenuating areas with reduced amounts of contrast material [6]. For this purpose, two distinct CT techniques have emerged. Static

Abbreviations: CCTA, coronary CT angiography; CMR, cardiac magnetic resonance; dCTMPI, dynamic CT myocardial perfusion imaging; CTMPI, CT myocardial perfusion imaging; DECT, dual-energy CT; DSCT, dual source CT; ICA, invasive coronary angiography; sCTMPI, static CT myocardial perfusion imaging; SPECT, single photon emission computed tomography; TAC, time attenuation curves.

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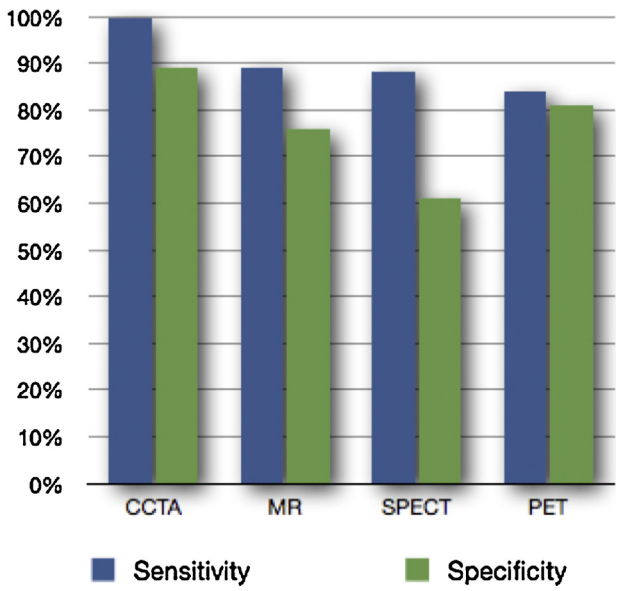

Fig. 1. Sensitivity and specificity of non-invasive imaging tests for the detection of coronary artery disease.

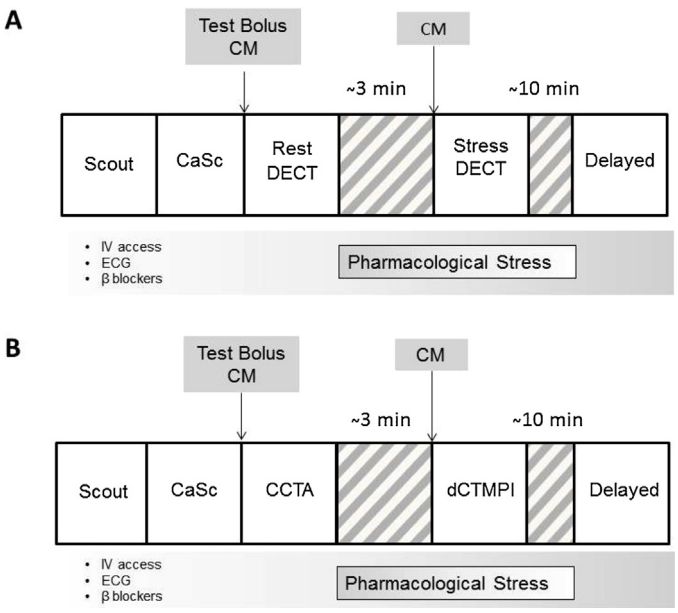

Fig. 2. Clinical protocols describing the appropriate rest, stress and delayed enhancement acquisition timing both for static (A) and dynamic (B) myocardial perfusion studies.

CT myocardial perfusion imaging (sCTMPI) uses static distribution of contrast material during early arterial attenuation to detect myocardial blood perfusion abnormalities. In contrast, dynamic CT myocardial perfusion imaging (dCTMPI) uses several consecutive acquisitions throughout the cardiac cycle to generate time attenuation curves (TAC) of myocardial perfusion by following the passage of a contrast bolus (Table 1).

The aim of this article is to provide a systematic overview of the available CT myocardial perfusion techniques, including commonly used pharmacological stress agents, technical prerequisites, imaging protocols, and published results.

2. Acquisition technique: general considerations

A comprehensive CT myocardial perfusion examination should include both rest and stress acquisitions in order to differentiate reversible from fixed myocardial perfusion defects [7]. Reversible ischemia is suspected when hypoattenuating myocardial areas are present only in the stress phase, whereas a myocardial infarction is characterized by a myocardial perfusion defect persisting at rest. Flow-limiting stenosis can cause hypoattenuation during the rest phase as well, but the diagnostic sensitivity of the rest phase is lower compared to the stress acquisition and the distinction between reversible and fixed defects is not possible.

Multiple approaches to the time order of rest and stress acquisitions have been proposed. Starting the examination with the rest phase provides the advantage of a pure CCTA study of coronary artery morphology before the evaluation of functional myocardial assessment [8]. On the other side, placing the stress phase before rest imaging avoids contamination of contrast material from the rest phase and enables maximal contrast difference between ischemic and non-affected myocardium [9]. However, elevated heart rate following stress administration could impair the quality of the subsequent rest acquisition and CCTA assessment.

Additionally, image acquisition can be repeated after 8–10 min of contrast medium administration to evaluate late myocardial enhancement, where a hyperattenuating myocardial pattern is indicative of non-viable myocardium. Compared with late enhancement in magnetic resonance imaging, CT provides a lower signal-to-noise ratio, making the detection of infarction more challenging [7]. For this reason, a late acquisition phase is not mandatory in clinical practice given the increase in total radiation dose without significant benefits.

Clinical protocols describing the appropriate rest and stress acquisition timing for both static and dynamic myocardial perfusion studies are presented in Fig. 2.

Table 1
CT myocardial perfusion techniques.

Tecnique	Advantages	Limitations
sCTMPI	CCTA acquisition can be used as rest phase Dual-energy improves iodine detection	No absolute perfusion quantification High radiation dose with rest/stress protocol State-of-the-art technology needed for Dual-Energy acquisition
dCTMPI	Absolute perfusion quantification	State-of-the-art CT technology High radiation dose Cannot used for the assessment of coronary artery morphology

3. Pharmacological stress agents

The administration of pharmacological stress agents is a prerequisite for the detection of reversible perfusion defects, significantly improving diagnostic sensitivity [10]. Several substances can be used in the pharmacological stress phase to induce an hyperemic myocardium, including adenosine, regadenoson, dobutamine or dipyridamole [11]. Due to safety considerations, the two most commonly utilized agents in CT perfusion are adenosine and regadenoson. Adenosine works on adenosine A1 receptors to directly vasodilate the coronary arteries, while regadenoson is a selective A2A receptor agonist which allows use in patients with asthma or chronic obstructive pulmonary disease [12,13].

Adenosine has an extremely short half-life of a few seconds, requiring a continuous infusion of a dose of 140 μg/kg/min for at least two minutes to induce an increase of 10–20 beats per minute over resting heart rate. Conversely, regadenoson can be administered in a single dose. Moderate complications are associated with both agents, including ventricular tachycardia and transient