Beyond Stenosis Detection

Computed Tomography Approaches for Determining the Functional Relevance of Coronary Artery Disease

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KEYWORDS

• Coronary CT angiography • Coronary artery disease • Myocardial perfusion imaging • Dual-energy CT • Fractional flow reserve • Transluminal attenuation gradient

KEY POINTS

- Pure anatomic assessment of coronary stenosis with coronary computed tomography (CT) angiography does not adequately predict hemodynamic relevance.
- Different CT techniques for the functional assessment of coronary stenosis are under investigation in clinical trials.
- These techniques can directly assess the presence of myocardial ischemia (CT myocardial perfusion imaging) or the hemodynamic significance of a specific coronary stenosis (CT-based fractional flow reserve or transluminal attenuation gradient).
- The combined acquisition of morphologic and functional data with a single imaging modality can allow a fast and comprehensive appraisal of coronary artery disease.

INTRODUCTION

In the past decade, coronary computed tomography angiography (CCTA) has developed into a robust imaging technique for the noninvasive assessment of coronary arteries. Systematic analysis of studies using regular-dose and low-radiation-dose CCTA revealed a pooled sensitivity and specificity of CCTA of 98% and 89%, respectively.[1] These results compare favorably with alternative noninvasive coronary artery disease (CAD) imaging tests, in which single-photon emission computed tomography (SPECT) reaches sensitivities and specificities of 88% and 61%, PET of 84% and 81%, and cardiac magnetic resonance imaging of 89% and 76%, respectively.[2]

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Although CCTA remains a morphologic technique that can accurately depict coronary anatomy and the atherosclerotic plaque burden, it still has the same limitations as invasive coronary angiography (ICA) in evaluating the hemodynamic significance of flow-limiting stenosis. A growing body of evidence has shown that the pure anatomic evaluation of coronary stenosis does not adequately predict the hemodynamic relevance,[3] as shown by the results of the FAME (Fractional Flow Reserve Versus Angiography for Multivessel Evaluation) trial,[4] in which patients who underwent coronary revascularization guided by a functional test showed an improved outcome. Likewise, a substudy of the COURAGE (Clinical Outcomes Utilizing Revascularization and Aggressive Drug Evaluation) trial showed an increased reduction of ischemia by percutaneous coronary intervention[5] when patients selected through a functional test. Moreover, without functional data, ICA and CCTA can only provide limited correlation with myocardial perfusion defects.[6,7] Because revascularization should be guided by information on the state of myocardial perfusion, increasing efforts are being made to determine the functional relevance of lesions by CCTA.

Thanks to recent technological advancements, new computed tomography (CT) techniques are emerging that hold promise for achieving a comprehensive appraisal of anatomic and functional aspects of coronary heart disease with a single modality.

In this regard the existing CT functional analysis techniques for coronary physiology evaluation can be classified as follows:

1. Techniques for the direct assessment of myocardial ischemia:
   - Dynamic CT myocardial perfusion imaging (dCTMPI)
   - Static CT myocardial perfusion imaging (sCTMPI).
2. Techniques for the direct assessment of coronary stenosis significance:
   - CT-based fractional flow reserve (FFR)
   - Transluminal attenuation gradient (TAG)

The first group includes those techniques in which a dedicated stress/rest examination is performed to directly detect the presence of perfusion defects in the myocardium. They usually require state-of-the-art CT technology with the acquisition of specific protocols and the administration of pharmacologic stress. The second group involves those techniques in which direct assessment of the hemodynamic significance of a flow-limiting stenosis is performed during the postprocessing of a standard CCTA data set, without the need for a dedicated acquisition protocol, pharmacologic stress, or state-of-the-art CT technology. The advantages and disadvantages of each of these techniques are summarized in **Table 1**.

Thus, this article provides a systematic overview of the available CT techniques for the functional analysis of flow-limiting stenosis of the coronary arteries.

TECHNIQUES FOR THE DIRECT ASSESSMENT OF MYOCARDIAL ISCHEMIA

CT assessment of myocardial perfusion is based on the distribution of the iodinated contrast material during its first pass through the myocardium as an indicator of myocardial blood flow. Because the contrast distribution is determined by the arterial blood supply, myocardial perfusion defects can be identified as hypoattenuating areas containing reduced amounts of contrast material.[8] In static myocardial perfusion imaging, a static image of myocardial attenuation during first-pass perfusion gives a snapshot of iodine distribution, whereas attenuation followed over several consecutive time points provides dynamic myocardial perfusion imaging.

DYNAMIC COMPUTED TOMOGRAPHY MYOCARDIAL PERFUSION IMAGING

Acquisition Technique and Data Analysis

Dynamic CT myocardial perfusion imaging is the only CT-based technology capable of directly measuring absolute myocardial perfusion. Through electrocardiogram (ECG)-synchronized, repetitive scanning of the myocardium and cardiac blood pool, time attenuation curves (TACs) are generated while the contrast bolus is undergoing first pass, arterial phase, and microcirculation.

The acquisition is usually performed in the systolic phase of the cardiac cycle because this provides several advantages, such as the constant length of the systolic phase regardless of heart frequency, less susceptibility to beam-hardening artifacts, and a shorter apicobasal length with a thicker myocardial wall.[9]

At present, there are 2 major approaches available for dynamic imaging. Multidetector CT (with 256 or 320 detectors) has the necessary detector width to cover the whole heart while the table is stationary.[10] Dual-source CT (DSCT) scanners are also able to perform dynamic myocardial perfusion by using a shuttle table mode.[11–13] Because the detector coverage of the DSCT is limited to 38 mm, the whole heart coverage can only be obtained by applying the shuttle mode, in