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Pictorial Essay

Quantitative myocardial CT perfusion: a pictorial review and the current state of technology development

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Abstract. Coronary artery disease (CAD) is one of the leading causes of morbidity and mortality, and is associated with substantial and increasing resource burden. A combined physiologic and anatomic assessment may improve identification of patients with CAD who would benefit from revascularization and reduce unnecessary diagnostic and interventional procedures. Cardiovascular computed tomography (CT) has the potential to provide a comprehensive evaluation of CAD in a single setting. Although coronary CT angiography has been widely implemented for clinical use, the application of myocardial CT perfusion (CTP) has been relatively restricted because of a few limitations, such as beam hardening and the high radiation dose delivered. In this article, we first review the fundamental basis of the qualitative, semiquantitative, and quantitative techniques for myocardial CTP and discussed the strength and weakness of each approach. Beam-hardening correction for myocardial CTP with image-based method and dual-energy CT are then discussed with example cases demonstrating the effectiveness of each method. Initial experiences suggest both techniques can reduce beam-hardening artifact to a satisfactory extent. An overview on dose reduction technologies, such as prospective ECG triggering and iterative reconstruction for myocardial CTP, is also provided. Preclinical studies suggest it is feasible to perform low-dose quantitative myocardial CTP without affecting perfusion measurement. Finally, the impact of scan length on myocardial CTP is addressed.

Introduction

Technologies of cardiovascular computed tomography (CT) continued to evolve in the past decade. Wider detector coverage and faster gantry speed have improved the diagnostic accuracy of coronary CT angiography (CTA) for the assessment of coronary artery disease (CAD).[1] High-grade stenoses identified by coronary CTA are not reliable predictor of physiologic ischemia, however.[2] Thus, a combined anatomic-physiologic assessment is preferred to improve the selection of patients with CAD who may benefit from revascularization.[3] Although single-photon emission CT (SPECT) has been the most commonly used technique for assessing myocardial ischemia, CT perfusion (CTP) could be the ideal tool for conjunctional use with coronary CTA for comprehensive evaluation of CAD in a single setting. Investigations of myocardial CTP began 2 decades ago[4,5]; however, the clinical use of this technique

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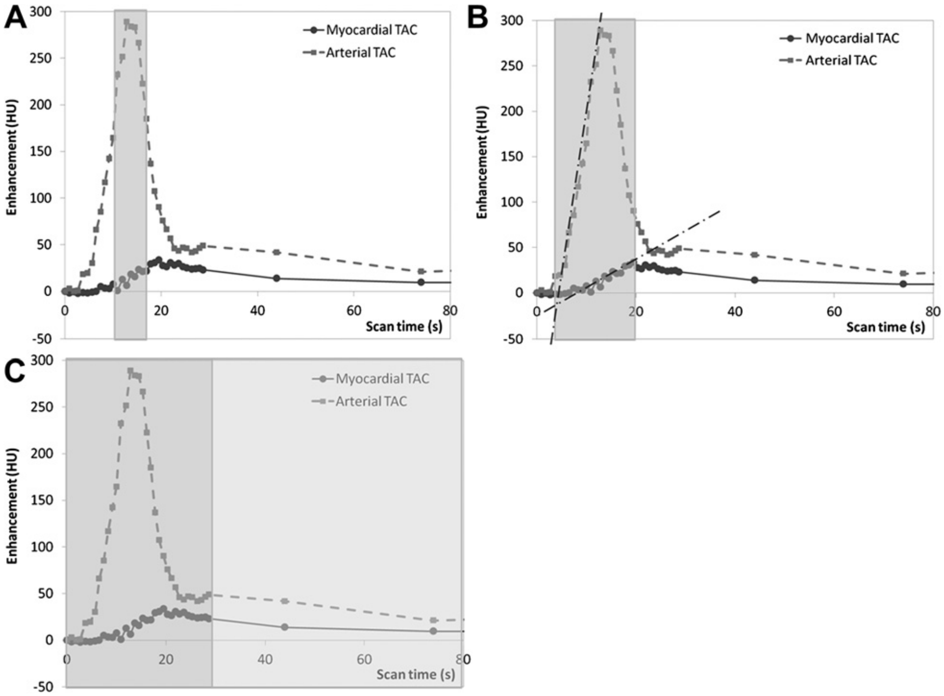

Figure 1 Scan protocol of (**A**) qualitative, (**B**) semiquantitative, and (**C**) quantitative myocardial CTP. The gray box in each graph represents the data-acquisition window with respect to the arterial and myocardial TAC after a bolus injection of contrast. The dashed line in (**B**) represents the upslope of each TAC. Quantitative myocardial CTP requires measurement of the entire TAC (**C**) and hence is associated with the highest radiation dose. For dose saving, a 2-phase acquisition protocol can be used. The second phase acquisition, represented by the light gray box in (**C**), can be performed at a much lower frequency (every 15 seconds) than the first phase (every 1 second). This is justified because change in contrast concentration in myocardium and its supply arteries toward the end of first-pass is significantly slower than that in the beginning of first-pass.

remains relatively restricted to date because of several issues, including beam hardening (BH), and high radiation dose. Novel CT technologies from recent years may provide solutions to these problems, and myocardial CTP could be ready for its prime time in the next few years. In this article, we review the fundamental bases of both qualitative and quantitative myocardial CTP techniques. CT technologies that can be implemented with myocardial CTP for BH correction and radiation dose reduction are also discussed.

Myocardial CTP

Qualitative method

The qualitative technique uses visual perception of density differences in the coronary CTA source images to distinguish ischemic (hypoperfused) from normal myocardium.[6,7] Thus, this method has the advantage of providing anatomical and functional assessment of CAD in a single test without additional contrast injection and radiation dose. The coronary CTA images are usually interpreted in 3 orthogonal views (axial, coronal, and sagittal) using a narrow window width and level setting to optimize visualization of myocardial contrast enhancement. Although the qualitative technique has demonstrated reasonable ability to detect infarction,[8] its ability to assess hypoperfusion is largely dependent on the timing of the coronary CTA acquisition. The signal density in myocardium accurately reflects the relative MP level only if the coronary CTA images are acquired during the peak myocardial contrast enhancement. Unfortunately, this cannot be guaranteed in most coronary CTA cases, as the acquisition is usually performed during the peak arterial contrast enhancement to optimize the visualization of coronary arteries (Fig. 1A), and the contrast arrival time in ischemic and infarcted myocardium can be more significantly delayed than that in coronary arteries.

As the qualitative method is based on visual interpretation of intensity differences, several criteria are used to minimize the false-positive rate owing to image artifacts arising from cardiac motion and BH. For instance, a true perfusion defect must persist through all cardiac phases, originate from subendocardium, and appear in the distribution of a coronary artery. The effect of BH is discussed in more detail in a separate section later. The main advantages of the qualitative over quantitative myocardial CTP are no additional radiation dose or contrast injection required. The disadvantage, however, is to assess cases of balanced ischemia as in cases of left main or triple-vessel CAD.

With the advent of dual-energy CT (DECT), images of the iodine concentration in the myocardium can be