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Optimal timing of image acquisition for arterial first pass CT myocardial perfusion imaging

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ABSTRACT

Purpose: To determine the optimal timing of arterial first pass computed tomography (CT) myocardial perfusion imaging (CTMPI) based on dynamic CTMPI acquisitions.
Methods and materials: Twenty-five patients (59 ± 8.4 years, 14 male)underwent adenosine-stress dynamic CTMPI on second-generation dual-source CT in shuttle mode (30 s at 100 kV and 300 mAs). Stress perfusion magnetic resonance imaging (MRI) was used as reference standard for differentiation of non-ischemic and ischemic segments. The left ventricle (LV) wall was manually segmented according to the AHA 16-segment model. Hounsfield units (HU) in myocardial segments and ascending (AA) and descending aorta (AD) were monitored over time. Time difference between peak AA and peak AD and peak myocardial enhancement was calculated, as well as the, time delay from fixed HU thresholds of 150 and 250 HU in the AA and AD to a minimal difference of 15 HU between normal and ischemic segments. Furthermore, the duration of the 15 HU difference between ischemic and non-ischemic segments was calculated.
Results: Myocardial ischemia was observed by MRI in 10 patients (56.3 ± 9.0 years; 8 male). The delay between the maximum HU in the AA and AD and maximal HU in the non-ischemic segments was 2.8 s [2.2–4.3] and 0.0 s [0.0–2.8], respectively. Differentiation between ischemic and non-ischemic myocardial segments in CT was best during a time window of 8.6 ± 3.8 s. Time delays for AA triggering were 4.5 s [2.2–5.6] and 2.2 s [0–2.8] for the 150 HU and 250 HU thresholds, respectively. While for AD triggering, time delays were 2.4 s [0.0–4.8] and 0.0 s [−2.2–2.6] for the 150 HU and 250 HU thresholds, respectively.
Conclusion: In CTMPI, the differentiation between normal and ischemic myocardium is best accomplished during a time interval of 8.6 ± 3.8 s. This time window can be utilized by a test bolus or bolus tracking in the AA or AD using the time delays identified here.

Abbreviations: CCTA, coronary computed tomography angiography; CAD, coronary artery disease; CT, computed tomography; MPI, myocardial perfusion imaging; SPECT, single photon emission computed tomography; MRI, magnetic resonance imaging; ICA, invasive coronary angiography; HU, Hounsfield unit; AA, ascending aorta; AD, descending aorta; ECG, electrocardiography; LV, left ventricle; MPR, multiplanar reformat reconstructions; AHA, American Heart Association; TAC, time-attenuation curves; ROIs, regions of interest.

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1. Introduction

Coronary computed tomography angiography (CCTA) is a reliable modality for the diagnosis of anatomical coronary artery disease (CAD) with a high negative predictive value [1,2]. However, assessing the hemodynamic significance of intermediate stenosis using CCTA is often challenging, as the effect of luminal narrowing on myocardial perfusion varies. Non-invasive techniques for myocardial perfusion imaging (MPI) are used to analyse the hemodynamic significance of a stenosis. These include single photon emission computed tomography (SPECT), magnetic resonance imaging (MRI) and invasive techniques (e.g. invasive coronary angiography (ICA) with fractional flow reserve measurement) [3]. With recent advances in CT technology, CT-based MPI emerges as an additional approach for the evaluation of the myocardial blood supply [4–10].

In CTMPI, an iodinated contrast agent is administered through an intravenous catheter and the subsequent distribution of the iodine contrast through the myocardium is evaluated. The CT assessment of the myocardial blood supply can be accomplished via two different scanning approaches: (1) a dynamic scan mode in which data are acquired at multiple time points, and (2) a static single-shot acquisition during first arterial pass. In the dynamic mode, the contrast enhancement of the myocardium is analyzed at multiple time points during the first-pass of the contrast, enabling calculation of myocardial blood flow over time and assessment of the true myocardial perfusion. In this scan mode, the table is shuttling between two scanning positions. The coverage of the dynamic scan mode is 7.3 cm, 2 times the detector size of 3.8 cm minus a 10% overlap between both scan positions. This method has an approximate time resolution of 2–3 s using dual-source CT scanners, acquiring images every second or third heartbeat. However, the increased number of acquisitions required with dynamic scanning results in a relatively high radiation dose, compared to static, single-shot techniques [8]. Although, radiation dose has come down in recent years, implementation into clinical practice is still in research phase.

As an alternative, the static, single-shot technique provides the myocardial iodine contrast distribution at a single point in time during first arterial pass. As a result, the single-shot technique cannot provide quantitative values for myocardial perfusion parameters. However, the static method can determine Hounsfield Unit (HU) differences between myocardial segments resulting from hemodynamically significant stenosis. Accurate timing of scan acquisition to yield optimal contrast differentiation between normal and ischemic myocardium is ensured through either a test bolus technique or bolus tracking approaches [11,12]. However, only one study analyzed the optimal timing of static perfusion CT scans in patients [13]. The need to establish optimal time delays remains in order to develop standardized static stress CT perfusion protocols. As such, the aim in this study was to define the optimal time delays for static single-shot CTMPI protocols during first arterial pass using different trigger points (AA and AD) and different trigger approaches (test bolus and bolus tracking).

2. Methods and materials

In this retrospective single-center study, we analyzed 26 patients with suspicion of CAD who had undergone dynamic CTMPI and adenosine stress perfusion MRI between November 2009 and July 2011 as part of a research protocol. The study protocol was approved by the local Institutional Review Board and informed consent was obtained from each patient. The study was conducted in HIPAA compliance. Stress MRI was used as reference standard. Two separate studies were performed: (1) a base study in which CT time delays were determined in the non-ischemic segments of all patients, and (2) a sub-study in 10 patients with perfusion defects indicated by stress MRI. In the latter, the optimal time delay for the differentiation between ischemic and non-ischemic segments on dynamic CT perfusion analysis was determined at three different slice locations: basal, mid-ventricular and apical.

2.1. MRI myocardial perfusion acquisition protocol

Patients were scanned on a 1.5-T MRI system (Magnetom Avanto; Siemens, Erlangen, Germany). Imaging parameters used for acquisition of perfusion images were: repetition time 2.8 ms; echo time 1.21 ms; flip angle 50°; field-of-view 380 × 80.2 mm; temporal resolution 150 ms; and slice thickness 10 mm. The protocol covered 3 short-axis slices (basal, mid-ventricular and apical) of the left ventricle (LV) in each heartbeat for 50 consecutive heartbeats. Gadopentate dimeglumine (Magnevist: 0.5 mol/L; Bayer-Schering, Berlin, Germany) was used as contrast agent at a dosage of 0.2 mL/kg per scan. Contrast was administered at 4 mL/s, followed by 15 mL saline chaser. Stress MPI was performed under infusion of adenosine (Adenoscan, Astellas, Tokyo, Japan; 140 μg/kg/min). Rest perfusion scanning was performed 10 min after stress scanning. Two experienced readers in consensus evaluated results of MRI MPI to determine ischemic and non-ischemic segments by visual analysis of first-pass perfusion defects using a picture archiving and communication system (Agfa Impax, Agfa Healthcare, Greenville, SC, USA). MR results were used as a reference for CTMPI assessment.

2.2. CT myocardial perfusion acquisition protocol

Dynamic CT perfusion was performed on a second-generation dual-source CT scanner (SOMATOM Definition Flash, Siemens, Forchheim, Germany). Stress imaging was performed 3 min after start of adenosine infusion with a dose of 140 μg/kg/min. Iopromide (Ultravist 370, Bayer AG, Berlin, Germany) was injected as a contrast bolus of 40–50 mL at an injection rate of 4–6 mL/s, resembling an iodine delivery rate ranging from 1.5 to 2.2 g/s, followed by a saline chaser. Data were acquired in shuttle mode, where the table is moving back and forth between two scanning positions. Scans were acquired using electrocardiographic (ECG) triggering at end-systole (250 ms after R-peak), with a tube voltage of 100 kV for both tubes, gantry rotation time of 280 ms, and a tube current of 300 mAs per rotation. Detector range of the scanner was 38 mm, and, with an overlap of 10%, resulted in a total z-volume coverage of 73 mm. Scans were started 4 s prior to contrast arrival in the heart to allow baseline non-contrast acquisition and total scan time was 30 s. Scan delay for the dynamic stress acquisition was determined using a test bolus.

2.3. CT myocardial perfusion analysis

MASS software (Research version 5.1, Leiden University Medical Center, Leiden, Netherlands) was used to evaluate CTMPI studies (Fig. 1). Cross sectional multiplanar reformat reconstructions (MPR) of 10 mm thickness were created at the basal, mid-ventricular and apical planes of the LV myocardium. In each individual heart, spacing between the three different MPR slices (basal, mid-ventricular and apical) was kept constant, varying between 8 and 26 mm for different patients, taking differences in LV size into account. The American Heart Association (AHA) 17-segment model was used to draw the myocardial segments[14]. The apical segments were excluded from the analysis, resulting in 16 analyzed myocardial segments per patient. Epicardial and endocardial contours were drawn manually by a researcher with 4 years of experience. Each slice was automatically divided into either six or four segments; six segments for basal and midventricular slices and four segments for