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Quantification of coronary flow using dynamic angiography with 320-detector row CT and motion coherence image processing: Detection of ischemia for intermediate coronary stenosis

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ABSTRACT

Objectives: Anatomical coronary stenosis is not always indicative of functional stenosis, particularly for intermediate coronary lesions. The purpose of this study is to propose a new method for quantifying coronary flow using dynamic CT angiography for the whole heart (heart-DCT) and investigate its ability for detecting ischemia from intermediate coronary stenosis.

Methods: Participants comprised 36 patients with coronary artery disease who underwent heart-DCT using 320-detector CT with tube voltage of 80 kV and myocardial perfusion scintigraphy (MPS). Heart-DCT was continuously performed at mid-diastole throughout 15–25 cardiac cycles with prospective ECG-gating after bolus injection of contrast media (12–24 ml). Dynamic datasets were computed into 90–100 data sets by motion coherence image processing (MCIP). Next, time-density curves (TDCs) for coronary arteries with a diameter >3 mm were automatically calculated for all phases using MCIP. On the basis of the maximum slope method, coronary flow index (CFI) was defined as the ratio of the maximum upslope of coronary artery attenuation to the upslope of ascending aorta attenuation on the TDC, and was used to quantify coronary flow. CFIs for the proximal and distal sites of coronary arteries with mild-to-moderate stenosis were calculated. Coronary territories were categorized as non-ischemic or ischemic by MPS. Receiver-operating-characteristic (ROC) analysis was performed to determine the optimal cutoff for CFI to detect ischemia.

Results: Distal CFI was significantly lower for ischemia (0.26 ± 0.08) than for non-ischemia (0.50 ± 0.17, $p < 0.0001$). No significant difference in proximal CFI was seen between ischemia (0.55 ± 0.23) and non-ischemia (0.62 ± 0.24). ROC analysis revealed 0.39 as the optimal cutoff for distal CFI to detect ischemia, with C-statistics of 0.91, 100% sensitivity, and 75% specificity.

Conclusions: This novel imaging technique allows coronary flow quantification using heart-DCT. Distal CFI can detect myocardial ischemia derived from intermediate coronary stenosis.

Abbreviations: AHA, American Heart Association; AUC, area under the curve; CAD, coronary artery disease; CCTA, coronary computed tomography angiography; CFI, coronary flow index; ECG, electrocardiography; FFR, fractional flow reserve; Heart-DCT, dynamic CT angiography for the whole heart; LAD, left anterior descending artery; LCX, left circumflex artery; MCIP, motion coherence image processing; MPR, multiplanar reconstruction; MPS, myocardial perfusion scintigraphy; RCA, right coronary artery; ROC, receiver-operating-characteristic; SPECT, single-photon emission computed tomography; TDC, time-density curve; VOI, volume of interest; WR, washout rate.

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1. Introduction

Coronary computed tomography angiography (CCTA) is a well-known and reliable method for detecting coronary stenosis in patients with coronary artery disease (CAD), [1]. However, anatomical coronary stenosis is not always indicative of functional stenosis and this is particularly true for intermediate coronary lesions [2,3]. According to established guidelines, the decision to perform angioplasty or bypass surgery should integrate anatomical information with a test that provides objective proof of ischemia [4,5].

Fractional flow reserve (FFR), which is measured during invasive coronary angiography, is regarded as the gold standard for determining hemodynamically significant coronary stenosis [6]. Although CCTA has been widely used to exclude significant coronary artery disease in patients with low to intermediate pretest probability, anatomic assessment by CCTA using diameter stenosis >50% does not correlate well with the functional assessment of FFR [7]. To overcome the weaknesses of conventional CCTA, more sophisticated CCTA analysis methods must be developed to detect hemodynamically significant. Recently, studies that use the quantification of coronary plaque, transluminal attenuation gradient [7], CT myocardial perfusion [8], and CT-derived FFR [9] have been conducted to validate their diagnostic performances.

Motion coherence image processing (MCIP) is a novel image processing technique, which performs deformable-registration to track all the voxels throughout multiple phases and interpolates images between phases to generate new phases. This imaging technique reduces noise, improves motion coherence and provides a tool to track specific voxels throughout phases [10,11]. We propose a new imaging technique for quantifying coronary flow using dynamic CT angiography for the whole heart (heart-DCT) with 320-row detector CT and MCIP, and investigated the ability for this method to detect ischemia with intermediate coronary stenosis.

2. Materials and methods

2.1. Study population

Data from 36 consecutive patients who had undergone CCTA with 320-detector row CT and adenosine-stress myocardial perfusion scintigraphy (MPS) with 201-thallium between April 2013 and April 2014 were retrospectively analyzed. All patients had been clinically referred for assessment of known or suspected CAD. CCTA was performed first, subsequently; MPS was performed to assess the presence of myocardial ischemia. MPS was performed within 1 month to assess coronary stenosis on CCTA. Revascularization therapy was not performed during the interval. Inclusion criteria were as follows: (i) patients with stable angina at effort or rest (documented ST-T change on electrocardiography (ECG), or relieved by administration of nitroglycerin); (ii) asymptomatic patients with high probability of CAD (i.e., multiple coronary risk factors), or abnormal findings on exercise ECG; and (iii) patients with intermediate coronary stenosis on CCTA. Exclusion criteria were as follows: (i) acute myocardial infarction (within 3 months); (ii) unstable angina (recent onset of angina within 1 month, or severe and worsening clinical symptoms); (iii) chronic atrial fibrillation; (iv) pregnancy, hyperthyroidism, or known allergic reaction to contrast media; (v) severe left ventricular dysfunction (left ventricular ejection fraction <20%); (vi) known history of bronchial asthma; (vii) congestive heart failure (New York Heart Association class IV); or (viii) greater than first-degree atrio-ventricular block. In all patients, MPS was performed to assess the presence of myocardial ischemia, and CCTA was performed within 1 month to assess coronary stenosis. Revascularization therapy was not performed during the interval. A detailed medical history was recorded for each patient, with particular attention to evidence of hypertension, diabetes mellitus, hyperlipidemia, and renal disease. Blood pressure was measured three times after a 5-min seated rest. All patients underwent a battery of laboratory tests, including tests for traditional atherosclerotic risk factors. The CAD risk factors considered in this study were hypertension, diabetes mellitus, hypercholesterolemia, chronic kidney disease, and smoking history. After all protocols were approved by the local ethics committee, informed consent was obtained from all patients. Patient characteristics are summarized in Table 1.

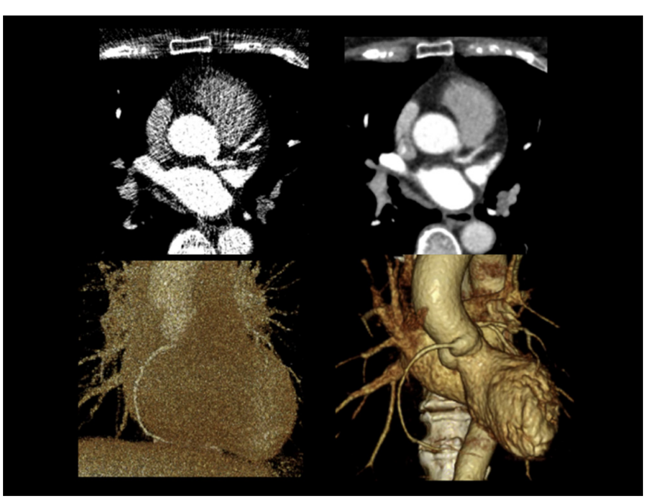

Fig. 1. Image reconstruction.
Reconstructed images (right) were obtained from adaptive iterative reduction and motion coherence image processing of original images (left). Image noise on reconstructed images is much less than on the original images.

Table 1
Characteristics of 36 patients with CAD.

Clinical characteristics	
Male (%)	20 (56)
Age (years, mean ± SD)	62 ± 15
Body mass index (mean ± SD)	23 ± 4
Hypertension (%)	22 (61)
Diabetes (%)	12 (33)
Hypercholesterlemia (%)	17 (47)
Chronic kidney disease (%)	7 (19)
Current smoker (%)	3 (8)
Past smoker (%)	14 (39)
Family history (%)	7 (19)
Parenthesis indicates percent	

2.2. Dynamic CT angiography for the whole heart

CT examinations were performed using a 320-row CT scanner (Aquilion One Vision Edition; Toshiba Medical Systems, Tokyo, Japan). Heart-DCT was performed in mid-diastole for 15–25 cardiac cycles using prospective ECG-gating during 20 s from 7 s after bolus injection of contrast media of 12–20 ml (3–5 ml/s, Iopamidol, 370 mgI/ml Iopamiron; Bayer HealthCare, Osaka, Japan) through a 20-gauge cannula in the right antecubital vein followed by 12–20 ml of saline with inspiratory breath hold. Bae has reported that the time to peak aortic enhancement from the start injection of duration 5 s is about 12 s in a porcine [12]. Also, Fleischmann has reported that the time to peak aortic enhancement at 4 ml/s of injection rate of contrast media of 16 ml is about 20 s in a human study [13]. On the basis of prior experimental studies, the scan begin time and duration were determined not to miss out the attenuation upslope and the peak point for ascending aorta throughout heart-DCT. Scan parameters were: gantry rotation time, 0.275 s; tube voltage, 80 kV;