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Dual energy imaging and intracycle motion correction for CT coronary angiography in patients with intermediate to high likelihood of coronary artery disease☆

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ABSTRACT

We explored whether intracycle motion correction algorithms (MCAs) might be applicable to dual energy computed tomography coronary angiography in patients with intermediate to high likelihood of coronary artery disease. MCA reconstructions were associated with higher interpretability rates (96.7% vs. 87.9%, $P<.001$), image quality scores (4.12±0.9 vs. 3.76±1.0; $P<.0001$), and diagnostic performance [area under the curve of 0.95 (95% confidence interval [CI] 0.92–0.97) vs. 0.89 (95% CI 0.86–0.92); $P<.0001$] compared to conventional reconstructions. In conclusion, application of intracycle MCA reconstructions to dual energy computed tomography acquisitions was feasible and resulted in significantly higher image quality scores, interpretability, and diagnostic performance.

1. Introduction

During the past decade, computed tomography coronary angiography (CTCA) has been established as the noninvasive diagnostic tool with the highest sensitivity and negative predictive value (NPV) for the evaluation of patients at intermediate risk of coronary artery disease (CAD) [1–3]. Notwithstanding, the unrestricted extrapolation of these results to the real-world scenario remains limited by technical, patient-related, and/or lesion-specific issues. Most of these limitations are related to the presence of motion artifacts or diffusely calcified plaques, commonly leading to overestimation of coronary stenosis and false-positive findings [4,5]. Calcified lesions usually seem larger on single energy CTCA (SECT) studies, being this mainly attributed to blooming and beam-hardening effects. Dual energy imaging (DECT) has recently emerged as a potential means to mitigate most of the aforementioned limitations, thereby possibly improving the assessment of CAD in selected populations where SECT fails to provide an accurate diagnosis. The basic principle of DECT is the acquisition of two datasets from the same anatomic location with rapid-switching kVp. This enables the generation of synthesized monochromatic image reconstructions that might attenuate technical issues related to the polychromatic nature of x-rays and the energy dependency of x-ray attenuation [6].

In parallel, we have recently demonstrated the ability of intracycle motion correction algorithms (MCAs) to compensate for coronary motion in SECT studies, leading to higher interpretability rates and image quality scores compared to conventional reconstructions [7]. In addition, this vendor-specific MCA has been shown to improve the diagnostic accuracy of CTCA using single energy CT in selected patient populations but has yet to be evaluated using dual energy CTCA [8].

We therefore sought to explore whether MCA might be applicable to DECT studies, by evaluating the interpretability and diagnostic accuracy of CTCA performed in patients suspected of CAD referred to invasive coronary angiography.

2. Methods

2.1. Study population

The present study was a single-center, investigator-driven, prospective investigation that involved patients with suspected CAD referred for invasive coronary angiography between May and August 2014. All patients included were more than 18 years old, in sinus rhythm, able to maintain a breath-hold for 15 s, and without a history of contrast-related allergy, renal failure, or hemodynamic instability. Additional exclusion criteria comprised a history of previous myocardial infarction

Abbreviations: CTCA, computed tomography coronary angiography; CAD, coronary artery disease; DECT, dual energy computed tomography; MCA, motion correction algorithm.

☆ We declare that Drs. Patricia Carrascosa and Jonathon Leipsic are Consultants of GE. There are no competing interests related to the manuscript for any of the other authors.

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Table 1
Demographical characteristics (n=32)

Age (years±S.D.)	62.6±11.8
Male (%)	23 (72%)
Body mass index (kg/m2±S.D.)	27.9±3.4
Heart rate (bpm±S.D.)	59.8±12.4
Diabetes (%)	5 (16%)
Hypertension (%)	20 (63%)
Hypercholesterolemia (%)	23 (72%)
Previous or current smoking (%)	20 (63%)
Family history of CAD (%)	10 (31%)
Previous myocardial infarction (%)	9 (28%)
Left ventricular ejection fraction (%±S.D.)	57.9±12.1%
Total cholesterol (mg/dl±S.D.)	194.6±50.8
High-density lipoprotein-cholesterol (mg/dl±S.D.)	47.6±15.0
Creatinine (mg/dl±S.D.)	0.95±0.2
Systolic blood pressure (mmHg±S.D.)	145.6±23.1
Diastolic blood pressure (mmHg±S.D.)	88.5±15.8
Baseline medication	
Aspirin (%)	28 (88%)
Statin (%)	23 (72%)
Angiotensin-converting enzyme inhibitor/ angiotensin II receptor antagonist (%)	19 (59%)
Beta-blocker/calcium antagonist (%)	26 (81%)
Anti-diabetic agents (%)	5 (18%)
Clinical presentation	
Anginal chest pain (%)	25 (78%)
Asymptomatic with positive stress test (%)	7 (22%)

within the previous 30 days, previous percutaneous coronary revascularization or coronary bypass graft surgery, or chronic heart failure. Patients under rate-control medications were advised to withhold for the previous 24 h. Coronary risk factors and clinical status were recorded at the time of the CT scan, and clinical variables were defined as indicated by the Framingham risk score assessment. No rate-control medications were administrated prior to the scan.

The aim of our study was to evaluate the interpretability, image quality, and diagnostic performance of the MCA compared to conventional reconstructions (without MCA) using DECT in patients referred to invasive angiography due to suspected CAD.

The institutional review board approved the study protocol, which complied with the Declaration of Helsinki, and written informed consent was obtained from all patients.

2.2. Image acquisition

All studies were acquired using a 64-slice high-definition CT scanner (Discovery HD 750, GE Healthcare, Milwaukee, WI, USA). Sixty to 80 ml of iodinated contrast (iobitridol, Xenetix 350™, Guerbet, France) were injected using a three-phase injection protocol, as follows: Phase 1: 80% of the total iodinated contrast volume being injected undiluted at a rate of 4.5 to 5.0 ml/s; Phase 2: the other 20% of the contrast medium mixed at a 50% saline dilution, injected at a rate of 4.5 to 5.0 ml/s; and Phase 3: a 30- to 40-ml saline chasing bolus at a rate of 4.5 to 5.0 ml/s. A bolus tracking technique was used to synchronize the arrival of contrast at the level of the coronary arteries with the start of the scan. Image acquisition was performed after sublingual administration of 2.5–5 mg of isosorbide dinitrate.

All studies were acquired using prospective electrocardiogram (ECG)-gating applying a 100-ms padding centered at 75% of the cardiac cycle for patients with a heart rate (HR) lower than 60 bpm, a 200-ms padding centered at 60% of the cardiac cycle for patients with a HR between 60 and 74 bpm, and a 100-ms padding centered at 40% of the cardiac cycle for patients with a HR higher than 74 bpm. DECT was performed by rapid switching (0.3–0.5 ms) between low and high tube potentials (80–140 kV) from a single source, thereby allowing the reconstruction of low and high energy projections and generation of monochromatic image reconstructions ranging from 40 to 140 keV. Iterative reconstruction was performed in all cases at 40% adaptive statistical iterative reconstruction. Other scanner-related parameters were a collimation width of 0.625 mm and a slice interval of 0.625 mm. All patients underwent coronary artery calcium (CAC) scoring before the enhanced (dual energy computed tomography coronary angiography [DE-CTCA]) scan.

2.3. Image analyses

CTCA image analyses were performed off-line on a dedicated workstation, using a commercially available dedicated software tool (AW 4.6, GE Healthcare) by consensus of two experienced Level 3-certified coronary CTCA observers (PC, AD), blinded to the clinical data and to the reconstruction mode since images were anonymized and loaded by a third party. The same observers were randomly assigned MCA or conventional reconstructions of each patient, with at least a 2-week window period between paired examinations. In addition, as a post-hoc analysis, after an additional 2-week period, the same observers were assigned to reanalyze MCA reconstructions with energy levels available only up to 69 keV. This ancillary analysis, since it involved the whole dataset, further served as surrogate for reproducibility analysis.

Briefly, the MCA multiphase reconstruction (Snapshot Freeze, GE Healthcare, Milwaukee, WI, USA) algorithm, after automated coronary vessel tracking, utilizes information from two adjacent cardiac phases within a single cardiac cycle to characterize vessel motion (vessel path and velocity) in order to determine the actual vessel position at the prespecified target phase and adaptively compensate for any residual motion at that phase. Contrary to multisector reconstructions techniques, MCA aims at coronary-specific motion and is less vulnerable to

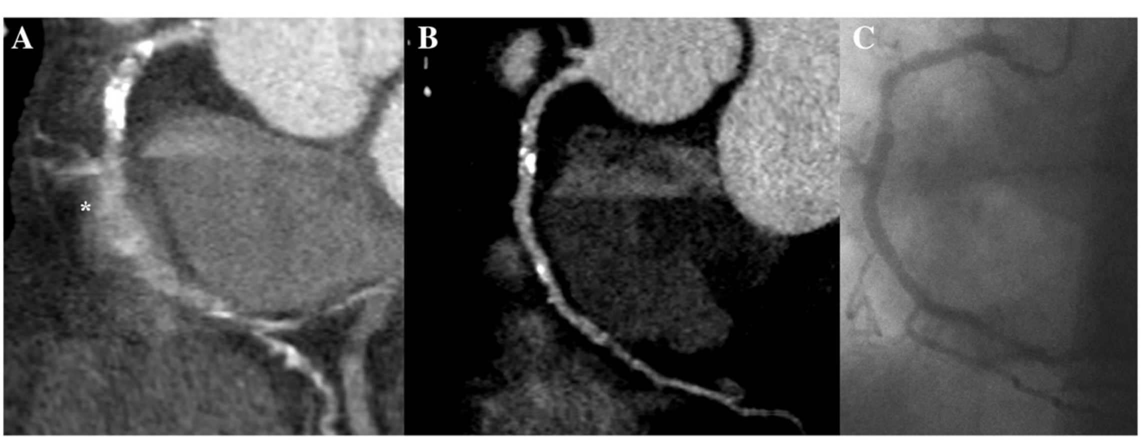

Fig. 1. Dual energy CTCA (curved multiplanar reconstructions) acquired at a HR of 69 bpm in a 70-year-old with multiple coronary risk factors, previous myocardial infarction, and shortness of breath. Using conventional (without MCA) reconstructions, severe motion artifacts are observed at the right coronary artery (Panel A, *) that preclude the assessment. After application of MCA (Panel B), the vessel is clearly depicted, and a significant lesion is identified and further confirmed at invasive angiography (Panel C).