Original Investigation

Virtual Monochromatic Imaging in Patients with Intermediate to High Likelihood of Coronary Artery Disease: Impact of Coronary Calcification

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Rationale and Objectives: We sought to explore the image quality and diagnostic performance of virtual monochromatic imaging derived from dual-energy computed tomography coronary angiography (DE-CTCA) in patients with intermediate to high likelihood of coronary artery disease (CAD) and the influence of calcification.

Materials and Methods: Consecutive symptomatic patients with suspected CAD referred for invasive coronary angiography who underwent DE-CTCA and a coronary artery calcium scoring before the invasive procedure comprised the study population.

Results: Sixty-seven patients were included. Image quality was significantly lower at 45 keV reconstructions (mean Likert score 45 keV 3.57 ± 0.6, 65 keV 4.07 ± 0.5, and 85 keV 4.09 ± 0.6; $P < .0001$). Patients with moderate calcification showed a trend toward a significant improvement in the diagnostic performance with 65 keV vs 45 keV reconstructions (45 keV, area under the curve 0.92 [95% confidence interval 0.89–0.95] vs 65 keV, area under the curve 0.96 [95% confidence interval 0.93–0.98], $P = .06$). The diagnostic performance of DE-CTCA was significantly lower in segments with higher coronary artery calcium scoring compared to segments with none or mild calcification, independent of the energy level applied.

Conclusions: In patients with intermediate to high likelihood of CAD, DE-CTCA had a good diagnostic performance, although significantly lower in segments with severe calcification.

Key Words: Spectral; imaging; specificity; kilovolt; angiogram.

INTRODUCTION

Computed tomography coronary angiography (CTCA) has been established as a valuable noninvasive diagnostic tool for the assessment of symptomatic patients with low to intermediate likelihood of coronary artery disease (CAD) (1–3). Notwithstanding, patients with intermediate to high likelihood of CAD have been consistently excluded from clinical studies involving this technology and consequently from diagnostic algorithms. To some extent, this has been attributed to the intricate distinction between heavily calcified plaques and luminal opacification that hamper the precise quantification of coronary stenosis (4). Calcified plaques usually seem larger on conventional single-energy computed tomography due to a number of technical issues such as blooming, beam hardening, and partial-volume effects, frequently leading to false-positive findings and therefore to potential unnecessary referral to invasive angiography (5).

Virtual monochromatic imaging derived from dual-energy computed tomography coronary angiography (DE-CTCA) shows promise to attenuate some of the aforementioned limitations and therefore might provide a more accurate assessment of high-risk patients (6–8). Briefly, the basic principle of DE-CTCA is the acquisition of two datasets from the same anatomic location with different kVp, which allows for synthesized monochromatic image reconstructions at different

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energy levels ranging from 40 to 140 keV. Although at the expense of higher image noise and blooming, lower energy levels yield higher intraluminal enhancement that allows a substantial iodine volume load reduction (8,9). In contrast, higher energy levels not only render a reduction in image noise and blooming but are also associated with significant reduction in luminal attenuation. We therefore sought to evaluate the image quality and diagnostic performance of DE-CTCA and the influence of different energy levels and extent of coronary calcification to accurately detect coronary stenosis in patients with intermediate to high likelihood of CAD.

METHODS

The present study was a single-center, investigator driven, prospective investigation that involved patients with suspected CAD referred for invasive coronary angiography (ICA). Between May 2014 and January 2015, consecutive symptomatic patients referred for ICA who accepted to undergo DE-CTCA and a coronary artery calcium scoring (CACS) within 1 month before the invasive procedure were included in the study. Exclusion criteria comprised age ≤18 years, atrial fibrillation, inability to maintain a breath-hold for 15 seconds; history of contrast-related allergy, renal failure (serum creatinine level greater than 1.5 mg/dL or estimated glomerular filtration rate <60 mL/min/1.73 m2), or hemodynamic instability. Additional exclusion criteria comprised patients with low and low to intermediate (<50%) likelihood of CAD according to the Diamond and Forrester updated model, a history of previous myocardial infarction within the previous 30 days, previous percutaneous coronary intervention or coronary bypass graft surgery, or chronic heart failure (10). Coronary risk factors and clinical status were recorded at the time of the computed tomography (CT) scan, and clinical variables were defined as indicated by the Framingham risk score assessment.

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

Image Acquisition

Patients were scanned using a 64-slice high definition scanner (Discovery HD 750, GE Healthcare, Milwaukee, WI). Nonenhanced (CACS) CT scans were performed using electrocardiographic gating at 75% of the cardiac cycle, using a 2.5-mm slice thickness and a tube potential of 120 kV.

DE-CTCA was performed after intravenous administration of iodinated contrast (iobitridol, Xenetix 350, Guerbet, France) through an antecubital vein. A total of 60–80 mL of iodinated contrast was 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 4.5–5.0 mL/s; phase 2: the other 20% of the contrast medium mixed at a 50% saline dilution, injected at a rate of 4.5–5.0 mL/s; and phase 3: a 30–40 mL saline chasing bolus injected at a rate of 4.5–5.0 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. Patients with a heart rate of >65 beats per minute received 50 mg oral metoprolol 1 hour before the scan or 5 mg intravenous propralonol if needed to achieve a target heart rate of less than 60 bpm.

DE-CTCA was acquired using prospective electrocardiographic gating applying a 100-ms padding centered at 75% of the cardiac cycle for patients with a heart rate lower than 60 bpm, a 200-ms padding centered at 60% of the cardiac cycle for patients with a heart rate between 60 and 74 bpm, and a 100-ms padding centered at 40% of the cardiac cycle for patients with a heart rate higher than 74 bpm. DE-CTCA 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. Other scanner-related parameters were a collimation width of 0.625 mm and a slice interval of 0.625 mm.

Image Analysis

DE-CTCA image analyses were performed off-line on a dedicated workstation, using a commercially available dedicated software tool (AW 4.6, GE Healthcare, Milwaukee, WI). An independent observer generated blinded reconstructions at three independent energy levels (45 keV, 65 keV, and 85 keV). Datasets were randomly assigned for analysis by consensus of two experienced level 3-certified coronary CTCA observers (radiologist PC, cardiologist AD), blinded to the clinical data and to energy level applied. Iterative reconstruction, applied in the raw data space, was performed in all available cases at 40% adaptive statistical iterative reconstruction. Adjustments of window width and level were left at the observer's discretion for each energy level. Axial planes, curved multiplanar reconstructions, and maximum intensity projections were obtained and used at 1- to 5-mm slice thickness, according to the 18-segment Society of Cardiovascular Computed Tomography classification (11). Furthermore, thin multiplanar reconstructions using both cross-sectional and longitudinal views were used to assess plaque morphology and severity. Segments with a reference diameter lower than 1.5 mm were not included in the analysis. Each segment was graded as follows: normal; nonsignificant stenosis (<50%); significant stenosis (≥50%); or uninterpretable. Uninterpretable segments due to motion artifacts or severe concentric calcification were assumed as positive for the diagnostic performance analysis. Segments distal to a total occlusion were not included in the analysis because conventional ICA usually does not provide accurate assessment of the distal runoffs.

Quantitative image quality assessment was performed using a 5-point Likert scale, as follows: (1 and 2) nondiagnostic: impaired image quality due to motion artifacts or severe calcification that precluded appropriate assessment; (3) sub-