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Research paper

Comparison of adaptive statistical iterative and filtered back projection reconstruction techniques in quantifying coronary calcium

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ABSTRACT

Background: Adaptive statistical iterative reconstruction (ASIR) has been used to reduce radiation dose in cardiac computed tomography. However, change of image parameters by ASIR as compared to filtered back projection (FBP) may influence quantification of coronary calcium.
Objective: To investigate the influence of ASIR on calcium quantification in comparison to FBP.
Methods: In 352 patients, CT images were reconstructed using FBP alone, FBP combined with ASIR 30%, 50%, 70%, and ASIR 100% based on the same raw data. Image noise, plaque density, Agatston scores and calcium volumes were compared among the techniques.
Results: Image noise, Agatston score, and calcium volume decreased significantly with ASIR compared to FBP (each $P < 0.001$). Use of ASIR reduced Agatston score by 10.5% to 31.0%. In calcified plaques both of patients and a phantom, ASIR decreased maximum CT values and calcified plaque size.
Conclusion: In comparison to FBP, adaptive statistical iterative reconstruction (ASIR) may significantly decrease Agatston scores and calcium volumes.

1. Introduction

The detection of coronary calcium by computed tomography (CT) is widely used to assess coronary heart disease risk and may permit monitoring of the progression of atherosclerotic plaque burden in the coronary arteries.[1–4] As for coronary CT angiography (CTA), minimizing radiation exposure during coronary calcium scanning is essential and respective guidelines recommend a target radiation dose of 1.0 to 1.5 mSv for coronary calcium scanning.[5] However, in "real world" application with currently available hardware and techniques, the dose for calcium scoring is often higher and may even exceed that of coronary CT angiography (CTA).[6–8]

Iterative reconstruction reduces image noise.[9,10] For one such algorithm (ASIR, GE Healthcare), Leipsic et al reported significantly improved image quality of coronary CT angiography (CTA) when using a composite of 40 to 60% ASIR with filtered back projection (FBP) compared to FBP alone.[10] Furthermore, several authors have reported acceptable image quality in spite of substantial reduction of radiation dose with the use of ASIR.[11–13]

To determine both the Agatston score (coronary calcium score) and the calcium volume, lesions are identified as calcium if their CT attenuation value is above a threshold of 130 HU in more than 2 contiguous pixels located over the course of the coronary arteries. To calculate the Agatston score, slice thickness should be 3.0 mm, and the area of the calcified lesion is multiplied by a weighting factor that depends on peak CT attenuation value and ranges from one (maximum CT values of 130 to 199 HU), to four (≥400 HU). No such weighted factors are used when calculating calcium volume.[1] Therefore, CT attenuation values above 130 HU, even when only present in one single pixel, affect especially the Agatston score.

Currently available population reference values for the coronary calcium score were obtained from data sets acquired exclusively with FBP. Although Gebhard et al. reported decreased Agatston scores and calcium volumes with ASIR in 50 patients,[14] the reason for lower Agatston scores is so far not fully understood. Therefore, using a large number of patients, we undertook this study to confirm whether Agatston score and calcium volume differ significantly between FBP and ASIR when both are obtained from acquisitions obtained at a constant radiation dose.

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2. Methods

2.1. Patients

Our university's institutional review board approved the study and waived written informed consent for this retrospective investigation which used CT data sets that were acquired for clinical purposes.

We retrospectively evaluated images of 440 consecutive patients referred for coronary CTA who underwent ECG-gated non-contrast CT for coronary calcium scanning as the first step of a coronary CTA examination[15,16], in our institution between January 2012 and February 2013. We excluded 12 patients whose reconstructed data with ASIR were not available, 67 patients with one or several implanted coronary artery stents, and 9 patients with chronic total occlusion and an Agatston score ≥1000, so that the final study cohort included 352 consecutive patients.

Patients underwent noncontrast CT before coronary CTA for suspected ischemic heart disease (229 patients), presurgical screening (71 patients, including aortic and iliac artery aneurysms in 42 patients, aortic dissection in 12, arteriosclerosis obliterans in eight, cancer in five, valvular disease in three, and atrial septal defect in one), abnormal ECG findings (33 patients), low left ventricular ejection fraction on echocardiography (9 patients), suspected cardiomyopathy (4 patients), cardiac mass (2 patients), postoperative screening (2 patients), coronary artery aneurysm after Kawasaki disease (one patient), or coronary artery fistula (one patient).

2.2. CT technique and radiation exposure

All examinations were performed with a 64-MDCT scanner (Lightspeed VCT VISION, GE Healthcare, Waukesha, WI, USA). All patients underwent prospectively ECG-triggered axial acquisition (triggered at 75% of the RR interval) for coronary calcium imaging using 350 msec rotation time, 64 × 0.625 mm collimation, field of view of 25 cm, and 120-kVp tube voltage. Reconstructed slice thickness was 2.5 mm. Tube current and voltage were selected as follows. First 100 patients: BMI <21 Kg/m^2, 100 mA; BMI ≥21 Kg/m^2 and BW ≤ 80 Kg, 150 mA; and BMI > 21 Kg/m^2 and BW > 80 Kg, 200 mA. Second set of 252 patients: BMI <25 Kg/m^2, 150 mA and BMI ≥25 Kg/m^2, 200 mA.

Patients whose baseline heart rate exceeded 63 beats per minute received oral beta-blockers, either 25 mg atenolol on the early morning of the examination day or 20 to 60 mg metoprolol one to 1.5 hours before CT.

Radiation dose was determined from the volume CT dose index (CTDIvol) and dose length product (DLP), effective dose was calculated using $\kappa = 0.014$ mSv-mGy^{-1}-cm^{-1}.

2.3. Phantom study

We created phantom to simulate coronary calcification using 4 materials with various CT attenuation values, all exceeding 130 HU (polyether ether ketone resin [PEEK], polyether sulphone resin [PES], polyphenylene sulfide resin Techtron® HPV [HPV], and polyvinyl chloride [PVC]) (Fig 1, 10 to 20 mm in diameter). We first scanned large samples of each the materials in a water tank using 70 mA tube current, and then embedded small pieces of all 4 of the materials into a long cylindrical phantom of 4 mm diameter (50% stenosis; length 5 mm) (Fig. 2; FUYO Corporation, Tokyo, Japan) that contained a transparent resin of 40 HU (acrylonitrile-butadiene-styrene [ABS]) to simulate blood in the coronary artery. This model was submersed in a tank of water and imaged by CT. We used tube currents of 10, 20, 50, and 70 mA for the calcified plaque model to observe the influence of ASIR on CT attenuation values at various levels of image noise.

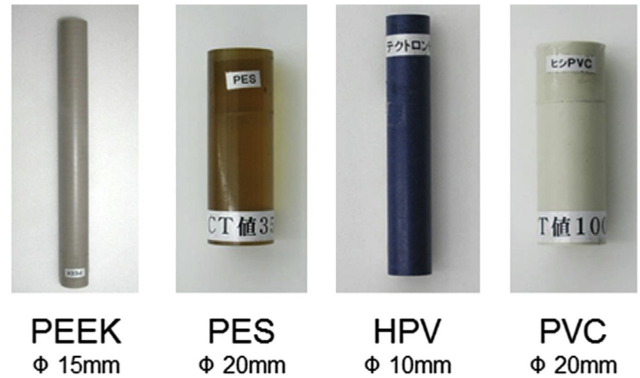

Fig. 1. Four materials used in the phantom. PEEK, polyether ether ketone resin; PES, polyether sulphone resin; HPV, polyphenylene sulfide resin Techtron® HPV; PVC, polyvinyl chloride.

2.4. Image reconstruction and analysis

Images were reconstructed with FBP (ASIR 0%), ASIR-FBP composites (ASIR 30%, 50%, and 70%), and ASIR 100%. A radiology technologist with 7 years of experience in coronary calcium scanning and scoring measured the standard deviation (SD) of attenuation values to estimate image noise in a region of interest (ROI) of 150 mm^2 in the ascending aorta at the level of the left main coronary artery ostium for patients and image noise in the water tank for the phantom. Measurements were performed on axial images obtained using the 5 different reconstruction techniques (FBP only [ASIR 0%], FBP combined with ASIR 30%, 50%, 70%, and ASIR 100%). The 5 reconstructed data sets were viewed simultaneously; use of an automatically linked scroll function ensured that all images were at the same level.

We used SmartScore 4.0 software (Advantage Workstation VolumeShare4) to calculate Agatston scores and calcium volumes using the 5 different data sets. Calcified lesions were defined as the presence of more than 2 contiguous pixels with CT attenuation values above 130 HU that could be assigned to a coronary artery. Once calcified lesions were manually identified, the workstation automatically performed quantification.

Based on the Agatston score determined by FBP, patients were classified into 4 groups according to the extent of calcification. These four classes were: Agatston score = 0, 1 ≤ Agatston score ≤99, 100 ≤ Agatston score ≤400, and Agatston score >400, as previously described.[17,18] We evaluated the number of patients whose class changed with the use of ASIR as compared to FBP.

To evaluate any change in the CT values of calcified plaques with ASIR, the mean and maximum CT values and the numbers of pixels above 130 HU of the calcified plaques were measured in the left anterior descending arteries (LAD) of 5 patients with similar image noise (14 or 15 HU) (Fig. 3).

In order to evaluate whether lesion size has an effect on the influence of ASIR on mean and maximum CT values, CT values of the 4 different phantom materials (Fig 1, 10 to 20 mm in diameter) were measured using large ROIs (mean 204 mm^2, range 66 to 265 mm^2) and in calcified plaque phantoms (Fig 2, 4-mm semicircular shape). These measurements were performed in precisely the same axial location for the 5 reconstruction techniques.