The Influence of Iterative Reconstruction on Coronary Artery Calcium Scoring—Phantom and Clinical Studies

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Rationale and Objectives: We compared the effect of iterative model reconstruction (IMR), filtered back projection (FBP), and hybrid iterative reconstruction (HIR) on coronary artery calcium (CAC) scoring.

Materials and Methods: CAC scans of 30 consecutive patients (18 men and 12 women, age 70.1 ± 12.2 years) were reconstructed with FBP, HIR, and IMR, and the image noise was measured on all images. Two radiologists independently measured the CAC scores using semiautomated software, and interobserver agreement was evaluated. Statistical analysis included the Spearman correlation coefficient and Bland-Altman analysis.

Results: The mean image noise on FBP, HIR, and IMR images was 48.0 ± 7.9, 29.6 ± 4.8, and 9.3 ± 1.3 Hounsfield units, respectively. The difference among all reconstruction combinations was significant ($P < .01$). The CAC score on HIR and IMR scans was 4.2% and 8.9% lower, respectively, than the CAC score on FBP images. There was no significant difference in the mean CAC score among the three reconstructions. The interobserver correlation was excellent for all three reconstructions ($r^2 = 0.96$ FBP, 0.99 HIR, 0.99 IMR); the best Bland-Altman measure of agreement was with IMR, followed by HIR and FBP.

Conclusion: For CAC scoring, IMR can reduce the image noise and blooming artifacts, and consequently lowers the measured CAC score. IMR can lessen measurement variability and yield stable, reproducible measurements.

Key Words: Iterative reconstruction; coronary artery calcium; measurement variability; image quality; Agatston score.

INTRODUCTION

Coronary artery calcium (CAC) is a strong predictor of future cardiovascular events (1,2). Multidetector computed tomography (MDCT) is commonly used to assess CAC as part of individual risk evaluations (3), and CAC scores are obtained at CT screening (4). As more patients undergo CAC scoring and repeat scanning for treatment monitoring (5,6), CAC measurements must yield robust results with low variability to allow meaningful comparisons. A disadvantage of the most commonly used quantification method by Agatston scoring is its limited reproducibility at repeated examinations owing to factors such as the image noise, motion artifacts, and the partial volume effect, etc. (7). This led to the introduction of two new algorithms, the calcium volume (8) and the calcium mass score (9), to complement and possibly replace the Agatston score. However, the Agatston score remains the most widely used scoring method because there is strong evidence that it is highly useful in individuals with atherosclerotic heart disease.

As iterative reconstruction (IR) helps to reduce the quantum noise associated with standard convolution-filtered back projection (FBP) reconstruction, it is increasingly integrated in clinical CT studies (10). Earlier studies indicated that the use of a hybrid IR (HIR) algorithm for cardiac CT, compared to the use of FBP, improves the image quality, allows for a reduction in radiation exposure, and improves the image quality (11). HIR comprises two denoising components, a sinogram

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restoration phase that reduces correlated noise and bias artifacts in the projection space, and an iterative denoising process in the image space that reduces the uncorrelated quantum-mottle noise. However, some image noise persists and artifacts may be introduced because of the non-global model of noise reduction. Iterative model reconstruction (IMR), a knowledge-based IR algorithm, is the latest advance in the field of reconstruction techniques. Compared to prior-generation IR, IMR is mathematically more complex, but also more accurate and can provide significantly better image quality than FBP and HIR at cardiac CT (12,13). However, the effects of IMR on CAC scoring are still unclear. Renker et al. (14) reported that IR significantly reduced blooming artifacts and calcium volumes on cardiac CT images. If blooming artifacts are reduced by IR, the effects on the detection of small lesions, the assessment of the CAC score, and subsequent risk classification may be possible. We performed phantom and clinical studies to compare the influence of IR on CAC scoring with the effect of standard FBP.

MATERIALS AND METHODS

This investigation consisted of phantom and clinical studies using the same CT system. The ethics committee of our hospital approved this retrospective study and waived individual informed patient consent.

CT Data Acquisition

All CT scans in our phantom and clinical studies were performed on a 256-slice CT scanner (Brilliance iCT; Philips Healthcare, Cleveland, OH) using prospective electrocardiogram triggering. The parameters for CAC imaging were detector configuration, 128 mm × 0.625 mm detector collimation with dynamic z-focal spot (longitudinal coverage of 8 cm); gantry rotation time, 0.27 seconds; and tube voltage, 120 kVp.

CT Image Reconstruction

Raw data were reconstructed with FBP, HIR (iDose^4; Philips Healthcare), and IMR (Philips Healthcare); a field of view of 20.0 cm with a 512 × 512 pixel matrix using a medium cardiac kernel (CB) for FBP and HIR, and cardiac routine mode for IMR. The slice thickness and section interval were the same at 3.0 mm. We applied moderate-level HIR reconstruction (iDose^4 level 4; this level yields a noise reduction factor of 0.29) routinely used at our institute. For IMR, there are three noise reduction levels (L1–L3), with L3 providing the maximum noise reduction. We targeted a moderate noise reduction (relative to HIR) and used L2 for IMR.

CAC Score Measurements

We performed CAC scoring on axial images using a commercially available image-processing workstation (Virtual Place Advance Plus; Aze, Tokyo, Japan) and the Agatston method (15). The software identified coronary artery plaques with an area >1 mm^2 and a density of greater than 130 Hounsfield units. Coronary plaques were manually selected and the semi-automatic software calculated the CAC score (Agatston score). In addition, the CAC volume and mean CAC attenuation were registered.

Phantom Study

We used an anthropomorphic thorax phantom (QRM-Cardio-Phantom; QRM GmbH, Moehrendorf, Germany) with a 200 × 300 mm body diameter and a 100 mm depth designed as a calibration standard for the quantification of coronary calcium (Fig 1). The phantom included artificial lungs and a spine insert surrounded by material mimicking soft tissue. At the position of the heart, there was a 100-mm-diameter cylindrical hole for the placement of a calibration insert containing three sets of calcified cylinders measuring 1, 3, and 5 mm in both diameter and height; their calcium hydroxyapatite density

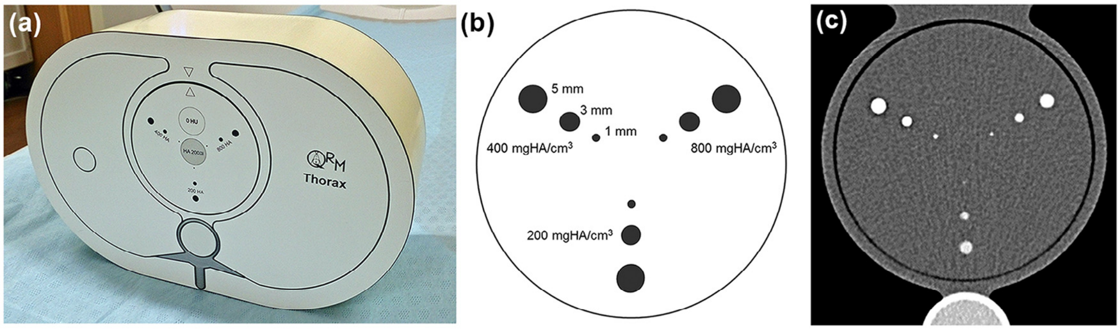

Figure 1. **(a)** Photograph of the anthropomorphic thorax phantom used to quantify coronary artery calcium (QRM-Cardio-Phantom; QRM GmbH, Moehrendorf, Germany). **(b)** Diagram of the frontal view of the calibration insert containing three sets of calcified cylinders measuring 1, 3, and 5 mm in diameter; their calcium hydroxyapatite density equals 200, 400, and 800 mg HA/cm^3, respectively. **(c)** Transverse computed tomography image of the anthropomorphic thorax phantom with nine different calcifications.