A Knowledge-based Iterative Model Reconstruction Algorithm:

Can Super-Low-Dose Cardiac CT Be Applicable in Clinical Settings?

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Rationale and Objectives: To investigate whether "full" iterative reconstruction, a knowledge-based iterative model reconstruction (IMR), enables radiation dose reduction by 80% at cardiac computed tomography (CT).

Materials and Methods: A total of 23 patients (15 men, eight women; mean age 64.3 ± 13.4 years) who underwent retrospectively electrocardiography-gated cardiac CT with dose modulation were evaluated. We compared full-dose (FD; 730 mAs) images reconstructed with filtered back projection (FBP) technique and the low-dose (LD; 146 mAs) images reconstructed with FBP and IMR techniques. Objective and subjective image quality parameters were compared among the three different CT images.

Results: There was no significant difference in the CT attenuation among the three reconstructions. The mean image noise of LD-IMR (18.3 ± 10.6 Hounsfield units [HU]) was significantly lowest among the three reconstructions (41.9 ± 15.3 HU for FD-FBP and 109.9 ± 42.6 HU for LD-FBP; $P < .01$). The contrast-to-noise ratio of LD-IMR was better than that of FD-FBP and LD-FBP ($P < .01$). Visual evaluation score was also highest for LD-IMR.

Conclusions: The IMR can provide improved image quality at super-low-dose cardiac CT with 20% of the standard tube current.

Key Words: Cardiac CT; iterative reconstruction; radiation dose; image quality.

Cardiac computed tomography (CT) has emerged as a useful diagnostic imaging modality for the noninvasive assessment of coronary artery disease in select patient groups (1). Although the diagnostic performance of cardiac CT is high for the detection and exclusion of obstructive coronary artery disease (2,3), there are concerns regarding potential stochastic risks related to ionizing radiation (4). According to Hausleiter et al. (5), the mean effective dose at cardiac CT was 12 mSv; the range was 5–30 mSv. To minimize the patient dose, conventional electrocardiographic (ECG)-dependent tube current modulation is used, achieving moderate dose savings of 37%–40% (6). Another radiation dose saving technique, prospective "step-and-shoot" ECG-triggering, allows for a radiation dose reduction of 77%–79% (7,8). However, it requires a steady low heart rate (HR), which is not obtainable in all patients, and therefore, retrospectively ECG-gated cardiac CT is still useful for some patients. Also, the evaluation of cardiac function is not possible because images are acquired at a single, predetermined, end-diastolic, quiescent phase. It is critically important to balance the desire for low-radiation doses with the likelihood of obtaining diagnostically useful images.

An iterative reconstruction algorithm for CT was introduced to help reduce the quantum noise associated with standard convolution–filtered back projection (FBP) reconstruction algorithms (9). Studies that evaluated the quality of images acquired with a hybrid type of iterative reconstruction indicated that a radiation dose reduction of 23%–66% was possible while maintaining the image quality (10,11), but a certain amount of image noise and artifacts are still present. Iterative model reconstruction (IMR), a fully iterative algorithm, represents the latest advance in the field of reconstruction techniques. It applies a knowledge-based approach that yields improved image quality and virtually noise-free images through the iterative minimization of the penalty-based cost function. IMR technique can reconstruct the cardiac CT images within 5 minutes, and we posit it can be applicable in clinical practice. To our knowledge, there

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is no reported study involving comparative evaluation on a clinical setting of the knowledge-based iterative reconstruction algorithm and FBP algorithm at cardiac CT.

Under the hypothesis that IMR could reduce image noise and artifact and produce virtually noise-free images at low-dose (LD) cardiac CT, we investigated the effect of IMR on the quantitative and qualitative image evaluation by comparing images acquired at low-radiation doses (20% dose) and images obtained at standard radiation doses with FBP reconstruction.

MATERIALS AND METHODS

Phantom Study

We first performed phantom studies on a 256-slice CT instrument (Brilliance iCT; Philips Healthcare, Cleveland, OH) to determine whether the IMR algorithm improved image quality at cardiac CT performed with 20% of the standard tube current.

The anthropomorphic moving heart phantom (pulsating cardiac phantom; Fuyo Co., Tokyo, Japan) we used consists of a rubber bag with vessel platforms; it facilitates synchronized ECG gating during multidetector CT data acquisition. To obtain an attenuation of 300 Hounsfield units (HU), the pulsating heart phantom was filled with iodine contrast material and distilled water and immersed in distilled water (mean attenuation, 4.5 HU). Tubes made of silicone simulating coronary artery vessels with stenotic regions were implanted in the vessel platforms; the phantom coronary artery length and inner lumen diameter were 50.0 mm and 3.0 mm, respectively. The stenotic degrees were 0% and 50%; plaque had an attenuation value of 65 HU. The lumen of the phantom coronary artery was filled with diluted contrast material (Iopamiron 300; Bayer Healthcare, Osaka, Japan) to reach a target intraluminal attenuation of approximately 300 HU. We used prospective ECG-gated scanning with a mid-diastole trigger centered at 75% of the R-R interval. The scan parameters were detector configurations: detector collimation, 128 × 0.625 mm; slice thickness, 0.67 mm; gantry rotation time, 0.27 seconds; and display field of view (FOV), 120 × 120 mm. An ECG was acquired during the scan at a heart rate of 60 beats per minute (bpm). The tube current–time product was 350 mAs and 70 mAs. The tube voltage was 120 kVp. The 350 mAs and 70 mAs images were reconstructed with FBP using a medium cardiac kernel; for the 70 mAs images, we also used the IMR algorithm (Philips Healthcare, Cleveland, OH).

For qualitative image analysis, images including transverse source images, multiplanar reformations, and thin-slab maximum-intensity projections were evaluated independently by eight radiologists with 3–18 years of experience (mean, 11.1 years). The CT data sets were presented in random order, and the readers were blinded to the acquisition parameters. They were allowed to adjust the window level and width, and they used a 4-point subjective scale to grade overall image quality. The visual evaluation scores for image noise and artifact were 1 (poor) = present and unacceptable, 2 (fair) = present and interfering with the depiction of coronary arteries, 3 (good) = present but not interfering with the depiction of coronary arteries, and 4 (excellent) = minimal or absent with clear depiction of the coronary arteries.

One of the authors (Se.O.) measured the image noise and intraluminal attenuation of the coronary artery phantom for each reconstruction technique. Image noise was determined at the portion of the moving heart phantom that contained distilled water. The noise index was the standard deviation (SD) of the pixel values within a 50-mm diameter circular region of interest (ROI). For each reconstruction setting we used 10 consecutive images in the z direction. Image noise was measured within ROIs drawn at three different locations, and the average value of the three measurements was noted down. Intraluminal attenuation of the coronary artery phantom was also measured on the same 10 consecutive images in the z direction. The contrast-to-noise ratio (CNR) was calculated by subtracting the attenuation of the distilled water from the intraluminal attenuation and then dividing the difference by the image noise.

TABLE 1. Patient Characteristics

Characteristics	Value
Number of patients	23
Age (years)	64.3 ± 13.4
Female/male	8/15
Body weight (kg)	62.0 ± 9.2
Body mass index (kg/m^2)	23.1 ± 2.5
Average heart rate (beats/min)	54.5 ± 3.8

Data are mean ± standard deviation.

Clinical Study

This prospective study received institutional review board approval; prior informed consent was obtained from all patients.

Study population. We prospectively enrolled 23 consecutive patients (15 men, eight women; mean age 64.3 ± 13.4 years, age range 20–80 years) who underwent retrospective helical ECG-gated cardiac CT with ECG-dependent tube current modulation between March and April 2012. All had suspected or confirmed coronary artery disease and were referred for cardiac CT for clinical reasons based on guidelines promulgated by the American College of Cardiology (1). Exclusion criteria for cardiac CT were allergy to contrast medium, renal insufficiency (estimated glomerular filtration rate less than 40 ml/min/1.73 m^2), unstable clinical condition, and inability to perform a breath hold. The patient characteristics are summarized in Table 1.

Cardiac CT acquisition. All patients were examined on a 256-slice CT system (Brilliance iCT). The parameters were detector configurations: detector collimation, 128 × 0.625 mm; slice thickness, 0.67 mm; gantry rotation time, 0.27 seconds; pitch, 0.16; tube voltage, 120 kVp; and tube current–time product