Evaluation of Coronary Artery Image Quality with Knowledge-based Iterative Model Reconstruction

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Rationale and Objectives: To evaluate knowledge-based iterative model reconstruction (IMR) to improve image quality and reduce radiation dose in coronary computed tomography angiography (cCTA).

Materials and Methods: We evaluated 45 consecutive cCTA studies, including 25 studies performed with an 80% systolic dose reduction using tube current modulation (TCM). Each study was reconstructed with filtered back projection (FBP), hybrid iterative reconstruction (iDose^4), and IMR in a diastolic phase. Additional systolic phase reconstructions were obtained for TCM studies. Mean pixel attenuation value and standard deviation (SD) were measured in the left ventricle and left main coronary artery. Subjective scores were obtained by two independent reviewers on a 5-point scale for definitions of contours of small coronary arteries (<3 mm), coronary calcifications, noncalcified plaque, and overall diagnostic confidence for the presence/absence of stenosis.

Results: There was no significant difference in pixel intensity among FBP, iDose^4, and IMR (P > .8). For diastolic phase images, noise amplitude in the left main coronary artery was reduced by a factor of 1.3 from FBP to iDose^4 (SD = 99 vs. 74; P = .005) and by a factor of 2.6 from iDose^4 to IMR (SD = 74 vs. 28; P < .001). For systolic phase TCM images, noise amplitude in the left main coronary artery was reduced by a factor of 2.3 from FBP to iDose^4 (SD = 322 vs. 142; P < .001) and by a factor of 3.0 from iDose^4 to IMR (SD = 142 vs. 48; P < .001). All four subjective image quality scores were significantly better with IMR compared to iDose^4 and FBP (P < .001). The reduction in image noise amplitude and improvement in image quality scores were greatest among obese patients.

Conclusions: IMR reduces intravascular noise on cCTA by 86%–88% compared to FBP, and improves image quality at radiation exposure levels 80% below our standard technique.

Key Words: CT reconstruction; CT image quality; coronary CTA; iterative reconstruction.

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Since the introduction of the EMI computed tomography (CT) scanner in 1971, clinical CT image reconstruction has been based on filtered back projection (FBP) to reconstruct two-dimensional images from x-ray attenuation measurements in multiple one-dimensional planes. The original EMI scanner did provide an option for iterative reconstruction, but iterative reconstruction was not applied to clinical CT until recently because of computational requirements. Increased computational power now allows the application of iterative reconstruction techniques that were developed for lower resolution nuclear medicine images to high resolution CT. A history of CT reconstruction along with a synopsis of newer iterative reconstruction techniques are summarized in a recent review (1).

The first commercially available iterative reconstruction systems for CT used hybrid methods that combined FBP with iterative reconstruction to provide noise reduction. This noise reduction can be leveraged to improve image quality or to compensate for high noise with lower tube current acquisitions. Adaptive statistical iterative reconstruction (GE Healthcare, Waukesha, WI) (2,3) and iDose^4 (Philips Healthcare, Cleveland, OH) (4,5) are examples of this approach. These techniques decrease the noise in reconstructed images compared to FBP. Model-based iterative reconstruction by GE Healthcare (6,7) and iterative model reconstruction (IMR) by Philips are the latest generation of commercially available iterative techniques that rely on statistical and system models and approach reconstruction as an optimization process. These newer techniques may simultaneously provide further reduction in image noise, potential dose savings, and improved image quality.

Coronary CT angiography (cCTA) demonstrates fine anatomic details of small epicardial arteries. To successfully image these vessels, early adopters of cCTA used high radiation doses (8). With increasing clinical use of cCTA, many dose reduction techniques—including iterative reconstruction—have been introduced to minimize radiation

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dose with cCTA (9,10). The purpose of this study was to evaluate knowledge-based IMR to improve image quality and to reduce radiation dose in cCTA. To evaluate improvement in image quality with IMR, we reviewed diastolic phase reconstructions of cCTA examinations. To evaluate the potential for dose reduction with IMR, we reviewed additional systolic phase reconstruction obtained with reduced tube current using tube current modulation (TCM).

METHODS

This The Health Insurance Portability and Accountability Act (HIPAA)-compliant study was approved by our university institutional review board (control #13D.23). The requirement for written informed consent was waived for this retrospective study of clinically acquired cCTA data.

We evaluated 45 consecutive electrocardiogram (ECG)-gated cCTA studies acquired on a 256-slice iCT scanner (Philips Healthcare) with helical technique. cCTA studies were performed for evaluation of coronary anatomy with clinical indications including chest pain or follow-up of an abnormal/indeterminate stress test. Our standard cCTA protocol uses a kilovoltage peak (kVp) of 100–120 with an effective milliampere second value (mAs = mA × rotation time/helical pitch) of 600–800 based on the size of each patient. Our injection protocol delivers 60 mL of intravenous contrast (ioversol 350; Mallinckrodt Hazelwood, MO) at 6 mL/second followed by a saline chaser of 50 mL injected at 5 mL/second.

To minimize the presence of motion artifact in our studies, patients with a baseline heart rate over 60 beats per minutes (bpm) are treated with intravenous metoprolol in 5 mg aliquots every 5 minutes (up to a maximum dose of 20 mg) titrated to a heart rate below 60 bpm. A sublingual spray with 800 μg of nitroglycerin is delivered approximately 2 minutes before the examination.

To reduce patient radiation exposure, TCM was applied when appropriate. TCM in cardiac scans is a dose saving technique that reduces tube current at cardiac phases away from the phase of interest. Among patients with a stable heart rate below 65 bpm, the phase of interest for visualization of the coronary arteries is almost always mid-diastole. Overall radiation exposure can be reduced in these patients by modulating tube current to a lower level during systole. In this study, TCM was applied in those 25 of our 45 patients who demonstrated a stable heart rate below 65 bpm before the initiation of the scan. In our practice, this means that during the systolic portion of the cardiac cycle, only 20% of the mAs used during diastole is delivered, resulting in noisy photon-limited systolic phase images.

The raw data from each study was reconstructed with FBP, iterative reconstruction (iDose^4), and knowledge-based reconstruction IMR (Philips Medical Systems, Cleveland, OH) using identical parameters of 0.8-mm section thickness and 250-mm field of view. All the cases were reconstructed with these three reconstruction techniques in a diastolic phase (at 78% of the R–R interval). In addition, the 25 studies performed with TCM were also reconstructed with all three reconstruction techniques in a systolic phase (at 40% of the R–R interval).

Each case was evaluated by two independent reviewers on a Brilliance workstation (Philips Healthcare) using the cardiac viewer package. This software package permits simultaneous scrolling/rotation/viewing of multiple linked windows in axial and variable thickness slab maximum intensity projections. The two reviewers each had at least 1 year of experience using the Brilliance workstation for viewing cCTA cases. Each reviewer first evaluated all the diastolic phase images and then reviewed the systolic phase images 2 weeks later. For each case, the FBP, iDose^4, and IMR images were evaluated simultaneously. The mean and standard deviation (SD) of pixel attenuation values were computed in a standardized region of interest in both the left ventricle and left main coronary artery. Standard deviation of pixel attenuation value in a homogeneous region provides a quantitative measure of noise amplitude. Additional subjective rating scores of the coronary arteries were obtained from each reviewer using a 5-point scale for definitions of (1) contours of small coronary arteries (<3 mm), (2) small coronary calcifications, (3) contour of noncalcified plaque, and for (4) overall diagnostic confidence for presence/absence of stenosis. The 5-point scale for definition was defined as 1 = not visible, 2 = visible, but poorly defined, 3 = mediocre definition, 4 = good definition with slight blurring, and 5 = excellent definition. For diagnostic confidence regarding the presence/absence of stenosis, the scale was defined as 1 = nondiagnostic, 2 = diagnostic with limitations, 3 = diagnostic for major coronary vessels, 4 = diagnostic without limitations, and 5 = completely diagnostic with excellent visualization of all coronary branches.

Statistical Analysis

Statistical analysis was performed with Stata 12.1 software (StataCorp, College Station, TX). To demonstrate whether mean CT attenuation was impacted by reconstruction technique, pixel attenuation measurements were compared by analysis of variance (ANOVA) based on the reconstruction technique (FBP vs. iDose^4 vs. IMR). To determine whether image noise was impacted by the reconstruction technique, the standard deviations of pixel attenuation within a defined region of interest were compared to a similar ANOVA. In these situations where a significant result was obtained with ANOVA, paired *t* test comparisons were performed of ratings obtained with FBP to those obtained with iDose^4, and of ratings obtained with iDose^4 to those obtained with IMR. A parallel analysis was applied to compare the subjective image quality ratings for the three reconstruction techniques. To assess the impact of body habitus, the comparison of FBP, iDose^4, and IMR was repeated as a stratified subanalysis among three patient groups determined by body mass index (BMI), including those with normal weight (BMI of 10–25), overweight (BMI >25–30), and obesity (BMI >30). This subanalysis was limited to diastolic phase imaging because of sample size considerations. Interobserver agreement for the subjective ratings of

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