Radiology

Evaluation of Heavily Calcified Vessels with Coronary CT Angiography: Comparison of Iterative and Filtered Back Projection Image Reconstruction[1]

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Purpose: To prospectively compare traditional filtered back projection (FBP) and iterative image reconstruction for the evaluation of heavily calcified arteries with coronary computed tomography (CT) angiography.

Materials and Methods: The study had institutional review board approval and was HIPAA compliant. Written informed consent was obtained from all patients. Fifty-five consecutive patients (35 men, 20 women; mean age, 58 years ± 12 [standard deviation]) with Agatston scores of at least 400 underwent coronary CT angiography and cardiac catheterization. Image data were reconstructed with both FBP and iterative reconstruction techniques with corresponding cardiac algorithms. Image noise and subjective image quality were compared. To objectively assess the effect of FBP and iterative reconstruction on blooming artifacts, volumes of circumscribed calcifications were measured with dedicated volume analysis software. FBP and iterative reconstruction series were independently evaluated for coronary artery stenosis greater than 50%, and their diagnostic accuracy was compared, with cardiac catheterization as the reference standard. Statistical analyses included paired *t* tests, Kruskal-Wallis analysis of variance, and a modified McNemar test.

Results: Image noise measured significantly lower (P = .011–.035) with iterative reconstruction instead of FBP. Image quality was rated significantly higher (P = .031 and .042) with iterative reconstruction series than with FBP. Calcification volumes measured significantly lower (P = .019 and .026) with iterative reconstruction (44.3 mm^3 ± 64.7 and 46.2 mm^3 ± 68.8) than with FBP (54.5 mm^3 ± 69.5 and 56.3 mm^3 ± 72.5). Iterative reconstruction significantly improved some measures of per-segment diagnostic accuracy of coronary CT angiography for the detection of significant stenosis compared with FBP (accuracy: 95.9% vs 91.8%, P = .0001; specificity: 95.8% vs 91.2%, P = .0001; positive predictive value: 76.9% vs 61.1%, P = .0001).

Conclusion: Iterative reconstruction reduces image noise and blooming artifacts from calcifications, leading to improved diagnostic accuracy of coronary CT angiography in patients with heavily calcified coronary arteries.

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A large body of literature has shown that coronary computed tomography (CT) angiography can be used to sensitively rule out coronary artery stenosis in patients with chest pain (1). Nevertheless, those studies also consistently demonstrate that, despite advances in CT technology, the specificity of this test frequently remains limited by heavy coronary artery calcifications, which are the most common reason for false-positive findings. Heavy calcifications cause blooming artifacts, which can lead to overestimation of lesions (2), often prompting unnecessary coronary catheterization or myocardial perfusion studies (3,4).

The current standard CT image reconstruction technique is filtered back projection (FBP). However, FBP has limitations vis-à-vis three-dimensional cone-beam geometry, data completeness, and low photon environments (5). To some extent, blooming artifacts arising from heavy calcifications are attributable to these technical shortcomings (6).

Iterative reconstruction techniques have been proposed for over 3 decades to improve CT image quality by reducing quantum noise and artifacts (7) but were used mainly in the context of emission tomography (8). Only recently has computer power evolved enough to enable iterative image reconstruction within a clinically acceptable time frame for general CT applications. Beneficial effects of iterative reconstruction techniques in CT applications throughout the body have since been reported (9–13). However, the potential of this approach to improve the diagnostic accuracy of coronary CT angiography, especially in problematic scenarios (eg, the presence of heavy calcifications), has not been explored.

Accordingly, the aim of our prospective study was to compare traditional FBP with iterative image reconstruction for the evaluation of heavily calcified arteries with coronary CT angiography.

Advances in Knowledge

- Heavy coronary artery calcifications show significantly lower volumes at coronary CT angiography when iterative image reconstruction is used compared with traditional filtered back projection (FBP), indicating decreased blooming artifacts from calcified coronary atherosclerotic plaques.
- Compared with FBP, iterative image reconstruction significantly improves accuracy, specificity, and positive predictive value (PPV) of coronary CT angiography for the evaluation of coronary artery stenosis in patients with heavy vessel calcifications.

Materials and Methods

U.J.S. is a consultant for Bayer Healthcare (Berlin, Germany), Medrad (Indianola, Pa), and Siemens Healthcare (Forchheim, Germany), whose products were used in this investigation. The authors who are not consultants for those companies had control of inclusion of any data and information that might present a conflict of interest.

Patients

This study was part of a larger investigation evaluating the accuracy of coronary CT angiography for detection of coronary artery stenosis in symptomatic patients referred for cardiac catheterization. The study was approved by the institutional review board of the Medical University of South Carolina and was conducted in accordance with Health Insurance Portability and Accountability Act regulations. Written informed consent was obtained from all patients. We prospectively included coronary CT angiograms of 55 consecutive patients (35 men, 20 women; mean age, 58 years ± 12 [standard deviation]) with an Agatston score of at least 400, which is indicative of substantial calcified plaque burden. Exclusion criteria were a history of contrast material reaction and impaired renal function (creatinine higher than 1.5 mg/dL and/or glomerular filtration rate lower than 60 mL/min).

Implication for Patient Care

- An increase in the specificity and PPV of coronary CT angiography with iterative reconstruction techniques could reduce the number of unnecessary follow-up studies performed as a result of false-positive findings at coronary CT angiography in patients with heavily calcified plaques.

Scanning Technique

Calcium scoring and coronary CT angiography were performed with a second-generation dual-source CT scanner (Somatom Definition Flash; Siemens Healthcare). Prior to contrast material–enhanced coronary CT angiography, calcium scoring was performed in all patients by using a prospective electrocardiographically (ECG)-triggered high-pitch spiral acquisition technique (14). Transverse images were reconstructed with a section thickness of 3 mm and 50% overlap. The coronary CT angiography technique was chosen individually for each patient depending on heart rate and/or rhythm and body mass index, with the goal of minimizing radiation exposure. Scan techniques included traditional retrospective ECG gating with default use of ECG-dependent tube current modulation, prospective ECG triggering, and prospective ECG-triggered high-pitch spiral acquisitions. Contrast enhancement was achieved by injecting 60–90 mL of iodinated contrast material (370 mg I/mL iopromide, Ultravist;

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Abbreviations:
ECG = electrocardiography
FBP = filtered back projection
PPV = positive predictive value
ROI = region of interest

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Potential conflicts of interest are listed at the end of this article.

Bayer Healthcare), injected at 6 mL/sec through an 18-gauge intravenous antecubital catheter by using a dual-syringe injector (Stellant D; Medrad). Acquisition parameters were as follows: detector collimation, 2 × 64 × 0.6 mm; gantry rotation time, 280 msec; and tube current–time product, 320 mAs per rotation. The tube potential used was 120 kV in patients with a body mass index of 25 kg/m^2 or greater, 100 kV in patients with a body mass index of less than 25 kg/m^2 but greater than or equal to 20 kg/m^2, and 80 kV in patients with a body mass index of less than 20 kg/m^2. Images were acquired in the craniocaudal direction from above the origin of the coronary arteries to below the dome of the diaphragm. Effective radiation dose was derived by multiplying the dose-length product by a chest-specific conversion coefficient (κ = 0.014 mSv/Gy/cm) (15).

Image Reconstruction

Images were reconstructed from the coronary CT angiography raw data with both FBP and iterative image reconstruction (Iterative Reconstruction in Image Space [IRIS]; Siemens Healthcare) (Fig 1). This iterative reconstruction approach is based on an initial master FBP reconstruction with a very sharp convolution algorithm, or kernel, still containing all frequencies and, therefore, all information of the initial raw data. Subsequent iterative processing loops are applied to the image volume with the goal of reducing image noise while preserving spatial resolution. During each iteration, general image properties (eg, edge information and contrast-to-noise ratio) are analyzed based on a noise model of the system, which is directly derived from the raw data. The Gaussian noise model is applied in a regularization step. Image noise is estimated from image volume data by locally computing the minimum noise variance. The strength of the regularization controls the effect of the edge-preserving low-pass filter in each update of the iteration procedure (5). The result of the regularization step is compared with the initial data to generate an update image, which is added to the previous data set before the next iteration is performed. Therefore, the iterative loops enable noise reduction while preserving edge information and low-contrast structures. Iterative and FBP reconstructions were performed at a section thickness of 0.75 mm and a position increment of 0.4 mm. Corresponding vascular and high-spatial-resolution kernels were applied for FBP (B26f and B46f, respectively) and iterative reconstructions (I26f and I46f, respectively). The B46f and I46f kernels, which are sharp edge-preserving convolution algorithms, were included because of the previously described beneficial effects of these higher-spatial-frequency algorithms on the evaluation of high density structures, such as heavy coronary artery calcifications and stents (16–19).

Image Noise, Attenuation, and Subjective Image Quality

All data sets were transferred to a standalone image processing workstation (Syngo MMWP VE 36A; Siemens). In each data set, one observer (M.R.) measured image noise, which was defined as the standard deviation of the measured attenuation (in Hounsfield units) within circular regions of interest (ROIs) in the ascending aorta, interventricular septum, and left ventricular cavity. The size of the ROIs was adapted to account for anatomic differences of our patients; however, between the different reconstruction approaches, the ROI size was kept constant within each patient. Subjective image quality was independently rated by two radiologists (U.J.S. and T.H., with 10 and 5 years experience in coronary CT angiography, respectively). FBP and iterative reconstructed images were reviewed in random order. Images were rated on a five-point Likert scale according to the severity of image noise, quality of contour delineation, and general image impression (1 = poor, 2 = fair, 3 = moderate, 4 = good, 5 = excellent).

Volumetric Analysis of Coronary Artery Calcifications

One observer (M.R.) used a threshold-based volumetry software tool (Volume Analysis, version VE31A; Siemens) to determine the volumes of fragmented and diffuse (20) coronary artery calcifications within FBP and iterative reconstruction data sets. Calcifications were semiautomatically segmented by defining ROIs around calcifications, which were then automatically propagated to the neighboring sections and manually corrected, if necessary. Voxels within these ROIs with attenuation values in the range of contrast material were automatically excluded from the segmentation, with the goal of only including calcium. To achieve this, we measured the maximum contrast attenuation within the ascending aorta and added 20% to this measurement to define the minimum attenuation level of voxels to be included in the volumetric analysis. This level was kept constant between the different reconstruction techniques in individual patients.

Coronary CT Angiography versus Coronary Catheterization

All data sets and reconstructions were jointly evaluated by two radiologists (U.J.S., T.H.) for the presence of stenotic (>50%) coronary artery disease using the American Heart Association 15-segment model (21). Readers were blinded to the reconstruction technique. For lesion detection, readers were provided with a combination of the vascular and high-spatial-resolution algorithm reconstruction series based on FBP (B26f plus B46f) and iterative (I26f plus I46f) reconstruction. FBP and iterative reconstruction image series were presented in random order at least 3 weeks apart in the same patient to minimize reader recall. The readers were permitted to adjust window and level settings individually for each study. Cardiac catheterization served as the reference standard for stenosis detection and was performed with the conventional Judkins technique on the same day as the coronary CT angiography. At least two views of the right coronary artery and four views of the left coronary artery were interpreted for greater than 50% stenosis by two cardiologists (T.X.O. and P.L.Z., both with more than 15 years experience) in consensus by using the same 15-segment American Heart Association model.

Table 1

Patient Demographics and Scan Parameters

Parameter	Datum
Age (y)	58.2 ± 12.0
Male-to-female ratio	35:20
Height (cm)	170.4 ± 10.3
Weight (kg)	92.2 ± 20.7
Body mass index (kg/m^2)	31.6 ± 5.8
Heart rate (beats per minute)*	63.1 ± 8.0 (53–72)
Agatston score*	710 ± 289 (466–2934)
No. of patients at each tube potential	
80 kVp	1
100 kVp	10
120 kVp	44
Tube current–time product (mAs)	331.4 ± 22.9
CT dose index volume (mGy)	35.0 ± 21.2
Dose-length product (mGy · cm)	609.1 ± 394.3
Scan length (cm)	12.9 ± 1.8
Effective dose (mSv)	
Retrospective ECG gated (n = 35)	10.5 ± 4.2
Prospective ECG triggered (n = 11)	6.6 ± 3.1
High pitch spiral (n = 9)	2.3 ± 1.4

Note.—Unless otherwise specified, data are means ± standard deviations.

* Data in parentheses are the range.

Figure 1

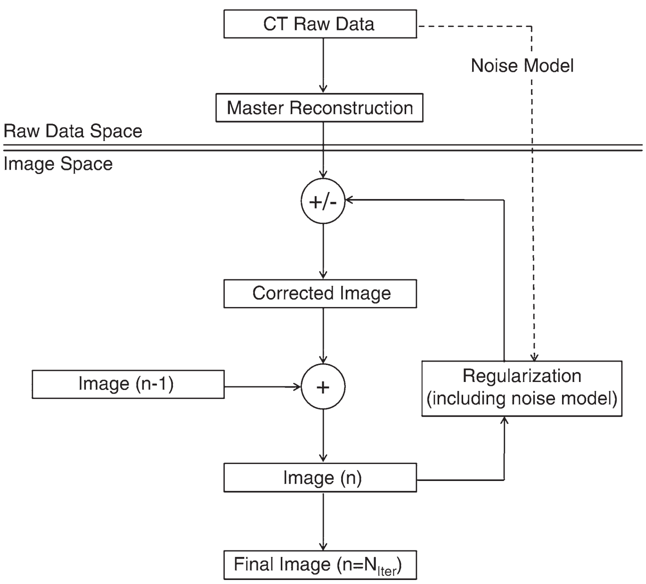


Figure 1: Schematic of the iterative reconstruction process (Iterative Reconstruction in Image Space [IRIS]; Siemens Healthcare). A single FBP image reconstruction initially takes place in the raw data domain to generate a master reconstruction. All further reconstruction steps take place in image space. Further steps include a regularization loop based on prior image information with the goal of suppressing artifacts and reducing image noise. − = subtraction of detected image noise, + = modeling of image noise and validation of corrections, n = image no. within iterative loop, n-1 = image of prior iterative loop, N_{Iter} = no. of iterations.

Statistical Analysis

Statistical analyses were performed by using dedicated statistical software (SPSS 12.0; SPSS, Chicago, Ill). The Shapiro-Wilk W test was used to identify normally distributed data. Significance was investigated with χ^2 statistics for categorical variables. Continuous variables are presented as means ± standard deviations and were compared by using one-on-one comparisons with either an independent t test for normally distributed data or a Mann-Whitney U test for nonnormally distributed data. Ordinal variables (ie, image quality) are presented as medians with interquartile ranges and were compared by using the Kruskal-Wallis analysis of variance. P values less than .05 were considered to indicate a significant difference. Interobserver agreement for subjective image quality was quantified by using κ statistics. The diagnostic accuracy (ie, accuracy, sensitivity, specificity, negative predictive value, and positive predictive value [PPV]) of each reconstruction technique for detection of large (>50%) stenoses was calculated with cardiac catheterization as the reference standard. Differences in diagnostic accuracy between the two reconstruction techniques were compared by creating matched sample tables and by using a modified McNemar test to calculate P values.

Results

All 55 coronary CT angiograms were successfully completed and considered to be of diagnostic image quality. Patient demographics and coronary CT angiogram characteristics are provided in Table 1. The average body mass index in our patient cohort was 31.6 kg/m^2, indicative of a high prevalence of obesity, and the average Agatston calcium score was 710, reflecting advanced atherosclerosis.

Image Noise, Attenuation, and Subjective Image Quality

In both image reconstructions using the vascular I26f and B26f as well as the high spatial resolution B46f and I46f convolution algorithms, mean image

Table 2

Mean Image Noise and Attenuation for the Four Different Reconstructions

	Vascular Algorithm			High-Spatial-Resolution Algorithm		
Anatomic Region	FBP with B26f Kernel	Iterative Reconstruction with I26f Kernel	*P* Value	FBP with B46f Kernel	Iterative Reconstruction with I46f Kernel	*P* Value
Mean Image Noise						
Ascending aorta	33.4 ± 11.7	24.9 ± 10.8	.013	48.3 ± 15.2	35.9 ± 10.0	.025
Interventricular septum	30.5 ± 13.7	22.9 ± 12.5	.023	52.8 ± 16.6	38.0 ± 13.1	.011
Left ventricular cavity	38.6 ± 16.9	31.9 ± 16.3	.035	64.1 ± 28.2	47.8 ± 21.3	.017
Mean Attenuation (HU)						
Ascending aorta	427.0 ± 131.8	430.7 ± 131.0	.085	431.7 ± 174.5	435.2 ± 176.9	.087
Interventricular septum	124.2 ± 42.2	119.1 ± 30.5	.069	128.7 ± 28.4	126.8 ± 35.2	.088
Left ventricular cavity	367.9 ± 133.0	372.1 ± 125.3	.075	373.1 ± 198.8	384.4 ± 216.4	.073

Note.—Unless otherwise specified, data are means ± standard deviations.

noise measured significantly lower using iterative reconstruction than FBP in all ROIs, while there was no significant difference in mean attenuation within the same anatomic regions (Table 2) (Fig 2).

Image quality of coronary CT angiograms reconstructed with iterative reconstruction was rated significantly higher than that of those reconstructed with FBP by both observers. With both iterative reconstructions (I26f and I46f kernels), the median image quality score was 5; whereas with both FBP reconstructions (B26f and B46f kernels), the median image quality score was 4. Pairwise Wilcoxon rank sum tests showed statistically higher ratings for iterative reconstruction than for FBP (I26f vs B26f, $P = .042$; I46f vs B46f, $P = .031$). Interobserver agreement was excellent for iterative and FBP reconstructions (I26f, $\kappa = 0.89$; I46f, $\kappa = 0.92$; B26f, $\kappa = 0.84$; B46f, $\kappa = 0.88$).

Volumetric Analysis of Coronary Artery Calcifications

A total of 142 circumscribed coronary artery calcifications were volumetrically analyzed among all four reconstructions. Coronary artery calcifications showed significantly lower volumes on iterative reconstruction images compared with FBP images (I26f vs B26f: 46.2 mm^3 ± 68.8 vs 56.3 mm^3 ± 72.5, $P = .026$; I46f vs B46f: 44.3 mm^3 ± 64.7 vs 54.5 mm^3 ± 69.5, $P = .019$) (Fig 3).

Figure 2

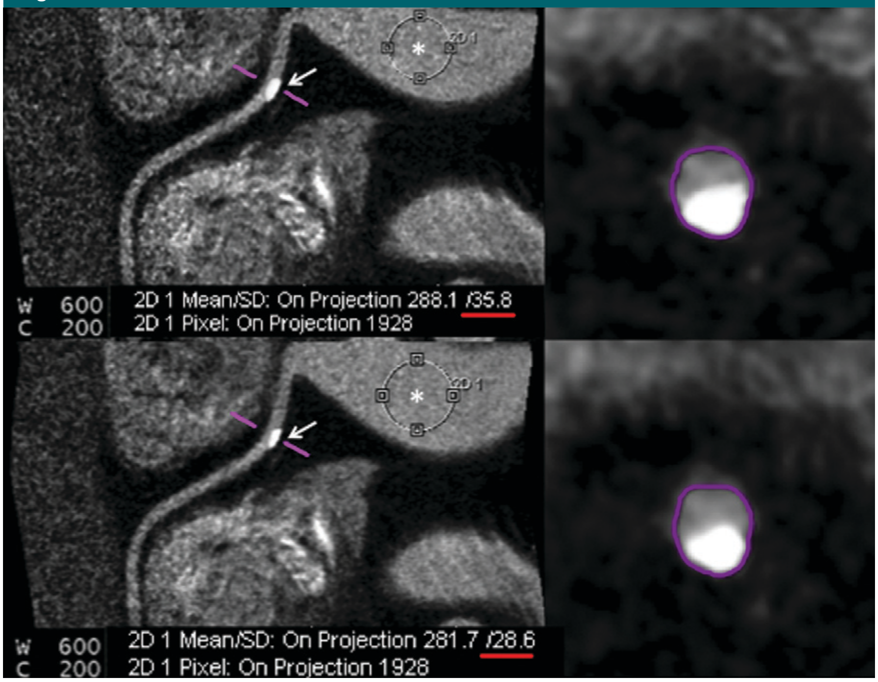


Figure 2: Contrast-enhanced retrospectively ECG-gated coronary CT angiographic images in a 63-year-old man (body mass index, 35.2 kg/m^2) referred for coronary catheterization because of chest pain on exertion. Left: Right coronary artery as curved multiplanar reformation along vessel centerline (purple). Right: Transverse sections through vessel (purple), orthogonal to centerline. Top: FBP reconstruction shows image noise in a circular aortic root ROI of 35.8 HU (red). Bottom: iterative reconstruction shows image noise in a circular aortic root ROI of 28.6 HU (red). Suppression of blooming artifacts in iterative reconstructions improves vessel lumen delineation adjacent to the calcified lesion (arrows) and facilitates estimation of the true degree of luminal narrowing.

Coronary CT Angiography versus Coronary Catheterization

A total of 825 coronary artery segments were analyzed with cardiac catheterization as well as with coronary CT angiography. Cardiac catheterization showed stenoses larger than 50% in 31 (56%) patients, with a total of 104 lesions. Six patients had one-vessel disease, 18 patients had two-vessel disease, and seven patients had three-vessel disease. By using iterative reconstruction instead of FBP, there was a significant improvement in overall accuracy, specificity, and PPV on a per-segment level and in specificity and PPV on a per-patient level for the detection of significant stenosis with coronary CT angiography (Table 3). In 33 of 825 segments and three of 55 patients, iterative reconstruction enabled reclassification from false-positive to true-negative results (Figs 4, 5). In one patient, an isolated short but important stenosis in the distal posterior descending artery was missed in both iterative reconstruction and FBP series.

Figure 3

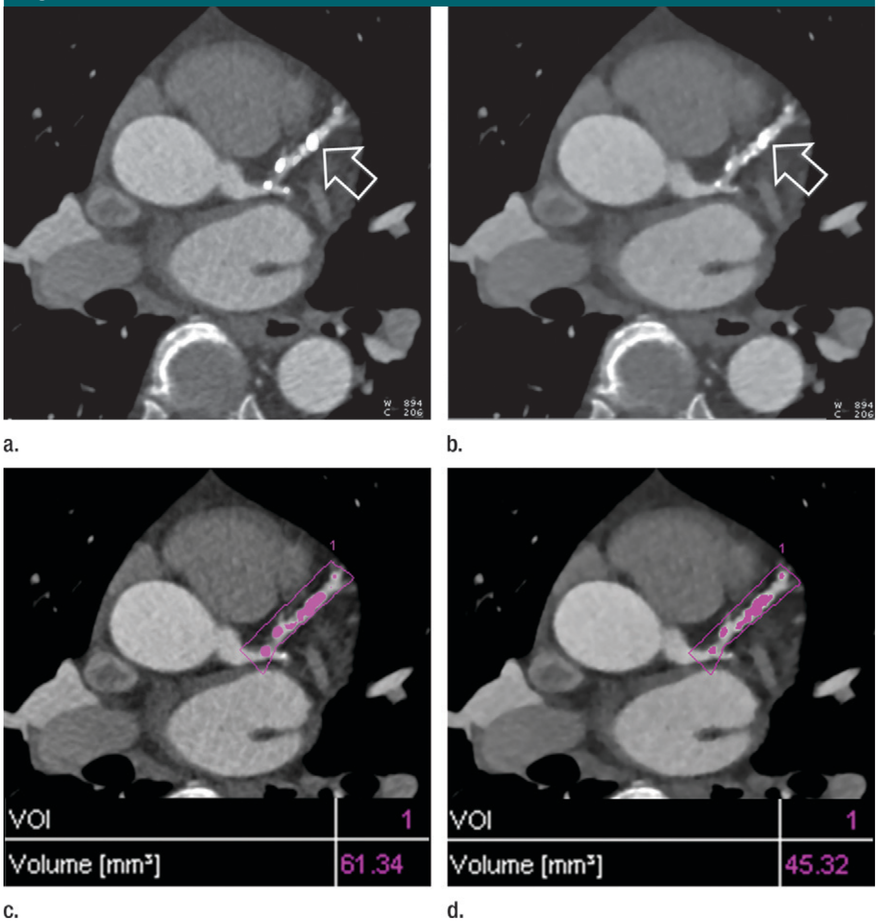


Figure 3: Contrast-enhanced prospectively ECG-triggered coronary CT angiographic images in a 76-year-old woman with chest pain and abnormal nuclear myocardial perfusion scan. Transverse **(a)** FBP and **(b)** iterative reconstruction images at the level of the aortic root show extensive calcified plaque burden (arrows) in the proximal left anterior descending coronary artery. Threshold-dependent volumetry of calcifications (purple) resulted in a measured volume of 61.34 mm^3 on **(c)** FBP reconstructions and of 45.32 mm^3 on **(d)** iterative reconstructions.

Discussion

Our findings show that the use of iterative reconstruction instead of traditional FBP significantly improves the specificity, PPV, and overall accuracy of coronary CT angiography for stenosis detection in patients with heavily calcified coronary arteries. These improvements are likely related to decreases in image noise, improved diagnostic image quality, and reduced blooming artifacts.

Advances in CT technology, with improvements in temporal and spatial resolution, have continuously increased the robustness and accuracy of coronary CT angiography for the noninvasive assessment of coronary artery disease (22,23). A multitude of studies have demonstrated the ability of this test to be used to reliably exclude coronary artery stenosis as compared with coronary catheterization (23–28) or as assessed through patient outcome (29–31). However, these studies have also identified several persistent limitations that remain considerable detractors from the diagnostic performance of coronary CT angiography. Among these are patient obesity, with associated high image noise, and the presence of heavy coronary artery calcifications (25,26,32). Blooming artifacts exaggerate the size of densely calcified plaques and limit the accurate evaluation of the adjacent coronary artery lumen, typically leading to overestimation of lesion severity. The resulting false-positive findings do not detract from this test's sensitivity; however, they decrease specificity, often leading to unnecessary subsequent layered testing to exclude stenotic coronary artery disease, which incurs additional cost, patient radiation exposure, and potential complications from coronary catheterization, thus limiting the clinical usefulness of coronary CT angiography (3,33).

Blooming artifacts from calcified plaques are partially attributed to the limited spatial and point-spread resolution of CT image reconstruction algorithms, which create a spillover effect from high-attenuation structures into adjacent lower-attenuation voxels, obscuring the coronary artery lumen (33–35). Blooming artifacts can be reduced by increasing spatial resolution through thinner collimated section widths and reconstruction thickness, as well as use of higher-resolution sharper reconstruction algorithms. However, these approaches come at the expense of higher image noise or higher radiation dose requirements for suppressing image noise when traditional FBP is used. Iterative reconstruction techniques, to a certain extent, allow decoupling of spatial resolution and image noise and offer the potential to selectively improve high-contrast resolution without affecting image noise in low-contrast areas (5,36).

Table 3

Diagnostic Accuracy of FBP and Iterative Reconstruction for the Detection of Coronary Artery Stenoses Larger than 50% versus Reference Standard Cardiac Catheterization

	Per Segment			Per Patient		
Parameter	FBP	Iterative Reconstruction	*P* Value	FBP	Iterative Reconstruction	*P* Value
Accuracy (%)*	91.8 (71.7, 91.1)	95.9 (78.2, 94.9)	.0001	83.6 (89.7, 93.5)	89.1 (94.3, 97.0)	NS
Sensitivity (%)*	95.2 (83.8, 99.4)	96.2 (83.8, 99.4)	NS	96.7 (89.2, 97.9)	96.7 (90.5, 98.5)	NS
Specificity (%)	91.2 (46.7, 82.0)	95.8 (59.5, 90.8)	.0001	66.7 (89.0, 93.1)	79.2 (94.1, 97.1)	.0189
Negative predictive value (%)*	99.2 (69.2, 99.7)	99.4 (73.1, 99.7)	NS	94.1 (98.1, 99.7)	95.0 (98.4, 99.8)	NS
PPV (%)*	61.1 (62.2, 89.9)	76.9 (69.0, 94.6)	.0001	78.9 (53.1, 68.6)	85.7 (68.6, 83.7)	.0403
No. of true-positive findings	99	100	NS	30	30	NS
No. of false-positive findings	63	30	.0001	8	5	NS
No. of true-negative findings	658	691	.0001	16	19	NS
No. of false-negative findings	5	4	NS	1	1	NS

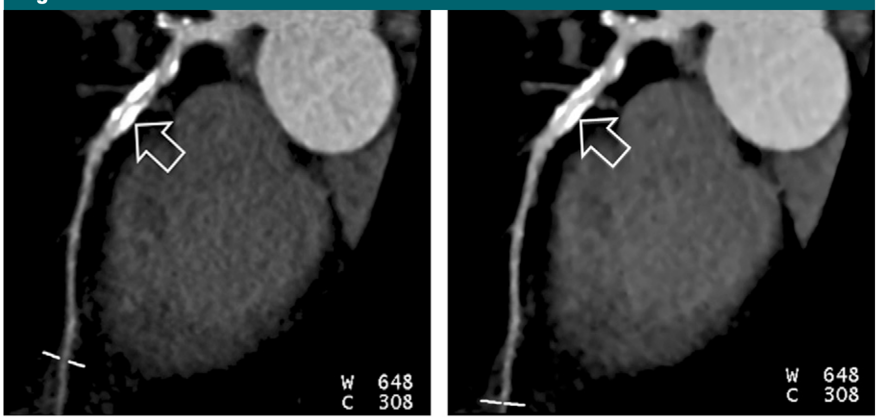
Note.—NS = not significant.

* Data in parentheses are 95% confidence intervals.

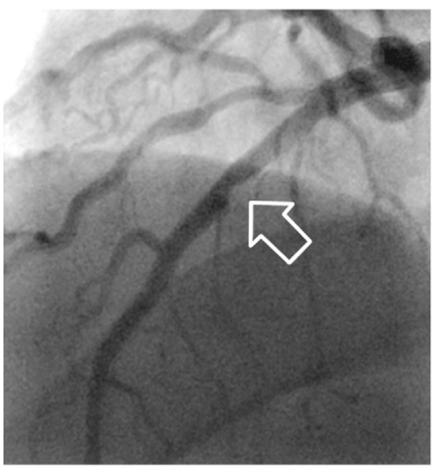
Accordingly, the properties of iterative reconstruction seem better suited than those of traditional FBP to address the requirements of coronary CT angiography, where both high spatial and contrast resolution are of importance for the evaluation of small target vessels containing both high-attenuation (calcifications, stents) and low-attenuation (noncalcified plaque) structures. As a postacquisition image reconstruction approach, the effects of iterative reconstruction should be largely independent of the image acquisition technique (eg, prospective ECG triggering vs retrospective ECG gating), although we did not subanalyze our results for this aspect.

The limitations of coronary CT angiography will not be completely overcome with iterative reconstruction techniques. However, the observed increase in specificity and PPV with use of this technique indicates the potential to reduce the need for unnecessary further testing in patients undergoing coronary CT angiography. We specifically selected for individuals with Agatston scores of at least 400, whereas the 2010 appropriate use criteria for cardiac computed tomography (37) consider the usefulness of coronary CT angiography in this scenario as uncertain. The more widespread implementation of iterative reconstruction techniques may hold potential for widening the scope of patients in whom

Figure 4



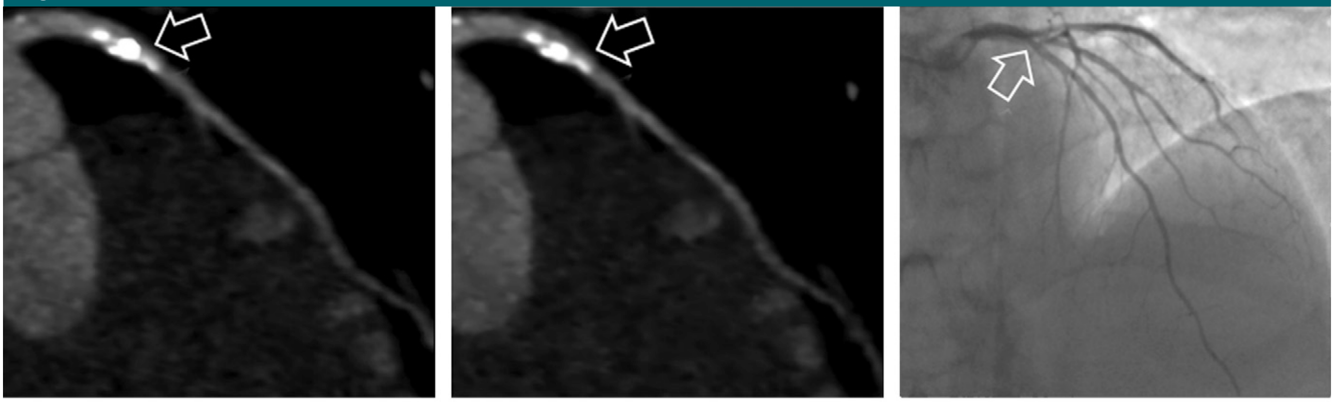
a. b.



c.

Figure 4: Contrast-enhanced prospectively ECG-triggered coronary CT angiographic images in a 55-year-old man with chest pain. Curved multiplanar reformations of the left anterior descending coronary artery show heavy calcifications (arrows) in the midportion of the vessel. Blooming artifacts limit evaluation of adjacent vessel lumen on **(a)** FBP reconstructions but are reduced on **(b)** iterative reconstructions, which enabled correct classification of the lesion as eccentric and only minimally stenotic, as confirmed with **(c)** subsequent coronary catheterization.

Figure 5



a. b. c.

Figure 5: Contrast-enhanced prospectively ECG-triggered coronary CT angiographic images in a 73-year-old man with chest pain. Curved multiplanar reformations of the left anterior descending coronary artery show heavy calcifications (arrows) in the proximal vessel. Blooming artifacts limit evaluation of adjacent vessel lumen on **(a)** FBP reconstructions, mimicking a substantial stenosis, but are reduced on **(b)** iterative reconstructions, which enabled correct classification of the lesion as not significantly stenotic, as confirmed with **(c)** subsequent coronary catheterization.

coronary CT angiography can be effectively and beneficially used.

In this investigation, we focused solely on possible improvements in diagnostic accuracy garnered by the use of iterative reconstruction over FBP in patients in whom heavily calcified coronary arteries pose a diagnostic challenge. Recent reports indicate the potential of radiation dose reduction through decreases in image noise with use of iterative reconstruction techniques (10,11). However, this was not the focus of our current study.

Due to the size of our cohort, only a limited number of patients were correctly reclassified as free of stenosis on the basis of iterative reconstruction, and the improvement in per-patient accuracy did not reach significance. However, the significant increases in specificity and PPV both on a per-segment and per-patient level hold promise to improve the relatively low performance (38) of this test for the evaluation of heavily calcified coronary arteries. In particular, when extrapolated to the overall number of patients undergoing coronary CT angiography, the benefits of reduced follow-up testing could be notable. A general inherent limitation of all studies that compare iterative reconstruction with traditional FBP is the fact that observers cannot be effectively blinded to the reconstruction technique because of the distinct differences in image characteristics between the two approaches. Moreover, in our study, all images were derived from the same raw data for each patient, leaving the possibility of some biases and inflated statistical significance owing to multireader effects that were not accounted for. The effect of interreader variation, which may have influenced the results on image quality, is likely small since the overall agreement between readers was excellent (>0.6), and the variance of κ statistics was lower than 10%. Based on the design of this study, intrareader variation was closely related to the choice of different kernels used and could be interpreted as a systematic influence across both reconstruction techniques. Another limitation is the absence of an outside reference standard, such as intravascular ultrasonography, to validate our volumetric measurements of coronary artery calcifications. Since we selected for patients with advanced atherosclerosis whose symptoms had indicated the need for coronary catheterization, the disease prevalence was high, exceeding 50%. Thus, the extrapolation of the general performance parameters of coronary CT angiography observed in our study to a population with a lower pretest likelihood of disease is limited by the well-known effects of disease prevalence on the predictive value of a test. However, this does not detract from the observation that a long-standing limitation of coronary CT angiography (ie, heavy calcifications) might be ameliorated by abandoning traditional FBP as the standard method for image reconstruction.

In summary, the results of our study suggest that accuracy, specificity, and PPV of stenosis detection with coronary CT angiography in heavily calcified vessels can be incrementally improved with use of iterative reconstruction instead of FBP. Accordingly, iterative reconstruction should be preferentially used in patients with advanced atherosclerosis to reduce the number of unnecessary follow-up studies.

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