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Impact of iterative reconstruction vs. filtered back projection on image quality in 320-slice CT coronary angiography

Insights from the CORE320 multicenter study

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Abstract

Iterative reconstruction has been shown to reduce image noise compared with traditional filtered back projection with quantum denoising software (FBP/QDS+) in CT imaging but few comparisons have been made in the same patients without the influence of interindividual factors. The objective of this study was to investigate the impact of adaptive iterative dose reduction in 3-dimensional (AIDR 3D) and FBP/QDS+-based image reconstruction on image quality in the same patients.

We randomly selected 100 patients enrolled in the coronary evaluation using 320-slice CT study who underwent CT coronary angiography using prospectively electrocardiogram triggered image acquisition with a 320-detector scanner. Both FBP/QDS+ and AIDR 3D reconstructions were performed using original data. Studies were blindly analyzed for image quality by measuring the signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR). Image quality was assessed qualitatively using a 4-point scale.

Median age was 63 years (interquartile range [IQR]: 56–71) and 72% were men, median body mass index 27 (IQR: 24–30) and median calcium score 222 (IQR: 11–644). For all regions of interest, mean image noise was lower for AIDR 3D vs. FBP/QDS+ (31.69 vs. 34.37, $P \leq .001$). SNR and CNR were significantly higher for AIDR 3D vs. FBP/QDS+ (16.28 vs. 14.64, $P < .001$ and 19.21 vs. 17.06, $P < .001$, respectively). Subjective (qualitative) image quality scores were better using AIDR 3D vs. FBP/QDS+ with means of 1.6 and 1.74, respectively ($P \leq .001$).

Assessed in the same individuals, iterative reconstruction decreased image noise and raised SNR/CNR as well as subjective image quality scores compared with traditional FBP/QDS+ in 320-slice CT coronary angiography at standard radiation doses.

Abbreviations: 3D = 3-dimensional, AIDR = adaptive iterative dose reduction, BMI = body mass index, CNR = contrast-to-noise ratio, CORE320 = coronary evaluation using 320-slice CT, CT = computed tomography, CTA = computed tomography angiography, FBP = filtered back projection, HU = Hounsfield unit, LAD = left anterior descending artery, LCX = left circumflex coronary artery, LM = left main coronary artery, QDS = quantum denoising software, RCA = right coronary artery, ROI = region of interest, SD = standard deviation, SNR = signal-to-noise ratio.

Keywords: adaptive iterative dose reduction, CT coronary angiography, image quality

1. Introduction

Computed tomography angiography (CTA) is being increasingly used for the evaluation of coronary artery disease in selected patients.[1] CT image reconstruction has traditionally relied on filtered back projection (FBP). However, with decreasing slice thickness the image noise increases which is compensated by higher X-ray tube settings and thus higher radiation doses.[2] For coronary artery imaging, wide volume cardiac CT scanning (e.g., 256 or 320 slices) has enabled whole heart imaging in a single

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cardiac cycle, which reduces the duration of image acquisition and the presence of stair-step artifacts.[3,4] On the other hand, wide volume cardiac CT imaging has provided additional challenges to image reconstruction due to increased X-ray scatter and spatial nonuniformity.[5]

In recent years, a number of iterative reconstruction algorithms have been developed that work in both the raw data and image data domains. Adaptive iterative dose reduction in 3-dimensional (AIDR 3D) (Toshiba Medical Systems, Otawara, Japan) is one of these algorithms.[6] The algorithm uses selected scanner-specific models to reduce the noise caused by photon starvation in the raw data domain. Following this an iterative process using anatomical-based information is performed in the image data domain to suppress noise and maintain edge detail. Blending is applied and the final image is created.[6]

Several reports suggest improved image quality with iterative reconstruction through reduced image noise.[7–11] However, data on the impact of AIDR 3D versus FBP for cardiac CT imaging are limited by small sample sizes and selected populations.[12] Importantly, most studies have compared both reconstruction methods retrospectively in patients who underwent imaging with either method but not both methods in the same patients.

To remove the influence of interindividual factors, we aimed to evaluate the effect of AIDR 3D on CTA image quality in comparison to FBP with quantum denoising software (QDS+) (Toshiba Medical Systems) in the same patients.

2. Materials and methods

2.1. Patient population

We studied 100 patients who were randomly selected from the CORE320 study population, a prospective, multicenter, international study designed to evaluate the diagnostic accuracy of 320-row detector CT for detecting obstructive coronary artery disease with associated myocardial perfusion defects.[13] The patient population of the coronary evaluation using 320-slice CT (CORE320) study has been previously described.[13] Briefly, patients with suspected coronary artery disease who were referred for invasive coronary angiography were included. Exclusion criteria were contraindications to iodinated contrast material, renal insufficiency (serum creatinine >1.5 mg/dL or calculated creatinine clearance of <60 mL/min), atrial fibrillation, tachyarrhythmia, advanced atrioventricular block, symptomatic heart failure, previous coronary artery bypass or cardiac surgery, coronary intervention within the last 6 months, intolerance of beta blockers, and severe pulmonary disease.[13] The study was approved by local and central (Johns Hopkins University) institutional review boards.

2.2. CT acquisition protocol and patient preparation

Patients fasted for at least 4 h and abstained from caffeine intake at least 12 h before the scan. Large bore (18–20 gauge) intravenous (i.v.) lines were inserted in the right and left antecubital veins for contrast and adenosine administration, respectively. Patients with systolic blood pressure ≥110 mm Hg received sublingual fast-acting nitrates.[14] If a patient's heart rate was >60 beats/min, then oral or i.v. metoprolol was given according to a published protocol.[14] All studies were performed using a 320-detector row CT scanner (Aquilion ONE, Toshiba Medical Systems). CTA was performed using prospective electrocardiogram triggering, 0.5-mm detector width, peak tube voltage of 120 kV, and gantry rotation time of 0.350 to 0.375 s. Tube current was adjusted according to patient body mass index (BMI), heart rate, and gender as previously described.[17] Iopamidol (Isovue 370, Bracco Diagnostics, Milan, Italy) was injected using a triphasic contrast injection protocol: 100% contrast, followed by 30% contrast and 70% saline mix, followed by 100% saline chaser. According to patient weight, contrast volume ranged from 50 to 70 mL. Bolus tracking in the descending aorta was used to initiate the scan.[14]

Coronary artery segmentation was based on the segmentation model developed in the CORE-64 study which included arterial segments of at least 1.0 mm in diameter and segmented according to a modified 29-segment American College of Cardiology and American Heart Association model nomenclature condensed to 19 segments.[15,16]

2.3. CT image reconstruction

Reconstructions were performed using the PhaseXact software (Toshiba Medical Systems), which automatically determined the cardiac phase with least cardiac motion for CTA image reconstruction. For this investigation, we used the same convolution filter (FC43) and reconstruction parameters (0.5-mm slice thickness with a 0.25 mm overlap and a field of view of 220 mm to include only the heart).

Images were reconstructed for each patient using 2 separate reconstruction algorithms:

Filtered back projection (FBP/QDS+) reconstruction: using QDS+ "a denoising software that may improve image quality."[17]

Iterative reconstruction: using AIDR 3D at the standard level.

2.4. Image quality analysis

The reconstructed CTA images were transferred to workstations with a commercial cardiac CT software package for image assessment (Vitrea FX version 3.0, Vital Images, Minnetonka, MN).

2.5. Objective analysis

Image signal, image noise, signal-to-noise ratio (SNR), and contrast-to-noise ratio (CNR) were recorded for all studied patients. These parameters were measured by manually placing regions of interest (ROIs) in the ascending aorta, the proximal left main (LM), left anterior descending (LAD), left circumflex (LCX), and right coronary arteries (RCA). For all measurements, the ROI sizes were kept constant: 100 mm^2 in the ascending aorta, 5 mm^2 in LM, and 3 mm^2 in LAD, LCX, and RCA without including parts of the coronary vessel wall. Similarly, we used consistent locations for all measurements: The ascending aortic root was examined at the level of the origin of the LM coronary artery on axial images while carefully avoiding inclusion of the aortic wall. For the LM, LAD, LCX, and RCA, only the proximal segments were used for placing ROIs with avoidance of vessel walls and calcified lesions or stents. All measurements were performed in an identical manner for both reconstruction protocols.

For calculating the mean CT value of perivascular fat (for determining CNR), ROIs were placed outside the vessel lumen just adjacent to the ROIs within the vessel lumen. Hounsfield units (HUs) were recorded from the ROIs including mean value (signal) and standard deviation (SD) (noise). The mean value for the aorta and 4 coronary arteries were used to define the study signal, noise, and SNR for all patients. Image signal was defined as the mean within the ROI (HU). Image noise was defined as the SD within the ROI. SNR was calculated as mean lumen HU/mean SD lumen HU. CNR was calculated using the formula: (mean lumen HU − mean fat HU)/SD fat HU.

2.6. Subjective analysis

Coronary segments of the 3 major coronary arteries and their major side branches were defined according to a previously described 19-segment model.[15] Using axial datasets, standard and curved multiplanar reformations and maximum intensity projections were employed to evaluate all relevant segments for both the FBP/QDS+ and iterative reconstructions. After reviewing all data, the image quality of coronary segments was scored using a 4-point scale: (1) Good—no artifacts, (2) Adequate—minor artifacts present, (3) Poor—moderate artifacts, limiting adequate interpretation, and (4) Noninterpretable—severe artifacts precluding interpretation. All stented segments were excluded from evaluation.

2.7. Statistical analyses

Statistical analyses were performed using IBM SPSS 20.0 (SPSS Inc., Chicago, IL) and SAS 9.4 (SAS Institute, Cary, NC). All variables are expressed as mean value ± SD. Differences in image quality parameters (qualitative image quality, image noise, SNR, and CNR) between the 2 scanning protocol groups were compared using a paired, 2-tailed t test. $P < .05$ was considered statistically significant for all data analyses. Interobserver agreements for subjective image quality were evaluated by Kappa statistics, and for the objective assessment; intraobserver correlation coefficient was used.

3. Results

3.1. Patient characteristics

Patients' demographics are provided in Table 1.

Table 1

Patient characteristics.

Characteristics	Variable as total number (%) or median [IQR]
Age	63 [56;71]
Male gender	72 (72%)
Race, n (%)	
Caucasian	45 (45%)
African American	13 (13%)
Asian	42 (42%)
Hypertension	84 (84)
Diabetes	43 (43)
Dyslipidemia	63 (66)
Previous MI	33 (36)
Family history of CAD	37 (40)
Prior PCI	34 (37)
Body mass index	27 [24;30]
Heart rate (during scan)	53 [48;58]
Calcium score	222 [11;644]
Contrast volume	60 [50;70]
CTA radiation dose, mSv	3.17 [2.82;3.65]

CAD = coronary artery disease, CTA = computed tomography angiography, IQR = interquartile range, MI = myocardial infarction, mSv = millisieverts, PCI = percutaneous coronary intervention.

Table 2

Subjective image quality assessment.

	FBP/QDS+	AIDR 3D	P
Mean image score	1.74 ± 0.6	1.60 ± 0.5	<.0001
LM	1.37 ± 0.6	1.26 ± 0.5	.004
LAD	1.79 ± 0.6	1.67 ± 0.6	<.0001
LCX	1.92 ± 0.7	1.77 ± 0.7	<.0001
RCA	1.65 ± 0.8	1.52 ± 0.8	<.0001

AIDR 3D = iterative image reconstruction, FBP/QDS+ = filtered back projection, LAD = left anterior descending coronary artery, LCX = left circumflex coronary artery, LM = left main coronary artery, RCA = right coronary artery.

3.2. Image quality assessment

3.2.1. Subjective image quality. Of a total of 1514 coronary segments examined, 92 stented segments were excluded from analysis leaving 1422 coronary segments for the subjective image quality assessment. The average image quality score per patient was greater for AIDR 3D than FBP/QDS+ (1.60 vs. 1.74, $P < .0001$). Similarly, the mean vessel score was better for AIDR 3D (Table 2). A representative example for the differences in image quality among the 2 reconstruction techniques is shown in Fig. 1.

Interobserver agreement was good for the subjective image quality assessment by Kappa statistics (0.795 for AIDR 3D vs. 0.757 for FBP/QDS+).

3.2.2. Objective image quality. Mean image noise per patient was significantly ($P < .001$) lower using AIDR 3D versus FBP/QDS+ in all ROIs; however, a significant difference was not found in the variability of noise between AIDR 3D versus FBP/QDS+ ($P = .26$) (Table 3). There were no significant differences for mean image signal (HU) within the same anatomical regions among the 2 reconstruction algorithms. Accordingly, SNR and CNR were greater using AIDR 3D versus FBP/QDS+ image reconstruction (Tables 3 and 4). Interobserver agreement was excellent for assessing image signal using AIDR 3D ($r = 0.902$) and good by using FBP/QDS+ ($r = 0.762$).

4. Discussion

In agreement with prior studies, our results revealed lower image noise levels and associated improved SNR and CNR with the use of iterative reconstruction compared with FBP/QDS+. Subjective assessment also yielded higher image quality scores for AIDR 3D versus FBP/QDS+, suggesting noise reductions with AIDR 3D result in meaningful improvement of image quality.

Three studies used both reconstruction algorithms in the same patients[6,12,18] albeit with smaller sample sizes compared with our study. Tatsugami et al[12] compared AIDR 3D and FBP/QDS + for 50 patients and found significant improvements in the quantitative image quality parameters, but their patient population had a mean BMI of only 23.9. Our study had a larger sample size and included patients with more overweight and obese patients. Feger et al found, in 30 patients, significant noise reduction and improved SNR and CNR using iterative reconstruction compared with FBP/QDS+ with no loss of contour sharpness. The mean BMI of their study population was $28.8 \pm 4.0\,kg/m^2$.[6] These findings are confirmed in our study, which has a larger, global sample compared with their study.

Another study compared image quality of 70 obese patients (mean BMI $33\,kg/m^2$) using iterative reconstruction versus FBP

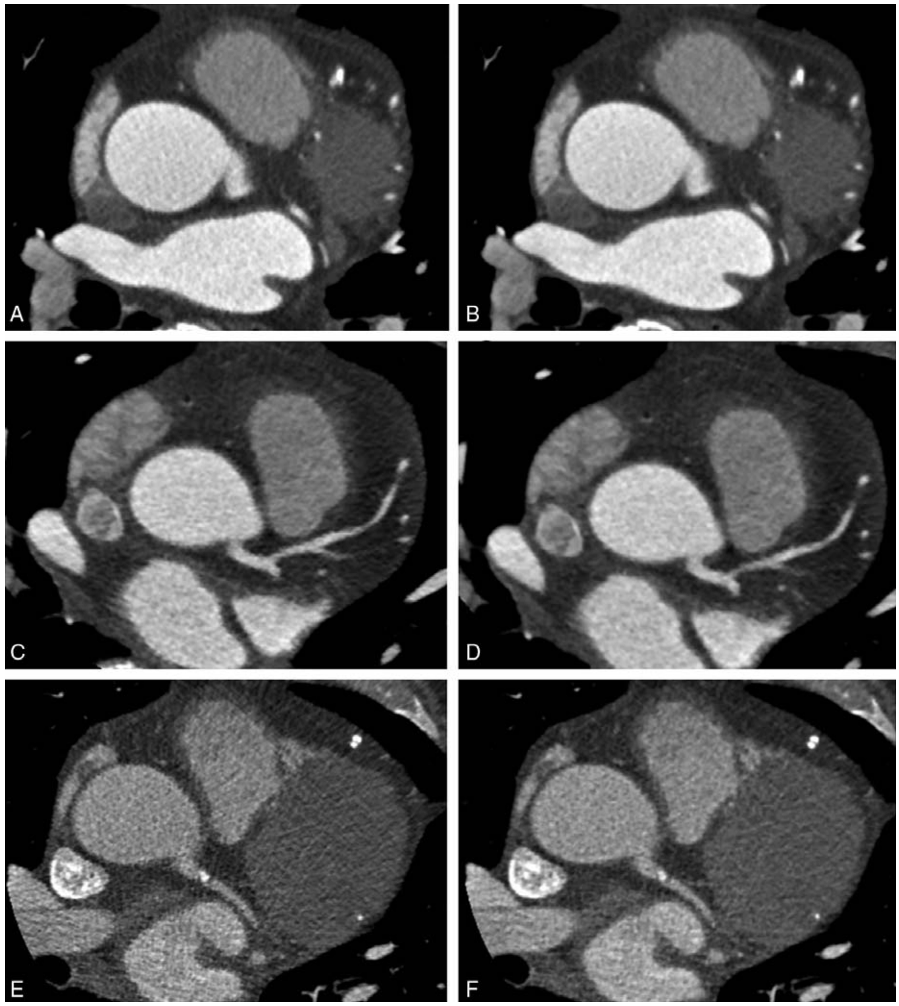

Figure 1. Comparison of image quality. Representative computed tomography angiographic images are shown directly comparing image quality between the 2 reconstruction methods. Panels A and B show images derived from a 56-year-old man with a BMI 23. Panel A shows an example of image reconstruction by FBP/QDS+ and panel B represents AIDR 3D image reconstruction. Panels C and D reveal images obtained in a 57-year-old man with a BMI 28. Panel C represents FBP/QDS+ reconstruction and panel D reflects AIDR 3D reconstruction. Panels E and F show images obtained in a 58-year-old woman with a BMI 31. Panel E shows the images using FBP/QDS+ reconstruction and panel F is derived using AIDR 3D reconstruction. AIDR 3D = adaptive iterative dose reduction in 3D, BMI = body mass index, FBP/QDS+ = filtered back projection/quantum denoising software plus.

on 64-slice CTA but their assessment occurred in different patients (35 patients in each group).[19] They found significantly improved image quality and visualization of distal coronary artery segments in overweight and obese individuals, without increasing image noise and radiation dose.[19]

The improvement of SNR and CNR values with AIDR 3D is the result of noise reduction without significant changes in signal values during reconstruction. At the same time, our study shows that noise reduction does not affect the spatial resolution. This point is critical because other techniques that lower noise levels cause either degradation in spatial resolution (e.g., increasing slice thickness) or require higher X-ray doses (increase of kVp or mAs).[20] Thus, we could not substantiate concerns from some studies that have suggested that a small reduction in spatial resolution may occur with the use of iterative reconstruction.[21]

The reduction in image noise and improved SNR and CNR with unchanged CT attenuation allow image acquisition at lower radiation doses when AIDR 3D is planned as opposed to FBP/QDS+.[22] Iterative reconstruction may be used for noise reduction to improve the image quality while maintaining the same radiation dose as FBP/QDS+, or reducing the delivered dose while maintaining an equivalent image quality.[23–27]

Table 3

Objective image quality assessment per patients.

	FBP/QDS+	AIDR 3D	*P*
Average total signal, HU	439.75 ± 62.6	437.76 ± 62.4	>.05
Average noise, HU	34.37 ± 7.2	31.69 ± 6.5	<.001
SNR	14.64 ± 3.5	16.28 ± 5.3	.001
CNR	17.06 ± 4.0	19.21 ± 6.0	<.001

AIDR 3D = adaptive iterative dose reduction in 3D, CNR = contrast-to-noise ratio, FBP/QDS+ = filtered back projection/quantum denoising software plus, HU = Hounsfield units, SNR = signal-to-noise ratio.

4.1. Study limitations

Iterative reconstruction reduces image noise but other sources of artifact, such as motion, are not affected. While we specifically and prospectively performed AIDR 3D for this investigation, image acquisition in CORE320 did not occur with the option of

Table 4

Objective image quality assessment per vessels.

	FBP/QDS+	AIDR 3D	P
Aorta signal, HU	446.31±59.6	446.49±59.4	>.05
Aorta noise, HU	31.38±8.4	28.62±6.6	<.001
Aorta SNR	15.08±4.0	17.50±15.3	>.05
Aorta CNR	17.81±4.7	20.73±17.4	>.05
LM signal, HU	447.16±85.8	447.62±80.8	>.05
LM noise, HU	34.09±11.5	30.20±10.9	.002
LM SNR	14.60±5.5	17.26±9.3	.005
LM CNR	16.97±6.2	20.32±10.3	.002
LAD signal, HU	439.80±78.1	436.45±75.4	>.05
LAD noise, HU	35.05±12.4	31.98±12.2	.036
LAD SNR	14.41±6.3	15.63±6.4	>.05
LAD CNR	16.75±7.2	18.51±7.6	.034
LCX signal, HU	429.62±81.5	424.79±72.8	>.05
LCX noise, HU	39.46±15.9	37.43±16.0	>.05
LCX SNR	12.92±6.8	13.82±7.1	>.05
LCX CNR	14.83±7.7	16.23±8.2	>.05
RCA signal, HU	433.79±84.6	430.27±81.9	>.05
RCA noise, HU	31.85±13.2	30.47±12.7	>.05
RCA SNR	16.17±7.7	17.06±8.3	>.05
RCA CNR	18.94±9.1	20.14±9.8	>.05

AIDR 3D = adaptive iterative dose reduction in 3D, CNR = contrast-to-noise ratio, FBP/QDS+ = filtered back projection/quantum denoising software plus, HU = Hounsfield units, LAD = left anterior descending coronary artery, LCX = left circumflex coronary artery, LM = left main coronary artery, RCA = right coronary artery, SNR = signal-to-noise ratio.

using AIDR 3D. Accordingly, scans were acquired with higher X-ray tube settings anticipating FBP/QDS+ for image reconstruction. As such, the magnitude of noise reduction with AIDR 3D compared with FBP/QDS+ was lower than with image acquisition in anticipation of AIDR 3D. In addition, we used the QDS+ when reconstructing the FBP image series. QDS+ is a denoising software, which may improve the image quality in the FBP arm.[17]

5. Conclusions

Assessed in the same individuals among a diverse population, we found iterative reconstruction to improve image quality by qualitative and quantitative evaluation at standard radiation doses.

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References

[1] Miller JM, Rochitte CE, Dewey M, et al. Diagnostic performance of coronary angiography by 64-row CT. N Eng J Med 2008;359:2324–36.

[2] Brooks RA, Di Chiro G. Theory of image reconstruction in computed tomography. Radiology 1975;117:561–72.

[3] Hsiao EM, Rybicki FJ, Steigner M. CT coronary angiography: 256-slice and 320-detector row scanners. Curr Cardiol Rep 2010;12:68–75.

[4] Coolens C, Breen S, Purdie TG, et al. Implementation and characterization of a 320-slice volumetric CT scanner for simulation in radiation oncology. Med Phys 2009;36:5120–7.

[5] Niu TY, Zhu L. Overview of X-ray scatter in cone-beam computed tomography and its correction methods. Curr Med Imaging Rev 2010; 6:82–9.

[6] Feger S, Rief M, Zimmermann E, et al. The impact of different levels of adaptive iterative dose reduction 3D on image quality of 320- row coronary CT angiography: a clinical trial. PLoS ONE 2015;10:1–6.

[7] Thibault JB, Sauer KD, Bouman CA, et al. A three-dimensional statistical approach to improved image quality for multislice helical CT. Med Phys 2007;34:4526–44.

[8] Leipsic J, Labounty TM, Heilbron B, et al. Adaptive statistical iterative reconstruction: assessment of image noise and image quality in coronary CT angiography. Am J Roentgenol 2010;195:649–54.

[9] Spears JR, Schoepf UJ, Henzler T, et al. Comparison of the effect of iterative reconstruction versus filtered back projection on cardiac CT postprocessing. Acad Radiol 2014;21:318–24.

[10] Layritz CM, Schmid J, Bietau C, et al. Improved image quality after use of iterative reconstruction in coronary Dual-Source CT angiographies of obese patients: comparison to traditional filtered back projection. Eur Heart J 2013;34(suppl 1):1137–212.

[11] Bittencourt MS, Schmidt B, Seltmann M, et al. Iterative reconstruction in image space (IRIS) in cardiac computed tomography: initial experience. Int J Cardiovasc Imaging 2011;27:1081–7.

[12] Tatsugami F, Matsuki M, Nakai G, et al. The effect of adaptive iterative dose reduction on image quality in 320-detector row CT coronary angiography. Brit J Radiol 2012;85:e378–82.

[13] Vavere AL, Simon GG, George RT, et al. Diagnostic performance of combined noninvasive coronary angiography and myocardial perfusion imaging using 320 row detector computed tomography: design and implementation of the CORE320 multicenter, multinational diagnostic study. J Cardiovasc Comput Tomogr 2011;5:370–81.

[14] George RT, Arbab-Zadeh A, Cerci RJ, et al. Diagnostic performance of combined noninvasive coronary angiography and myocardial perfusion imaging using 320-MDCT: the CT angiography and perfusion methods of the CORE320 multicenter multinational diagnostic study. Am J Radiol 2011;197:830–1.

[15] Miller JM, Dewey M, Vavere AL, et al. Coronary CT angiography using 64 detector rows: methods and design of the multi-centre trial CORE-64. Eur Radiol 2009;19:816–28.

[16] Scanlon PJ, Faxon DP, Audet AM, et al. ACC/AHA guidelines for coronary angiography: a report of the American College of Cardiology/ American Heart Association Task Force on practice guidelines (Committee on Coronary Angiography) developed in collaboration with the Society for Cardiac Angiography and Interventions. J Am Coll Cardiol 1999;33:1756–824.

[17] Okumura M, Ota T, Kainuma K, et al. Effect of edge-preserving adaptive image filter on low-contrast detectability in CT systems: application of ROC analysis. Int J Biomed Imaging 2008;2008:379486.

[18] Yoo R-E, Park E-A, Lee W, et al. Image quality of adaptive iterative dose reduction 3D of coronary CT angiography of 640-slice CT: comparison with filtered back-projection. Int J Cardiovasc Imaging 2013;29:669–76.

[19] Gebhard C, Fuchs TA, Fiechter M, et al. Image quality of low-dose CCTA in obese patients: impact of high-definition computed tomography and adaptive statistical iterative reconstruction. Int J Cardiovasc Imaging 2013;29:1565–74.

[20] Von Falck C, Galanski M, Shin HO. Informatics in radiology: sliding-thin-slab averaging for improved depiction of low-contrast lesions with radiation dose savings at thin-section CT. Radiographics 2010;30: 317–26.

[21] Hara AK, Paden RG, Silva AC. Iterative reconstruction technique for reducing body radiation dose at CT: feasibility study. Am J Radiol 2009;193:764–71.

[22] Nance JWJr, Schoepf UJ, Ebersberger U. The role of iterative reconstruction techniques in cardiovascular CT. Curr Radiol Rep 2013;1:255–68.

[23] Joemai R, Veldkamp W, Kroft L, et al. Adaptive iterative dose reduction 3D versus filtered back projection in CT: evaluation of image quality. AJR 2013;201:1291–7.

[24] Chen MY, Steigner ML, Leung SW, et al. Simulated 50% radiation dose reduction in coronary CT angiography using adaptive iterative dose reduction in three-dimensions (AIDR3D). Int J Cardiovasc Imaging 2013;29:1167–75.

[25] Tomizawa N, Nojo T, Akahane M, et al. Adaptive iterative dose reduction in coronary CT angiography using 320-row CT: assessment of radiation dose reduction and image quality. J Cardiovasc Comput Tomogr 2012;6:318–24.

[26] Di Cesare E, Gennarelli A, Di Sibio A, et al. Assessment of dose exposure and image quality in coronary angiography performed by 640-slice CT: a comparison between adaptive iterative and filtered back-projection algorithm by propensity analysis. Radiol Med 2014;119:642–9.

[27] Williams MC, Weir NW, Mirsadraee S, et al. Iterative reconstruction and individualized automatic tube current selection reduce radiation dose while maintaining image quality in 320-multidetector computed tomography coronary angiography. Clin Radiol 2013;68:e570–7.