ORIGINAL RESEARCH

Effects of Iterative Reconstruction Technique on Image Quality in Cardiac CT Angiography: Initial Experience

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Abstract

Objective: Iterative reconstruction algorithms offer potential radiation dose reduction while maintaining image quality. We attempted to compare image quality parameters of iterative reconstruction and conventional filtered back-projection (FBP) quantitatively in cardiac CT angiography, using second generation dual-source CT technology.

Methods: Ten patients were scanned using retrospective ECG-gated dual-source CT for assessment of native coronary artery disease. Multiphase datasets were reconstructed using FBP and iterative reconstruction techniques. Image noise was measured throughout 20 phases of the cardiac cycle (at varying tube currents). Contrast-to-noise ratios (CNR) were compared at 9 specific coronary artery locations in diastole.

Results: In all evaluated coronary artery locations, the CNR was significantly improved with iterative reconstruction when compared to conventional FBP (improvement: 39.5 ± 2.8%, $p<0.05$). Iterative reconstruction demonstrated less image noise across all cardiac phases (reduction: 22.1 ± 4.0%, $p<0.05$).

Conclusions: Iterative reconstruction offers the potential to increase CNR in cardiac CTA. Our experience suggests that iterative reconstruction algorithms have the potential to reduce radiation doses while maintaining similar objective image quality measures such as CNR and noise levels versus standard FBP reconstructions. Further work with comparison to invasive coronary angiography is needed to ensure maintained diagnostic accuracy.

Key words

Iterative reconstruction, Cardiac CTA, Coronary artery disease, Image quality

1 Introduction

Computed tomography (CT) now represents the primary source of medical radiation exposure to the population [1]. Cardiac CT angiography (CTA) exams offer reliable non-invasive visualization of the coronary arteries, and can reliably exclude significant coronary artery stenosis [2, 3]. This exam is possible because of continual improvements in scanner technology that have resulted in exquisite spatial and temporal resolution. Cardiac CT initially required one of the highest doses per anatomy scanned, due to the requisite ECG gating and challenge of visualizing small vessels, and this early experience with high radiation doses resulted in heightened awareness among the medical community. This in turn has spurred physicians and vendors to make numerous innovations in the field of radiation protection, specifically with respect to cardiac CTA. These innovations include low kV techniques [4-6], automatic tube current (mA) selection [7, 8], ECG-based tube current modulation [9], and prospective ECG triggering [10, 11].

However, lowering of radiation dose via tube current (mAs) reduction results in an increase in image noise [12] which might impair accurate assessment of luminal narrowing in CCTA when using standard reconstruction technique (i.e. filtered back projection)

Recently, new CT reconstruction algorithms, based upon iterative rather than traditional filtered back projection (FBP) reconstruction, have been introduced by several manufacturers [13, 14].

It has been shown that the use of iterative reconstruction algorithms result in better image quality at CCTA, mostly by reducing image noise and therefore improving contrast-to-noise ratio [13, 14]. Because these iterative reconstruction (IR) algorithms may be more efficient, manufacturers have proposed that they can allow reduced radiation doses while maintaining image quality commensurate with standard-dose FBP CT.

This alternative reconstruction technique has been used in positron-emission-tomography (PET) imaging prior to CT [15]. It uses a correction loop process to progressively refine image data. The iterative descriptor applies to the recursive nature of the process; iterative reconstructions have been described using raw data, statistical data, and reconstructed image data. A priori knowledge of imaging system characteristics are applied by comparing the current iteration's new reconstructed image with prior raw image projection data, and over the course of successive iterations, image quality is improved in some pre-defined domain (i.e. noise reduction). In essence, an iterative reconstruction technique employs information from measured projections to reconstruct images. However, unlike conventional filtered-back projection (FBP), iterative reconstruction simulates the expected measurements based on known CT system parameters. This estimation of the object or "forward projection" uses original reconstruction rays through the original image to create a new image. Through repetitive comparison with the original reconstruction, the simulated data sets are repetitively compared with the original reconstructed data sets and constantly improved in each cycle through non-linear processing. The results are more homogenous images with overall noise level reduction [16].

This process is demanding on computer processor power and can significantly increase reconstruction times; several manufacturers have developed methods that are now fast enough for routine clinical use (see Figure 1) [13, 17].

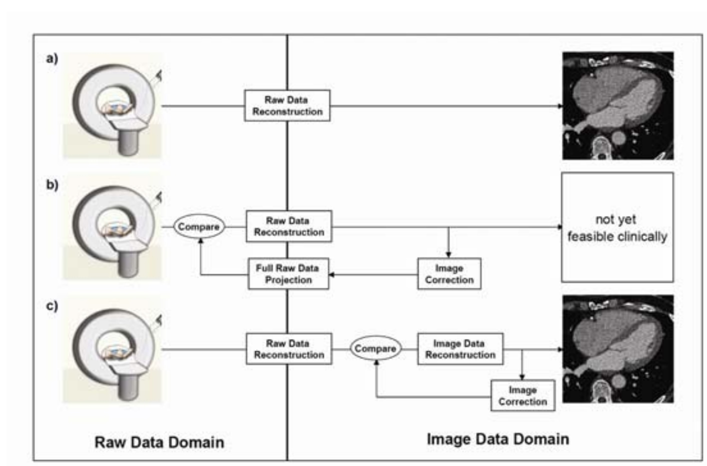

Figure 1. Comparison of different reconstruction algorithms.
Various Image Reconstruction Algorithms: a) traditional filtered back projection, images are reconstructed from raw data directly; b) true iterative reconstruction, images are reconstructed from raw data, then undergo multiple loops of comparison in the raw data domain, leading to slow reconstruction time; c) iterative reconstruction in image space, images are reconstructed from raw data, then undergo multiple loops of comparison in the image data domain, improving the reconstruction time.

The aim of this study was to compare quantitative image quality parameters in patients that underwent cardiac CTA for assessment of native coronary artery disease in data sets that were reconstructed with iterative reconstruction (IR) and traditional filtered back projection (FBP) at varied radiation doses. This work may help estimate the potential of this novel reconstruction algorithm for dose reduction in cardiac CTA.

2 Materials and methods

2.1 Financial disclosure

The study was approved by the human research committee of the institutional review board (Partners IRB) and compliance with the Health Insurance Portability and Accountability Act guidelines was maintained. The requirement for informed consent was waived for this retrospective study. The authors maintained full control over the study design and data.

2.2 Patients

In this retrospective study, we analyzed data from 10 consecutive patients—with a total of 90 segments—referred for evaluation of the coronary arteries by cardiac CT angiography.

2.3 MDCT scan protocol

MDCT exams were performed on a second generation dual-source CT (Somatom Definition FLASH, Siemens Medical Solutions, Forchheim, Germany), with two sets of x-ray tubes detector arrays. Each array enables data acquisition with 64 detector rows, and in combination with a z-flying focus (z-sharp, Siemens Medical Solutions, Forchheim, Germany), simultaneous data acquisition of 2×128 slices is possible.

After initial scout images, a timing bolus scan at the level of the ventricles was performed with 20 cc of iodinated contrast agent (iopamidol 370 g/cm^3 Isovue 370, Bracco Diagnostics, Princeton, NJ USA) to determine the peak descending aortic timing of the contrast agent. A bolus of contrast, based on scan length with a volume of 60-70 mL, was power-injected at 5-7 mL/s followed by a 40mL of saline at 5-7 mL/s. A retrospective ECG-gated volume dataset was acquired using ECG gated "optimal" tube current modulation (MinDose "Auto", Siemens Medical Solutions, Forchheim, Germany) [18]. This modulation algorithm allows for 100% of peak reference tube current at diastole, with limitation of tube current to 4% of the reference mA at systole. The operator can specify the duration of the peak tube current within the R-R interval; a reference table was set to automatically widen the tube current pulsing at higher heart rates. If heart rates temporarily became irregular, the scanner was configured to temporarily disable ECG pulsing until heart rates stabilized.

Volume data set was acquired with 64 mm × 0.6 mm collimation, a gantry rotation time of 280 ms, a pitch of 0.2-0.5 (automatically adapted based on heart rate), tube voltage of 80-120 kV (weight-based nomogram), and a tube current of 312-370 mAs/rotation (scout-based automatic reference tube current selection–CareDose 4D, Siemens Medical Solutions, Forchheim, Germany).

2.4 Estimation of radiation dose

The dose-length-product [(DLP); mGy x xm] was extracted from the scanner dose exposure record. The effective radiation dose was calculated by multiplying the DLP with a standard chest conversion factor of k=0.014 mSv / (mGy × cm) [18].

2.5 Image processing

Complete sets of image reconstructions were performed with FBP (B26 kernel) and again with IR (I26 kernel). These kernels (and the resulting image characteristics and noise filtration) are standard recommended kernels for coronary imaging as per the manufacturer, and share a relatively similar diagnostic profile. They were selected in order to maintain similar image characteristics, other than the method of reconstruction (filtered back-projection vs. iterative reconstruction).

Axial images were reconstructed with a slice thickness of 0.75 mm at a reconstruction increment of 0.5 mm in the best diastolic phase, using both a standard FBP algorithm, as well as an image-based filtered FBP and iterative reconstruction (IR) algorithm (Image Reconstruction in Image Space – IRIS, Siemens Medical Solutions, Forchheim, Germany). For every patient a multiphase axial dataset of 2mm slice thickness (reconstruction interval 1 mm) were reconstructed at 20 different points during the R-R interval (in 5% increments).

2.6 Image analysis

2.6.1 Multiphase image noise analysis

In every phase of the R-R cycle reconstructed (5% increments), image noise was measured using a circular region of interest (ROI) (area of 100 mm^2) placed in the contrast-enhanced lumen of the aorta on both the FBP and the matching IR images for each patient.

2.6.2 Contrast-to-noise ratio analysis

The single diastolic phase with the overall least coronary motion was selected for high-detail diagnostic image reconstruction using the scanner's proprietary software (BestPhase, Siemens Medical Solutions, Forchheim, Germany); the raw data was then used to reconstruct IR and FBP images with corresponding reconstruction kernels (I26 and B26, respectively); all other factors were held constant (0.75 mm image thickness, 0.5 mm reconstruction interval, 150 mm × 150 mm field of view centered on the heart).

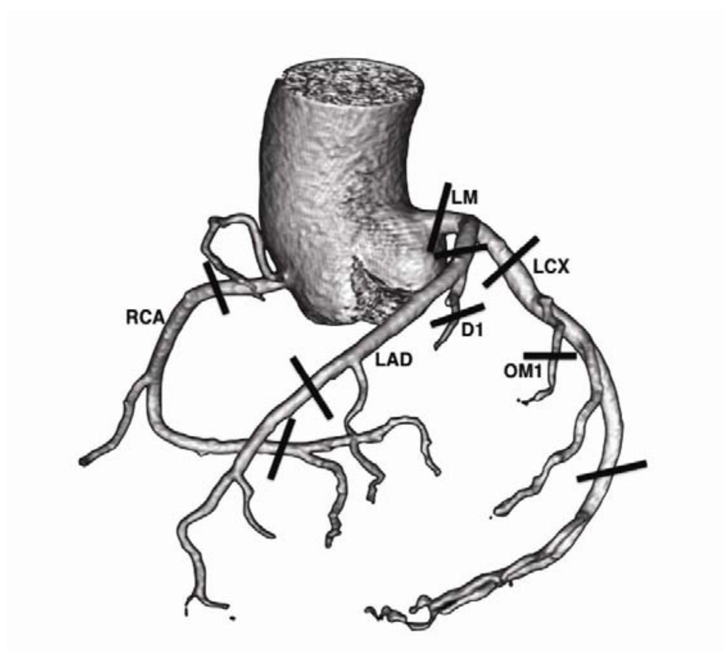

Figure 2. Coronary locations for contrast-to-noise measurements.

To determine the contrast-to-noise-ratio, nine regions of interest were placed in the coronary lumen and the adjacent tissue. The measurements were performed in nine locations (black bars).

Using the resulting axial images of each patient, nine circular regions of interest (2-4 mm^2) were placed in the lumen of the coronary arteries and the adjacent fatty epicardial connective tissue to measure the contrast-to-noise ratio (CNR) as described previously [19] in the following locations: left main coronary artery, proximal and distal (distal to the second diagonal branch) left anterior descending coronary artery, proximal first diagonal branch, proximal and distal left circumflex coronary artery, first obtuse marginal branch, proximal and distal (proximal to the origin of the posterior descending coronary artery) right coronary artery. These locations are marked on a sample coronary tree in Figure 2. A circular region of interest (100 mm^2) was placed in the contrast-enhanced lumen of the aortic root to measure image noise by determining the standard deviation of CT attenuation. CNR was calculated by the following formula as described previously: contrast-to-noise ratio = (CT attenuation lumen − CT attenuation adjacent tissue) / image noise [20].

2.7 Statistical analysis

Data analysis was performed using Stata IC version 11.0 (StataCorp LP, College Station, Texas). Continuous variables were expressed as mean ± standard deviation; categorical variables were expressed as percentage. Differences in continuous variables were assessed using unpaired Student's *t*-tests. A two tailed *p*-value < 0.05 was considered statistically significant. Intraclass correlation coefficient was used for interobserver agreement of contrast-to-noise ratio.

3 Results

Patient characteristics are shown in details in Table 1. Median radiation dose associated with each cardiac CTA exam was 6.3 mSv [5.0 to 9.4]. Rate of nondiagnostic segments, scan parameters and radiation doses for each patient are shown in table 2.

Table 1. Patient Demographics and Median Effective Radiation Dose (mSv)

Patient Demographics	
Age (yrs), mean±SD	52 ± 14
Male Gender (%)	80%
BMI (kg/m2), mean±SD	31 ± 9
Heart rate (bpm), mean±SD	60 ± 4
Hypertension (%)	70%
Dyslipidemia (%)	50%
Diabetes Mellitus (%)	20%
Smoking (%)	20%
Effective Radiation dose (mSv), median [range]	6.3 mSv [5.0-9.4]

3.1 Noise measurements

Noise measurements of the traditional FBP across all phases varied from 21.9 to 128.3 Hounsfield units (HU), with an average of 79.4 ± 41.6 HU. Iterative reconstruction's image noise varied from 16.2 to 106.9 HU, with an average of 62.8 ± 34.6 HU. Across every phase of the R-R interval, iterative reconstructions demonstrated less image noise than the corresponding FBP reconstructions, as illustrated in Figure 3. The difference in noise for each of the phase varied between 15.6 to 32.3%, with an average noise reduction at IR of 22.1 ± 4.0%. At all phases of the cardiac cycle (with varying levels of tube current), the noise reduction with IR was significant (all $p<0.01$). These differences are illustrated in Figure 4 and 5.

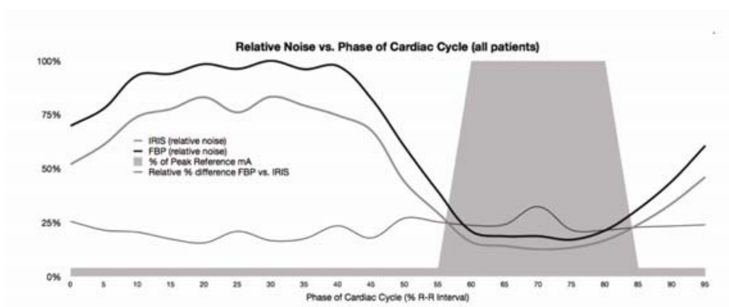

Figure 3. Noise and relative difference in noise in multiple car-diac phases. This diagram illustrates that across all phases of the cardiac cycle, IR images had less noise than FBP images. The relative difference is also shown. The shaded area denotes the prescribed pulsing window. Image noise is slightly irregular due to inter-patient variability in heart rhythm and resultant ECG pulsing.

Table 2. Nondiagnostic Segments, Scan Parameters and Radiation Dose for each Patient

Patient	Non-diagnostic Segments Rate	Scan Mode	ECG-gated TCM	Tube Voltage (kV)	Tube Current (mAs)	CTDI (mGy)	DLP (mGy x cm)	Effective Dose (mSv)	Scsn Length (cm)
No.1	0% (0/17)	RGT	Yes	120	376	73.4	699	9.8	13.0
No.2	0% (0/17)	RGT	Yes	80	304	14.6	141	2.0	15.3
No.3	0% (0/17)	RGT	Yes	120	107	38.5	354	5.0	13.9
No.4	0% (0/17)	RGT	Yes	100	141	21.2	350	4.9	22.8
No.5	0% (0/17)	RGT	Yes	100	166	29.7	360	5.0	16.3
No.6	0% (0/17)	RGT	Yes	120	97	40.5	481	6.7	17.4
No.7	0% (0/17)	RGT	Yes	120	261	35.3	419	5.9	15.2
No.8	0% (0/17)	RGT	Yes	120	85	49.1	585	8.2	15.5
No.9	0% (0/17)	RGT	Yes	120	130	55.1	713	10.0	16.7
No.10	0% (0/17)	RGT	Yes	120	227	53.8	1284	18.0	28.4

Note. Abreviations: RGT, retrospective ECG gated helical mode; ECG-gated TCM, electrocardiogram-gated tube current modulation; CTD, Ivol, volume weighted computed tomography dose index; DLP, dose-length-product.

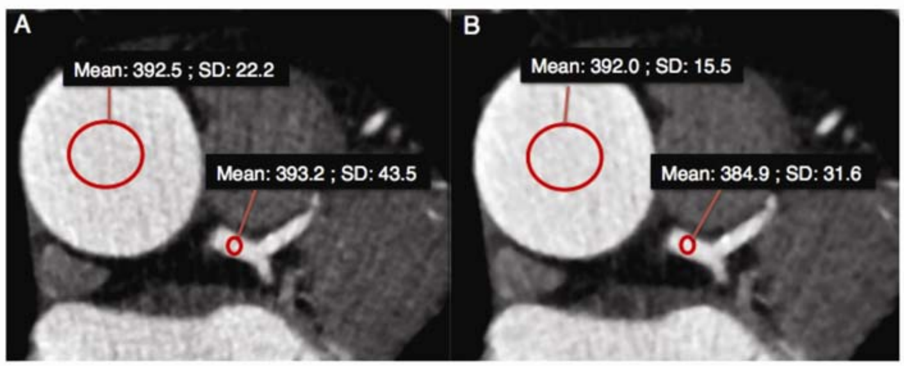

Figure 4. Comparison of image noise between FBP and IR. Image noise at FBP (A) is higher than at IR (B). Both images were reconstructed at an identical diastolic phase (65% R-R).

3.2 Contrast-to-noise ratio measurements

Inter-observer agreement of the CNR in all nine measured coronary locations and was found to be excellent (Intraclass Correlation Coefficient: 0.84). The average CNR of the nine examined regions in the coronary arteries of both reconstruction algorithms are illustrated in Table 2. In all coronary locations, there was significant improvement of the CNR in iterative reconstructions when compared to FBP. The difference in CNR ranges between 36.6% and 46.1%, with an average of 39.5 ± 2.8%.

4 Discussion

Recent research effort in CT image reconstruction algorithms has been focused on the development of iterative reconstruction techniques. However, true iterative reconstruction algorithms currently demand an immense amount of computer processing power and time, making them unsuitable for clinical use thus far [21]. In response, many scan manufacturers have released iterative reconstruction techniques that work within the image data domain, resulting in improved reconstruction time and clinical feasibility [13, 17]. Thus, advances in computer power and CT technology allow the incorporation of iterative reconstruction algorithms in the clinical setting. While IR techniques were formerly prohibitively time-intensive due to the necessity of several cycles of image data processing, now timely image reconstructions are possible.

In this preliminary experience, we evaluated iterative reconstruction methods in comparison to traditional FBP reconstruction. We found that image noise is consistently decreased in all phases of the cardiac cycle. The difference in the noise levels were statistically significant at the full tube current (reference tube current) in diastole and all the way down to the 4% of the reference tube current that was applied during systole. Furthermore, in the diastolic phase, the CNR values for iterative reconstructions were significantly better than those of FBP images in all nine coronary locations measured.

These initial results are promising, and consistently show that image quality can be objectively improved with the use of iterative reconstruction techniques. This study utilizes ECG-gated CT to enable the analysis of multiple images of the same patient anatomy at different radiation doses. Although iterative techniques could be compared to traditional FBP techniques at differing radiation doses by scanning patients twice, this type of study becomes ethically difficult due to the use of repeated exposure to ionizing radiation with no added benefit to the patient. Further, if repeated scans of the same patient are performed, the potential for other confounders (such as contrast enhancement, patient positioning, or heart rate) must be accounted for.

At CCTA, a lot of algorithms use tube current modulation to achieve dose reduction at CCTA [7-9]. The relation between radiation dose and tube current is linear and a reduction of the tube current is associated with an increase in image noise. However given a non-linear relation between image noise and tube current (noise is proportional to $1/\sqrt{\text{mAs}}$) when all other dose related factors are kept constant [12, 22], our results suggests that a considerable amount of radiation dose can be saved when using IR instead of FBP while maintaining the same objective image quality. The results also raise the possibility that IR algorithms may improve diagnostic image quality in routine patients, particularly when analyzing systolic images obtained at low mA values. This may be beneficial since systolic images obtained at low dose may only be used for evaluation of wall motion rather than coronary anatomy. For pure coronary assessment, data sets of cardiac CT are traditionally reconstructed and interpreted in end-diastole, which in most cases offers motion-free images. For evaluation of functional data sets (i.e. assessment of wall motion, etc.) animated “cine” images of all phases of the cardiac cycle are required. In order to save radiation dose, the tube current (mAs) is usually reduced during systole, resulting in a higher noise level during that phase. This is generally not a problem because the myocardial wall is a much thicker structure than the coronary lumen. The use of IR offers the possibility improve the noise level including the systolic phase of the cardiac cycle.

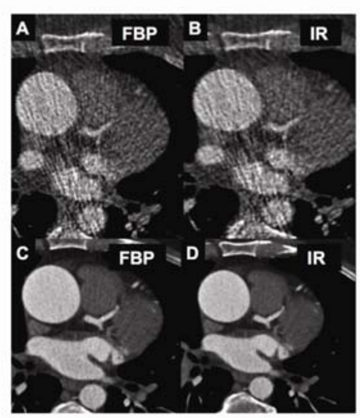

Figure 5. Comparison of image noise in end-systole and end-diastole.

FBP [A] at end-systole (35% R-R) versus IR at end-systole [B] demonstrates a 25% noise reduction relative to FBP. A 30% noise reduction vs. FBP [C] is achieved in end-diastole using IR [D]. At very low radiation doses, such as those used for systolic scans with ECG pulsing, the diagnostic benefit of noise reduction may be proportionally similar, but offer more significant diagnostic benefits.

An example of the benefits of reconstructing low-dose systolic images using IR is demonstrated in Figure 5. Further dose reduction is possible using prospectively-triggered axial sequential modes [10], or prospectively-triggered high pitch helical

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modes [23]; although we did not evaluate images obtained in these scan modes, our results suggest that the increased CNR gained by using iterative reconstructions would apply regardless of the phase of image acquisition.

5 Limitations

This initial retrospective study has some inherent limitations. The CT protocol was not completely identical in every patient, as amount of contrast, flow rate of contrast and z-coverage were tailored individually. However, comparisons of image quality between iterative reconstruction and FBP were performed in each individual patient, and therefore all parameters other than reconstruction algorithms were fixed. Finally, although IR consistently improves objective image quality parameters, this improvement may not necessarily add incremental diagnostic value. To validate this approach, an outcomes-based study such as sensitivity analysis versus a gold standard (i.e. catheter angiography) could be performed in future analyses.

6 Conclusions

Iterative image reconstruction increases CNR in cardiac CTA by approximately 39.5% while decreasing image noise by 22%; our experience suggests that, iterative reconstruction algorithms have the potential to reduce radiation doses while maintaining similar objective image quality measures such as CNR and noise levels versus standard FBP reconstructions. Iterative reconstruction may also offer the potential to improve diagnostic sensitivity in distal small coronary vessels. Further work is necessary, including comparison to a reference standard (invasive coronary angiography) to ensure that diagnostic accuracy is maintained.

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References

[1] Brenner DJ, Hall EJ. Computed tomography--an increasing source of radiation exposure. N Engl J Med. 2007; 357(22): 2277-84. PMid:18046031 http://dx.doi.org/10.1056/NEJMra072149

[2] Hoffmann U, Bamberg F, Chae CU, Nichols JH, Rogers IS, Seneviratne SK, et al. Coronary computed tomography angiography for early triage of patients with acute chest pain: the ROMICAT (Rule Out Myocardial Infarction using Computer Assisted Tomography) trial. J Am Coll Cardiol. 2009; 53(18): 1642-50. PMid:19406338 http://dx.doi.org/10.1016/j.jacc.2009.01.052

[3] Hoffmann U, Nagurney JT, Moselewski F, Pena A, Ferencik M, Chae CU, et al. Coronary multidetector computed tomography in the assessment of patients with acute chest pain. Circulation. 2006; 114(21): 2251-60. PMid:17075011 http://dx.doi.org/10.1161/CIRCULATIONAHA.106.634808

[4] Feuchtner GM, Jodocy D, Klauser A, Haberfellner B, Aglan I, Spoeck A, et al. Radiation dose reduction by using 100-kV tube voltage in cardiac 64-slice computed tomography: a comparative study. Eur J Radiol. 2010; 75(1): e51-6. PMid:19671491 http://dx.doi.org/10.1016/j.ejrad.2009.07.012

[5] Hausleiter J, Martinoff S, Hadamitzky M, Martuscelli E, Pschierer I, Feuchtner GM, et al. Image quality and radiation exposure with a low tube voltage protocol for coronary CT angiography results of the PROTECTION II Trial. JACC Cardiovasc Imaging. 2010; 3(11): 1113-23. PMid:21070998 http://dx.doi.org/10.1016/j.jcmg.2010.08.016

[6] Leschka S, Stolzmann P, Schmid FT, Scheffel H, Stinn B, Marincek B, et al. Low kilovoltage cardiac dual-source CT: attenuation, noise, and radiation dose. Eur Radiol. 2008; 18(9): 1809-17. PMid:18392829 http://dx.doi.org/10.1007/s00330-008-0966-1

[7] Deetjen A, Mollmann S, Conradi G, Rolf A, Schmermund A, Hamm CW, Dill T. Use of automatic exposure control in multislice computed tomography of the coronaries: comparison of 16-slice and 64-slice scanner data with conventional coronary angiography. Heart. 2007; 93(9): 1040-3. PMid:17395667 http://dx.doi.org/10.1136/hrt.2006.103838

[8] Hausleiter J, Meyer T, Hermann F, Hadamitzky M, Krebs M, Gerber TC, et al. Estimated radiation dose associated with cardiac CT angiography. JAMA. 2009; 301(5): 500-7. PMid:19190314 http://dx.doi.org/10.1001/jama.2009.54

[9] Jakobs TF, Becker CR, Ohnesorge B, Flohr T, Suess C, Schoepf UJ, et al. Multislice helical CT of the heart with retrospective ECG gating: reduction of radiation exposure by ECG-controlled tube current modulation. Eur Radiol. 2002; 12(5): 1081-6. PMid:11976849 http://dx.doi.org/10.1007/s00330-001-1278-x

[10] Scheffel H, Alkadhi H, Leschka S, Plass A, Desbiolles L, Guber I, et al. Low-dose CT coronary angiography in the step-and-shoot mode: diagnostic performance. Heart. 2008; 94(9): 1132-7. PMid:18519548 http://dx.doi.org/10.1136/hrt.2008.149971

[11] Stolzmann P, Leschka S, Scheffel H, Krauss T, Desbiolles L, Plass A, et al. Dual-source CT in step-and-shoot mode: noninvasive coronary angiography with low radiation dose. Radiology. 2008; 249(1): 71-80. PMid:18796669 http://dx.doi.org/10.1148/radiol.2483072032

[12] Mahesh M. MDCT Physics: The Basics- Technology, Image. Quality and Radiation Dose. LippincottWilliams & Wilkins. 2009.

[13] Bittencourt MS, Schmidt B, Seltmann M, Muschiol G, Ropers D, Daniel WG, et al. Iterative reconstruction in image space (IRIS) in cardiac computed tomography: initial experience. Int J Cardiovasc Imaging. 2010.

[14] Leipsic J, Labounty TM, Heilbron B, Min JK, Mancini GB, Lin FY, et al. Adaptive statistical iterative reconstruction: assessment of image noise and image quality in coronary CT angiography. AJR Am J Roentgenol. 2010; 195(3): 649-54. PMid:20729442 http://dx.doi.org/10.2214/AJR.10.4285

[15] Liow JS, Strother SC, Rehm K, Rottenberg DA. Improved resolution for PET volume imaging through three-dimensional iterative reconstruction. J Nucl Med. 1997; 38(10): 1623-31. PMid:9379203

[16] Scheffel H, Stolzmann P, Schlett CL, Engel LC, Major GP, Karolyi M, et al. Coronary artery plaques: cardiac CT with model-based and adaptive-statistical iterative reconstruction technique. Eur J Radiol. 2012; 81(3): e363-9. PMid:22197733 http://dx.doi.org/10.1016/j.ejrad.2011.11.051

[17] Marin D, Nelson RC, Schindera ST, Richard S, Youngblood RS, Yoshizumi TT, et al. Low-tube-voltage, high-tube-current multidetector abdominal CT: improved image quality and decreased radiation dose with adaptive statistical iterative reconstruction algorithm--initial clinical experience. Radiology. 2010; 254(1): 145-53. PMid:20032149 http://dx.doi.org/10.1148/radiol.09090094

[18] McCollough C CD, Edyvean S, Geise R, Gould B, Keat N, Huda W, et al. Diagnostic Imaging Council CT Committee: The Measurement, reporting, and management of radiation dose in CT. AAPM Report No. 96. 2008.

[19] Ferencik M, Nomura CH, Maurovich-Horvat P, Hoffmann U, Pena AJ, Cury RC, et al. Quantitative parameters of image quality in 64-slice computed tomography angiography of the coronary arteries. Eur J Radiol. 2006; 57(3): 373-9. PMid:16439091 http://dx.doi.org/10.1016/j.ejrad.2005.12.023

[20] Ferencik M, Moselewski F, Ropers D, Hoffmann U, Baum U, Anders K, e al. Quantitative parameters of image quality in multidetector spiral computed tomographic coronary imaging with submillimeter collimation. Am J Cardiol. 2003; 92(11): 1257-62. PMid:14636899 http://dx.doi.org/10.1016/j.amjcard.2003.08.003

[21] Silva AC, Lawder HJ, Hara A, Kujak J, Pavlicek W. Innovations in CT dose reduction strategy: application of the adaptive statistical iterative reconstruction algorithm. AJR Am J Roentgenol. 2010; 194(1): 191-9. PMid:20028923 http://dx.doi.org/10.2214/AJR.09.2953

[22] Halliburton SS, Abbara S, Chen MY, Gentry R, Mahesh M, Raff GL, et al. SCCT guidelines on radiation dose and dose-optimization strategies in cardiovascular CT. J Cardiovasc Comput Tomogr. 2011; 5(4): 198-224. PMid:21723512 http://dx.doi.org/10.1016/j.jcct.2011.06.001

[23] Achenbach S, Marwan M, Schepis T, Pflederer T, Bruder H, Allmendinger T, et al. High-pitch spiral acquisition: a new scan mode for coronary CT angiography. J Cardiovasc Comput Tomogr. 2009; 3(2): 117-21. PMid:19332343 http://dx.doi.org/10.1016/j.jcct.2009.02.008