Original Research

Radiation Dose and Image Noise Evaluation in Coronary Computed Tomography Angiography (CCTA) Using an Iterative Reconstruction Algorithm

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Key words: **iDose, effective dose.**

Introduction: The purpose of this study was to evaluate radiation dose reduction in coronary computerised tomography angiography (CCTA), using a commercially available iterative reconstruction (IR) algorithm as well as the behaviour of the image noise.

Methods: A total cohort of 47 patients underwent CCTA examination on a 64-slice multi-detector CT. They were divided into four groups according to the time when the examination was performed (before or after the installation of iDose) and the acquisition protocol followed (prospective or retrospective electrocardiography-ECG gated). The images acquired with reduced dose settings were reconstructed using two levels (L4 and L6) of the iDose^4 algorithm. Image noise was measured in all cases.

Results: In retrospective acquisition, images acquired with a 46% lower radiation dose and reconstructed with iDose^4 L6 provided noise comparable to that in the full-dose filtered back-projection images. For the prospective acquisition mode, a slight decrease (26%) in radiation dose resulted in noise improvement in low-dose images reconstructed with iDose^4 L4 (16% noise removal) and L6 (30% noise removal).

Conclusions: The fact that image quality is improved while radiation exposure is reduced indicates that there is room for a further reduction in exposure settings. Additionally, the combination of iDose^4 with prospective acquisition is able to significantly reduce the radiation dose associated with CCTA at values of about 2 mSv and even lower.

Manuscript received:
August 16, 2013;
Accepted:
February 20, 2014.

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Since the introduction of multi-detector computed tomography (MDCT) and dual-source CT technology, coronary CT angiography (CCTA) has acquired an increasing role in the clinical assessment of coronary artery disease (CAD).[1-4] It has been shown that CCTA is highly accurate compared to invasive diagnostic catheterisation and provides high sensitivity and specificity, and an excellent negative predictive value in the detection of CAD in patients with a low or intermediate risk of disease.[5-7] The non-invasive nature of CCTA and the constantly rising number of available MDCT scanners have led to increased numbers of CCTA procedures performed worldwide. However, the higher radiation exposure of CCTA compared to invasive catheterisation and its association with cancer induction remains a major concern.[5,8-10]

In response to this concern, various techniques to reduce radiation exposure in CCTA have been implemented.

These include anatomical-based tube-current modulation,[11,12] electrocardiogram (ECG)-based current modulation,[13,14] reduced X-ray tube voltage,[13,15] and prospectively ECG-gated scanning.[16-20] The ongoing evolution of computer technology has recently made iterative reconstruction (IR) algorithms commercially available and applicable in routine clinical practice. Retrospective studies have shown that IR improves diagnostic imaging quality compared to filtered back-projection (FBP) algorithms, by lowering the noise for the same radiation exposure conditions.[21-24] Regarding CCTA, various studies have shown that low-dose acquisition protocols in conjunction with an IR algorithm provide equivalent or even superior diagnostic results compared to those acquired with routine dose settings and FBP.[25-31] These studies also indicate that dose reduction up to 63% compared to FBP is achievable, depending on the proportion of iteration blending with FBP. These previous studies evaluated the ASIR algorithm,[25,30] the SAFIRE algorithm,[26,28] the IRIS algorithm,[27] or the iDose[4] algorithm using 256-MDCT scanners.[29,31]

The purpose of the current study was to evaluate the radiation doses and image noise for CCTA procedures performed on a 64-MDCT scanner with the use of a commercially available iterative reconstruction algorithm (iDose[4], Philips Healthcare, Cleveland, OH, USA) and to compare the findings with those from traditional FBP reconstruction for both retrospective ECG-gated or prospective ECG-triggered CCTA protocols.

Methods

Patient population

From June 2011 to October 2012, 51 patients with known or suspected CAD underwent CCTA examinations. The exclusion criteria were: body mass index >40 kg/m^2, heart rate >85 bpm, arrhythmia, contraindications for iodinated contrast, renal insufficiency, or a history of contrast media reaction. Four patients who underwent CCTA were excluded from the present study because of severe motion or blooming artefacts. Consequently, 47 patients (55.1 ± 15.9 years) who underwent CCTA were retrospectively reviewed in the present study. These patients were categorised into those who underwent CCTA examination before the installation of iDose (June 2011 to March 2012, 27 patients) and those who underwent CCTA after the iDose installation using reduced exposure settings (April–October 2012, 20 patients).

CCTA data acquisition and reconstruction

All patients were examined using a 64-slice CT scanner (Brilliance-iCT, Philips Healthcare, Cleveland, OH, USA). Of the 27 patients who underwent CCTA before the installation of iDose (only FBP reconstruction available), 8 (group 1) were examined using prospective axial ECG-triggering, while 19 (group 2) were examined using a retrospective helical ECG-gating CCTA protocol. The remaining 20 patients, who were examined after the iDose installation, were scanned with reduced dose settings and images were reconstructed with iDose[4]. Eight of these patients were scanned using a prospective axial ECG-triggering protocol (group 3) while 12 were scanned using a retrospective helical ECG-gated CCTA protocol with IR reconstruction (group 4). The selection of the scanning mode was based on the patients' heart rate: those with a heart rate <70 bpm were scanned in axial mode while those with higher heart rates were scanned in helical mode. Demographic characteristics and data acquisition parameters for all groups are presented in Table 1.

The scan procedure included a low-dose scout image for accurate positioning of the scanning volume. For the patients for whom IR was subsequently adopted, a low-dose acquisition protocol was selected. The adjustment of the exposure parameters to the requirements of the iDose algorithm was made gradually, according to the manufacturer's recommendations, with simultaneous image assessment by radiologists at every step of the optimisation procedure in order to ensure a diagnostically acceptable outcome. The raw data of groups 3 and 4 were reconstructed using iDose level 4 (50% IR blending with 50% FBP, according to the manufacturer) and level 6 (70% IR blending with 30% FBP, according to the manufacturer). In order to ensure homogenous contrast enhancement of the entire coronary tree, the initiation of the data acquisition process was determined by a computer-assisted bolus tracking program with a trigger threshold of 150 HU in the pulmonary artery trunk. CT data acquisition was started 8 s after triggering. All images were reconstructed at 75% of the cardiac cycle.

Image quality evaluation

All images included in the present study were diagnostically acceptable, as evaluated by two experienced radiologists. In order to evaluate the image noise, the standard deviation of the density values (HU) was derived from a 2 cm^2 region of interest (ROI) located in

Table 1. Patients' characteristics and acquisition parameters.

	Group 1	Group 2	Group 3	Group 4
Patient characteristics:				
Number of patients	8	19	8	12
Age (years)	51.9 ± 15.5	53.9 ± 17.0	54.9 ± 11.0	59.3 ± 18.0
Effective diameter (cm)	29.1 ± 3.1	28.6 ± 1.8	29.2 ± 1.5	28.3 ± 1.7
Heart rate (bpm)	55.6 ± 6.9	64.2 ± 10.6	55.9 ± 7.9	64.5 ± 10.2
Scanning parameters:				
Voltage (kVp)	120-140	120-140	120	100-140
mAs	182.5 ± 27.5	779.1 ± 62.9	135.6 ± 35.2	460.4 ± 82.0
Acquisition mode	Axial	Helical	Axial	Helical
Reconstruction algorithm	FBP	FBP	iDose	iDose
Scanning length (cm)	13.55 ± 2.3	14.5 ± 2.2	12.7 ± 1.1	14.8 ± 3.4
Slice thickness	0.67/0.9	0.67/0.9	0.67/0.9	0.67/0.9
Matrix size	512 × 512	512 × 512	512 × 512	512 × 512
Detector configuration (rows × mm)	64 × 0.625	64 × 0.625	64 × 0.625	64 × 0.625
Dose modulation	off	off	off	off
Filtration	XCB	XCB	XCB	XCB

the aortic root at the level of the left main coronary artery on an axial image. All measurements were performed precisely in the same location for all reconstructions. ROIs were placed, as illustrated in Figure 1, by a trainee radiologist in the 3rd year of his residency with 1-year's experience in CT angiography.

Radiation exposure estimation

Volume CT dose index ($CTDI_{vol}$) and dose–length product (DLP) were recorded from the console display of the CT scanner. To obtain the effective dose (ED), dose–length product was multiplied by an appropriate sex- and body habitus-averaged conversion coefficient for the adult thorax (k=0.0146 mSv·mGy^{-1}·cm^{-1}).[32]

Statistical analysis

All data are presented as mean value ± standard deviation. Differences in dose quantities and demographic characteristics among patient groups were compared using one-way analysis of variance (ANOVA). One-way ANOVA was also used to compare image noise measurements among the different patient groups, while Student's paired t-test was applied to compare noise measurements for the same groups of patients reconstructed using different iDose^4 levels. All statistical analysis was performed in an SPSS (version 19, SPSS Inc., Chicago, IL, USA) environment. A p-value ≤0.05 was considered to indicate statistical significance.

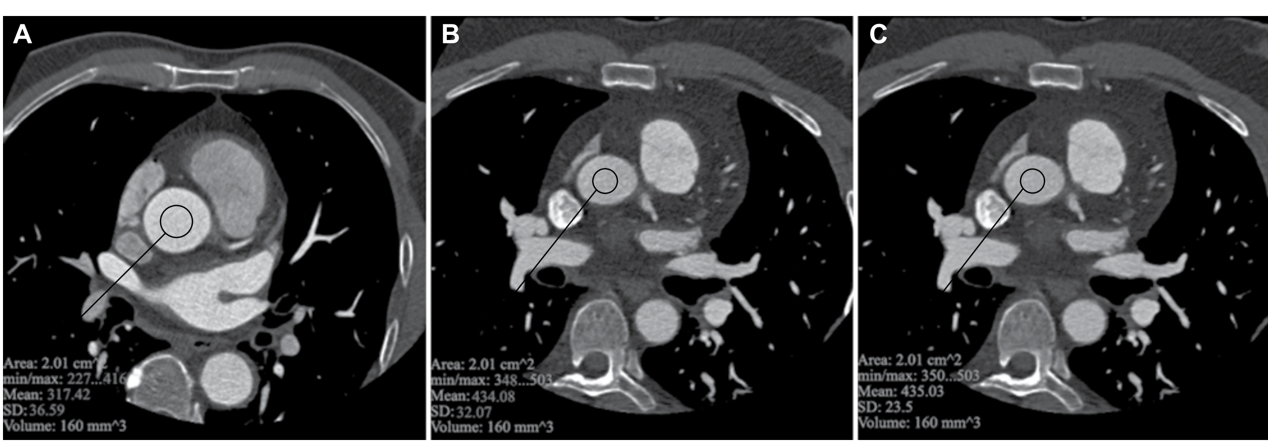

Figure 1. Objective measurements for image noise, defined as the standard deviation (SD) of a region of interest placed at the aortic root, for a filtered back-projection patient of group 1 (A), and a second patient of group 3 reconstructed with (B) iDose^4 level 4 and (C) iDose^4 level 6.

Table 2. Noise and radiation dose parameters for the four groups.

	Noise (HU)	$CTDI_{vol}$ (mGy)	DLP (mGy·cm)
Group 1	37.9 ± 12.7	16.2 ± 3.0	224.0 ± 73.3
Group 2	29.9 ± 6.1	51.2 ± 9.7	1025.6 ± 215.9
Group 3 (L4)	30.7 ± 7.1	12.5 ± 3.5	173.1 ± 59.7
Group 3 (L6)	26.3 ± 5.5		
Group 4 (L4)	40.7 ± 8.6	28.2 ± 8.8	557.3 ± 130.6
Group 4 (L6)	31.5 ± 7.6		

*L4, L6 indicate the levels of the iDose algorithm used. CTDI - CT dose index; DLP - dose-length product.

Results

Statistical analysis revealed no significant differences between the four patient groups as far as patients' age ($p=0.753$), effective diameter ($p=0.721$) and scanning length ($p=0.215$) were concerned. Heart rate was significantly higher ($p=0.001$) in patients who underwent helical acquisition compared to those underwent an axial scan; however, no difference in heart rates was recorded between groups 1/3 ($p=0.947$) or 2/4 ($p=0.93$).

Noise measurements together with CTDI and DLP are listed in Table 2. In the helical scanning technique, CTDI and DLP were 45% lower for group 4 than for group 2. As a result, group 4 images reconstructed with iDose level 4 had higher noise than group 2; however, when level 6 of the iDose algorithm was applied, no significant difference in image noise was observed.

In the prospective scanning technique, a CTDI (and DLP) reduction of 22.8% led to 16.6% noise removal for iDose level 4 and 30.6% for level 6. However, neither of these differences in CTDI/DLP and image noise were statistically significant ($p>0.05$).

The increase of iDose strength from 50% (level 4) to 70% (level 6) over FBP led to a noise removal of 14% and 22.6% for axial (group 3) and helical (group 4) acquisition modes, respectively. These results are in accordance with the vendor's instructions, which demonstrate a noise removal of 22% when going from level 4 (29% noise removal compared to FBP) to level 6 (45% noise removal compared to FBP) of iDose[4].

The effective doses for the four groups are illustrated in Figure 2. A dose reduction of 24% and 46% was recorded in axial and helical acquisition, respectively. Statistical analysis revealed that the difference in ED between groups 1 and 3 was not significant ($p=0.128$), while the difference between groups 2 and 4 was significant ($p<0.001$).

Another noteworthy point is that acquisition using a prospective protocol led to 3 to 5 times lower doses compared to the retrospective protocol.

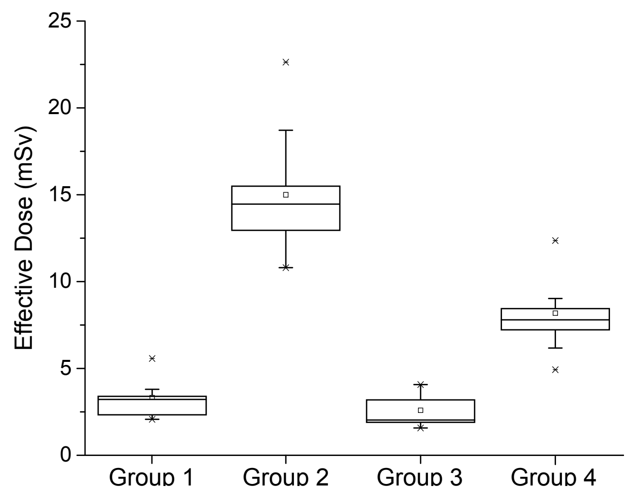

Figure 2. Effective doses (in mSv) for patients undergoing a prospective ECG-triggered CCTA protocol with filtered back-projection (FBP) reconstruction (group 1), a retrospective ECG-gated CCTA protocol with FBP reconstruction (group 2), a prospective ECG-triggered CCTA protocol with iDose4 reconstruction (group 3) and a retrospective ECG-gated CCTA protocol with iDose[4] reconstruction (group 4).

Discussion

In the present study, we assessed the application of an IR algorithm (iDose[4]) using prospectively and retrospectively ECG-gated 64-slice MDCT coronary angiography, and we also investigated the radiation dose reduction compared to FBP, taking into account the image noise as a criterion of image quality.

Our study demonstrated that the use of IR in CCTA is feasible in combination with 64-slice MDCT and that it permits a radiation dose reduction of 46% compared to FBP when using a retrospective acquisition technique, by maintaining the image noise using iDose level 6.

For prospective acquisition, it seems that a 27% reduction in CTDI resulted in iDose images (of both levels) with lower noise compared to FBP images of group 1. However, this slight decrease in acquisition settings, given the small patient sample sizes of groups 1 and 3, does not allow us to draw safe conclusions. The fact that a reduction in radiation exposure led to lower image noise for images reconstructed with levels 4 and 6 of $iDose^4$ indicates that there is room for an even higher decrease in exposure settings.

Our results also indicate that prospective ECG-triggered acquisition with FBP provides even lower radiation doses than retrospective acquisition (78% lower compared to FBP and 69% lower compared to IR, both $p<0.001$).

Various previous studies have investigated the applicability and achievability of dose reduction using IR in conjunction with CCTA. These previous studies evaluated the ASIR algorithm,[25,30] the SAFIRE algorithm,[26,28] and the IRIS algorithm,[27] and concluded that IR can provide a dose reduction ranging between 29% and 63%.[24-30] Current publications concerning the use of the iDose algorithm in CCTA are limited and concern exclusively 256-MDCT scanners. Hosch et al[29] reported a dose reduction of 47% using iDose level 5, while Hou et al[31] compared FBP with IR protocols of various levels of iDose and found a dose reduction of 44% for level 3 and 56% for level 4. Our results concerning a 64-MDCT scanner are in accordance with these findings.

Our results also highlight the efficacy of prospective acquisition in minimising the radiation dose during CCTA. Previously, our team[20] and others[16,17,19,33,34] have demonstrated that a substantial dose reduction is achievable, ranging from 69-85% compared to a corresponding retrospective acquisition scheme. For CCTA, retrospective acquisition is associated with higher radiation doses than prospective acquisition, since the X-ray beam is turned on throughout the cardiac cycle, whereas with prospective acquisition it is turned on for only a short portion of the R-R interval, typically during diastole. In the former case, data that are not used for image reconstruction are acquired during scanning, while in the latter case data acquisition (and radiation exposure) is limited to a predicted imaging window of interest. Our findings indicate that the application of a prospective acquisition protocol that limits radiation exposure to a specific phase of the cardiac cycle, in conjunction with FBP, has a more pronounced effect in lowering the patient's radiation exposure than the application of a retrospective scheme with IR reconstruction, which allows tube current (and radiation dose) reduction but entails radiation exposure throughout the cardiac cycle. A recent study has shown that IR reconstruction techniques using the $iDose^4$ reconstruction algorithm can maintain excellent image quality at a mean effective radiation dose of 1.21 ± 0.14 mSv in prospectively-triggered CCTA using 256-slice MDCT; this represents a 63% reduction compared to FBP reconstruction.[30] Thus, it is plausible to infer that, according to our present results, prospective acquisition in conjunction with IR reconstruction using the iDose algorithm in 64-slice CT scanners can also permit effective radiation doses lower than 2 mSv, while ensuring that the imaging quality is maintained. The fact that the $iDose^4$ algorithm allows significant dose reduction in heart imaging enables the introduction of new imaging procedures, such as myocardial CT perfusion,[35] that have been prohibited because of the high doses delivered to patients.

Conclusions

The use of IR in CCTA is feasible using a 64-slice MDCT scanner. Substantially lower radiation doses (up to 45% for $iDose^4$ level 6) are achievable with the use of IR algorithms instead of FBP in CCTA, without compromising the imaging quality. Prospective ECG-triggered acquisition provides even lower doses compared to retrospective acquisition with FBP; therefore, the combination of IR with prospective acquisition has the potential to significantly reduce the ED associated with CCTA to values of about 2 mSv, or even lower.

Acknowledgements

The iDose software and hardware were courteously provided by PHILIPS Healthcare under the auspices of the PHILIPS CT Publication of the year award won by our department in 2009. This research project is supported by a grand from the S. Niarhos Foundation.

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