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Coronary CT angiography: Comparison of a novel iterative reconstruction with filtered back projection for reconstruction of low-dose CT—Initial experience

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ABSTRACT

Objective: To prospectively compare subjective and objective image quality in 20% tube current coronary CT angiography (cCTA) datasets between an iterative reconstruction algorithm (SAFIRE) and traditional filtered back projection (FBP).
Materials and methods: Twenty patients underwent a prospectively ECG-triggered dual-step cCTA protocol using 2nd generation dual-source CT (DSCT). CT raw data was reconstructed using standard FBP at full-dose (Group_1a) and 80% tube current reduced low-dose (Group_1b). The low-dose raw data was additionally reconstructed using iterative raw data reconstruction (Group_2). Attenuation and image noise were measured in three regions of interest and signal-to-noise-ratio (SNR) as well as contrast-to-noise-ratio (CNR) was calculated. Subjective diagnostic image quality was evaluated using a 4-point Likert scale.
Results: Mean image noise of group_2 was lowered by 22% on average when compared to group_1b ($p < 0.0001$–0.0033), while there were no significant differences in mean attenuation within the same anatomical regions. The lower image noise resulted in significantly higher SNR and CNR ratios in group_2 compared to group_1b ($p < 0.0001$–0.0232). Subjective image quality of group_2 (1.88 ± 0.63) was also rated significantly higher when compared to group_1b (1.58 ± 0.63, $p = 0.004$).
Conclusions: Image quality of 80% tube current reduced iteratively reconstructed cCTA raw data is significantly improved when compared to standard FBP and consequently may improve the diagnostic accuracy of cCTA.

1. Introduction

Coronary CT angiography (cCTA) is a well-established technique for non-invasive evaluation of coronary artery disease [1,2]. The rapid development of CT system resulted in substantial advancement in temporal resolution of image acquisition, up to 75 ms with 2nd generation dual-source CT (DSCT). Nevertheless, cCTA still remains susceptible to motion artifacts, especially in patients with elevated heart rates and/or arrhythmia [3,4]. If one would reliably preclude motion artifacts in patients with arrhythmia a temporal resolution of approximately 19 ms would be required, which is far away from the temporal resolution achievable even with current state-of-the-art CT systems [5].

Retrospective ECG-gated cCTA without automated tube current modulation is the most robust cCTA technique in patients prone to motion artifacts but is associated with a significantly higher radiation dose when compared to prospectively ECG-triggered or single heart beat cCTA techniques [6]. However, ECG-gated cCTA without automated tube current modulation allows reconstruction of the coronary arteries during every phase of the cardiac cycle with a consistent image quality since the full tube current is applied throughout the whole cardiac cycle. In contrast, retrospective ECG-gated cCTA with automated tube current modulation as well as recently introduced adaptive prospective dual-step ECG pulsing combined with ECG-gated tube current modulation leads to only one 10% full tube current phase of the cardiac cycle (mostly 70% or

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30% of the R-R interval) whereas the remaining 90% of the R-R interval are acquired with only 20% of the full tube current [7]. Although 20% full tube current reconstructions allow sufficient evaluation of cardiac function the image quality is mostly insufficient for accurate evaluation of coronary artery stenosis. In the clinical scenario of unexpected motion artifacts that appear during the full tube current cardiac phase an increased image quality of 20% tube current reconstruction would be desirable to safely exclude coronary artery stenosis within segments that are affected by motion artifacts during the full tube current phase.

Thus, the purpose of this prospective study was to evaluate potentially increased image quality of iteratively reconstructed 20% tube current cCTA datasets in comparison to standard filtered back projection (FBP) 20% tube current datasets.

2. Materials and methods

2.1. Patient population

The study was approved by our institutional review board and was conducted in accordance with Health Insurance Portability and Accountability Act regulations. Written informed consent for scientific data analysis was obtained from all patients. We prospectively included cCTA studies of 20 consecutive patients (8 women; mean age 59.4 ± 7.8 years) who were referred for exclusion of coronary artery disease. Exclusion criteria were history of contrast material reaction, pregnancy, acute hypotension (<100 mm Hg systolic), clinical instability and impaired renal function (creatinine higher than 1.5 mg/dL and/or glomerular filtration rate lower than 60 mL/min).

2.2. CT image acquisition protocol

All cCTA studies were performed on a 2nd generation DSCT system (SOMATOM Definition Flash, Siemens Healthcare Sector, Forcheim, Germany) using a prospective dual-step ECG pulsing ($pECG_{dual\_step}$) protocol in which adaptive prospective ECG-triggered cCTA acquisitions are combined with ECG-gated tube current modulation at 20% mAs of full tube current [7]. $pECG_{dual\_step}$ cCTA images were acquired in cranio-caudal scan direction from above the ostium of the coronary arteries to below the dome of the diaphragm during a single breath-hold. Acquisition parameters were 2 mm × 128 mm × 0.6 mm detector collimation using z-flying focal spot technique (Siemens Healthcare Sector, Forcheim, Germany), 280 ms gantry rotation time, 34.5 mm/s table feed and an average of 331 mAs/rot for both tubes. A 120 kV tube potential was used in patients with a BMI > 25 kg/m^2 whereas the tube potential was reduced to 100 kV in patients with a BMI < 25 kg/m^2. ECG-dependent tube current modulation ("ECG-pulsing") was used per default in all patients. Contrast medium enhancement was achieved by injection of 60–90 ml of iodinated contrast material (iopromide, Ultravist 370 mgI/ml, Bayer-Schering, Berlin, Germany) injected at 6 ml/s through an 18-G intravenous antecubital catheter using a dual-syringe injector (Stellant D, Medrad, Indianola, PA). No manual ECG-editing was performed. FBP reconstructions were performed directly on the CT system, while iterative reconstructions were generated from raw data exported to an offline workstation provided by the vendor (Siemens Healthcare Sector, Forcheim, Germany).

2.3. FBP and iterative reconstruction series

FBP reconstructions at "full-dose" (100% tube current at 70% of R-R) and at "low-dose" (20% tube current at 20–90% R-R interval) were performed subsequently after cCTA using a standard vascular kernel (B26f, Siemens Healthcare Sector, Forcheim, Germany) with a slice thickness of 1.5 mm and an increment of 0.4. The same cCTA raw data was than transferred to an offline workstation, where a second set of 20% tube current cCTA images ("low-dose SAFIRE") was reconstructed at 90% of the R-R interval using iterative reconstruction (Sinogram Affirmed Iterative Reconstruction (SAFIRE), Siemens Healthcare Sector, Forcheim, Germany) with an iterative vascular kernel (I26f) with a slice thickness of 1.5 mm and an increment of 0.4. The field of view was individually adapted to patients' heart size but kept constant between FBP and iterative reconstructions. A detailed description of the iterative reconstruction algorithm used in this study was recently published elsewhere [8].

2.4. CT measurements

FBP and iterative reconstructions were transferred to a dedicated image processing workstation (Syngo MMWP VE 36A, Siemens Healthcare Sector, Forchheim, Germany). Identical circular regions of interest (ROIs) were drawn on full-dose (Group_1a) and low-dose (Group_1b) FBP cCTA images as well as on low-dose iteratively reconstructed cCTA images (Group_2). ROIs were placed in identical locations on identical sections of the three groups in the ascending thoracic aorta at the level of the left main coronary artery, left ventricular cavity and right ventricular cavity. ROIs were used to objectively measure attenuation values expressed as signal intensity (SI in Hounsfield Units (HU)) and image noise (standard deviation (SD) of SI). Subsequently signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) were calculated according to the methods used by Szucs-Farkas et al. [9]. In detail the following formulas were applied:

$$\mathrm{SNR} = \frac{\mathrm{SI_{ROI}}}{\mathrm{noise}}$$

$$\mathrm{CNR} = \frac{\mathrm{SI_{ROI}} - \mathrm{SI_{surrounding\_tissue}}}{\mathrm{noise}}$$

$\mathrm{SI_{surrounding\_tissue}}$ was measured within mediastinal fat adjacent to the ascending aorta as well as within the interventricular septum. Dose length product (DLP), patient weight, kV and mAs were recorded, and effective radiation dose (RD) was determined by multiplying the DLP with a conversion factor of 0.014 mSvm Gy^{-1}cm^{-1}, as proposed by the *European Guidelines for Multislice Computed Tomography* [10].

2.5. Subjective image quality

Two experienced radiologists with at least 5 years of experience in cCTA evaluated subjective image quality of FBP and iterative low-dose reconstructions using a 4-point Likert scale. Image sharpness was determined by evaluating the sharpness of the aortic wall at the level of the ascending aorta as well as sharpness of the left and right coronary arteries. Reconstructions with unacceptable noise/sharpness altering their diagnostic value were given a score of 1, images with above average noise/below average sharpness making their diagnostic value suboptimal were given a score of 2, images with average noise/sharpness and average diagnostic acceptability were rated 3, and images with no or low noise/good sharpness and distinct anatomical detail were rated with a score of 4.

Additionally, study interpretability was assessed. The proportion of coronary segments that were deemed interpretable for each study was compared with the number of existing segments. Studies were evaluated using the American Heart Association 15 segment