Journal of Cardiovascular Computed Tomography 10 (2016) 69–75

Contents lists available at ScienceDirect

Journal of Cardiovascular Computed Tomography

journal homepage: www.JournalofCardiovascularCT.com

Research paper

Finding the optimal dose reduction and iterative reconstruction level for coronary calcium scoring

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ARTICLE INFO

Article history:
Received 23 February 2015
Received in revised form
1 August 2015
Accepted 18 August 2015
Available online 28 August 2015

Keywords:
Agatston score
Coronary artery calcifications
Computed tomography
Iterative reconstruction

ABSTRACT

Objective: To assess the maximally achievable computed tomography (CT) dose reduction for coronary artery calcium (CAC) scoring with iterative reconstruction (IR) by using phantom-experiments and a systematical within-patient study.
Methods: Our local institutional review-board approved this study and informed consent was obtained from all participants. A phantom and patient study were conducted with 30 patients (23 men, median age 55.0 (52.0–56.0) years) who underwent 256-slice electrocardiogram-triggered CAC-scoring at four dose levels (routine, 60%, 40%, and 20%-dose) in a single session. Tube-voltage was 120 kVp, tube-current was lowered to achieve stated dose levels. Data were reconstructed with filtered back-projection (FBP) and three IR levels. Agatston, volume and mass scores were determined with validated software and compared using Wilcoxon signed ranks-tests. Subsequently, patient reclassification was analyzed.
Results: The phantom study showed that Agatston scores remained nearly stable with FBP between routine-dose and 40%-dose and increased substantially at lower dose. Twenty-three patients (77%) had coronary calcifications. For Agatston scoring, one 40%-dose and six 20%-dose FBP reconstructions were not interpretable due to noise. In contrast, with IR all reconstructions were interpretable. Median Agatston scores increased with FBP from 26.1 (5.2–192.2) at routine-dose to 60.5 (11.6–251.7) at 20% dose. However, IR lowered Agatston scores to 22.9 (5.9–195.5) at 20%-dose and strong IR (level 7) with Agatston reclassifications in 15%.
Conclusion: IR allows for CAC-scoring radiation dose reductions of up to 80% resulting in effective doses between 0.15 and 0.18 mSv. At these dose-levels, reclassification-rates remain within 15% if the highest IR-level is applied.

1. Introduction

Coronary artery calcium (CAC), as measured by non-contrast cardiac computed tomography (CT), is a strong predictor for future cardiovascular events and mortality.[1–4] Although the presence of CAC does not necessarily imply the presence of flow-limiting coronary artery obstruction, current international guidelines recommend the use of CAC scoring for risk re-stratification of asymptomatic individuals at low-to-intermediate and intermediate risk of cardiovascular disease based on traditional risk factors. In 2007, 600,000 CAC scans were performed in the United States alone, a number expected to increase with the recent guideline support.[3,5] The radiation dose of approximately 1 mSv for CAC scans may be considered relatively low,[6] but in the context of screening growing numbers of healthy individuals, exposure will become considerable on a population level.[7]

Traditionally, CAC scans were reconstructed with an image

Abbreviations: BMI, body mass index; CAC, coronary artery calcium; CT, computed tomography; ECG, electrocardiogram; DLP, dose-length product; FBP, filtered back projection; ICC, intra-class correlation coefficients.

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http://dx.doi.org/10.1016/j.jcct.2015.08.004
1934-5925/

reconstruction algorithm called filtered back projection (FBP). With more powerful computer processing now widely available, iterative reconstruction techniques are being used clinically for CT image reconstruction. Although these iterative reconstruction algorithms are more computationally intensive they have the potential to provide better image quality and indirectly create opportunities for radiation dose reductions.[8–13] However, the optimal combination of radiation dose reduction and iterative reconstruction setting has not yet been evaluated for CAC scoring. Therefore, the aim of the current study was to assess the maximally achievable dose reduction with iterative reconstruction by using a phantom study and subsequently a systematical within-patient study design using CAC scoring at multiple radiation dose levels.

2. Methods

2.1. Phantom study

Prior to the patient study, a phantom study was performed to evaluate the potential radiation dose reduction and make a more informed choice regarding acquisition protocols in the patient study. A commercially available anthropomorphic calcium scoring phantom (QRM GmbH, Moehrendorf, Germany) was scanned with a 256-slice CT system (iCT, Philips Healthcare, Best, The Netherlands). The phantom was surrounded by an external ring (medium size) in order to simulate the thoracic attenuation of an average size patient.[14] An electrocardiogram (ECG) simulator was used at 60 beats per minute to trigger the image acquisition. CT parameters were 120 kVp and 55 mAs (reference level) and the tube-current was decreased with steps of 5 mAs down to 10 mAs. Data were reconstructed with FBP and hybrid iterative reconstruction (iDose^4, Philips Healthcare, Best, The Netherlands) at increasing levels from 3 to 7. Agatston scores of 6 inserts (3 cylindrical inserts of 5 mm diameter and 3 cylindrical inserts of 3 mm diameter) containing hydroxyapatite at different concentrations (800 mg/cm^3, 400 mg/cm^3 and 200 mg/cm^3) were quantified with commercially available software (Heartbeat CS, Philips Healthcare, Best, The Netherlands).

2.2. Patients

Our local institutional review board approved this prospective study and written informed consent was obtained from all participants. Thirty patients with a clinical indication for a cardiac CT successively underwent 4 calcium scoring CT scans in a single session. Patients were scanned between January 2014 and August 2014. Only patients of 50 years or older were selected since the effects of the additional radiation exposure was considered less potentially harmful in these patients compared to younger patients. The routine dose level for CAC scoring of patients $\geq$80 kg at our institution is approximately 0.9 mSv. Additional scans at 60%, 40% and 20% of the routine radiation dose would cumulatively result in a maximal additional dose of 1.1 mSv, for a total of approximately 2 mSv.

2.3. CT protocol and analysis

Image acquisition was performed with a 256-slice CT system (iCT, Philips Healthcare, Best, The Netherlands). If the patient had a resting heart rate above 60 beats per minute at the Cardiology outpatient clinic, the patient was instructed to take 50 mg Metoprolol orally two hours prior to the CT examination. Patients were placed in the supine position and an ECG-trace was recorded during the procedure. If the heart rate was higher than approximately 70 beats per minute, 20 mg of Metoprolol was administered intravenously. First, a locator image was made to select the acquisition region, ranging from the carina of the trachea to the inferior surface of the heart. Second, if the heart rate was regular, acquisition was performed during the mid-diastolic phase with a prospectively ECG-triggered axial scan protocol. In case of an irregular heart rate, acquisition was performed during the systolic phase, also with a prospectively ECG-triggered axial scan protocol. Image acquisition was performed at routine, 40%-reduced, 60%-reduced and 80%-reduced doses for each patient. To make sure patients' heart rates were similar and patients would not move between acquisitions, the technician planned the four acquisitions beforehand. Therefore, the scans were acquired consecutively within a matter of seconds. The following parameters were used: slice thickness, 3 mm; matrix size 512×512 pixels. Tube voltage was kept constant at 120 kVp and tube current-time products depended on body size. Tube current-time products were 50, 30, 20, and 10 mAs for patients with a body weight <80 kg and 60, 36, 24, and 12 mAs for patients with a body weight $\geq$80 kg, respectively. Dose was reduced by decreasing tube current since CAC acquisition protocols are validated at a tube voltage of 120 kVp. Volumetric CT dose index ($CTDI_{vol}$), dose-length product (DLP) and mean heart rates were recorded for each scan. Effective doses were estimated by multiplying DLP with the effective dose estimate of 0.0145 mSv/(mGy $\times$ cm) for the chest.[15]

Raw data were reconstructed with standard FBP and three hybrid iterative reconstruction levels (iDose^4 levels 1, 4 and 7, Philips Healthcare, Best, The Netherlands). Iterative reconstruction algorithms allow for radiation dose reduction due to less noisy images.[13] iDose^4 offers seven levels of noise reduction. Higher iDose^4 levels result in less noise compared to lower levels.

CAC was quantified as Agatston scores, volume scores and mass scores with commercially available validated software (Heartbeat CS, Philips Healthcare, Best, The Netherlands). Signal densities above 130 Hounsfield units (HU) were identified by the software package as potential calcifications. Two observers independently selected the semi-automatically identified regions that were located within the coronary arteries. Subsequently Agatston scores, volume scores and mass scores were quantified by the software package.

2.4. Data analysis

BMI values and heart rates were compared between interpretable and not-interpretable scans using the Mann-Whitney U test. Within-patient CAC scores assessed at different dose levels with different reconstruction algorithms were compared to the reference score (routine radiation dose reconstructed with FBP). Interobserver agreement was evaluated with two-way random single measures intra-class correlation coefficients (ICCs). ICC values above 0.7 were interpreted as good and ICC values above 0.8 were considered excellent.[16] Statistical differences of CAC scores were analyzed with the Friedman test for paired non-parametric continuous data and subsequently post-hoc analyses were performed with the Wilcoxon signed ranks test. Patients were classified based on reference Agatston scores (routine radiation dose reconstructed with FBP): very low risk (score = 0), low risk (0 < score < 10), moderate risk (10 $\leq$ score < 100), moderately high risk (100 $\leq$ score < 400) and high risk (score $\geq$ 400).[13,17,18] Subsequently, the effect of radiation dose reduction and reconstruction settings on reclassification of Agatston scores was evaluated. The risk categories based on reference Agatston scores (routine radiation dose reconstructed with FBP) were used as the reference risk category. Reclassification was defined as a change in risk category for the same patient at a low-dose protocol compared to the reference risk category. Finally recommended CAC scoring