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Research paper

Dose reduction techniques in coronary calcium scoring: The effect of iterative reconstruction combined with low tube voltage on calcium scores in a thoracic phantom☆

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ABSTRACT

Objectives: To define a dose-reduced coronary calcium CT protocol that provides similar calcium score values as a conventional 120 kVp protocol.

Methods: A thorax phantom containing 100 calcifications was scanned with the reference protocol (120 kVp, 90 ref mAs, FBP) and 30 dose-reduced protocols (70–110 kVp, 90 ref mAs, FBP and iterative reconstruction (IR) levels 1–5) with 3rd generation dual-source CT. For protocols that yielded similar detectability and calcium scores as the reference protocol, additional scans were acquired at reduced ref mAs. Kendall's τ_b and independent-samples-median test were used to determine trends and differences in contrast/signal-to-noise ratio (CNR and SNR), dose and calcium scores.

Results: The detectability and calcium scores decreased at increasing IR levels ($\tau b < -0.825$, $p < 0.001$) and increasing tube voltage ($\tau_b < -0.679$, $p < 0.001$). For 90 kVp-IR3 and 100 kVp-IR1, similar detectability and calcium score was found compared to the reference protocol ($p > 0.206$). For these protocols, lower tube currents did not affect the detectability and Agatston score ($p > 0.206$), while CNR and SNR were similar/higher compared to the reference protocol ($0.008 < p < 0.206$). Dose reduction was 60.6% (90 kVp-IR3) and 43.6% (100 kVp-IR1).

Conclusions: The protocol of 90 kVp-IR3 and 100 kVp-IR1 yielded similar calcium detectability, Agatston score and image quality as the reference protocol, with dose reduction up to 60.6%.

1. Introduction

The utility and usage of cardiac computed tomography (CT) has grown exponentially over the last few decades [1]. Within this context, radiation dose reduction of cardiac CT examinations has gained more and more importance due to the widespread use of the technique [2]. Dose reduction has mainly focused on coronary CT angiography (cCTA), and the main breakthrough in cCTA dose reduction was the introduction of faster imaging, tube voltage reduction and iterative reconstruction [3]. However, besides faster imaging techniques, the techniques have not been systematically implemented for coronary artery calcium (CAC) scoring.

Iterative reconstruction is a commonly used reconstruction technique that enables radiation dose reduction (when used in combination with a lower tube current) by reducing image noise and improving image quality. Previous studies have shown that iterative reconstruction algorithms of different vendors show a trend towards lower Agatston scores and lower calcification volume, while differing in effects on calcification mass [4–6]. Another method to reduce radiation dose, is the application of lower tube voltage. While iterative reconstruction has been found to reduce the Agatston score, a lower tube voltage increases the Agatston score if the calcium threshold is kept at 130 Hounsfield Units (HU) [7–9].

Radiation dose reduction for CAC scanning might be feasible by

Abbreviations: ADMIRE, Advanced modeled based iterative reconstruction; cCTA, Coronary CT angiography; CNR, Contrast-to-noise ratio; DSCT, Dual-source computed tomography; FBP, Filtered-back projection; FOV, Field-of-view; IR, Iterative reconstruction; IQR, Interquartile range; ROI, Region of interest; SNR, Signal-to-noise

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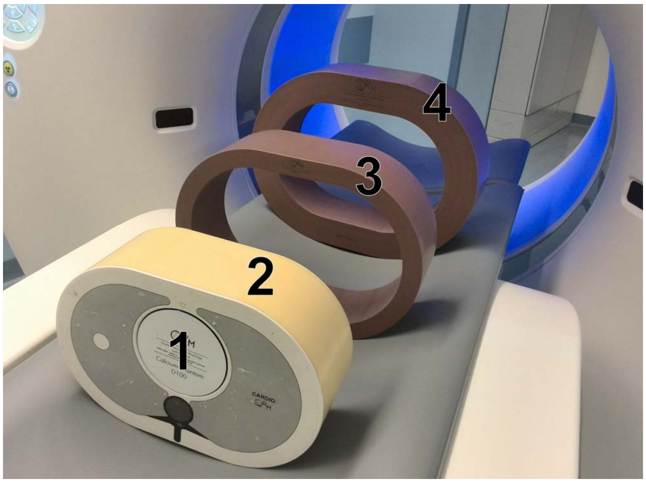

Fig. 1. Overview of phantom set-up. 1) The calcium insert with 100 small calcifications was placed inside the 2) anthropomorphic thorax phantom, representing a small patient size. Additional fat equivalent phantom rings were consecutively placed around the thorax to represent 3) medium and 4) large patient size.

combining low tube voltages with a modeled based iterative reconstruction algorithm at different strengths. In clinical practice, cardiovascular risk stratification is based on the Agatston score derived from scans acquired at 120 kVp and reconstructed with filtered-back projection (FBP). Therefore, any new acquisition protocol should give comparable stratification results as the conventional 120 kVp protocol to be implementable in clinical practice.

The purpose of this study was to define a radiation dose reduced CAC CT protocol that provides similar calcium score values as the traditional 120 kVp protocol.

2. Material and methods

This study was performed using an anthropomorphic cardiac CT thorax phantom representing small patient size (Thorax, QRM, Möhrendorf, Germany) in which a calcium insert was placed, see Fig. 1. Fat rings in the second part of the experiment (see below) represented medium and large size patients. The cylindrical calcium insert included 100 very small calcifications with sizes of 0.5–2.0 mm and density of 90–540 mgHA (D100 insert, QRM, Möhrendorf, Germany). Furthermore, the phantom contained a calibration plane with five cylinders with a diameter of 30 mm with densities of 0, 80, 230, 360 and 530 mgHA/cc, which represented respectively no, very low, low, intermediate and high density calcifications. The five cylinders were used to calibrate for mass measurements.

2.1. Image acquisition and reconstruction

The thorax phantom was scanned with 3rd generation dual-source CT (DSCT) (SOMATOM Definition Force, Siemens, Erlangen, Germany) in high-pitch spiral mode. As reference, data sets were acquired at a tube voltage of 120 kVp and tube current of 90 ref mAs and reconstructed with FBP. This study contained three steps. In the first step, data sets were acquired at low tube voltages of 70, 80, 90, 100 and 110 kVp and tube current of 90 ref mAs. This data were reconstructed with FBP and advanced modeled based iterative reconstruction using five different strength levels: 1–5 (ADMIRE, Siemens, Erlangen, Germany), resulting in 30 combination protocols. Data were reconstructed with a field-of-view (FOV) of 250 mm and a 512 × 512 matrix, a sharp reconstruction filter (Qr36d), slice thickness of 3.0 mm and an increment of 1.5 mm.

The combination protocols of lowered tube voltage and iterative reconstruction strength level that yielded similar calcium detectability (number of detected calcifications out of 100) and calcium scores as the reference protocol were selected for step 2. In step 2, the dose of the selected protocols was reduced by lowering the quality reference mAs in 20% steps, to 72, 54, 36 and 18 ref mAs. Again, the calcium detectability and calcium scores were compared to the reference protocol. Finally, by adding a medium and large fat ring to the thorax phantom (step 3), the impact of these dose reduced protocols were also evaluated for medium and large patient size, by applying the ref mAs that yielded similar results as the reference protocol in step 2. All acquisitions were repeated five times with a small translation and rotation between each scan.

2.2. Data analysis

Image quality was determined by calculating the contrast-to-noise ratio (CNR) and signal-to-noise (SNR) of all the protocols. Regions of interest (ROI) with diameter of 20 mm were drawn and mean HU and standard deviation (SD) of the ROI were registered. Target ROI was the calibration plane of 230 mgHA/cc, and the background ROI was the calibration plane of 0 mgHA/cc representing normal myocardium. The CNR and SNR were calculated as follows:

$$CNR = \frac{meanHU_{target} - meanHU_{background}}{\sqrt{SD_{target}{}^2 + SD_{background}{}^2}} \tag{1}$$

$$SNR = \frac{meanHU_{target}}{SD_{target}} \tag{2}$$

The median radiation dose of each protocol was registered by registering the CTDIvol of each scan. Quantification of calcium was expressed as (1) the number of calcifications that were detected, referred to as calcium detectability, and (2) the total calcium score, denoted as the Agatston score, volume and mass score. Calcium detectability and scores were determined with calcium scoring software (CaScoring, Aquarius iNtuition Viewer, Version 4.1.11, TeraRecon Inc, Foster City, USA) for all scans acquired in step 1, 2 and 3. A calcification was defined as an area comprising ≥2 connected pixels with a density of ≥ 130 HU. Standard scoring algorithms for Agatston score, volume and mass were used, and median and interquartile range (IQR) of the repetitions were calculated [10]. Agatston variability was calculated as follows:

$$Variability = \frac{median(|x_i - median(x)|)\cdot 100\%}{median} \tag{3}$$

In which the median of the absolute difference in Agatston score is divided by the median Agatston score.

2.3. Statistical analysis

Kendall's tau-b (τ_b) was used to analyze trends in Agatston, volume and mass score for the different iterative reconstruction strength levels and tube voltages. The dose reduction protocols were compared to the reference protocol. A difference in median CNR, SNR, detectability and calcium scores was determined by using independent-samples-median test and a difference in distribution was determined by using Mann-Whitney *U* test ($\alpha = 0.05$) (SPSS Statistics, version 22, IBM, USA).

3. Results

3.1. Results of 30 combination protocols of lowered kVp and iterative reconstruction strength levels (step 1)

3.1.1. Image quality

The median CNR and SNR were 10.1 (9.4–10.4) and 14.2 (13.1–14.7), respectively, for the reference protocol of 120 kVp. For the 30 protocols of 70–110 kVp, the median CNR ranged from 9.2–22.1, and the SNR ranged from 13.1–29.1.

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