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CT coronary calcium scoring with tin filtration using iterative beam-hardening calcium correction reconstruction

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A R T I C L E I N F O

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A B S T R A C T

Objectives: To investigate the diagnostic accuracy of CT coronary artery calcium scoring (CACS) with tin pre-filtration (Sn100 kVp) using iterative beam-hardening correction (IBHC) calcium material reconstruction compared to the standard 120 kVp acquisition.

Background: Third generation dual-source CT (DSCT) CACS with Sn100 kVp acquisition allows significant dose reduction. However, the Sn100 kVp spectrum is harder with lower contrast compared to 120kVp, resulting in lower calcium score values. Sn100 kVp spectral correction using IBHC-based calcium material reconstruction may restore comparable calcium values.

Methods: Image data of 62 patients (56% male, age 63.9 ± 9.2years) who underwent a clinically-indicated CACS acquisition using the standard 120 kVp protocol and an additional Sn100 kVp CACS scan as part of a research study were retrospectively analyzed. Datasets of the Sn100 kVp scans were reconstructed using a dedicated spectral IBHC CACS reconstruction to restore the spectral response of 120 kVp spectra. Agatston scores were derived from 120 kVp and IBHC reconstructed Sn100 kVp studies. Pearson's correlation coefficient was assessed and Agatston score categories and percentile-based risk categorization were compared.

Results: Median Agatston scores derived from IBHC Sn100 kVp scans and 120 kVp acquisition were 31.7 and 34.1, respectively ($p = 0.057$). Pearson's correlation coefficient showed excellent correlation between the acquisitions ($r = 0.99$, $p < 0.0001$). Agatston score categories and percentile-based cardiac risk categories showed excellent agreement ($\kappa = 1.00$ and $\kappa = 0.99$), resulting in a low cardiac risk reclassification of 1.6% with the use of IBHC CACS reconstruction. Image noise was 24.9 ± 3.6HU in IBHC Sn100 kVp and 17.1 ± 3.9HU in 120 kVp scans ($p < 0.0001$). The dose-length-product was 13.2 ± 3.4 mGy cm with IBHC Sn100 kVp and 59.1 ± 22.9 mGy cm with 120 kVp scans ($p < 0.0001$), resulting in a significantly lower effective radiation dose (0.19 ± 0.07 mSv vs. 0.83 ± 0.33 mSv, $p < 0.0001$) for IBHC Sn100 kVp scans.

Conclusion: Low voltage CACS with tin filtration using a dedicated IBHC CACS material reconstruction algorithm shows excellent correlation and agreement with the standard 120 kVp acquisition regarding Agatston score and cardiac risk categorization, while radiation dose is significantly reduced by 75% to the level of a chest x-ray.

Abbreviations: BMI, body mass index; CACS, coronary artery calcium scoring; CAD, coronary artery disease; CCTA, coronary CT angiography; CI, confidence interval; $CTDI_{vol}$, volumetric CT dose index; DLP, dose-length-product; DSCT, dual-source CT; ED, effective dose; FBP, filtered-back-projection; HU, hounsfield units; IBHC, iterative beam hardening correction; SD, standard deviation

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1. Introduction

CT coronary artery calcium scoring (CACS) is a well-established screening test to assess cardiovascular risk and to guide the aggressiveness of prevention [1,2]. The test is typically performed in *a priori* healthy, asymptomatic individuals. Like all imaging involving ionizing radiation, CACS should be performed according to the guiding principle of radiation protection: radiation exposure "as low as reasonably achievable" (ALARA principle) while maintaining adequate image quality for the given scenario [3]. Technical improvements in the last decade have enabled significant reductions in radiation dose in cardiac CT angiography (CCTA) [4–6]. However, the acquisition protocol for CACS has not significantly changed, despite advances in the relevant software and hardware. Iterative reconstruction techniques, which have become routine in most centers for CCTA, have variable effects on calcium quantification, often precluding their adoption in CACS [7–9]. Furthermore, standard CACS acquisition protocols recommend maintaining a fixed peak tube voltage of 120 kVp to ensure calcium scores according to the Agatston method [10], whereas tube voltages in CCTA acquisitions have steadily decreased. These factors have led to continuous reductions in radiation exposure associated with CCTA, while CACS is still associated with average radiation doses of 1–1.5 mSv [3,10].

Third generation dual-source CT (DSCT) with tin filtration can reduce the radiation dose of low-dose non-contrast enhanced scans [11,12]. Recently, the potential of CT tin filtration (Sn100 kVp) for low voltage CACS has been demonstrated with excellent accuracy and a significant reduction in radiation dose compared to the standard 120 kVp acquisition. However, the Sn100 kVp acquisition showed a systematic decrease in Agatston scores with consequent changes in patient categorization and cardiac risk classification [13].

Tin filtration results in a harder x-ray spectrum of the Sn100 kVp acquisition compared to the standard 120 kVp spectrum, as it possesses a slightly higher mean. The resulting reduction in calcium Hounsfield units (HU) values affects the overall calcium Agatston score. Third generation DSCT also supports Iterative Beam Hardening Correction (IBHC), a raw data-based beam hardening correction reconstruction technique. A dedicated spectral IBHC CACS material reconstruction can restore the spectral response of standard 120 kVp spectrum, which may enable the derivation of comparable Agatston score values from the Sn100 kVp acquisition.

Thus, we sought to investigate the accuracy of CACS using Sn100 kVp acquisition with IBHC-based calcium material reconstruction compared to the standard 120 kVp protocol.

2. Material and methods

2.1. Study population

This single-center retrospective study was approved by the local Institutional Review Board and written informed consent was obtained from all patients. The study was performed in compliance with HIPAA regulations. Data of 66 patients who underwent a clinically indicated CACS and a dedicated ECG-triggered 100 kVp calcium scan with tin filtration (Sn100 kVp) as part of a research study between February and May 2016 were retrospectively analyzed. Exclusion criteria comprised known coronary artery disease (prior percutaneous stent implantation or coronary artery bypass grafting). Furthermore, patients with implanted mechanical prosthetic valves ($n = 2$) or cardiac devices ($n = 2$) were excluded to prevent imaging artifacts. Thus, a total of 62 patients were included for further analysis.

2.2. CT acquisition parameters and image reconstruction

CT acquisition was performed with a 3rd generation DSCT system (SOMATOM Force, Siemens Healthcare, Forchheim, Germany) equipped with a fully integrated circuit detector system (Stellar Infinity, Siemens) and two x-ray tubes (Vectron, Siemens).

Traditional calcium scoring was performed via a prospectively ECG-triggered non-contrast sequential acquisition performed at 40% (HR ≥ 80bpm) or 70% (HR < 80bpm) of the cardiac cycle using the following parameters: tube voltage 120 kVp; automated tube current modulation (CARE Dose4D, Siemens), reference tube current-time product of 80 mAs, collimation: 44 × 1.2 mm, gantry rotation time 0.25 s, matrix size 512 × 512 pixels.

As a research test, an additional prospectively ECG-triggered non-contrast dual source scan with tin filtration was performed on the scanner by means of custom software. Tin filtration was used on both tubes with a tube voltage of 100 kVp (Sn100 kVp) triggered at 40% (HR ≥ 80bpm) or 70% (HR < 80bpm) of the cardiac cycle with the following scan parameters: automated tube current modulation (CARE Dose4D, Siemens) with a reference tube current of 300 mAs/rot, collimation: 42 × 1.2 mm, gantry rotation time 0.25 s.

The standard 120 kVp scans were reconstructed with a routine weighted filtered back projection (WFBP) algorithm, using a medium sharp convolution kernel (Qr36), 3.0 mm section thickness, and an increment of 1.5 mm. The Sn100 kVp studies were reconstructed using a WFBP algorithm with a dedicated IBHC-based calcium material reconstruction, with a medium sharp convolution kernel (Qr36), 3.0 mm section thickness and increment of 1.5 mm. Typical reconstruction field of view (FOV) was 160 × 160 mm, depending on patient anatomy, in a 512 × 512 pixel image matrix.

2.3. Image analysis of CACS scans

Dedicated post-processing evaluation software (*syngo*.via VB10 Calcium Scoring, Siemens Healthcare, Forchheim, Germany) was used for objective and subjective image analyses. Quantification of coronary artery calcium on non-contrast scans was performed by two independent observers with more than 3 and 5 years of experience in cardiovascular imaging. Both were blinded to patient characteristics and the imaging report. The extent of calcification, defined as a plaque with an area $\geq 1.03\ mm^2$, was determined using the Agatston score with a detection threshold of 130 HU [1]. To facilitate observer blinding, the minimum time between the evaluations of calcium on corresponding series was 1 week for both observers. The total Agatston score was recorded and values for both acquisitions were compared. Agatston score categories were as follows: 0, 1–10, 11–100, 101–400, 401–1000, and > 1000 [14]. Accordingly, Agatston score percentile-based risk categorization was as follows: 0% (very low), 1–25% (low), 26–50% (mild), 51–75% (moderate), 76–95% (high), and > 95% (very high) [15]. Signal and noise were determined by placing a region of interest ($1\ cm^2$) in the left ventricle. Consistent placement and size of the region of interest was ensured throughout all examinations. The mean (i.e. signal) and standard deviation (SD; i.e. noise) of HU were recorded and the signal-to-noise ratio (SNR) was calculated by dividing the mean HU by the SD. Observers evaluated subjective image quality based on a 4-point Likert scale: 1 = poor, 2 = fair, 3 = good and 4 = excellent. To estimate radiation dose, the volumetric CT dose index ($CTDI_{vol}$), effective tube current-time product and dose-length-product (DLP) were recorded. Effective radiation dose (ED) was estimated by multiplying the DLP with a standard conversion factor of 0.014 mSv/mGy cm [16].

2.4. Statistical analysis

MedCalc (MedCalc Software, version 15, Ostend, Belgium) and SPSS (SPSS 23.0, IBM, Chicago, USA) were used for statistical analysis. Continuous variables were expressed as mean ± SD. Normal distribution was assessed using the Kolmogorov-Smirnov test. Differences in patient demographics, characteristics, and CT acquisition parameters of the 120 kVp and IBHC Sn100 kVp acquisitions were evaluated using the