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Iterative model reconstruction reduces calcified plaque volume in coronary CT angiography

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ABSTRACT

Objective: To assess the impact of iterative model reconstruction (IMR) on calcified plaque quantification as compared to filtered back projection reconstruction (FBP) and hybrid iterative reconstruction (HIR) in coronary computed tomography angiography (CTA).
Methods: Raw image data of 52 patients who underwent 256-slice CTA were reconstructed with IMR, HIR and FBP. We evaluated qualitative, quantitative image quality parameters and quantified calcified and partially calcified plaque volumes using automated software.
Results: Overall qualitative image quality significantly improved with HIR as compared to FBP, and further improved with IMR ($p < 0.01$ all). Contrast-to-noise ratios were improved with IMR, compared to HIR and FBP (51.0 [43.5–59.9], 20.3 [16.2–25.9] and 14.0 [11.2–17.7], respectively, all $p < 0.01$) Overall plaque volumes were lowest with IMR and highest with FBP (121.7 [79.3–168.4], 138.7 [90.6–191.7], 147.0 [100.7–183.6]). Similarly, calcified volumes (>130 HU) were decreased with IMR as compared to HIR and FBP (105.9 [62.1–144.6], 110.2 [63.8–166.6], 115.9 [81.7–164.2], respectively, $p < 0.05$ all). High-attenuation non-calcified volumes (90–129 HU) yielded similar values with FBP and HIR ($p = 0.81$), however it was lower with IMR ($p < 0.05$ both). Intermediate- (30–89 HU) and low-attenuation (<30 HU) non-calcified volumes showed no significant difference ($p = 0.22$ and $p = 0.67$, respectively).
Conclusions: IMR improves image quality of coronary CTA and decreases calcified plaque volumes.

1. Introduction

Automated plaque quantification with coronary computed tomography angiography (CTA) allows highly reproducible assessment of plaque dimensions, however its performance is influenced by image quality [1–3]. Most coronary CTA studies have been reconstructed with noise prone filtered back projection (FBP). With hardware evolution, vendors facilitated the introduction of computationally intense iterative image processing techniques, potentiating low-dose CT imaging with improved image quality [4–7]. Hybrid iterative reconstruction (HIR) utilizes statistic-model based denoising both in raw and image domains, providing up to 55% noise reduction for cardiac image acquisition at standard tube settings [8]. Moreover, two recent studies demonstrated that HIR has no significant effect on plaque morphology assessment [9,10]. Three-dimensional raw data based reconstruction techniques were

Abbreviations: CTA, computed tomography angiography; CX, circumflex artery; FBP, filtered back projection; HIR, hybrid iterative reconstruction; HU, Hounsfield units; IMR, iterative model reconstruction; LAD, left anterior descending artery; RCA, right coronary artery; SCCT, Society of Cardiovascular Computed Tomography.

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Table 1
Patient demographics and imaging parameters.

Patient data (N = 52)	
Age (years), median [IQR]	66.0 [59.0–71.8]
BMI (kg/m^2), median [IQR]	27.5 [25.0–30.8]
Female gender, n (%)	13 (25)
Cardiovascular risk factors, n (%)	
Hypertension	41 (78.8)
Diabetes	9 (17.3)
Dyslipidemia	28 (53.8)
PAD	7 (13.5)
Stroke	5 (9.6)
Smoking	20 (38.5)
Prior use of beta blocker, n (%)	22 (42.3)
CTA characteristics, median [IQR]	
Contrast agent (ml)	95.0 [90.0–95.0]
DLP (mGy × cm)	308.0 [307.0–308.0]
Average heart rate (beats/min)	57.0 [52.0–60.0]

SD: standard deviation; IQR: interquartile range; BMI: body mass index; PAD: peripheral arterial disease; DLP: dose length product.

introduced with forward modeling of system geometry (focal spot size, shape of X-ray beam, interactions of emitted photons with tissue and detector) additionally to statistical modeling [11]. Preliminary data showed the potential of model based iterative reconstruction techniques to achieve more robust noise reduction and/or improved image quality of coronary CTA [12,13].

There is a growing body of evidence regarding the prognostic value of quantified coronary plaque volume for adverse events. Our study group previously demonstrated significant changes in coronary calcium scores using novel iterative reconstruction algorithms [14]. We hypothesize that novel model based iterative reconstruction could influence measured plaque volumes that ultimately influence individual risk assessment. Therefore, we aimed to further elucidate the effects of the latest iterative model reconstruction (IMR) on coronary plaque assessment as compared to HIR and FBP.

2. Material and methods

2.1. Study population

We studied 52 consecutive individuals who underwent routine clinical coronary CTA examination due to suspected coronary artery disease. Patients who showed calcified and/or partially calcified plaque were included in the further analysis to study plaque characteristics. As we used automated plaque quantification, partially calcified lesions were not further distinguished to predominantly non-calcified or predominantly calcified plaque types, as recommended the Society of Cardiovascular Computed Tomography (SCCT) for qualitative plaque reading [15]. We excluded patients with previous bypass surgery or coronary stent implantation. To minimize the impact of motion artifact on image quality, patients not in sinus rhythm and/or with a heart rate of ≥65 beat per minute during CTA data acquisition were excluded. Informed consent was waived by the institutional review board (IRB) due to the retrospective design of the study. No additional data acquisition was performed in addition to routine care CTA examinations. Patient demographics are summarized in Table 1.

2.2. Coronary CTA scan protocol

All examinations were performed with a 256-slice scanner (Brilliance iCT 256, Philips Healthcare, Best, The Netherlands) with prospective ECG-triggered acquisition mode. Images were acquired in cranio-caudal direction during a single breath-hold in inspiration. The following imaging parameters were used for data acquisition: 128×0.625 mm detector collimation, 270 ms gantry rotation time, 120 kV tube voltage and 300 mAs tube, field-of-view of 18 cm with a matrix of 512×512. A mid-diastolic triggering was used with 3% padding. Iomeprol contrast media with an iodine concentration of 400 mg/ml (Iomeron 400, Bracco Ltd, Milan, Italy) was injected into an antercubital vein via an 18-gauge catheter and dual-syringe system. A triphasic injection protocol (1. saline; 2. 100% contrast; 3. 25% contrast) with 90–95 ml contrast agent was used at a flow rate of 5.0-5.5 ml/s. We used bolus tracking technique with a region of interest (ROI) placed in the left atrium for proper scan timing. Table 1 shows CTA main characteristics.

2.3. CTA image reconstruction

All coronary CTA images were reconstructed with FBP, HIR (iDOSE^4, Philips Healthcare, Cleveland, OH, USA) and IMR (IMR, Philips Healthcare, Cleveland, OH, USA). To ensure data consistency, all three datasets for each patient were generated on an external prototype workstation dedicated for the study. We reconstructed all images with 0.8 mm slice thickness, 0.4 mm increment and medium cardiac kernel. We applied a moderate iteration level for HIR (level 4 of 1–7) and IMR (level 2 of 1–3).

2.4. CTA data analysis

We used a commercially available DICOM viewer (Osirix, version 5.5.1; Osirix Foundation, Geneva, Switzerland) for image quality assessment. Image quality parameters were evaluated blinded to reconstruction type in a random order. For qualitative assessment we reviewed single datasets using fixed window settings (window width of 200 HU and window level of 700 HU). For quantitative analysis we displayed the triplets of datasets side by side for each patient to ensure the same level of ROI placement. We transferred the datasets present with any calcified or partially calcified plaque to a dedicated offline workstation (QAngio, version 2.1; Medis Medical Imaging Systems, Leiden, The Netherlands) for further plaque characterization. One reader with 5 years of experience in coronary CTA read all studies. 20 randomly selected datasets were reevaluated by another reader with 3 years of experience in coronary CTA to assess intra-observer differences.

2.5. Qualitative image quality analysis

We used the guidelines of the SCCT for the assessment of the coronary segments [15]. The proximal and distal segments of the left anterior descending artery (LAD), circumflex artery (CX) and right coronary artery (RCA) were evaluated. As we aimed to assess the differences between proximal and distal coronary segments, middle coronary segments and side branches were not included in our analysis. Four point Likert-scale was used to rate subjective image quality parameters on axial slices [16]. Overall image quality was defined as a summary of image sharpness, image noise and blooming artifacts, if present and rated as follows: non-diagnostic (0); moderate, considerable artifacts with diagnostic image quality (1); good, minor artifacts (2) and excellent (3) image quality. Subjective noise was further analyzed and categorized according to the graininess on the coronary CTA image: severe image noise (0); above average (1); average (2); no image noise (3).

2.6. Quantitative image quality analysis

Circular regions of interest (ROIs; 3–4 mm^2) were manually placed in the coronary arteries and pericoronary fat to obtain median CT number in Hounsfield units (HU). ROIs were placed in a homogenous region of the proximal and distal segments of LAD, CX