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Research article

Impact of advanced modeled iterative reconstruction on interreader agreement in coronary artery measurements

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ABSTRACT

Objectives: To evaluate the influence of advanced modeled iterative reconstruction (ADMIRE) on coronary artery computed tomography angiography (cCTA) measurements in comparison to filtered back projection (FBP).

Material and methods: Phantom scans and coronary CTA studies of 27 patients were acquired with a third generation dual-source CT scanner. Images were reconstructed using FBP and ADMIRE. Phantom measurements were used as reference standard. In patient studies, representative axial slices of each coronary artery segment without (n = 308) and with coronary plaques (n = 40) were assessed in identical positions for comparison of FBP and ADMIRE reconstructions. Image analyses included quality assessment, phantom and coronary artery measurements, plaque analysis, and interreader agreement of two independent and blinded readers.

Results: Mean image noise was lower on ADMIRE reconstructions with 31.3 ± 9.9 HU compared to 55.9 ± 15.7 HU on FBP reconstructions ($p < 0.001$). Measurement precision and interreader agreement of both observers were assessed satisfactorily on phantom images in comparison to the full width half maximum method. In patients, correlation of lumen diameters of both observers improved using ADMIRE with a Pearson's r = 0.987 (95% confidence interval [CI], 0.983–0.989; $p < 0.001$) compared to FBP images with r = 0.939 (95% CI, 0.924–0.951; $p < 0.001$). Applying ADMIRE, agreement of both observers for lumen diameter measurements significantly increased ($p < 0.001$). This was also observed for the degree of stenosis ($p < 0.001$) with r = 0.560 using FBP (95% CI, 0.301–0.742) and with r = 0.818 using ADMIRE (95% CI, 0.680–0.900). Plaque density measurements correlated closely with a Pearson's r of 0.951 in FBP (95% CI, 0.909–0.974) and 0.967 in ADMIRE (95% CI, 0.939–0.983).

Conclusions: Advanced modeled iterative reconstruction significantly improves coronary artery assessment in coronary CTA in comparison to FBP by improved image quality due to image noise removal. This renders improved interobserver agreement for coronary lumen diameter and degree of stenosis measurements without influencing mean plaque attenuation.

1. Introduction

Current guidelines consider cCTA the preferred tool for diagnosis and risk assessment in patients with low or intermediate pretest probability for coronary artery disease (CAD) [1]. In the last decades, filtered back projection (FBP) had been the standard image reconstruction algorithm in computed tomography, and it still is for coronary calcium measurements, whereas increasing computational power allows for replacing FBP by iterative reconstruction (IR) algorithms.

Advanced modeled IR (ADMIRE) was introduced with the third-generation of dual-source CT scanners and has been demonstrated to produce convincing image quality with effective doses of as low as 0.3 mSv in a selected population [2–4].

We sought to investigate, if image reconstruction using ADMIRE allows for an improved coronary artery evaluation in comparison to FBP. Our aim was to focus on the more clinical and disease-related questions, whether this new technique affects assessment of coronary artery diameter, mean plaque attenuation, degree of stenosis and interrater agreement, as results from these measurements can have significant impact on therapy and judgement of disease outcome [5,6]. It is important that IR does not lead to potentially relevant miscalculations of imaging results, as e.g. a previous study on coronary calcium

Abbreviations: bpm, beats per minute; CAD, coronary artery disease; cCTA, coronary computed tomography angiography; FBP, filtered back projection; FWHM, full width at half maximum; HU, Hounsfield units; IR, iterative reconstruction; kVp, kilovoltage peak; mSv, millisievert; SD, standard deviation

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scoring has shown [7]. Based on the results of phantom experiments, which were used as reference, we compared interrater agreement in coronary artery analyses of both reconstruction techniques in a non-selected cohort of consecutive patients referred for coronary computed tomography angiography (cCTA).

The purpose if this study was to evaluate the influence of advanced modeled IR (ADMIRE) on cCTA in comparison to FBP.

2. Material and methods

2.1. Study population

The requirement for approval or written informed consent for this retrospective study was waived by the institutional review board. All CT examinations had been performed upon clinical indication. A total of 27 consecutive patients undergoing cCTA for the diagnostic workup of suspected CAD were included. Indications for cCTA were in accordance with current national and international guidelines, and all patients had a low to intermediate risk of CAD [1,8].

2.2. CTA acquisition technique applied for cCTA in patients

In the absence of contraindications, patients with heart rates over 65 beats per minute (bpm) received 47.5 mg of metoprolol per os 60 min prior to scanning. Immediately before acquisition of the cCTA, all patients sublingually received 0.8 mg of glyceryl trinitrate (Nitrolingual® akut Spray, Pohl-Boskamp, Hohenlockstedt, Germany).

Scans were performed with a 192-slice third-generation dual-source CT scanner (SOMATOM Force, Siemens Healthineers, Forchheim, Germany), equipped with two integrated circuit detectors (Stellar Infinity, Siemens), one covering a 50 cm scan field of view, the other covering a 35.4 cm scan field of view. Firstly, a standard calcium scoring protocol for determination of Agatston scores was performed (data not included in the study). Scan range of the cCTA ranged from 1 cm cranial the coronary arteries to 1 cm caudal the heart as displayed in the calcium scoring scan. Depending on heart rate during the calcium scoring scan, cCTA was performed with one of the following protocols: in case of a heart rate up to 65 bpm with a prospectively ECG-gated high-pitch spiral during one heart cycle ($n = 9$), in case of a heart rate between 66 and 75 bpm with a prospectively ECG-gated sequential acquisition ($n = 13$) and in patients with a heart rate higher than 75 bpm with a retrospectively ECG-gated spiral ($n = 5$). Adjusted to body weight either 50 or 60 ml of iodinated contrast media (Ultravist® 370 mg, Bayer Vital, Leverkusen, Germany) were injected, followed by a 40 ml saline chaser at a flow rate of 5 ml/s through an antecubital vein with a dual-head power injector (CT motion™, ulrich medical, Ulm, Germany). Scans were initiated by bolus tracking with a region of interest (ROI) placed in the ascending aorta, automatically starting acquisition of the cCTA 9 s after reaching a preset attenuation threshold of 100 Hounsfield units (HU). All scans were acquired in dual-source mode with a collimation of 96 × 0.6 mm, diagonal flying focal spot and a gantry rotation time of 250 ms. Automatic exposure control was active, enabling both the adjustment of tube voltage (CAREkV, Siemens) and tube current (CAREDose, Siemens) based on the topogram information.

2.3. CTA acquisition technique applied for coronary artery phantom experiments

Phantom experiments were performed using a dedicated, stationary coronary artery phantom for defining a reference standard and for validating coronary artery measurements of both observers in patients. The coronary artery phantom was constructed with a straight, round plastic tube with a defined lumen diameter of 3.5 mm. The tube lumen was filled with contrast material diluted to a density of 350 HU at 120 kVp for representing a coronary artery. The tube was placed in a plastic box filled with an emulsion of sunflower oil and Lipiodol® Ultra-Fluid (Guerbet, Roissy CdG Cedex, France) adjusted to a density of −70 HU at 120 kVp, simulating the attenuation of epicardial fat. This phantom construction had been used and was validated in previous studies [9,10]. The phantom was installed on the CT table and exactly aligned along the z-axis using the gantry lasers. Scans of the coronary artery phantom were performed at different tube voltages, ranging from 70 kVp to 150 kVp in 10 kVp steps with a complementary scan at 150 kVp employing an additional tin filter. Images were reconstructed in axial plane for displaying the orthogonal round lumen of the plastic tube using identical reconstruction parameters as used for the cCTA scans of patients, which are described in the following paragraph.

2.4. Image reconstruction technique of phantom scans and cCTA scans in patients

Images were reconstructed with a slice thickness of 0.6 mm, an increment of 0.3 mm, and a field-of-view of 180 mm with an image matrix of 512 × 512 pixels. Each data set was reconstructed with FBP and with IR using a medium-soft (Bv40) convolution kernel optimized for vascular imaging (ADMIRE, Siemens). A strength level of 4 was chosen for the IR according to the study of Gordic et al. and considered an optimal setting for noise removal and image quality [4]. Details and operation mode of the applied IR kernel have been discussed before [11].

2.5. Assessment of coronary artery phantom images

Images were quantitatively analyzed by two independent and blinded readers. Readers contoured the circular margin of the plastic tube lumen using a free-hand region of interest (ROI) tool (OsiriX 8.0, Pixmeo SARL, Bernex, Switzerland). The measured area (A) of this ROI and its mean density were documented. The area measurements were used to calculate effective lumen diameters (d) using the formula $d = 2 \times \sqrt{(A/\pi)}$. Standard deviations of the ROI mean density were used to assess the noise removal potential of ADMIRE in comparison to FBP at different tube voltages. Additionally, the full width at half maximum (FWHM) method was used to calculate objective measurements of the tube lumen diameter. The slope of the FWHM curve was used as a parameter for assessing contrast sharpness. FWHM measurements were considered the reference standard. The manual lumen measurements of both observers were compared with the FWHM results, to individually assess the measurement precision of both observers. Further, this method was chosen for substantiating the reliability of manual patient measurements of both observers, as the clinical reference standard conventional coronary angiography was not available.

2.6. Image quality assessment of cCTA in patients

For quality assessment of cCTA, mean attenuation and noise defined as standard deviation of the attenuation were measured by drawing a region-of-interest (ROI) in the ascending aorta. Signal-to-noise ratio (SNR) was calculated as mean attenuation in the ascending aorta divided by image noise.

2.7. Quantitative assessment of coronary arteries on cCTA reconstructions in patients

2.7.1. Coronary lumen measurements

Images were analyzed using commercially available 3D reading software (syngo.via, Siemens Healthineers, Forchheim, Germany) using the dedicated coronary artery CTA analysis tool. In each data set reconstructed with FBP and ADMIRE, automatic segmentation and calculation of Curved Planar Reformations of the coronary arteries was performed without user interaction. Axial slices orthogonal to the