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Low concentration contrast medium for dual-source computed tomography coronary angiography by a combination of iterative reconstruction and low-tube-voltage technique: Feasibility study

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ABSTRACT

Objectives: To assess the impact of low-concentration contrast medium on vascular enhancement, image quality and radiation dose of coronary CT angiography (cCTA) by using a combination of iterative reconstruction (IR) and low-tube-voltage technique.

Materials and methods: One hundred patients were prospectively randomized to two types of contrast medium and underwent prospective electrocardiogram-triggering cCTA (Definition Flash, Siemens Healthcare; collimation: 128 mm × 0.6 mm; tube current: 300 mA s). Fifty patients received Iopromide 370 were scanned using the conventional tube setting (100 kVp or 120 kVp if BMI ≥ 25 kg/m^2) and reconstructed with filtered back projection (FBP). Fifty patients received Iodixanol 270 were scanned using the low-tube-voltage (80 kVp or 100 kVp if BMI ≥ 25 kg/m^2) technique and reconstructed with IR. CT attenuation was measured in coronary artery and other anatomical regions. Noise, image quality and radiation dose were compared.

Results: Compared with two Iopromide 370 subgroups, Iomeprol 270 subgroups showed no significant difference in CT attenuation (576.63 ± 95.50 vs. 569.51 ± 118.93 for BMI < 25 kg/m^2, p = 0.647 and 394.19 ± 68.09 vs. 383.72 ± 63.11 for BMI ≥ 25 kg/m^2, p = 0.212), noise (in various anatomical regions of interest) and image quality (3.5 vs. 4.0, p = 0.13), but significantly (0.41 ± 0.17 vs. 0.94 ± 0.45 for BMI < 25 kg/m^2, p < 0.001 and 1.14 ± 0.24 vs. 2.37 ± 0.69 for BMI ≥ 25 kg/m^2, p < 0.001) lower radiation dose, which reflects dose saving of 56.4% and 51.9%, respectively.

Conclusions: Combined IR with low-tube-voltage technique, a low-concentration contrast medium of 270 mg I/ml can still maintain the contrast enhancement without impairing image quality, as well as significantly lower the radiation dose.

1. Introduction

From clinical perspective, reducing the amount of iodine as much as possible would help to avoid contrast-induced nephropathy (CIN) in patients at risk, because the probability of CIN is mainly determined by the amount of iodine delivered to patients [1,2]. Hence, under the same volume and injection flow rate, a low iodine concentration contrast medium can be a solution to reduce the iodine burden of patients. However, a previous study compared several types of contrast medium with different iodine concentrations at the same volume and injection flow rate for multiple detector-row computed tomography (MDCT) angiography of the coronary arteries, and have shown that lower vascular attenuation could be achieved with the lowest iodine concentration [3]. That is, the lower the iodine concentration, the lower the density will be within the region of interest. Low density in cardium and vessels may result in degraded image quality and diagnostic accuracy.

To overcome this limitation, low-tube-voltage technique may be a choice. Several studies have demonstrated that acquisition scans with reduced tube voltage (kVp) would improve contrast conspicuity in CT angiography (CTA) studies [4–6]. The use of a low tube voltage, such as 80 kVp, would result in higher CT values (contrast enhancement), because the mean effective energy of the X-ray spectrum is closer to the *K*-edge of iodine (33.2 keV) [6]. This approach has been widely used in CTA studies. However, lowering kVp might lead to degraded image quality because of higher susceptibility for beam hardening artifacts and increased image noise due to low photon flux. This concern has prevented the clinical implementation of low kVp technique.

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However, iterative reconstruction techniques (IRT) introduced into the market lately are less susceptible to artifacts and show therefore less image noise. They can reduce image noise to a great extent, and effectively increase signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR). They are therefore able to achieve equivalent or better image quality in abdominal and thoracic CT scans compared to routine-dose filtered back projection (FBP) reconstruction algorithms [7–9]. This technique has also been extended to coronary CTA (cCTA) scans. Recent studies have shown that IRT can reduce radiation dose in cCTA by 44–76% compared to FBP without impairing image quality [10–12]. In consequence, IRT can compensate for image quality in low tube voltage scans.

Although IRT has shown to reduce image noise and dose radiation in cCTA, a new iterative reconstruction technique (SAFIRE) has not been formally used to evaluate the influence of low iodine concentration contrast medium for dual-source CT (DSCT) coronary angiography. We assume that SAFIRE would retain the image quality and image noise as well as reduce radiation dose when both low iodine concentration contrast medium and low tube voltage technique were used. The goal of this study was to assess the impact of low concentration contrast medium on the attenuated CT values and image noise in cCTA when using a combination of iterative reconstruction and low-tube-voltage technique.

2. Materials and methods

2.1. Patient population

A total of 100 patients (56 man, 44 women; mean age, 54 ± 10 years; age range, 34–79 years) were referred to noninvasive DSCT coronary angiography for suspected coronary artery disease. All patients were enrolled prospectively in the study. Patients with arrhythmia, renal insufficiency (a serum creatinine level more than 1.5 mg/dl), a history of allergic reaction to contrast medium, previous history of surgery or stenting for coronary artery diseases, heart failure, untreated hyperthyroidism and women who were pregnant or nursing were not eligible for study participation. Patients with a prescanning heart rate of 90 beats per minute (bpm) or higher were excluded. Patients underwent calcium scoring with an Agatston score of at least 400, which is indicative of substantial calcified plaque burden were also excluded. The institutional review board approved this study and all patients had provided written informed consent to participate in this study. Patients were randomly assigned into two groups (of 50 patients each), which were differed by the iodine concentration of contrast medium that was administered. Group A patients received Iopromide 370 (370 mg I/ml, Ultravist 370, Bayer Schering Pharma, Berlin, Germany) and group B patients received Iodixanol 270 (270 mg I/ml, Iodixanol 270, GE Healthcare). Each group was further divided into two subgroups (of 25 patients each) with respect to the body mass index (BMI) (BMI < 25 kg/m^2 or BMI ≥ 25 kg/m^2) in which tube voltage was individualized. For each patient, age, sex, height, body weight and heart rate before scanning were recorded.

2.2. CT image acquisition

All studies were performed on a second generation 128-slice DSCT system (SOMATOM Definition Flash, Siemens Healthcare, Forchheim, Germany). All patients were instructed about breath holding and the importance of immobility during scanning. Just before the injection of contrast medium, 0.5–1.0 mg nitroglycerin was administered sublingually for vessel dilation. All scans were performed in a craniocaudal direction with prospective electrocardiogram (ECG)-triggering sequential protocol. The cCTA scanning parameters were chosen individually for each patient depending on the BMI. The scanning parameters for two groups were as follows: range of data acquisition at 65–75% of the R–R interval when baseline heart rate (HR) was ≤70 bpm or 35–45% of the R–R interval when baseline HR was >70 bpm, slice collimation 2 mm × 64 mm × 0.6 mm with a z-flying focal spot, gantry rotation time 280 ms, reference tube current–time product 300 mA s, tube voltage 100 kV (BMI < 25 kg/m^2) or 120 kV (BMI ≥ 25 kg/m^2) in Iopromide 370 group and 80 kV (BMI < 25 kg/m^2) or 100 kV (BMI ≥ 25 kg/m^2) in Iodixanol 270 group, respectively.

The contrast medium was injected with an 18-guage needle through the right antecubital veins by use of a dual-syringe power injector (Stellant-Dual Flow; Medrad, Pittsburgh, PA, USA). A total of 1 ml/kg of body weight of contrast medium, followed by 40 ml of saline solution was administered. Injection rate was 5 ml/s for both contrast medium and the saline solution. Contrast medium injection was timed by bolus tracking in a sample region of interest, the ascending aorta, with the scan begun 10 s after exceeding a threshold of 100 Hounsfield units (HU). The resulting iodine flux (iodine delivery rate, IDR) was 1.85 g iodine/s for Iopromide 370 and 1.35 g iodine/s for Iodixanol 270, respectively. The IDR was calculated as follow: IDR (g I/s) = [iodine concentration (mg I/ml) × injection rate of contrast medium (ml/s)]/1000 mg/g [13].

2.3. Image data reconstruction

Images from the Iopromide 370 group were reconstructed using a conventional FBP algorithm with a medium smooth kernel designed for cardiac imaging (B26f). The resulting images from the Iodixanol 270 group were reconstructed with sinogram-affirmed iterative reconstruction (SAFIRE, Siemens Healthcare, Forchheim, Germany) algorithm using the corresponding vascular kernel (I26f). Five adjustable increments (strength 1–5) are available for adaptation of the noise model. As recommended by manufacturer, a medium strength of level 3 was used in Iodixanol 270 group. Transverse images were reconstructed at 0.75-mm slice thickness with a 0.5-mm increment and in a matrix size of 512 × 512. All images were anonymized and transferred to an external workstation (*syngo* MMWP VE 36A, Siemens Healthcare, Forchheim, Germany) for further image analysis. With the use of axial data, two experienced cardiac radiologists also reconstructed curved multiplanar reformation (CPR) images of the coronary arteries for image quality evaluation.

2.4. Evaluation of contrast enhancement in coronary arteries

All axial and three-dimensional reconstructed coronary images were analyzed in consensus by two experienced cardiac radiologists (Zheng MW and Zhao HL, with 10 and 8 years experience in cCTA, respectively) who were blinded to contrast medium, scanning protocol and reconstruction algorithm used. Axial slices or oblique axial sections in the dataset were selected to determine the best location of the attenuation value using a region of interest (ROI) at the proximal segment of the four main coronary arteries (right coronary artery, RCA; left main artery, LM; left anterior descending artery, LAD; and left circumflex artery, LCX) [14] (Fig. 1). The mean attenuation value of measurement in each coronary segment for three times was determined as the contrast enhancement of coronary arteries. The ROIs were drawn as large as possible within the vessels with care taken to avoid calcified plaques, soft plaques, and motion artifacts.

2.5. Assessment of image noise, attenuation and subjective image quality

In each dataset in two iodine concentration groups, one radiologist measured image noise, the standard deviation of the measured