European Journal of Radiology 81 (2012) 3141–3145

Contents lists available at SciVerse ScienceDirect

European Journal of Radiology

journal homepage: www.elsevier.com/locate/ejrad

# Image quality and radiation dose of low dose coronary CT angiography in obese patients: Sinogram affirmed iterative reconstruction versus filtered back projection

Rui Wang[a,1], U. Joseph Schoepf[b,2], Runze Wu[c,3], Ryan P. Reddy[b,2], Chuanchen Zhang[d,1], Wei Yu[a,4], Yi Liu[a,5], Zhaoqi Zhang[a,*]

[a] Department of Radiology, Beijing Anzhen Hospital, Capital Medical University, 100029 Beijing, China
[b] Heart & Vascular Center, Medical University of South Carolina, Ashley River Tower, 25 Courtenay Drive, Charleston, SC 29425-2260, USA
[c] Siemens Healthcare China, 7 Wangjing Zhonghuan Nanlu, 100102 Beijing, China
[d] Department of Radiology, Liaocheng People Hospital, 252000 Shandong, China

ARTICLE INFO

*Article history:*
Received 28 December 2011
Received in revised form 19 April 2012
Accepted 19 April 2012

*Keywords:*
Radiation dose
Obesity
CT angiography
Iterative reconstruction
Image quality

ABSTRACT

*Purpose:* To investigate the image quality and radiation dose of low radiation dose CT coronary angiography (CTCA) using sinogram affirmed iterative reconstruction (SAFIRE) compared with standard dose CTCA using filtered back-projection (FBP) in obese patients.
*Materials and methods:* Seventy-eight consecutive obese patients were randomized into two groups and scanned using a prospectively ECG-triggered step-and-shot (SAS) CTCA protocol on a dual-source CT scanner. Thirty-nine patients (protocol A) were examined using a routine radiation dose protocol at 120 kV and images were reconstructed with FBP (protocol A). Thirty-nine patients (protocol B) were examined using a low dose protocol at 100 kV and images were reconstructed with SAFIRE. Two blinded observers independently assessed the image quality of each coronary segment using a 4-point scale (1 = non-diagnostic, 4 = excellent) and measured the objective parameters image noise, signal-to-noise ratio (SNR), and contrast-to-noise ratio (CNR). Radiation dose was calculated.
*Results:* The coronary artery image quality scores, image noise, SNR and CNR were not significantly different between protocols A and B (all $p > 0.05$), with image quality scores of $3.51 \pm 0.70$ versus $3.55 \pm 0.47$, respectively. The effective radiation dose was significantly lower in protocol B ($4.41 \pm 0.83$ mSv) than that in protocol A ($8.83 \pm 1.74$ mSv, $p < 0.01$).
*Conclusion:* Compared with standard dose CTCA using FBP, low dose CTCA using SAFIRE can maintain diagnostic image quality with 50% reduction of radiation dose.


## 1. Introduction

CT coronary angiography (CTCA) is considered as a reliable noninvasive modality for imaging the coronary arteries and a potential alternative method to invasive coronary angiography for exclusion of CAD in select patients [1]. However, use of CTCA for noninvasive diagnosis of CAD in the obese population is challenging, because of the increase of X-ray photon attenuation and scattering as well as the decrease in signal-to-noise ratio. Therefore, both image quality and diagnostic accuracy are significantly compromised [2–4].

Several techniques can improve image quality in obese patients, such as body mass index (BMI) adapted scan protocols [5], and half-scan reconstruction techniques on dual-source CT [6,7]. However, these techniques cause significantly higher radiation dose in obese patients [6,7].

Recently, iterative reconstruction algorithms have been reintroduced into clinical use. Sinogram affirmed iterative reconstruction (SAFIRE) is a raw-data-based iterative reconstruction algorithm which compares reconstructed and measured data in the raw data domain and iteratively corrects the images. Recently, it has been demonstrated that, compared to filtered back-projection (FBP), the application of SAFIRE at CTCA provides superior image quality and potential radiation dose reduction in unselected patients [8]. However, image quality and impact on radiation dose have not been studied in obese patients. Therefore, the objective of

* Corresponding author. Tel.: +86 10 64456962; fax: +86 10 64456962.
*E-mail addresses:* rui_wang1979@yahoo.cn (R. Wang), schoepf@musc.edu (U.J. Schoepf), runze.wu@gmail.com (R. Wu), reddyr@musc.edu (R.P. Reddy), zhangchuanchen666@163.com (C. Zhang), yuwei02@gmail.com (W. Yu), liuyi198311@yahoo.cn (Y. Liu), zhaoqi5000@vip.sohu.com (Z. Zhang).
[1] Tel.: +86 10 64456562; fax: +86 10 64456962.
[2] Tel.: +1 843 876 7147; fax: +1 843 876 3157.
[3] Tel.: +86 10 64765905; fax: +86 10 64765905.
[4] Tel.: +86 10 64456962; fax: +86 10 64456962.
[5] Tel.: +86 10 64456121; fax: +86 10 64456962.

0720-048X/$ – see front matter © 2012 Elsevier Ireland Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.ejrad.2012.04.012

our investigation was to determine, whether a low dose CTCA scan protocol using iterative reconstruction can maintain image quality compared with a routine radiation dose CTCA scan protocol using FBP in obese patients.

## 2. Materials and methods

### 2.1. Patient population

From January 2011 to July 2011, a total of 78 consecutive obese patients (33/45 female/male, age 31–72 years) who had been referred for CTCA to exclude CAD were enrolled. For all patients, clinical data was collected including age, gender, body weight, body height, symptoms, and common cardiovascular risk factors. The BMI was calculated from body weight and body height. According to the WHO classification, obesity was defined as a BMI larger than 30 kg/m$^2$ [9]. Exclusion criteria were previous reaction to iodinated contrast media, heart failure (New York Heart Association class III or IV), arrhythmias (atrial fibrillation, etc.), renal insufficiency (serum creatinine > 1.4 mg/dL), and coronary artery bypass grafts. The study was approved by the Institutional Ethics Committee. Written informed consent was obtained from each participating patient.

The patients were randomized into two groups. In group 1 ($n$ = 39) patients, a routine radiation dose scan protocol (protocol A) was performed. In group 2 ($n$ = 39) patients, a low dose protocol (protocol B) was performed.

### 2.2. CTCA acquisition and reconstruction

All CTCA exams were performed on a first generation DSCT scanner system (Somatom Definition, Siemens Healthcare, Forchheim, Germany) using a prospectively ECG-triggered step-and-shot (SAS) CTCA protocol. In protocol A, the tube voltage was 120 kV and tube current was 354–430 mAs with automatic anatomic tube current modulation. In protocol B, the tube voltage was 100 kV and tube current was 286–370 mAs, also with automatic anatomic tube current modulation. The other scan parameters were kept constant between protocols A and B. The padding of the acquisition window for the SAS mode was set depending on the mean heart rate: below 60 bpm at 70% R-R interval (without padding), for heart rates of 61–80 bpm at 30–80% R-R, and above 80 bpm at 30–50% R-R. For both protocols A and B, the scan range extended from 1 cm below the level of the tracheal bifurcation to the diaphragm and scans were acquired in a cranio-caudal direction. The detector collimation was 2 mm × 32 mm × 0.6 mm, resulting in acquisition of 2 mm × 32 mm × 0.6 mm sections by means of the z-flying focal spot technique. The gantry rotation time was 330 ms. No beta-blockers were given prior to the scan.

The contrast agent was intravenously injected via an 18-gauge needle placed in the right antecubital vein by a dual-head power injector (Stellant D, Medrad, Indianola, PA, USA). Depending on scan duration, 90–100 mL contrast agent (Ultravist, 370 mgI/mL iopromide, Bayer, Wayne, NJ, USA) was injected, followed by 30 mL saline (0.9% sodium chloride) as a bolus chaser. The injection rate for all phases was 5–5.5 mL/s. Bolus tracking was performed with a region of interest (ROI) placed within the root of the ascending aorta, and image acquisition was automatically triggered 6 s after intra-aortic attenuation reached the predefined threshold of 100 HU.

Data acquired with the routine dose CTCA scan protocol in group 1 were reconstructed using FBP (protocol A), raw data of the low dose scan protocol in group 2 (protocol B) were reconstructed using the SAFIRE algorithm. Image reconstruction was performed using the cardiac phase with the least motion (enabled by the use of padding) with the following parameters: 0.75 mm section thickness, 0.5 mm reconstruction increment, and temporal resolution of 83 ms. FBP series were reconstructed with a medium smooth convolution kernel ("B26f"). For SAFIRE series, the corresponding "I26f" kernel was used, which matches the resolution of the "B26f" kernel.

### 2.3. Image quality analysis

All images were transferred to a commercial workstation (MMWP, Siemens Healthcare, Forchheim, Germany) to evaluate subjective and objective image quality over a period of 4 weeks. Two radiologists (W.Y. and C.Z. with 10 and 3 years of experience in cardiovascular imaging) independently evaluated the image quality on axial sections, and with use of curved multiplanar reconstructions of the coronary artery tree, using the segmental classification of the American Heart Association guidelines (AHA) [10]. Coronary segments with a minimal diameter of 1.5 mm at their origin were included. The observers were blinded to the acquisition and reconstruction parameters.

The image quality of coronary segments was scored using a four-point scale as previously described [11]: 1 for segments with poor vessel opacification, prominent structural discontinuity, lacking of vessel wall definition, and high image noise that resulted in non-diagnostic studies; 2 for fair, diagnostic image quality with fair vessel opacification, minimal structural discontinuity, and some motion artifacts or image noise; 3 for good vessel opacification, no structural discontinuity, minor motion artifacts or noise; and score 4 for excellent vessel opacification, no structural discontinuity, no motion artifacts, and minimal noise. Scores of 2–4 were considered as diagnostic image quality.

In order to evaluate the observer-dependent acceptance of image noise impression for protocols A and B, subjective image noise was assessed using a three-point scale. Grade 1 was given for CT examinations with too much noise, affecting the image interpretation. Grade 2 indicated normal, expected noise levels. Lastly, grade 3 referred to unusually low, less than usual noise.

The objective image noise, signal-to-noise ratio, and contrast-to-noise ratio were quantified as objective image quality parameters. The image noise (SD of Hounsfield units) was measured by manually placing ROIs at consistent locations within the aortic root, the LM, and the proximal parts of the RCA, LAD, and LCX. For all measurement within the aorta, the ROI size, shape and position were kept constant. Calcification or plaque within the aortic and coronary wall was carefully avoided during ROI placement. The signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) were calculated using the formulas: SNR = mean_lumen/SD_lumen and CNR = (mean_lumen − mean_fat)/SD_fat, respectively, where mean_lumen is the mean CT value of the vessel lumen, mean_fat is the mean CT value of the perivascular fat and SD is the standard deviation or image noise of images.

### 2.4. Radiation dose

The volume CT dose index ($CTDI_{vol}$) and dose-length product (DLP) were recorded from the CT console after each CTCA examination. The effective dose was calculated by multiplying the DLP by a conversion coefficient of 0.014 mSv × mGy$^{-1}$ × cm$^{-1}$ [12].

### 2.5. Statistical analysis

Continuous variables are described as mean ± standard deviation (SD) and analyzed by independent-sample $t$-test. Categorical variables are described as frequencies or percentages and analyzed by chi-square test. The inter-observer agreement of subjective image quality was evaluated by Kappa statistics. All statistical analyses were performed using a commercial statistical software

**Table 1**
Patient characteristics and radiation dose.

| Characteristic | Protocol A (120 kV) | Protocol B (100 kV) |
|---|---|---|
| Number of patients | 39 | 39 |
| Age (years) | 52.8 ± 10.6 | 53.7 ± 7.5 |
| Sex (M/F) | 23/16 | 22/17 |
| HR (bpm) | 73.9 ± 12.0 | 71.7 ± 6.8 |
| Height (cm) | 162.83 ± 8.40 | 166.27 ± 8.15 |
| Weight (kg) | 87.86 ± 15.94 | 89.57 ± 11.40 |
| BMI (kg/m$^2$) | 31.67 ± 5.05 | 32.31 ± 2.73 |
| No. of Class I obesity | 30 | 31 |
| No. of Class II–III obesity | 9 | 8 |
| $CTDI_{vol}$ (mGy) | 47.73 ± 9.40 | 23.37 ± 4.74 |
| DLP (mGy cm) | 630.41 ± 124.39 | 315.33 ± 59.19 |
| ED (mSv) | 8.83 ± 1.74 | 4.41 ± 0.83 |

package (SPSS 16.0, SPSS, Chicago, IL, USA). Any $p$-value $\leq 0.05$ was considered as a statistically significant difference.

## 3. Results

### 3.1. Patient characteristics

All 78 patients (45 male and 33 female) successfully underwent CTCA and were included in the analysis. According to the WHO obesity classification, 61 patients were Class I obese (BMI 30.0–34.9 kg/m$^2$), 13 patients were Class II obese (BMI 35.0–39.9 kg/m$^2$), and 4 patients were Class III obese (BMI > 40.0 kg/m$^2$). The average effective radiation dose for protocol A was 8.83 ± 1.74 mSv while for protocol B it was 4.41 ± 0.83 mSv. The two cohorts were well matched regarding age, heart rate, and BMI (all $p > 0.05$). Detailed patient characteristics are provided in Table 1.

### 3.2. Coronary image quality

#### 3.2.1. Subjective image quality

A total of 874 coronary segments in 78 patients were identified. 31 coronary segments were excluded due to motion artifacts, poor lumen opacification or extensive calcification obscuring the lumen, thus 843 coronary segments were evaluated for subjective image quality. The agreement between the two observers was excellent (Kappa = 0.85). In protocol A, the mean image quality score of coronary segments was 3.51 ± 0.70. In protocol B, the mean of image quality scores of coronary segments was 3.55 ± 0.47. The image quality of the SAFIRE series using protocol B was not significantly different from that of protocol A (all $p > 0.05$, Fig. 1 and Table 2). Diagnostic image quality scores of 2 or higher were found in 92.7% of all segments with protocol A (391/422), and in 93.9% of segments with protocol B (395/421). Subjective image quality scores are summarized in Table 2. The subjective image noise score was 1.97 ± 0.32 and 2.01 ± 0.25 for protocols A and B, respectively. The image noise scores were not significantly different between protocols A and B ($p > 0.05$). The occurrence and severity of motion artifacts and calcification with impact on image quality did not significantly differ among the protocols A and B (Table 2).

#### 3.2.2. Objective image quality

Inter-observer agreement was excellent for measurements of the attenuation and image noise within the aorta, the LM, and the proximal portions of the RCA, LAD and LCX ($r = 0.82$, $r = 0.79$, $r = 0.85$, $r = 0.82$, $r = 0.85$, respectively; $p < 0.001$). The SAFIRE series of protocol B had higher SNR, CNR and image noise than FBP reconstructed series in protocol A, but these differences did not reach statistical significance (Table 3, $p > 0.05$).

### 3.3. Radiation dose

Radiation dose estimates are listed in Table 1. The DLP was significantly higher with protocol A (630.41 ± 124.39 mGy cm) than with protocol B (315.33 ± 59.19 mGy cm, $p < 0.001$). Subsequently the effective dose was significantly higher in protocol A (8.83 ± 1.74 mSv) than in protocol B (4.41 ± 0.83 mSv; $p < 0.01$) which corresponds to a relative 50% reduction in effective radiation dose for protocol B.

## 4. Discussion

Our study demonstrates that low dose CTCA using SAFIRE can maintain the same diagnostic image quality as FBP despite a 50% radiation dose reduction.

### 4.1. Image quality in obese patients

Degradation of image quality at CTCA in obese or overweight patients is a well recognized limitation of this test [2,5], as there is a significant decrease in accuracy in patients with BMI > 30 kg/m$^2$ [2,4]. Alkadhi et al. found, that the ratio of non-evaluable segments increased from 1.4% in patients with BMI ≤ 26.0 kg/m$^2$ to 2.4% in overweight and obese patients with a BMI > 26.0 kg/m$^2$ [3]. This deterioration of image quality in obese patients results from poorer SNR, CNR, and image noise by increased photon absorption and scatter [13].

To improve the image quality, dedicated scan protocols and reconstruction techniques have been developed whose primary aim is to improve photon flux through obese patients. Leschka and Chinnaiyan [6,7] demonstrated that use of a half-scan reconstruction mode and a higher tube voltage (140 kV) can significantly improve image quality in obese patients. However, the drawbacks of such approaches are the increased patient radiation dose and decrease in temporal resolution.

Our findings indicate that the use of iterative reconstruction in routine clinical practice provides a viable option for imaging obese patients. Compared with the FBP algorithm, iterative reconstruction has been demonstrated to deliver superior image quality at CTCA in general populations [14,15]. In our study, we specifically focused on the performance of iterative reconstruction algorithms at CTCA in the obese patient population. Quantitative image analysis showed that low dose CTCA with the SAFIRE algorithm allowed significant radiation reduction without loss of image quality. These results are consistent with the recent studies reported by Moscariello [8] and Park [15].

### 4.2. Radiation dose in obese patients

It has been recognized that obese patients receive 32–54% higher radiation doses than non-obese patients [6]. Effective radiation doses from CTCA of ~22 mSv in the helical acquisition mode [7] and of 5.2–18.1 mSv in a SAS mode have been reported to patients with a BMI of >30 kg/m$^2$ or with a thick chest wall (i.e. breast tissue) [16]. As demonstrated by Moscariello et al. [8], the radiation dose savings with SAFIRE at CTCA may exceed 50% in general populations. Our results show that low dose CTCA protocol with SAFIRE can reduce 50% of the radiation exposure in obese patients while maintaining diagnostic image quality.

A tube voltage of 100 kV at CTCA is often used as an effective means to lower radiation dose [17]. However, the use of 100 kV is generally restricted to patients with a BMI of <25–30 kg/m$^2$ or a weight of <95 kg [17,18], as the main limitation of the 100 kV protocol is that insufficient X-ray photons reach the detectors leading to excessive image noise [19]. In our study, we applied a 100 kV

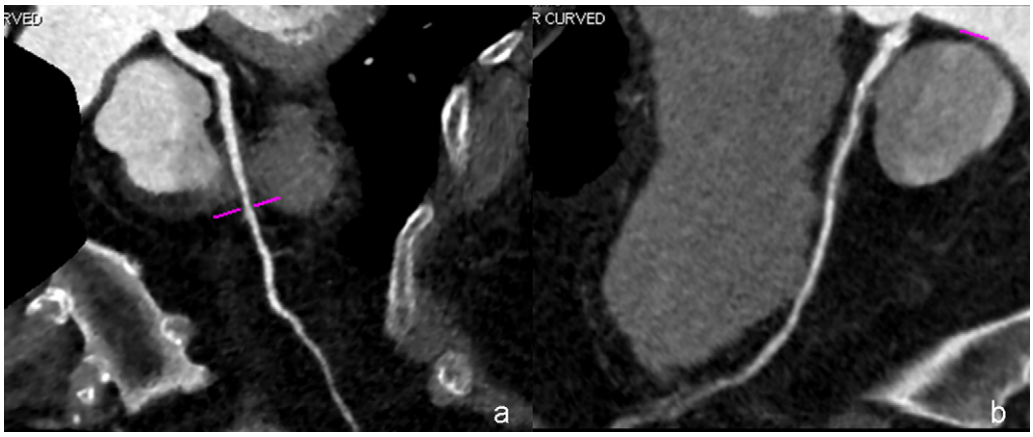


**Fig. 1.** Comparison of image quality between protocol A and protocol B. A 67-year-old woman with a BMI of 32.05 kg/m$^2$ underwent 100 kV SAS DSCT angiography with SAFIRE reconstruction. Image quality was rated as excellent (score 4). CPR shows an LAD without significant stenosis (a). A 69-year-old woman with a BMI of 32.42 kg/m$^2$ underwent 120 kV SAS DSCT angiography with FBP reconstruction. Image quality was rated as good (score 3). CPR shows moderate stenosis of the proximal LAD segment (b). CPR views of the LAD show comparable image quality between protocol A (a) and protocol B (b).

protocol in obese patients who would generally not be considered eligible for low kilo-voltage protocols. Despite this, compared with the routine radiation dose protocol (120 kV), the 100 kV with SAFIRE protocol (protocol B) resulted in only slightly higher image noise compared to full-dose routine protocol with FBP (protocol A).

In the 120 kV group, our study patients had a higher mean radiation dose, 8.83 mSv, than reported in previous investigations using the SAS mode [20]. The difference resulted from our use of a SAS protocol with padding. The SAS protocol is one of the most efficient dose reduction techniques, as it allows for detection of 98% of the coronary segments in patients with regular heart rates [21]. Nevertheless, a major disadvantage of conventional SAS mode CTCA is the requirement of stable and slow heart rates because only a narrow predefined R-R interval is available [21]. Using SAS plus padding is performed during a predefined width across the R-R interval of the cardiac cycle resulting in a relatively higher radiation dose compared to SAS acquisitions without padding, but allows for more flexibility vis-à-vis faster or more irregular heart rates. Accordingly, our study results showed diagnostic image quality in 93.2% (786/843) of all coronary segments.

Is there an optimal tube voltage that can balance the image quality, patient diameter, tissue composition and patient dose? Leschka and colleagues suggested that scanning severely obese patient with 140 kV yields higher image quality but naturally involves higher radiation dose [6]. However, in obese patients the effective radiation dose equivalent could be overestimated with current conversion formulas as larger patient diameters provide photon shielding to radiosensitive internal organs. A low kV protocol, which is considered as a dose saving method, is ordinarily not applicable in the investigation of obese patient due to intolerable increases in image noise [7]. Our results suggest, however, that a 100 kV protocol could still be feasible in obese patients, when

**Table 2**
Subjective image quality scores for coronary artery.

| | Protocol A (120 kV) with FBP | Protocol B (100 kV) with SAFIRE | *p* value |
|---|---|---|---|
| Average image score[a] | 3.51 ± 0.70 | 3.55 ± 0.47 | >0.05 |
| No. of segments with image quality score 4[b] | 257 (60.9%) | 253 (60.1%) | >0.05 |
| No. of segments with image quality score 3[b] | 113 (26.8%) | 126 (30.0%) | >0.05 |
| No. of segments with image quality score 2[b] | 21 (5.0%) | 16 (3.8%) | >0.05 |
| No. of segments with image quality score 1[b] | 31 (7.3%) | 26 (6.1%) | >0.05 |

[a] Values are presented as mean ± standard deviation.
[b] Values are presented as number of segments (percentage).

**Table 3**
Comparison of image noise, SNR and CNR between the two protocols.

| | Protocol A (120 kV) with FBP | Protocol B (100 kV) with SAFIRE | *p* value |
|---|---|---|---|
| AO SD (HU) | 26.53 ± 5.16 | 27.64 ± 3.90 | >0.05 |
| AO SNR | 13.44 ± 3.75 | 15.58 ± 3.15 | >0.05 |
| AO CNR | 19.70 ± 4.86 | 20.82 ± 4.71 | >0.05 |
| RCA SD (HU) | 20.04 ± 4.78 | 22.12 ± 3.19 | >0.05 |
| RCA SNR | 18.06 ± 6.12 | 19.33 ± 5.85 | >0.05 |
| RCA CNR | 38.35 ± 16.96 | 40.49 ± 10.56 | >0.05 |
| LM SD (HU) | 18.03 ± 4.93 | 20.45 ± 3.84 | >0.05 |
| LM SNR | 20.55 ± 6.83 | 21.52 ± 6.54 | >0.05 |
| LM CNR | 38.95 ± 15.46 | 44.82 ± 15.71 | >0.05 |
| LAD SD (HU) | 18.92 ± 5.06 | 20.39 ± 5.74 | >0.05 |
| LAD SNR | 18.73 ± 5.35 | 20.18 ± 5.72 | >0.05 |
| LAD CNR | 41.05 ± 20.22 | 41.97 ± 10.98 | >0.05 |
| LCX SD (HU) | 19.17 ± 6.11 | 20.18 ± 5.56 | >0.05 |
| LCX SNR | 19.02 ± 7.57 | 20.37 ± 4.19 | >0.05 |
| LCX CNR | 40.38 ± 16.85 | 44.31 ± 13.72 | >0.05 |

Values are mean ± standard deviation.

combined with iterative reconstruction. One needs to keep in mind, however, that the biological effects of low kV radiation protocols remain insufficiently understood. While low kV protocols decrease physical radiation dose parameters such as the DLP along with the CT dose index (CTI), the proportion of absorbed radiation inversely correlates to kV. Future research should aim at a better understanding of radiation damage incurred by different photon energies and at identifying an "optimal trade-off" between kV, energy dose, object diameter, and tissue composition.

### 4.3. Clinical implication

Our results suggest that with iterative reconstruction techniques, CTCA provides satisfactory image quality in obese patients without the risks of invasive procedures. Ergo, it is a feasible diagnostic alternative for these patients. We also demonstrated the feasibility of applying a 100 kV protocol with iterative reconstruction in obese patients, who traditionally were excluded from this radiation protection strategy because of their body habits.

### 4.4. Limitations

There were several limitations in this study. First, the diagnostic accuracy of CTCA with SAFIRE algorithm was not evaluated using invasive coronary angiography as a reference standard. Future studies focusing on a direct comparison between CTCA and conventional catheter angiography in this patient group are required. Second, the sample sizes were relatively small. Our results require further validation within a larger study population. Our patient enrollment was consecutive and the majority of our patients had Class I obesity. Consequently, our conclusions may not be applicable to patients with morbid obesity and further study, specifically of patients with excessively high BMI is warranted. Third, BMI may not a precise predictive parameter for soft tissue-related attenuation in the scan field of cardiac CT. BMI is purely dependent upon net weight and height ignoring differing ratios of adipose and lean tissue as well as differing forms of adiposity, i.e. breast tissue, versus a more uniform fat distribution. Lastly, although 100 kV protocol increases iodine contrast which highlights the coronary in CTCA, the potential disadvantages on biological effects for low kV radiation are not clear yet.

## 5. Conclusions

In conclusion, our results suggest that a low dose CTCA protocol combined with iterative reconstruction can reduce the radiation requirements by 50% while maintaining diagnostic image quality in the obese patient population.

## Conflict of interest statement

Runze Wu is a consultant at Siemens Healthcare; UJS is a consultant for and receives research support from Bayer, Bracco, GE, Medrad, and Siemens; other authors have no conflicts of interest.

## References

[1] Miller JM, Rochitte CE, Dewey M, et al. Diagnostic performance of coronary angiography by 64-row CT. New England Journal of Medicine 2008;359(22):2324–36.
[2] Raff GL, Gallagher MJ, O'Neill WW, Goldstein JA. Diagnostic accuracy of noninvasive coronary angiography using 64-slice spiral computed tomography. Journal of the American College of Cardiology 2005;46(3):552–7.
[3] Alkadhi H, Scheffel H, Desbiolles L, et al. Dual-source computed tomography coronary angiography: influence of obesity, calcium load, and heart rate on diagnostic accuracy. European Heart Journal 2008;29(6):766–76.
[4] Brodoefel H, Tsiflikas I, Burgstahler C, et al. Cardiac dual-source computed tomography: effect of body mass index on image quality and diagnostic accuracy. Investigative Radiology 2008;43(10):712–8.
[5] Alkadhi H, Stolzmann P, Scheffel H, et al. Radiation dose of cardiac dual-source CT: the effect of tailoring the protocol to patient-specific parameters. European Journal of Radiology 2008;68(3):385–91.
[6] Leschka S, Stinn B, Schmid F, et al. Dual source CT coronary angiography in severely obese patients trading off: temporal resolution and image noise. Investigative Radiology 2009;44(11):720–7.
[7] Chinnaiyan KM, McCullough PA, Flohr TG, Wegner JH, Raff GL. Improved noninvasive coronary angiography in morbidly obese patients using dual source computed tomography and half-scan reconstruction. Journal of Cardiovascular Computed Tomography 2009;3(1):35–42.
[8] Moscariello A, Takx RA, Schoepf UJ, et al. Coronary CT angiography: image quality, diagnostic accuracy, and potential for radiation dose reduction using a novel iterative image reconstruction technique—comparison with traditional filtered back projection. European Radiology 2011;21(10):2130–8.
[9] James PT. Obesity: the worldwide epidemic. Clinics in Dermatology 2004;22:276–80.
[10] Austen WG, Edwards JE, Frye RL, et al. A reporting system on patients evaluated for coronary artery disease: report of the Ad Hoc Committee for Grading of Coronary Artery Disease, Council on Cardiovascular Surgery, American Heart Association. Circulation 1975;51(4 (Suppl.)):5–40.
[11] Brodoefel H, Reimann A, Burgstahler C, et al. Noninvasive coronary angiography using 64-slice spiral computed tomography in an unselected patient collective: effect of heart rate, heart rate variability and coronary calcifications on image quality and diagnostic accuracy. European Journal of Radiology 2008;66(1):134–41.
[12] Stolzmann P, Scheffel H, Schertler T, et al. Radiation dose estimates in dual-source computed tomography coronary angiography. European Radiology 2008;18(3):592–9.
[13] Husmann L, Leschka S, Boehm T, et al. Influence of body mass index on coronary artery opacification in 64-slice CT angiography. RoFo 2006;178(10):1007–13.
[14] Bittencourt MS, Schmidt B, Seltmann M, et al. Iterative reconstruction in image space (IRIS) in cardiac computed tomography: initial experience. International Journal of Cardiovascular Imaging 2010;27(7):1081–7.
[15] Park EA, Lee W, Kim KW, et al. Iterative reconstruction of dual-source coronary CT angiography: assessment of image quality and radiation dose. International Journal of Cardiovascular Imaging 2011 [Epub ahead of print; December 21].
[16] Rybicki HJ, Steigner ML. Initial evaluation of coronary images from 320-detector row computed tomography. International Journal of Cardiovascular Imaging 2008;24(5):535–46.
[17] Leschka S, Stolzmann P, Schmid FT, et al. Low kilovoltage cardiac dual-source CT: attenuation, noise, and radiation dose. European Radiology 2008;18(9):1809–17.
[18] Raff GL. Radiation dose from coronary CT angiography: five years of progress. Journal of Cardiovascular Computed Tomography 2010;4(6):365–74.
[19] Gutstein A, Dey D, Cheng V, et al. Algorithm for radiation dose reduction with helical dual source coronary computed tomography angiography in clinical practice. Journal of Cardiovascular Computed Tomography 2008;2(5):311–22.
[20] Tatsugami F, Husmann L, Herzog BA, et al. Evaluation of a body mass index-adapted protocol for low-dose 64-MDCT coronary angiography with prospective ECG triggering. American Journal of Roentgenology 2009;192(3):635–8.
[21] Stolzmann P, Leschka S, Scheffel H, et al. Dual-source CT in step-and-shoot mode: noninvasive coronary angiography with low radiation dose. Radiology 2008;249(1):71–80.