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Third generation dual-source computed tomography coronary angiography with high-pitch spiral mode versus prospectively-gated sequential mode: comparison of radiation exposure and image quality

Aydan Avdan Aslan, Gonca Erbaş, Leyla Salımlı, Koray Kılıç, Mehmet Araç

Department of Radiology, Gazi University, Faculty of Medicine, Ankara, Turkey

ABSTRACT

Objectives: To compare high-pitch spiral (HPS) and prospectively-gated step-and-shoot (SAS) coronary CT angiography (CCTA) using third generation dual-source CT regarding objective and subjective image quality parameters and radiation exposure.
Methods: Eighty pairs of patients matched for gender, age, heart rate and BMI were enrolled in this retrospective study. High-pitch spiral and prospectively ECG-gated sequential CCTA were performed using third generation dual-source CT. The signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) in the left ventricle were calculated for each group. Image quality were also scored using four-point scale. Student t-test was used to compare SNR, CNR and mean effective dose values (ED) and Wilcoxon test was used to compare image quality scores. Interrater aggreement were evaluated using Cohen's kappa statistics.
Results: Between-group differences in terms of age, gender, BMI, heart rate, and Agatston score were statistically not significant. Mean SNR and CNR was higher in prospective SAS protocol (16.5 ± 6.2 vs. 14.7 ± 4.9, $p = 0.047$ and 13.0 ± 5.2 vs. 11.2 ± 4.3, $p = 0.02$). Image quality scores showed no significant difference between two scan protocols ($p > 0.05$). Regarding radiation exposure, CT dose index (CTDIvol), dose length product (DLP) and ED was significantly lower for high-pitch group ($p < 0.0001$).
Conclusions: HPS CCTA using DSCT enables > 70% dose reduction while maintaining the image quality compared to prospectively ECG-gated SAS protocol. Therefore, HPS CCTA protocol can be preferred in patients appropriate for prospective ECG-triggered protocol.
Keywords: Coronary CT angiography, high-pitch, image quality, radiation dose

Coronary CT angiography (CCTA) is frequently used in routine clinical practice and partially replaced invasive coronary angiography to detect coronary artery disease (CAD) with its high sensitivity and negative predictive value [1]. CCTA has also been included in guidelines for the exclusion of CAD in intermediate-risk patients with symptoms [2, 3].

As radiation exposure was the major concern in CCTA, various innovations have been generated to reduce radiation exposure without comprising image

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Address for correspondence: Aydan Avdan Aslan, MD., Gazi University, Faculty of Medicine, Department of Radiology, Emniyet, Mevlana Blv., No:29, 06560 Yenimahalle, Ankara, Turkey. E-mail: aydanavdanaslan @gmail.com, Phone: +90 312 284 11 66, Fax: +90 322 202 44 44

quality [4]. Among the dose reduction tecniques developed, the prospective electrocardiographic (ECG)-gated CCTA caused the highest reduction in the effective dose (ED) [5]. In contrast to performing data acquisition at the entire cardiac cycle in retrospective ECG-gated CTCA or low pitch spiral (LPS) mode, the diastolic stage of the cardiac cycle is used for imaging in prospective electrocardiographic (ECG)-gated step-and-shoot (SAS) mode which avoids X-ray exposure in other phases [6]. Besides, second and third-generation dual-source CT (DSCT) systems have introduced prospectively ECG-gated high-pitch spiral scan mode (HPS), which enables entire data acquisition within a single heartbeat allowing even more radiation dose reduction [7].

Despite the fact that prospective ECG-triggered protocols provide an opportunity to scan with less radiation exposure, in clinical practice, they are not appropriate in patients with tachycardia, arrhythmia, and obesity due to higher motion artifacts and image noise. Retrospective ECG-gated CTCA protocols are still needed in patients with rapid unstable heart rates or to perform functional analysis [8, 9]. Although HPS technique provides further dose reduction, image quality should also be considered to select the optimal prospective ECG-triggered protocol in this selected patient group. Neefjes *et al*. [10] revealed that the image quality obtained with HPS mode was lower compared with SAS mode in patients with heart rate of ≥ 55 beats per minute (bpm). In addition, Seppelt *et al*. [11] compared HPS and SAS mode in a matched study population and higher signal-to-noise (SNR) ratio and image quality was found in SAS protocol. On the other hand, Smettei *et al*. [12] reported no significant difference in subjective image quality between SAS and HPS protocols.

In this study, we aimed to compare objective and subjective image quality parameters and radiation exposure between prospective ECG-triggered SAS and HPS protocols in age, gender, body-mass index (BMI) and heart rate matched patient cohorts.

METHODS

Study Population

This retrospective study was approved by Institutional Ethical Review Board and written informed consent was waived (IRB Approval number:377, Date: June 8th, 2020). From July 2017 to August 2021 a total of 80 consecutive patients (Group A) who underwent CCTA with clinical suspicion of CAD using 192-slice DSCT scanner with ultra-fast, low dose high-pitch mode (FLASH) were enrolled. An age, gender, BMI and heart rate- matched control group (Group B) were also selected retrospectively from a cohort that had CCTA with prospective SAS scanning protocol from July 2017 to August 2021. Patients with stent, coronary artery bypass grafts, cardiac devices, and patients younger than 18 were excluded from the study.

Patient Preparation and CTA protocol

A 192-slice DSCT scanner (Somatom Force, Siemens Healthineers) was used to perform both scanning protocols. Propranolol hydrochloride (10 mg, up to 40 mg if needed) was administered orally prior to examination to achieve a heart rate below 70 beats/min. Two different CCTA acqusition protocols were used. In group A, prospectively ECG-triggered HPS protocol were used. Group B received a CCTA with prospectively ECG-triggered SAS mode. Scan parameters of both protocols were summarized in Table 1. Intravenous contrast agent was injected with a flow rate of 5-6 ml/sn followed by 50 ml isotonic saline chaser. The scan was initiated using the real-time bolus tracking method with a region of interest placed at left atrium lumen and attenuation treshold set to 75 Hounsfield units. Automatic tube potential selection and tube current modulation (CareDose4D, Siemens Healthineers) was used for all examinations. A model-based iterative algorithm (ADMIRE, strength level 3; Siemens Healthineers) and a soft reconstruciton kernel (Bv40) were used to reconstruct all images. For the radiation exposure evaluation, CT-dose index (CTDI) and dose-length product (DLP) provided by the scanner were recorded. The effective dose (ED) was calculated by multiplying DLP with a conversion factor (0.014 mSv/mGycm) [13].

Image Quality Assessment

All images were evaluated by a radiologist with 8 years experience in cardiovascular imaging and a radiology resident who completed cardiac imaging training independently. Both readers were blinded for the scanning protocols and clinical information of the patients. Image quality was scored on a 4-point scale as

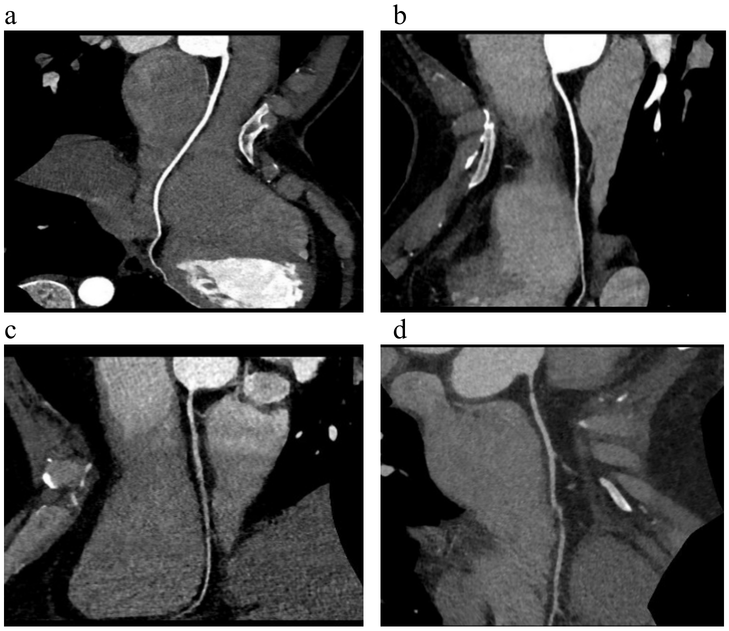

Fig. 1. Images of right coronary artery showing examples of 4-point subjective image quality scale for coronary CT angiography with high-pitch spiral mode (A-D). A Very good image quality, without any artifacts, image quality (IQ) score = 4 B Good image quality, presence of minor artifacts, IQ = 3 C Adequate image quality to exclude severe stenosis, IQ = 2 D Non-diagnostic image quality, presence of severe artifacts, IQ = 1.

follows: 4 = very good, complete delineation of vessel walls without motion artifacts; 3 = good, presence of minor artifacts but maintained ability to evaluate luminal stenosis; 2 = adequate, presence of major artifacts but sufficient to rule out severe stenosis, 1 = non-diagnostic, presence of severe artifacts (Fig. 1). Both readers assessed the images independently and discrepancies between readers were resolved by consensus in another reading session.

Quantitative assessment was performed by measuring attenuation values of the left ventricle with a region-of-interest (ROI, size 80 mm^2). The mean attenuation value was determined as signal and the standard deviation value as noise. The signal-to-noise ratio was defined as the quotient of signal value and the noise value. The contrast-to-noise ratio was calculated by dividing the difference between left ventricle lumen attenuation and left ventricle wall attenuation by the image noise.

Statistical Analysis

The data were analyzed by using IBM SPSS Statistics Software (version 22; IBM, USA), and a p value of 0.05 or less indicate statistically significance. The continuous data were expressed as mean ± standard deviation (SD), and categorical data were expressed as counts and percentages. Chi-square and Student t-test were used to compare categorical variables and continuous variables, respectively. The Wilcoxon test was used to compare subjective image quality scores between two patient groups. Interrater agreement was evaluated using Cohen κ coefficient. Agreements were considered as: poor, κ < 0.21; fair, κ = 0.21-0.40; moderate, κ = 0.41-0.60; substantial, 0.61-0.80; and excellent, κ > 0.80.

RESULTS

A total of 160 patients (n = 80 in each group) were enrolled in this study. Both groups were consisted of 40 men and 40 women. As the patient groups were matched in regard to gender, age, heart rate and BMI, there was no statistically significant difference between groups. The mean age of the patients was 51.90 years in high-pitch protocol and 53.34 years in prospective step-and-shoot protocol. BMI was 27.55 ± 3.68 kg/m^2 versus 28.16 ± 4.05 kg/m^2 in high-pitch protocol and prospective step-and-shoot protocol respectively. Mean heart rate was 72.21 bpm in high-

Table 1. Baseline characteristics of study population

Characteristics	High-pitch spiral CCTA	Step-and-shoot CCTA	*p* value
Age	51.90 ± 12.280	53.34 ± 12.793	0.469
Male sex, n (%)	40 (50)	40 (50)	1
Body mass index	27.55 ± 3.683	28.16 ± 4.055	0.328
Heart rate (beats/min)	72.21 ± 9.612	74.41 ± 9.567	0.149
Agatston score	58.37 ± 159.73	71.75 ± 207.65	0.654

Table 2. Image noise and image quality parameters in both groups

	High-pitch spiral CCTA	Step-and-shoot CCTA	*p* value
Noise	33.684 ± 8.859	32.649 ± 10.113	0.502
Signal-to-noise ratio (SNR)	3.640 ± 1.275	3.452 ± 1.300	0.371
Contrast-to-noise ratio (CNR)	12.149 ± 5.279	13.171 ± 5.294	0.235

pitch protocol and 74.41 bpm in prospective step-and-shoot protocol. No significant difference were found in terms of Agatston score between groups ($p = 0.65$). Baseline characteristics of the study population are summarized in Table 1.

There were no significant difference between groups regarding noise levels (33.6 ± 8.8 HU vs. 32.6 ± 10.1 HU, $p = 0.50$). No significant difference in mean SNR and CNR was observed between two scan protocols (3.6 ± 1.2 vs. 3.4 ± 1.3, $p = 0.37$ and 12.1 ± 5.2 vs. 13.1 ± 5.2, $p = 0.23$) (Table 2). Image noise and objective image quality parameters for each acquisition mode are shown in Table 2.

Regarding subjective image quality scores, no significant differences were found between two scan protocols ($p > 0.05$). Interrater agreement for image quality assessment on per-vessel level was substantial (LMCA κ: 0.69; LAD κ: 0.62; Cx κ: 0.61; RCA κ: 0.61).

With regard to radiation dose, CTDIvol, DLP and ED was significantly lower for high-pitch group ($p < 0.0001$). The mean ED for the patients was 1.29 ± 1.01 mSv (range: 0.12-3.93) in low dose high-pitch group and 6.72 ± 4.43 mSv (range: 1.30-29.61) in prospective SAS protocol. Radiation doses of two acquisition modes are summarized in Table 3.

DISCUSSION

In this study we compared prospective ECG-gated SAS and HPS protocol regarding objective and subjective image quality parameters and radiation exposure in a age, gender, heart rate and BMI matched patient population using third-generation DSCT system. There was no significant difference in objective and subjective image quality between two scan protocols. Radiation dose with HPS mode was significantly lower than SAS mode.

The main point of selecting an optimal CCTA scan protocol is to achieve high-quality images with the lowest possible radiation exposure. Among the improvements in the CT technology, the use of prospective ECG-triggered protocols provides greatest dose

Table 3. Radiation doses in both groups

	High-pitch spiral CCTA	Step-and-shoot CCTA	*p* value
CTDIvol (mGy)	9.424 ± 10.419	34.310 ± 23.226	**< 0.001**
DLP (mGy×cm)	92.720 ± 72.377	480.216 ± 316.884	**< 0.001**
ED (mSv)	1.298 ± 1.013	6.723 ± 4.436	**< 0.001**

CTDIvol = volume CT dose index, DLP = dose length product, ED = effective dose reduction while maintaining image quality [14, 15]. With the help of DSCT systems, the high-pitch protocol has become available, which leads reduction in acquisition time hence decreasing radiation exposure. Third-generation DSCT systems with their high performance x-ray tube, wider longitudinal coverage, faster rotation time and iterative reconstruction algorithms contribute to obtain better image quality with a lesser radiation exposure. Lin *et al*. [16] reported that third-generation DSCT systems provide a 20% incerase in image quality of HPS scan compared to second-generation CT systems. Linsen *et al*. [17] also showed that HPS CCTA with third-generation DSCT offers better subjective and objective image quality despite a more rapid heart rate compared to second-generation DSCT.

Despite the ongoing improvements in CT technology, prospective ECG-triggered protocol can not totally replace retrospective ECG-triggered protocols. Traditionally, prospective ECG-triggered protocols require a low (< 70 bpm) and stable heart rate as these protocols are more susceptible to motion artifacts compared to retrospective ECG-triggered protocol. It has been shown that at least one coronary segment is nondiagnostic in patients who couldn't achieve the target heart rate despite premedication [18]. Ochs *et al*. [19] stated that HPS protocol is most applicable to non-obese patients with stable heart rate ≤ 65 bpm and a calcium score ≤ 600 since image quality worsen above these limits.

Among the factors affecting image quality, it has been revealed that calcium score calculated by Agatston method is the factor that most affect image quality of HPS protocol. Obesity and heart rate ≥ 65 bpm were also reported as other factors that reduce image quality [19]. Besides, the fact HPS protocol is more susceptible to motion artifacts compared to SAS and LPS protocols, may also result in impaired image quality.

Comparing the image quality of different CCTA acquisition methods is difficult as repeating each protocol in the same patient would not be appropriate regarding radiation exposure. Matching both patient groups in terms of factors affecting image quality is necessary to create comparable patient cohorts. Previous studies comparing HPS CCTA and prospective SAS CCTA protocols have generally made evaluation without patient selection. Nevertheless, in studies that selected patient groups and built comparable cohorts reported variable results. Jia *et al*. compared turbo high-pitch CCTA and prospective SAS mode regarding diagnostic accuracy and image quality and revealed that turbo high-pitch CCTA scan mode offers highly accurate images for significant stenosis, especially in patients with heart rate < 71.5 bpm and coronary calcium score < 444.1 [20]. On the other hand, Seppelt *et al*. [11] found significantly lower SNR and subjective image quality scores for HPS compared to SAS protocol. In the present study, no significant difference in SNR and CNR values were observed. Moreover, there was no significant difference in subjective image quality between two scan mode.

With regard to radiation exposure, the mean ED in the HPS mode was 1.29 ± 1.01 mSv which is in line with previous studies. Seppelt *et al*. [11] found that the mean ED in the SAS mode was more than three times that of the HPS mode. Smettei *et al*. [12] also revealed that FLASH mode provide 62% radiation dose reduction than SAS mode while maintaining image quality. In our study, HPS mode provides > 80% reduction in the radiation exposure compared to SAS protocol without comprising image quality.

Limitations

This work has several limitations that need to be mentioned. First, this retrospective study analyzed limited study population with relatively low heart rate at a single-center. Multi-center studies with larger sample size should be conducted to validate our results. Second, the diagnostic accuracy of detecting coronary artery stenosis for both groups were not evaluated since it was not the aim of this study. Lastly, the potential effect of heart rate variability on image quality was not included in this study.

CONCLUSION

In summary, the current study results revealed that HPS CCTA provides significant dose reduction compared to prospective SAS CCTA without comprising image quality. In this context, HPS CCTA protocol can be preferred in patients appropriate for prospective ECG-triggered protocol.

Authors' Contribution

Study Conception: AAA, GE, LS, KK, MA; Study

Design: AAA, GE, LS, KK, MA; Supervision: GE; Funding: N/A; Materials: N/A; Data Collection and/or Processing: AAA, LS; Statistical Analysis and/or Data Interpretation: AAA; Literature Review: AAA; Manuscript Preparation: AAA, and Critical Review: GE.

Conflict of interest

The authors disclosed no conflict of interest during the preparation or publication of this manuscript.

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