J HK Coll Radiol. 2008;11:81-84

ORIGINAL ARTICLE

CME

# Clinical Evaluation of Radiation Dose Benefit and Image Quality of the Step-and-Shoot Technique Electrocardiogram-gated Coronary Computed Tomography Angiography

**GG Lo,[1] JKF Chan,[1] SK Yu,[2] CW Lau,[1] YF Leung[1]**

*[1]Department of Diagnostic Radiology, and [2]Department of Radiotherapy, Hong Kong Sanatorium and Hospital, Hong Kong*

## ABSTRACT

***Objective:*** *To evaluate the radiation dose reduction benefit and image quality performance of SnapShot Pulse in step-and-shoot mode for helical coronary computed tomography angiography.*

***Methods:*** *Twenty coronary computed tomography angiography scans using SnapShot Pulse in step-and-shoot mode were randomly selected. Only patients with heart rate less than 65 bpm were included. The image quality and radiation dose of the 20 scans were compared with those of 20 randomly selected coronary computed tomography angiography scans performed previously using the helical mode. All examinations were performed on the same computed tomography scanner using the standard injection protocol. Two radiologists were involved in the evaluation of image quality of each segment of the coronary arteries in a double-blind manner using a 4-point scoring system.*

***Results:*** *There was no statistically significant difference in the image quality assessment between the 2 groups. The radiation dose was at least 3 times lower for SnapShot Pulse in step-and-shoot mode compared with that in helical mode.*

***Conclusion:*** *Coronary computed tomography angiography using the SnapShot Pulse technique in step-and-shoot mode can confer a beneficial radiation dose reduction, while preserving the image quality, when compared with conventional helical mode.*

***Key Words:*** *Coronary angiography, Radiation dosage, Tomography, X-ray computed*

## INTRODUCTION

According to the International Commission on Radiological Protection,[1] the estimated risk of radiation-induced stochastic effects is $7.3 \times 10^{-4}$ for coronary computed tomography angiography (CCTA) at an effective dose of 10 mSv. This risk should be reduced. Dose reduction methods include hardware design such as a bowtie filter[2] and software design such as an adaptive noise reduction filter.[3] Optimisation of imaging parameters such as reducing applied tube voltage and tube current are also effective.[4]

Recently, a new technique called SnapShot Pulse (SSP) in the step-and-shoot mode of acquisition has been developed, and reports of better performance in the management of irregular heart rate and reduced radiation dose to patients have been published.[5] The SSP technique uses prospective electrocardiogram (ECG) to define a temporal window usually at 75% diastolic phase for half-scanning data acquisition. A CT scanner at the Department of Diagnostic Radiology, Hong Kong Sanatorium and Hospital, Hong Kong, was upgraded recently to provide this new feature. It is important to evaluate the performance of any new technique or equipment after implementation or installation, respectively, to optimise the applications. The aim of this study was to evaluate the dose benefit and image quality of the SSP technique for CCTA.

## METHODS

In this retrospective study, 20 CCTA scans were randomly selected from all the scans that used SSP in step-and-shoot mode. Scans were performed on a 64-slice CT scanner (LightSpeed VCT XT, GE Healthcare

*Correspondence:* *Mr SK Yu, Department of Radiotherapy, G/F, Li Shu Pui Block, 2 Village Road, Happy Valley, Hong Kong. Tel: (852) 2835 8970; Fax: (852) 2892 7509; E-mail: benyu@hksh.com*

Submitted: 16 January 2008; Accepted: 18 April 2008.

Technologies, Wisconsin, USA) with default imaging settings using the standard injection protocol. The gantry rotation speed of the scanner was 0.35 seconds per rotation, translating to a temporal resolution of 0.175 seconds per rotation (50% of the gantry rotation speed). Since only the single-sector reconstruction algorithm was available for the SSP technique, the application was limited to patients with a heart rate less than 70 bpm. For patients with a higher heart rate, acquired data may come from different cardiac cycles, leading to motion artifact in the reconstructed images. Therefore, only patients with a heart rate less than 65 bpm were selected, regardless of other factors such as age, sex, or body habitus.

Using the same selection criterion, 20 control CCTA scans were randomly selected from previous CCTA scans using helical mode for comparison. No ECG mA modulation was applied for the control scans and the helical pitch was auto-determined based on the patient's heart rate. All images were reconstructed using the same algorithm so that direct comparison could be made. The estimated effective dose of each scan was calculated as the product of the conversion coefficient (k = 0.017 mSv/mGycm)[6] and the measured dose length product. The recorded dose for the 2 groups was compared using the unpaired *t* test.

Two experienced radiologists evaluated the image quality of each segment of the coronary arteries in a double-blind manner using a 4-point scoring system. The segments evaluated were as follows:

- proximal right coronary artery (RCA) — segment 1
- mid RCA — segment 2
- distal RCA — segment 3
- posterior descending RCA — segment 4
- main left coronary artery (LCA) — segment 5
- proximal LCA — segment 6
- mid LCA — segment 7
- distal LCA — segment 8
- first diagonal — segment 9
- second diagonal — segment 10
- proximal left circumflex (LCX) artery — segment 11
- distal LCX artery — segment 12
- left marginal branch — segment 13
- left posterolateral marginal branch — segment 14.

A score of 4 meant that the anatomical structures were clearly visualised and the confidence level for reaching a diagnosis was nearly 100%; a score of 3 meant that the visualisation and confidence level were approximately 75%; a score of 2 meant that the visualisation and confidence level were approximately 50%; and a score of 1 meant that the visualisation and confidence level were ≤25%.

Before the assessment, the scans from both groups were randomly mixed and all technical annotations were concealed. During the assessment, the readers reviewed the images at a workstation (Advantage Windows Workstation, GE Healthcare Technologies, Wisconsin, USA) with the freedom to adjust the viewing features.

Statistical analysis was undertaken using the 2-tailed paired *t* test to compare the mean score of each segment and all segments as a whole between the 2 groups.

## RESULTS

As shown in Table 1, the average doses received by patients in the study group (7.1 mSv; SD, 1.9 mSv) and the control group (24.1 mSv; SD, 3.7mSv) were significantly different ($p < 0.01$). However, there were no significant differences in the mean scores of image quality between the 2 groups ($p \geq 0.05$; Table 2), except for segments 1 and 10 in the results from reader 1. For these 2 segments, the mean score in the study group was significantly higher than the mean score in the control group. The average mean score of all segments from reader 1 was 3.64 for the study group, which was statistically comparable to the average mean score of 3.54 for the control group ($p = 0.27$). Similar results were obtained for reader 2, in that the average mean scores were 3.94 and 3.90 for the study group and control group, respectively ($p = 0.28$).

## DISCUSSION

CCTA has been performed mainly in helical mode, for which the table is continuously moving at a constant speed and the X-ray beam is continuously turned on while the data are collected helically. However, only data from the defined temporal window in diastolic phase is used for image reconstruction. Since small helical pitch (0.1 to 0.3) is normally applied to ensure that the entire heart volume is completely covered, patients receive a high radiation dose as the irradiated regions overlap. The radiation dose can be reduced if the helical pitch is larger. However, gaps will be present between scans in an adjacent cardiac cycle if the helical pitch is too large. Large gaps can result in image artifacts. This problem is more pronounced in the presence of arrhythmia, as the helical pitch is not dynamically adjusted based on the ECG signal. Therefore, small helical pitch

**Table 1.** Heart rate and radiation dose for all patients receiving coronary computed tomography angiography (n = 40).

| Study group (n = 20) | | Control group (n = 20) | |
|---|---|---|---|
| Heart rate (bpm) | Radiation dose (mSv) | Heart rate (bpm) | Radiation dose (mSv) |
| 43-45 | 8.0 | 45-49 | 23.0 |
| 44-50 | 5.8 | 48-50 | 25.0 |
| 46-49 | 6.9 | 48-56 | 25.0 |
| 46-51 | 7.8 | 49-50 | 27.0 |
| 47-57 | 9.0 | 50-52 | 30.0 |
| 49-51 | 8.3 | 50-61 | 22.0 |
| 50-52 | 7.2 | 54-54 | 28.0 |
| 51-53 | 6.7 | 55-56 | 25.0 |
| 53-54 | 10.0 | 55-57 | 17.0 |
| 53-59 | 7.3 | 55-57 | 25.0 |
| 54-56 | 7.2 | 56-57 | 26.0 |
| 54-56 | 8.3 | 56-58 | 28.0 |
| 54-57 | 5.4 | 57-60 | 22.0 |
| 55-58 | 2.4 | 57-58 | 25.0 |
| 56-58 | 5.8 | 57-60 | 16.0 |
| 56-58 | 9.0 | 58-59 | 22.0 |
| 57-58 | 5.4 | 58-60 | 28.0 |
| 58-59 | 8.3 | 58-60 | 20.0 |
| 61-63 | 10.0 | 61-62 | 26.0 |
| 64-66 | 4.0 | 64-67 | 21.0 |
| Average dose, 7.1 mSv; SD, 1.9 mSv. | | Average dose, 24.1 mSv; SD, 3.7 mSv. | |

**Table 2.** Mean score of the image quality of each segment for all patients receiving coronary computed tomography angiography (n = 40).

| Segment | Reader 1 | | | Reader 2 | | |
|---|---|---|---|---|---|---|
| | Study group | Control group | p Value* | Study group | Control group | p Value* |
| 1 | 3.85 | 3.55 | 0.04 | 3.95 | 3.80 | 0.32 |
| 2 | 3.55 | 3.65 | 0.53 | 3.80 | 3.35 | 0.06 |
| 3 | 3.90 | 3.80 | 0.52 | 3.95 | 3.90 | 0.66 |
| 4 | 4.00 | 3.95 | 0.33 | 4.00 | 3.90 | 0.33 |
| 5 | 3.95 | 4.00 | 0.33 | 4.00 | 3.90 | 0.33 |
| 6 | 3.85 | 3.80 | 0.73 | 3.95 | 4.00 | 0.33 |
| 7 | 3.75 | 3.75 | 1.00 | 3.95 | 3.90 | 0.66 |
| 8 | 3.90 | 3.80 | 0.52 | 3.95 | 4.00 | 0.33 |
| 9 | 3.60 | 3.90 | 0.11 | 3.95 | 4.00 | 0.33 |
| 10 | 3.25 | 2.20 | 0.02 | 3.95 | 4.00 | 0.33 |
| 11 | 3.90 | 3.95 | 0.56 | 4.00 | 3.95 | 0.33 |
| 12 | 3.75 | 4.00 | 0.10 | 4.00 | 3.95 | 0.33 |
| 13 | 3.35 | 3.05 | 0.44 | 3.85 | 3.95 | 0.53 |
| 14 | 2.40 | 2.20 | 0.67 | 3.85 | 3.95 | 0.53 |
| 1-14 | 3.64 | 3.54 | 0.27 | 3.94 | 3.90 | 0.28 |

* p Values were calculated using the 2-tailed paired *t* test.

is inevitably used to ensure continuous volume coverage, even in the presence of arrhythmia, leading to a high radiation dose for patients.

In 2006, Hsieh et al developed a new acquisition approach for CCTA, SSP, that was implemented for clinical use (LightSpeed VCT XT, GE Healthcare Technologies, Wisconsin, USA).[5] SSP is a step-and-shoot technique. In this mode of acquisition, an axial scan is performed while the table is stationary. The X-ray beam is turned off and the table is moved to the next position for another axial scan triggered by ECG gating. If arrhythmia occurs, the table stays at the same location, without data acquisition, until a normal R-peak is detected. Since the table does not move during arrhythmia, there is no gap between adjacent scans as there is in helical mode, so only a small overlap is required as a safety margin to avoid longitudinal truncation. The SSP technique in step-and-shoot mode can theoretically enable patients to receive a lower radiation dose than with the conventional helical mode. Since the same X-ray tube current can be used during data acquisition, similar image quality can be achieved.

Comparison of the scan time between the step-and-shoot mode and the helical mode shows that the major difference is the inter-scan delay, which is the time required to move the table to the next location for the subsequent scan. There is no inter-scan delay in helical mode since data acquisition is continuous, but this delay is inevitable in step-and-shoot mode due to care taken during acceleration and deceleration when moving patients from one position to another. The scan time in helical mode depends on the pitch, detector size, and the distance to travel. In step-and-shoot mode, the scan time is the product of the time of a step-and-shoot scan (acquisition time plus the inter-scan delay time) and the number of scans required to cover the heart. If the inter-scan delay time is short, the total acquisition time is shorter in step-and-shoot mode than in helical mode and vice versa. As the heart rate increases, heart motion during the temporal data acquisition window becomes more serious and leads to blurring of the reconstructed images. Although a technique called 'multi-sector', in which the half-scan dataset is divided into multiple sectors, can be employed to collect data over multiple cardiac cycles, this feature is only available in helical mode. Therefore, the application of the step-and-shoot mode is limited to patients with a heart rate of ≤70 bpm.

In this study, the radiation dose using SSP in step-and-shoot mode was shown to be less than 30% of the dose using helical mode. However, the image quality scores of the 2 modes awarded through independent assessment by experienced radiologists were found to be statistically equivalent.

CCTA using the SSP technique in step-and-shoot mode can confer a beneficial radiation dose reduction, while preserving the image quality, when compared with conventional helical mode.

# REFERENCES


1. 1990 Recommendations of the International Commission on Radiological Protection. ICRP Publication 60. Ann ICRP. 1990;22.
2. McCollough CH, Primak AN, Saba O, et al. Dose performance of a 64-channel dual-source CT scanner. Radiology. 2007; 243:775-84.
3. Raupach R, Bruder H, Stierstorfer K, Suess C, Flohr T. A novel approach for efficient edge preserving noise reduction in CT volume data [abstract]. In the Radiological Society of North America Scientific Assembly and Annual Meeting Program. Oak Brook: Radiological Society of North America; 2005:524.
4. Abada HT, Larchez C, Daoud B, Sigal-Cinqualbre A, Paul JF. MDCT of the coronary arteries: feasibility of low-dose CT with ECG-pulsed tube current modulation to reduce radiation dose. AJR Am J Roentgenol. 2006;186(Suppl):S387-90.
5. Hsieh J, Londt J, Vess M, Li J, Tang X, Okerlund D. Step-and-shoot data acquisition and reconstruction for cardiac X-ray computed tomography. Med Phys. 2006;33:4236-48.
6. European guidelines for quality criteria for computed tomography. Luxembourg: European Commission; 2000.