ORIGINAL ARTICLE

Coronary CT angiography using a prospective protocol. Comparison of image quality and radiation dose between dual source CT and single source CT∗

R. Duartea,b,∗, D. Mirandaa,b, G. Fernández-Pérezc, J.C. Costaa

a JCC-Diagnóstico por Imagen, Hospital Particular Viana do Castelo, Portugal
b Department of Radiology, Centro Hospitalar Vila Nova de Gaia, Espinho, Portugal
c Department of Radiology, Hospital Ntra. Sra. de Sonsoles, Ávila, Spain

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KEYWORDS
High-pitch spiral acquisition; Coronary computed tomography angiography; Radiation dose

Abstract
Objective: To compare the image quality and radiation dose in a group of patients undergoing coronary CT angiography using a 128-slice dual source helical CT scanner with high pitch and prospective acquisition and those in a group of patients with similar clinical characteristics undergoing coronary CT angiography using a 128-slice single-source CT scanner with prospective sequential acquisition.

Material and methods: We included 80 patients with heart rates ≤65 beats/min: 40 underwent sequential 128-slice single source CT with prospective synchronization and the other 40 underwent 128-slice dual source helical CT with high pitch and prospective synchronization. Two radiologists independently assessed the quality of the images of the coronary arteries on the 80 coronary CT angiograms: image quality was classified on a four-point scale in which 1 represented excellent and 4 deficient. The effective dose of radiation was also calculated.

Results: The clinical characteristics of the patients in the two groups were similar. The image quality obtained with dual source CT was significantly better than that obtained with single source CT (p=0.006). The mean effective dose of radiation in the group undergoing dual source CT was 36% lower than in the group undergoing single source CT (1.4±0.6 mSv vs 2.2±0.9 mSv; p<0.01).

Conclusion: Although both sequential 128-slice single source CT with prospective acquisition and 128-slice dual source helical CT with high pitch and prospective acquisition provide good image quality and low effective doses of radiation, 128-slice dual source helical CT with prospective acquisition provides better image quality and results in a lower effective dose of radiation.

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∗ Corresponding author.
E-mail address: guerra.duarte@gmail.com (R. Duarte).

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PALABRAS CLAVE
Adquisición helicoidal con pitch alto; Coronariografía mediante tomografía computarizada; Dosis de radiación

Coronariografía mediante tomografía computarizada con sincronización prospectiva. Comparación de la calidad de imagen y dosis de radiación con equipos de 128 detectores de fuente única y doble fuente

Resumen
Objetivo: Comparar la calidad de imagen y la dosis de radiación de un grupo de pacientes a los que se les realizó una coronariografía mediante tomografía computarizada helicoidal de doble fuente (TCDF) de 128 cortes con pitch alto y adquisición prospectiva con la calidad de imagen y la dosis de radiación de un grupo de pacientes con similares características clínicas con los que se les realizó una coronariografía por tomografía computarizada de fuente única (TCFU) de 128 cortes con adquisición secuencial prospectiva.

Material y métodos: Se incluyeron 80 pacientes con una frecuencia cardíaca < 65 lat/min: a 40 de ellos se les realizó una TC secuencial de fuente única de 128 cortes y sincronización prospectiva, y a los 40 restantes se les realizó una TC helicoidal de doble fuente de 128 cortes, con pitch alto y sincronización prospectiva. Dos radiólogos evaluaron de manera independiente la calidad de imagen de las arterias coronarias de 80 estudios de coronariografía por TC (CCT) empleando una escala de 1 a 4 (en la que 1 es imagen de excelente calidad y 4 calidad deficiente). También se calculó la dosis de radiación efectiva.

Resultados: Ambos grupos presentaban características clínicas similares. La calidad de imagen del grupo de TCDF fue significativamente mayor que la del grupo de TCFU (p = 0,006). La dosis media de radiación efectiva del grupo de TCDF fue significativamente más baja que la del grupo de TCFU (1,4 ± 0,6 mSv frente a 2,2 ± 0,9 mSv; p < 0,01), lo que representa una reducción de dosis del 36% en el primer grupo.

Conclusión: Aunque tanto la TC secuencial de fuente única de 128 cortes con adquisición prospectiva como la TC helicoidal de doble fuente de 128 cortes con pitch alto y adquisición prospectiva presentan una calidad de imagen alta con dosis de radiación efectiva bajas, la TC helicoidal de doble fuente de 128 cortes y adquisición prospectiva proporciona una mejor calidad de imagen y una dosis de radiación efectiva menor.

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Introduction

The success of noninvasive coronary computed tomography angiography (CCTA) for the assessment of coronary artery disease (CAD) depends on the temporal and spatial resolution of the computed tomography (CT) scanners. Therefore, it is not surprising that one of the major technological advances in CT scanners is precisely a noticeable improvement of the temporal and spatial resolution, which coupled with the increasing number of detectors by a scanner, led to a continuous improvement of image quality and diagnostic accuracy of CCTA. Retrospective electrocardiographic (ECG)-gating CCTA provides a robust high diagnostic accuracy for evaluation of CAD. However, since this technique requires use of very low pitch, usually in the range of 0.2–0.4, the associated radiation dose is typically high and radiation doses as high as 30 mSv have been reported. The high radiation dose associated with retrospective CCTA and the inherent risk of cancer are important sources of concern and remains a major limitation to its widespread use. Therefore, several strategies to reduce the radiation dose associated with CCTA have been developed and include ECG-based tube current modulation, individual tube voltage adaptation, minimizing z-axis and anatomic-based tube current modulation. Nevertheless, a recent review reported that even when these strategies are frequently applied the mean radiation dose associated with retrospective CCTA was 12 mSv.

Prospective ECG-triggering sequential CCTA scanning technique, also called “step and shoot” technique, is a well-established radiation dose saving strategy, in which the X-ray beam is turned on only at a predefined portion of cardiac cycle and turned off during the rest of the R-R cycle.

Recently, a new acquisition technique called prospectively ECG-triggering high-pitch spiral (Flash spiral) has been developed. This acquisition technique uses pitch values of 3.0 or more and is only possible with dual-source geometry in which the gaps in the trajectory of the first detector resulting from the ultra-fast table motion are filled in by the second detector, allowing the acquisition of the entire volumetric data in 250 ms using only a single cardiac cycle with an effective radiation doses as low as 1 mSv in appropriately selected patients. To date no study has evaluated and compared the image quality and radiation dose of CCTA performed using two low-dose prospective scanning protocols between a 128-slice single-source computed tomography (SSCT) and a 128-slice dual-source computed tomography (DSCT).

Therefore, our purpose was to compare the image quality and patient radiation dose between a group of patients who underwent CCTA performed with prospective sequential 128-slice SSCT with a group of patients who underwent CCTA performed with prospectively high-pitch spiral 128-slice DSCT.
Materials and methods

Patient sample

Our institutional review board approved this study. All patients included in this study were referred to our institution for CCTA to assess or exclude the presence of CAD for a variety of clinical indications (Table 1).

Exclusion criteria

Exclusion criteria were as follows: non-sinus rhythm, prior coronary artery stent placement or coronary artery bypass surgery, known hypersensitivity to iodinated contrast material, heart rate higher than 65 bpm after the administration of the maximum dose of metoprolol and insufficient renal function.

Prospective group—Between December 2009 and February 2010, 41 consecutive CCTA were performed with a 128-slice DSCT scanner using prospectively high-pitch acquisition (Fig. 1). One patient was unable to achieve a heart rate lower than 65 bpm after the administration of the maximum dose of metoprolol and was excluded. Therefore, the final study group included 40 patients. All patients have signed a written informed consent.

Retrospective group

An initial comparison study group of 40 patients who underwent CCTA with 128-slice SSCT using prospective sequential acquisition was assembled by reviewing consecutive CCTA studies (Fig. 1). Studies were reviewed in reverse chronologic order, beginning with those obtained in December 2009 and concluding with those obtained in September 2009. An author, who did not participate in the image quality scoring, matched on the basis of the clinical indication for CCTA the patients in the SSCT group with the patients in DSCT group. Thus, the final comparison study group consisted of 40 patients who underwent 128-slice SSCT using prospective sequential acquisition.

Computed tomography technique

A baseline blood pressure and heart rate were recorded for all patients, once they were in the scanner table. In all cases a clear QRS complex was obtained and whenever the heart rate was greater than 65 bpm and in the absence of contraindications, intravenous metoprolol (Beloc, AstraZeneca, London, United Kingdom) was administered. We started with an initial bolus of 3 mg, and in those cases in which heart rate remained above 65 bpm, up to 5 additional doses were injected (maximum of 15 mg) every 3–5 min. Sublingual nitroglycerin (0.4 mg Nitromint, Quilaban, Absam, Austria) was also administrated 3 min before the exam acquisition to guarantee the maximum vasodilator effect in coronary arteries, in the absence of contraindications.

An automatic double head injector (Stellant; Medrad, Germany) was used in all the CCTA examinations for contrast administration using a biphasic injection: 50 ml of contrast material (Ultravist 370, Bayer-Schering Pharma, Germany) was injected, followed by 50 ml saline solution, at flow rate of 5 ml/s.

Circulation time from the antecubital fossa to the aortic root was determined in each patient by additional bolus test with administration of 10 ml of contrast material at the same rate flow. Maximal aortic enhancement was measured by placing a 1-cm² region of interest (ROI) in the ascending aorta and a delay of 5 s was added to the maximal aortic enhancement time to account for the difference in

| Table 1: Clinical indications for coronary computer tomography angiography. |
|-----------------------------|-----------------------------|
| Clinical indication         | SSCT group (n = 40)         | DSCT group (n = 40)         |
| Angror                      | 14 (35%)                    | 19 (47.5%)                  |
| Atypical chest pain         | 14 (35%)                    | 8 (20%)                     |
| Inconclusive stress-test    | 10 (25%)                    | 9 (22.5%)                   |
| Positive stress-test        | 2 (5%)                      | 4 (10%)                     |

Percentages in parenthesis. Chi-square test was used for comparisons of groups (p value of 0.37).

SSCT, single-source computed tomography; DSCT, dual-source computed tomography.
Figure 2  CCTA images obtained with 128-slice DSCT scanner using prospectively high-pitch spiral acquisition of a 57-year-old male with a heart rate of 64 bpm (160 cm, 70 kg, effective radiation dose 1.2 mSv). The patient has a mild stenosis in the proximal left anterior descending due to a long soft plaque with a calcified nodule. No stenoses are present in the right coronary artery and left circumflex coronary artery. (a) 3D volume rendering reconstruction of the heart and coronary arteries. Curved multiplanar reformations of the (b) right coronary artery, (c) left circumflex coronary artery, (d) left anterior descending coronary artery and (e) transaxial image at the level of the soft plaque in the proximal left anterior descending coronary artery. The image quality of each coronary artery is excellent with optimal opacification and definition of the vessel margin, without motion artefacts (score 1).

enhancement pattern between the bolus in the CCTA examination and the test bolus.

Parameters for SSCT group, using a 128-slice single-source scanner (Somatom Definition AS128, Siemens Medical Solutions, Germany) with prospective sequential acquisition, were: gantry rotation time of 300 ms and temporal resolution of 150 ms, collimation 64 mm × 0.6 mm, resulting in 128 reconstructed slices per gantry rotation using a z-flying focal spot technique, covering the complete heart volume data in three to five slabs in the cranio-caudal direction. Full tube current was applied only at 70% of the RR interval. Gantry rotation was extended from 360° to 460° during diastole – so called “phase optimization”, allowing additional reconstructions from 60% to 80% of the R–R interval.

Parameters for DSCT group, using a 128-slice dual-source scanner (‘Definition FLASH’, Siemens Healthcare, Forchheim, Germany) with two X-ray tubes and two detectors arranged at an angular offset of 95° and prospectively high-pitch acquisition, were: gantry rotation time of 280 ms, temporal resolution of 75 ms, and a collimation was 2 mm × 64 mm × 0.6 mm. Together with a z-flying focal spot, this allows simultaneous acquisition of data in 2 × 128 slices per gantry rotation, covering the complete heart volume data in only one cardiac cycle in the caudo-cranial direction. Image acquisition started at 60% of the R–R interval.

In both groups body weight-adapted tube voltage was used, selecting a 100 kV tube voltage when patient weight was equal or less than 80 kg and a 120 kV tube voltage was used in those weighing more than 80 kg. An automatic adaptation of the tube current to patient-specific parameters such as the size and attenuation of the body region (Care Dose 4D; Siemens Healthcare, Germany) was used in both groups.

Coronary artery image quality analysis

Coronary segments of the three main coronary arteries and their major side branches were defined according to the 15-segment American Heart Association guidelines. Segment 16 was added for *ramus intermedius*, if present. All segments with a luminal diameter of 1.5 mm or larger at their origin were evaluated.

CCTA studies from SSCT group and those from DSCT group were randomly presented during each reading session. For SSCT group studies, the reviewers examined images reconstructed at 60%, 65%, 70%, 75%, and 80% of the R–R interval and scored each coronary artery segment for image quality by using the reconstructed percentage judged to be best for that segment. For DSCT group studies, while the data window of the topmost cross-sectional image started at 60% of the R–R interval, subsequent images were reconstructed progressively later in the 220–330 ms data acquisition window.

Two radiologists independently assessed the image quality at different times of each coronary artery segment on the axial CCTA sections and multiplanar reformations for diagnostic quality based on a semiquantitative four-point grading scale. Score 1 corresponds to images of excellent image quality without any artefacts (Fig. 2).

Score 2 corresponds to good image quality with discrete blurring of vessel margin and no stair-step artefacts (Fig. 3).

Score 3 corresponds to fair image quality with some motion
Coronary CT: Comparison between 128-slice single- and dual-source computed tomography

Figure 3  CTA images obtained with 128-slice DSCT scanner using prospectively high-pitch spiral acquisition of a 55-year-old male with a heart rate of 59 bpm (172 cm, 79 kg, effective radiation dose 1.1 mSv). Curved multiplanar reformations of the right coronary artery with discrete blurring of vessel margin but with good opacification and no structural discontinuity or stair-step artefacts (score 2).

artefacts or blurring of vessel margin, fair vessel opacification, or minimal structural discontinuity (Fig. 4).

Score 4 corresponds to poor image quality due to manifest motion artefacts. Scores between 1 and 3 were considered as appropriate for diagnostic purposes.

Whenever reviewers differed on the image quality score after their independent reading sessions, the higher numerical score in the evaluation of the image quality score was used for statistical analysis.

Radiation dose

The effective radiation dose was calculated by multiplying the dose-length product (DLP) documented in the scan protocol for each CTA acquisition by the conversion coefficient for the chest CT in adults ($k = 0.017$).

Statistical analysis

All statistical analyses were performed by using commercially available software (SPSS 16.0; SPSS Inc., Chicago, USA). Comparison of patient data between the two groups was performed by using Student’s $t$-test for comparing continuous variables, an $\chi^2$ test for categorical variables and a Mann–Whitney Test for non-parametric (ordinal) variables. Continuous variables were expressed as means ± standard deviations, categorical variables as percentages and non-parametric variables as medians.

Interobserver agreement in subjective image quality scoring was assessed by using kappa statistics ($k$): A $k$ value greater than 0.81 corresponded to excellent interobserver agreement, $k$ values of 0.61–0.80 corresponded to substantial or good interobserver agreement, $k$ values of 0.41–0.60 corresponded to moderate interobserver agreement, and $k$ values of 0.21–0.40 corresponded to fair interobserver agreement.

Statistical differences with $p < 0.05$ were selected as the level of significance.

Results

Matching of groups

Patients in SSCT group and those in DSCT group did not differ significantly in terms of their clinical indications for examination (Table 1). There was no significant difference between the groups for heart rate, sex, age and body weight (Table 2).

Quality scores

There was excellent agreement between the reviewers for segment image quality scores of each segment ($k = 0.92$). In their independently evaluation, the reviewers disagreed over whether a segment was large enough to score for 10 segments (1%).

In SSCT group, from a theoretically 600 possible segments a total of 552 segments with a luminal diameter equal or greater than 1.5 mm were analyzed. In DSCT group, from a theoretically 600 possible segments a total of 574 segments with a luminal diameter equal or greater than 1.5 mm were analyzed. The difference in segment numbers between the two groups was due to anatomical variations (31 and 17 segments were anatomically absent respectively for SSCT group and DSCT group) and small vessel with luminal...
diameter minor than 1.5 mm at their origin (17 and 9 segments, respectively, for SSCT group and DSCT group).

Of the 552 coronary artery segments imaged with SSCT scanner, 533 (96.6%) were considered to have sufficient image quality for diagnosis purposes, whereas 19 (3.4%) were considered to be nonevaluable (score 4), while all of the 574 coronary artery segments imaged with DSCT scanner were considered to have sufficient image quality for diagnosis purposes (Table 3).

On a per segment basis, the comparison between SSCT and DSCT in the image quality was scored as excellent (score 1) in 365 (66.1%) vs 496 (86.4%), as good in 134 (24.3%) vs 72 (12.6%), as fair in 34 (6.2%) vs 6 (1.0%), respectively.

The image quality score for DSCT group was significantly higher than that for SSCT group ($p = 0.006$).

Acquisition time

The imaging time for DSCT group (0.26 ± 0.05 s, range 0.2–0.3 s) was significantly lower than that for SSCT group (5.8 ± 0.8 s, range 4.1–7.9 s; $p < 0.01$).

Radiation dose

There was also a statistically significant difference in the patient effective radiation dose between the SSCT group (2.2 ± 0.9 mSv, range 1.0–4.0 mSv) and the DSCT group (1.4 ± 0.6 mSv, range 0.6–2.6 mSv; $p < 0.01$) (Table 4). The mean difference in both methods was 0.8 mSv with a confidence interval between 0.4 and 1.1 mSv (95% CI) and resulting in a reduction in radiation dose of 36% with DSCT.

Discussion

CCTA requires high temporal resolution to limit cardiac motion artefacts, high spatial resolution to visualize smaller vessels and short imaging time to reduce respiratory motion artefacts.

Since the introduction of the 4-slice scanners in 2000, marked improvements in the temporal and spatial resolution, as well as the increasing numbers of detectors per scanner, allowed a substantial reduction of motion artefacts and number of coronary segments not assessable. These technologic advances have not only improved the image quality, but also the sensitivity and specificity for the diagnosis of CAD.

In 2006, the advent of DSCT scanners, which uses two X-ray tubes and two detectors arranged at near to a 90° angle and requires only a one-quarter rotation of the gantry to acquire the X-ray data required to reconstruct one image, doubled the temporal resolution when compared to SSCT scanners with the same gantry rotation speed, provided additional improvement in temporal resolution and further increase in specificity and accuracy for diagnosing significant stenosis.

Prospective ECG-triggering is an acquisition technique associated with low radiation exposure and several studies have shown that it allows a significant reduction of the radiation dose without loss of image quality and diagnostic accuracy. This acquisition technique requires a minimum time in which the tube current is turned on during each heartbeat. An extra time before and after this minimum time can be added depending on the amount of perceived beat-to-beat variability to allow the reconstruction to adapt to minor heart rate variations and produce consistent image quality. This additional time is referred to as “padding” and corresponds to the additional time that the X-ray beam is turned on in addition to the minimum time necessary to acquire an image of the heart in a single point in the diastole. Thus, in patients with excellent heart rate control, the use of minimal or no padding can provide an additional significant reduction of the radiation dose without compromising the image quality. The drawback of using a reduced

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<th>Table 2</th>
<th>Patients characteristics.</th>
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<tr>
<td>Characteristics</td>
<td>SSCT group (n = 40)</td>
</tr>
<tr>
<td>Age, years</td>
<td>62 ± 7</td>
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<tr>
<td>Male sex, n</td>
<td>29 (73%)</td>
</tr>
<tr>
<td>Heart rate, bpm</td>
<td>60 ± 5</td>
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<tr>
<td>Body weight, kg</td>
<td>70 ± 10</td>
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</tbody>
</table>

Percentages in parenthesis.
SSCT, single-source computed tomography; DSCT, dual-source computed tomography.

<table>
<thead>
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<th>Table 3</th>
<th>Image quality scores.</th>
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<tr>
<td>Image quality score</td>
<td>SSCT group (n = 40)</td>
</tr>
<tr>
<td>Score 1 (excellent)</td>
<td>365 (66.1%)</td>
</tr>
<tr>
<td>Score 2 (good)</td>
<td>134 (24.3%)</td>
</tr>
<tr>
<td>Score 3 (fair)</td>
<td>34 (6.2%)</td>
</tr>
<tr>
<td>Score 4 (poor)</td>
<td>19 (3.4%)</td>
</tr>
<tr>
<td>Median image quality score</td>
<td>1.0 ± 0.2</td>
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</table>

Percentages in parenthesis.
SSCT, single-source computed tomography; DSCT, dual-source computed tomography.
The authors recognize several important limitations. First, assessment of image quality was subjective. Nevertheless, other investigators of CCTA image quality have used the same semiquantitative image quality scoring scales that we used. Second, although the reviewers were not informed at the time of image scoring about the scanner and acquisition protocol for each patient, the R–R interval reconstruction percentages were different for each technique, and this difference precluded complete blinding. Finally, we did not analyze the influence of the calcium score on image quality or perform stenosis grading and classification to determine the diagnostic performance, and so further studies are necessary to clarify the diagnostic accuracy.

In conclusion, both prospective sequential 128-slice SSCT and flash spiral 128-slice DSCT provide high image quality at a low effective radiation dose. Nevertheless, the DSCT provides higher image quality and further reduces the effective radiation dose, as compared with the SSCT.

### Table 4  Patient radiation dose.

<table>
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<th>SSCT group</th>
<th>DSCT group</th>
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<tr>
<td>DLP (mGy·cm)</td>
<td>125 ± 51</td>
<td>81 ± 34</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Effective radiation dose (mSv)</td>
<td>2.2 ± 0.9</td>
<td>1.4 ± 0.6</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>

Mean ± SD.

SSCT, single-source computed tomography; DSCT, dual-source computed tomography.

**Coronary CT: Comparison between 128-slice single- and dual-source computed tomography**

**Authorship**

1. Person responsible for the study’s integrity: RD, DM, JCC and GCFP.
2. Conception of the study: RD and GCFP.
3. Design of the study: RD and GCFP.
4. Data acquisition: RD, DM and JCC.
5. Data analysis and interpretation: RD, DM and JCC.
6. Statistic treatment: RD.
7. Bibliographic search: RD and DM.
8. Writing of the paper: RD and GCFP.
9. Critical revision of the manuscript with intellectually relevant contributions: GCFP.
10. Approval of final version: RD, DM, JCC and GCFP.

**Conflicts of interest**

The authors declare no conflict of interest.

**References**


