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CARDIOVASCULAR IMAGING

ORIGINAL ARTICLE

Reduction of cardiac motion artifact in step-and-shoot coronary CT angiography with third-generation as compared with second-generation dual-source CT scanners

Liang Jin*
Ji'an Zhou*
Yiyi Gao*
Wei Zhao*
Ming Li
Zhizhong Wang

PURPOSE
We aimed to compare the effects of misregistration (stair-step artifact) occurrence during coronary computed tomography angiography (CCTA) using third- and second-generation dual-source computed tomography (DSCT) scanners.

METHODS
CCTA was performed in consecutive patients with suspected coronary heart disease. Patients were randomly assigned to two groups and imaged using a third-generation (n=68; group A) or second-generation (n=63; group B) DSCT scanner. Heart rate (HR), heart rate variability (HRV), the number of acquisition steps required, and the anatomical cardiac length of each patient were recorded and compared between the two groups. Qualitative interpretation and analyses were scored with respect to subjective image quality and misregistration (stair-step artifact) by two interpreters. Cohen's kappa was used to evaluate the consistency between the observers.

RESULTS
All CCTA images (100%) on both DSCT scanners yielded satisfactory image quality, with a subjective image quality score of 4.21±0.17. The consistency between the two observers with respect to misregistration and subjective scores were good (κ= 0.91 and 0.92, respectively). Both the number of acquisition steps required and the scan length of each patient in group A differed significantly ($p < 0.001$) from those in group B; there were significantly fewer artifacts in group A than in group B ($p < 0.001$). Misregistration artifacts did not correlate with the HRs or HRVs between two required acquisition steps ($p > 0.20$).

CONCLUSION
As compared with second-generation DSCT, the reduced number of acquisition steps required and the shorter scan length in third-generation DSCT reduced the occurrence of misregistration artifacts in CCTA images.

From the Departments of Radiology (L.J., Y.G., W.Z., M.L. ✉ *ming_li@fudan.edu.cn*) and Medicine (J.Z.), Huadong Hospital, affiliated to Fudan University, Shanghai, China; Institute of Functional and Molecular Medical Imaging (M.L.), Fudan University, Shanghai, China; Caoxian People's Hospital (Z.W. ✉ *406591844@qq.com*), Shandong, China.

*Liang Jin and Ji'an Zhou, contributed equally to this work.

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Coronary computed tomography angiography (CCTA) has gained widespread acceptance as the first choice for noninvasive assessment of a wide variety of cardiac diseases, as it has strong negative-predictive value and is effective in ruling out coronary artery disease in symptomatic patients, particularly those with intermediate risk (1). However, despite recent advances in cardiac computed tomography (CT) technologies, such as faster gantry rotation and an increased number of detector rows, CCTA images remain vulnerable to a number of artifacts due to patient- and technique-specific causes. Artifacts in cardiac CT may cause image degradation and interference in diagnosis (2–4), leading to either underdiagnosis or overtreatment, both of which are associated with increased patient morbidity and mortality (5).

Misregistration (stair-step) artifact, a type of cardiac motion artifact, appears when the heart is not in an identical position during consecutive heartbeats, because of arrhythmias (5). Avoiding misregistration artifacts between adjacent acquisition steps remains a challenge in step-and-shoot CCTA (6). Numerous studies have investigated step-and-shoot CCTA with different types of CT scanners. A previous study investigated misregistration artifacts with a 64-slice single-source CT (7), another study investigated image quality obtained with 128-slice

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dual-source CT (DSCT) (8), while yet another study investigated the effect of heart rate (HR) and heart rate variability (HRV) on image quality when using a 256-slice CT scanner (6). Most guidelines state that decreasing the mean HR and HRV is the most important factor for minimizing cardiac motion artifacts (9, 10), including misregistration artifacts. However, it is not clear whether the incidence of misregistration artifacts would be similar in the new-generation DSCT scanners, with their faster gantry speed and increased Z-coverage.

Hence, the aim of this study was to investigate the frequency of occurrence of misregistration artifacts in step-and-shoot CCTA with a third-generation DSCT scanner, as compared with that of a second-generation DSCT scanner.

Methods

Patient data and enrollment

This prospective study was approved by the local ethics committee (2019K005) and the need for obtaining informed patient consent was waived. Patients with suspected coronary artery disease who underwent CCTA between August 2018 and January 2019 were enrolled in the study. The following patients were excluded: 1) patients who were allergic to iodine contrast agent; 2) patients with severe hepatic and renal insufficiency; 3) patients with decompensated cardiac insufficiency; 4) patients who were administered drugs to control HR before examination; and 5) patients who could not hold their breath or had a stent implant or coronary artery bypass graft. Thus, 131 patients were included in the study.

CT data acquisition and image reconstruction

The patients were randomly divided into group A (n=68) and group B (n=63) using a random number generator. A third-generation DSCT scanner (Somatom Force, Siemens Healthineers) was used for group A, where the collimation was 2×96×0.6 mm and the rotation time was 0.25 s/rot. A second-generation DSCT (Somatom Definition Flash, Siemens Healthineers) was used for group B, where the collimation was 2×96×0.6 mm and the rotation time was 0.28 s/rot. The scan range corresponded to the minimum scan length necessary to cover the complete cardiac anatomy, craniocaudally, from the reconstructed axial images. A calcium score scan was performed to implement the scan plan before performing the actual CCTA scan. Prospectively electrocardiogram (ECG)-triggered sequential CCTA with automated tube current modulation and tube potential selection (CAREDose4D and CAREkV) was the standard of care to keep the radiation dose as low as possible, with the range of exposure dose (ECG-pulsing) set at 30%–80% in the R-R interval. The bolus tracking technique was implemented with an iodine contrast medium. Threshold monitoring was set at the aortic root region, with an enhancement threshold of 80 HU for both DSCT scanners. Contrast medium (Iopamiro, 370 mgI/mL) and saline were injected into the elbow vein using a 20 G closed intravenous catheter system through a high-pressure syringe.

The optimal phase (end-systolic or end-diastolic) of coronary artery display was reconstructed automatically using the console on the DSCT device. A B40v kernel set at advanced modeled iterative reconstruction strength 3 with a slice thickness of 0.75 mm was used in group A, while an I26f kernel with sinogram-affirmed iterative reconstruction strength set at 3 with a slice thickness of 0.75 mm in group B.

All images were analyzed using the AW 4.7 Advantage Workstation (GE Healthcare).

HR and HR variability

For each patient, HR was recorded after scanning as the average of the cycles during X-ray exposure. HRV was defined as the beat-to-beat variability between adjacent acquisition steps (Fig. 1).

Calculation of the number of required acquisition steps, anatomical cardiac length, and collimations used

First, the number of acquisition steps required for each scan was recorded after CCTA. The anatomical cardiac length in each patient was then calculated through the table position information on images from the coronary sinus and the origin of the coronary arteries to the termination of the coronary arteries.

With the third-generation DSCT scanner, the number of acquisition steps required was dependent on the scan length, according to the collimation setting, where one cardiac cycle corresponded to the width of an adaptive detector (64×0.6 to 96×0.6), with 10%–17% overlap (11); the collimation used was calculated in the same way as for the second-generation DSCT.

Qualitative interpretation and analysis

Two cardiac radiologists (reader 1 with 5 years' experience in cardiac imaging; reader 2 with 15 years' experience in cardiac imaging) interpreted the images. Individual adjustments of the window center and window width level settings by radiologists were allowed for diagnosis. CCTA axial images, combining multiplanar reconstruction images, were initially read by each reader in a double-blind manner in isolation and interpreted as being positive or negative for misregistration (stair-step) artifacts between the two required acquisition steps. Images were marked as "0" if negative for these artifacts, "1" if one artifact appeared in images, "2" if two artifacts appeared in images, and each artifact was recorded in one-to-one correspondence with its associated cardiac cycle. Each misregistration artifact was strictly differentiated from breathing artifacts.

Main points

- Reducing misregistration artifacts during coronary CT angiography would improve diagnostic image quality.
- The wide-coverage detector on third-generation dual-source CT scanners helps to reduce the required number of acquisition steps.
- By reducing the number of acquisition steps, there is a lower chance for occurrence of misregistration artifacts.

Figure 1. Heart rate (HR) is the average mean of the cycles during X-ray exposure only. For example, in this figure, the average HR was (61+55+56)/ 3 = 57.33 bpm. HR variability (HRV) was defined as beat-to-beat variability between adjacent acquisition steps. For example, in this figure, HRV1 was 61-55= 6, while HRV2 was 56-55= 1.

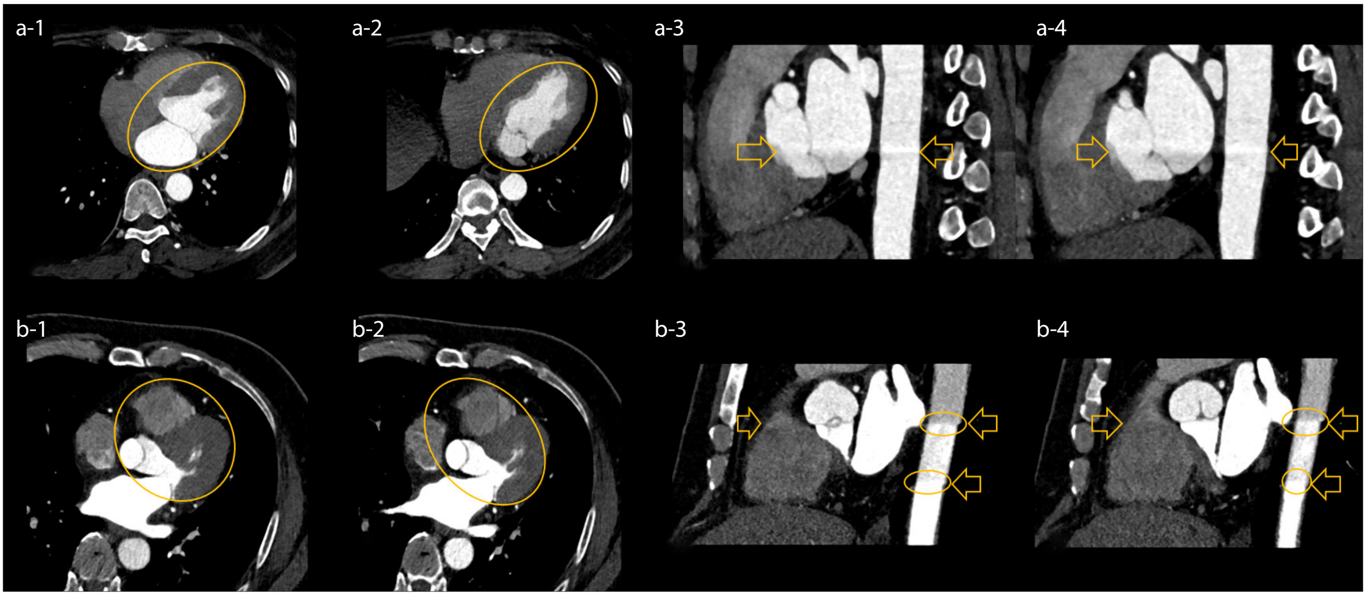

Figure 2. a, b. A 50-year-old female was scanned using two required acquisition steps on a Somatom Force scanner, with a misregistration (stair-step) artifact seen on both axial *(yellow area)* and sagittal *(yellow arrows)* images **(a1–a4)**. However, the artifacts did not degrade the diagnostic image quality of vessel lumen. A 61-year-old male was scanned using three required acquisition steps on Somatom Definition Flash, with a misregistration artifact seen on both axial *(yellow area)* and sagittal *(yellow arrows)* images **(b1–b4)**; nevertheless, image quality was sufficient for coronary diagnosis.

Then, images were scored based on axial images and volume reading; the segmentation standard involving 15 segments of the American Heart Association from 1975 (excluding the intermediate branch) was adopted (12). Scoring was based on a 5-point Likert scale, as follows: 1 point indicated the worst image quality, where the blood vessel outlines were not sufficiently clear to allow diagnosis; 2 points denoted poor quality, where most of the blood vessel outlines were not sufficiently clear to allow diagnosis; 3 points indicated moderate quality, where the blood vessel outlines could be distinguished and diagnosis could be performed, but diagnostic accuracy might be affected; 4 points denoted good quality, where most of the blood vessel outlines were clear, with only a few artifacts, which basically did not affect the diagnosis; and 5 points indicated excellent quality, where the blood vessel outlines were clear and no artifacts were present, and diagnosis was possible. Images that were scored ≥3 points were considered to be diagnosable, where image quality did not affect the diagnosis.

Radiation dose in CCTA

Only the radiation dose related to CCTA scanning was estimated; radiation related to the scout view, coronary artery calcium score, and radiation dose of the automatic bolus tracking technique were not included. Dose-length product (DLP) was automatically provided by the CT scanner. Effective radiation dose was estimated by multiplying the DLP by a conversion factor of 0.014 (13).

Statistical analysis

IBM SPSS Statistics Version 22 (IBM Corp.) was used for statistical analyses. The Kolmogorov–Smirnov test was used to test whether data was normally distributed. Differences in age, HR, the number of acquisition steps required, anatomical cardiac length, collimation settings, DLP and effective dose between the two groups were tested for statistical significance using the Mann–Whitney U test. Chi-square test was applied to analyze sex distribution and artifact incidence between the two groups and Spearman's correlation test was used to compare the relationship between artifacts and HR/HRV. p values $<$ 0.05 were considered statistically significant. The nonparametric variables were expressed as the medians and interquartile ranges (IQR, 25th and 75th percentiles).

Kappa analysis was performed to evaluate the consistency between the observers with respect to misregistration (stair-step) artifacts, slab (banding) artifacts, and subjective scores. The κ value was defined as follows: <0.20, almost no agreement; 0.21–0.40, slight agreement; 0.41–0.60, intermediate agreement; 0.61–0.80, good agreement; and 0.81–1.00, almost perfect agreement.

Results

The mean age was 61 years (IQR, 54–69 years), mean HR was 67.50 bpm (IQR, 57–73.7 bpm), and mean HRV was 1.50 bpm (IQR, 1–2.5 bpm).

Forty CCTAs (58.8%) in group A were scanned using three acquisition steps, with three HR values and two HRV values, while the remaining 28 (41.2%) required two acquisition steps, with two HR values and one HRV value. In group B, all 63 CCTAs (100%) were scanned using three acquisition steps, with three HR values and two HRV values.

Significantly fewer acquisition steps were required in group A (3; IQR, 2–3) than in group B (3; IQR, 3–3; $p < 0.001$). The scan length in group A (98.99 mm; IQR, 95–101.3 mm) was significantly shorter than that in group B (103.51 mm; IQR, 103.5–103.5 mm; $p < 0.001$), while the anatomical cardiac length was similar in both groups (98 mm; IQR, 92.6–98 mm vs. 102.50 mm; IQR, 92.5–102.5 mm; $p = 0.29$) (Table 1).

All images of the 131 patients (61 women) had satisfactory image quality and all misregistration artifacts were true stair-step artifacts (Fig. 2). The agreement between the two observers regarding misregistration artifacts was excellent (κ= 0.91) and the average subjective score between the two observers was 4.21±0.17 (κ= 0.92).

In each group, misregistration artifacts showed no correlation with the HRVs between two required acquisition steps or with HRs ($p > 0.20$) (Table 2). In group A, two artifacts appeared in 23 CCTA images (33.8%), one appeared in 17 images (25%), and none appeared in 28 images (41.2%). This was significantly different from group B ($p < 0.001$), in which two artifacts appeared in 49 images (77.8%), and none appeared in 14 images (22.2%). Moreover, in group A, in 40 CCTA images with three required acquisition steps, two artifacts appeared in 23 CCTA images (57.5%), no image showed one artifact only (0%), and no artifacts appeared in 17 images (42.5%). This was significantly different from the 28 images in group A that required two acquisition steps ($p < 0.001$): one appearance in 17 (60.7%) and no artifacts in 11 (39.3%). The incidence of misregistration artifacts was lower in images obtained with third-generation than with second-generation DSCT scanners (Table 3).

Discussion

We investigated the incidence of misregistration artifacts during step-and-shoot CCTA using a third-generation DSCT scanner; this had not been reported to date. We found that third-generation DSCT required fewer acquisition steps and consequently reduced the incidence of misregistration artifacts during CCTA compared with second-generation DSCT. Moreover, we found that these artifacts were not correlated with HR or HRV.

We separated the misregistration artifacts from breathing artifacts by evaluating the lung vessels, the liver dome shape, or the sternum outside of the cardiac anatomy. Misregistration artifacts can be mistaken for a lesion when they occur in cardiac images (14). Husmann et al. (7) showed that artifacts occurred less frequently in the thoracic wall than in the coronary arteries; therefore, we only focused on artifacts in CCTA images. A previous study suggested that a sudden change in HR may cause misregistration artifacts, due to differences in image reconstruction phases between consecutive heartbeats (15); this may explain why the temporal resolution of first-generation DSCT was not adequate. A sudden HRV would cause the HR to exceed 65 bpm, which may also be the main reason for the inadequacy of single-source 64-slice CT (7). Considering the worse image quality in patients with arrhythmias causing extra systoles, Feuchtner et al. (8) suggested that a stable sinus rhythm is needed for prospective step-and-shoot ECG-triggered dual-step (pECGdual-step) mode. Muenzel et al. (6) demonstrated that stair-step artifacts between adjacent CT image volumes were significantly increased in patients with a high HR (≥ 65 bmp, 65–128 bpm), while there was no significant effect of HRV on both inter- and intra-image artifacts during CT examination by using a 256-row CT scanner. They found that the limited Z-coverage of second-generation DSCT could cause step-and-shoot CCTA to be influenced by the HRV. Stolzmann et al. (16) also considered that HRV was responsible for stair-step artifacts occurring in step-and-shoot mode CCTA with first-generation DSCT scanners. A previous study pointed out that the HR along the z-axis is not stable and that image quality is significantly degraded by

Table 1. Comparison of parameters between groups A and B

	Group A (n=68)	Group B (n=63)	*p*
Number of required acquisition steps	3 (2–3)	3 (3–3)	<0.001
Anatomical cardiac length (mm)	98 (92.6–98)	102.50 (92.5–102.5)	0.29
Collimation setting (mm)	67.76 (61.4–84.2)	64 (64–64)	0.006
Scan length (mm)	98.99 (95–101.3)	103.51 (103.5–103.5)	<0.001
Age (year)	62 (56.3–68.8)	59 (53–69)	0.24
HR (bpm)	68.33 (61.8–75.9)	65.33 (55.7–72.7)	0.50
Dose-length product	213.90 (171.2–247.6)	167 (132.9–209.9)	<0.001
Effective dose (mSv)	2.87 (2.39–3.41)	2.61 (1.94–3.21)	<0.001

The nonparametric variables were expressed as the medians and interquartile ranges (25th and 75th percentiles).
Group A, scanned with a third-generation DSCT scanner; Group B, scanned with a second-generation DSCT scanner; HR, heart rate.

Table 2. Correlation between HR and misregistration artifact, between HRV and misregistration artifact

		HR1 in Group A (n=68)	HR2 in Group A (n=68)	HRV1 in Group A (n=68)
Misregistration artifact between HR1 and HR2 in Group A	ρ	-0.03	-0.10	0.09
	p	0.78	0.41	0.42
		HR2 in Group A (n=68)	HR3 in Group A (n=40)	HRV2 in Group A (n=40)
Misregistration artifact between HR2 and HR3 in Group A	ρ	0.01	0.04	-0.07
	p	0.94	0.81	0.68
		HR1 in Group B (n=63)	HR2 in Group B (n=63)	HRV1 in Group B (n=63)
Misregistration artifact between HR1 and HR2 in Group B	ρ	0.15	0.12	-0.04
	p	0.24	0.34	0.74
		HR2 in Group B (n=63)	HR3 in Group B (n=63)	HRV2 in Group B (n=63)
Misregistration artifact between HR2 and HR3 in Group B	ρ	0.12	0.13	0.10
	p	0.34	0.30	0.43

Correlation is significant at the 0.01 level (2-tailed).
Group A, scanned with a third-generation DSCT scanner; Group B, scanned with a second-generation DSCT scanner.
ρ, Spearman's correlation coefficient; HR, heart rate; HRV, heart rate variability.

Table 3. Results of artifact appearances by chi-square test in different groups

Sex	Group A (n=68)	Group B (n=63)	*p*
Male	29	40	0.023
Female	39	23	
No. of misregistration artifacts	Group A (n=68), n (%)	Group B (n=63), n (%)	*p*
Two artifacts	23 (33.8)	49 (77.8)	< 0.001
One artifact	17 (25)	0 (0)	
No artifact	28 (41.2)	14 (22.2)	
No. of misregistration artifacts	3 required steps in group A (n=40), n (%)	2 required steps in group A (n=28), n (%)	*p*
Two artifacts	23 (57.5)	0 (0)	< 0.001
One artifact	0 (0)	17 (60.7)	
No artifact	17 (42.5)	11 (39.3)	

Group A, scanned with a third-generation DSCT scanner; Group B, scanned with a second-generation DSCT scanner.

stair-step artifacts due to HRV (5). Moreover, other studies also reported that, because the coverage of the detectors is limited, misregistration artifacts caused by HRV still diminished image quality (17, 18). In contrast, our study found that the appearance of stair-step artifacts was not correlated with either HR or HRV, on both second- and third-generation DSCT scanners (Tables 2). The highly stable image quality at higher HRs, guaranteed by better temporal resolution of the third-generation DSCT scanners, and the lack of significant effects of HRV on stair-step artifacts, agreed with the results of Muenzel et al. (6). This indicated that decreasing the mean HR and HRV will not be an effective way of reducing stair-step artifacts, with a limitation of HR ≤100 bpm, on both DSCT scanner types. Finally, the fixed phase selection from 10%–90% of the R-R interval (best diastolic or systolic phase) for different HR at each required step may be the main reason for misregistration artifacts when combining two adjacent volumes; nevertheless, we found that, even when the HR was stable (57–57 bpm), misregistration artifacts still occurred in images, which could only be explained by the different cardiac outputs at each beat.

Our study demonstrated that the misregistration artifact incidence was significantly reduced with a third-generation DSCT scanner, due to the significant difference in the number of required acquisition steps (Table 1), while the anatomical cardiac length was similar in groups A and B. In our comparison between the two groups, as well as between subgroups of group A, we found that the misregistration artifact incidence was significantly lower when only two acquisition steps were required than when three acquisition steps were required, indicating that the risk is reduced to only one critical link between two acquisition steps. This was in line with the results obtained with 256-slice CT (6). This may explain the benefits of using the 5.76 cm wide coverage detector with an adaptive detector collimation in group A (vs. a 3.84 cm with fixed collimation in group B) (11). The wider detectors of the third-generation DSCT scanner cover 1/3 times more cardiac anatomy per rotation, and adaptive collimation provides the precise range of cardiac anatomy (11). For example, for anatomical cardiac length shorter than (64×0.6 + 64×0.6×[1%–17%] + 64×0.6×[1%–17%]) two acquisition steps would be required on a 5.76 cm wide detector, compared to three steps on a 3.84 cm wide detector.

Our study was subject to limitations. There were no patients with HR >100 bpm in our cohort; the impact of such a HR will need to be investigated in a future study. The HR between groups should ideally have been similar, but the HR in our groups differed statistically significantly; nevertheless, this difference did not affect our results. The effects of artifacts on diagnostic accuracy were not investigated because the artifact-positive rate in the recruited patients was insufficient. The effective dose may not have been sufficient in our study, but this point was not the main topic of this study.

In conclusion, the misregistration artifact incidence was significantly reduced in CCTA images obtained with a third-generation DSCT scanner as compared with those obtained with a second-generation DSCT scanner. This indicates that with fewer acquisition steps required, there is less chance for occurrence of misregistration artifacts. Thus, third-generation DSCT scanners offer advantages over second-generation DSCT scanners for CCTA.

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Conflict of interest disclosure

The authors declared no conflicts of interest.

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