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256-slice CT coronary angiography in atrial fibrillation: The impact of mean heart rate and heart rate variability on image quality

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ABSTRACT

Objective: The aim of this study was to evaluate the image quality of 256-MDCT in atrial fibrillation and to compare the findings with those among patients in sinus rhythm.
Materials: All reconstructed images were evaluated by two independent experienced readers blinded to patient information, heart rate, and ECG results to assess the diagnostic quality of images of the coronary artery segments using axial images, multi-planar reformations, maximum intensity projections, and volume rendering technique.
Results: No statistical significance was detected in terms of the overall image quality between patients in sinus rhythm and with atrial fibrillation. Pearson's correlation analysis showed no significant association between image quality and mean heart rate no matter for patients in sinus rhythm or with atrial fibrillation. Similarly, there was no correlation between image quality and heart rate variability for either patients in sinus rhythm or with atrial fibrillation. Our results showed that the optimal reconstruction window depends on patient's HR, and the pattern for patients in atrial fibrillation is similar to that obtained from non-atrial fibrillation patients.
Conclusion: This study shows the potential of using 256-MDCT coronary angiography in patients with atrial fibrillation. Our results suggest that when appropriate reconstruction timing window is applied, patients with atrial fibrillation do not have to be excluded from MDCT coronary angiographic examinations.

1. Introduction

Progressive improvements in CT coronary angiography (CTCA) have been shown to provide high diagnostic quality imaging in patients with sinus rhythm. However, atrial fibrillation remained as a contraindication for CTCA because of the difficulty in synchronizing an irregular heartbeat with table gantry movement, which led to inappropriate data sampling and resulted in sever motion artifact [1–4]. Atrial fibrillation is the most common type of arrhythmia, and the incidence increases markedly with aging. To decrease image distortion in patients with atrial fibrillation as well as patients with high heart rates, cardiac CT requires high temporal resolution, which depends on the gantry rotation times, type of ECG triggering, reconstruction methods, pitch, and other factors. Previous investigators have shown that imaging examinations obtained from 64-MDCT [5,6], dual source 64-MDCT [7–9], and 320-MDCT [10] scanners is possible in patients with atrial fibrillation. To our knowledge, assessment of image quality and the potential advantage offered by 256-MDCT with a temporal resolution of 135 ms [11,12] have not been reported yet. Thus, the aim of this study was to evaluate the image quality of 256-MDCT in atrial fibrillation and to compare the findings with those among patients in sinus rhythm.

2. Materials and methods

2.1. Patients

Between August 2009 and April 2010, 28 patients with atrial fibrillation (4 women, 24 men; mean age, 63.4 ± 11.6; mean body

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mass index, 25.4 ± 3.4 kg/m^2) and 28 patients in sinus rhythm (11 women, 17 men; mean age, 53.5 ± 9.9; mean body mass index, 26.0 ± 4.2 kg/m^2) were consecutively enrolled and examined with coronary 256-MDCT angiography. For both groups, the exclusion criteria were renal insufficiency (serum creatinine level >1.5 mg/mL), previous adverse reaction to iodinated contrast agent, unstable clinical condition, pregnancy, inability to follow breath-hold instructions. Patients in sinus rhythm with a heart rate (HR) greater than 90 bpm and patients with atrial fibrillation having a mean HR or high HR greater than 90 and 100 bpm, respectively, were prescribed with beta-blocker (40–120 mg according to body weight) prior to scanning to reduce heart rate. This study was institutional review board-approved, and written informed consent was obtained.

2.2. Image acquisition

All CT angiography examinations were performed using a 256-slice MDCT scanner (Brilliance iCT; Philips Medical Systems, Eindhoven, Netherlands). In all patients, a bolus (70 ml at 5 ml/s) of contrast media (Optiray 350 mg/ml, Tyco Healthcare, Montreal, Canada) followed by a saline chaser (30 ml at 5 ml/s) was administered into an antecubital vein using a dual-head injector (Stellant D, Medrad Inc., Warrendale, PA, USA). Contrast agent application was controlled by bolus tracking using a region of interest in the ascending aorta and a threshold of 110 Hounsfield units above the baseline attenuation to trigger the scan. The scanning parameters were as follows: detector collimation 128×0.625 mm, slice collimation 256×0.625 mm by means of a z-flying focal spot, gantry rotation time 270 ms, tube voltage 120 kV, tube current 800–900 mAs (adjusted automatically according to body habitus), full R–R retrospectively gated scanning. HR-dependent pitch was set at 0.16 for patients with HR ≤ 62 bpm and 0.18 for patients with HR >62 bpm. Scan direction was craniocaudal starting above the coronary ostia and ending at the diaphragm below all cardiac structures.

2.3. Image reconstruction

In each patient, MDCT data were reconstructed using the 180° cardiac interpolation algorithm [13] and the adaptive cardio volume approach [14]. Firstly, 20 data sets were reconstructed in 5% steps from 0% to 95% of the R–R interval. The reconstruction phase of least motion artifacts was further reconstructed with 1% step to seek the most optimal reconstruction timing. If considered necessary, additional images were reconstructed using ECG editing at the time of anomalies of the ECG signal due to premature heartbeat. The ECG-editing procedure consisted of an arbitrary modification (i.e. disablement, deletion, insertion, or repositioning) of the number and position of temporal windows to provide to the reconstruction software information with the least residual motion. Each dataset were reconstructed at 0.9 mm slices in 0.5 mm interval on 512 by 512 matrices with medium soft-tissue convolution kernel (XCC). After removing patient and ECG information, all reconstructed images were transferred to a dedicated workstation (Extended Brilliance Workspace 4.0, Philips) equipped with cardiac post-processing software.

2.4. Data analysis

All reconstructed images were evaluated by two independent experienced readers blinded to patient information, HR, and ECG results to assess the diagnostic quality of images of the coronary artery segments using axial images, multi-planar reformations, maximum intensity projections, and volume rendering technique. The segments were evaluated according to the 16-segment classification of the American Heart Association. This classification includes the right coronary artery (RCA, segments 1–4), the left main coronary and left anterior descending artery (LM-LAD, segments 5–10), and the left circumflex artery (LCX, segments 11–15). If present, the intermediate artery was segment 16. For each coronary segment, image quality was graded on a 4-point Likert ranking scale as follows: (1) no motion artifacts and clear delineation of the segment; (2) minor artifacts and mild blurring of the segment; (3) moderate artifacts and moderate blurring without structure discontinuity; (4) severe artifacts and doubling or discontinuity in the segment preventing diagnostic evaluation.

2.5. Statistical analysis

Statistical analysis was performed using statistical software (NCSS version 2007, NCSS). Comparisons of continuous variables in clinical characteristics and scan conditions were performed with an unpaired Student's t test. Agreement between the two reviewers was assessed using kappa statistics. For each patient, Pearson's correlation analysis was performed to compare the image quality with the mean HR and heart rate variability (HRV). The image quality from patients with atrial fibrillation and patients with sinus rhythm was compared with Wilcoxon signed ranks test. In a subanalysis, atrial fibrillation patients were subdivided into mean HR of $\leqq 72$ bpm (low HR group) and >72 bpm (high HR group). The image quality of the MDCT data between the two subgroups was compared with Mann–Witney U test. A p value of less than 0.05 was considered significant.

3. Results

In the 56 patients consecutively enrolled, HRV for patients in atrial fibrillation was higher than that for sinus rhythm, while no significant difference was seen in terms of mean HR. A total of 757 segments were available for analysis of overall image quality assessments, consisting of 381 segments in atrial fibrillation patients and 376 segments in sinus rhythm patients. Good agreement was obtained between the observers on motion scores (Kappa value = 0.82). The image quality is illustrated in Table 1. No statistical significance was detected in terms of the overall image quality between the two groups. Pearson's correlation analysis showed no significant association between image quality and mean HR no matter for patients in sinus rhythm (Fig. 1a) or with atrial fibrillation (Fig. 1b). Similarly, there was no correlation between image quality and HRV for either patients in sinus rhythm (Fig. 1c) or with atrial fibrillation (Fig. 1d). Demographic data and objective image quality parameters for patients with atrial fibrillation stratified into two groups on the basis of mean HR are listed in

Table 1
Overall image quality scores of patients with atrial fibrillation and in sinus rhythm.

Characteristic	Atrial fibrillation	Sinus rhythm	p value
No. of patients	28	28	–
No. of segments	381	376	–
Average heart rate (bpm)	73.6 ± 10.2	71.2 ± 7.9	NS
Heart rate variability (bpm)	13.3 ± 4.8	1.3 ± 0.8	<0.001
Overall image quality score	1.8 ± 0.3	1.7 ± 0.3	NS
Score 1 (%)[a]	32.0 (122/381)	39.6 (149/376)	–
Score 2 (%)	58.8 (224/381)	52.4 (197/376)	–
Score 3 (%)	8.9 (34/381)	8.0 (30/376)	–
Score 4 (%)	0.3 (1/381)	0.0 (0/376)	–

[a] Data in parentheses are numbers of segments used to calculate the percentages.

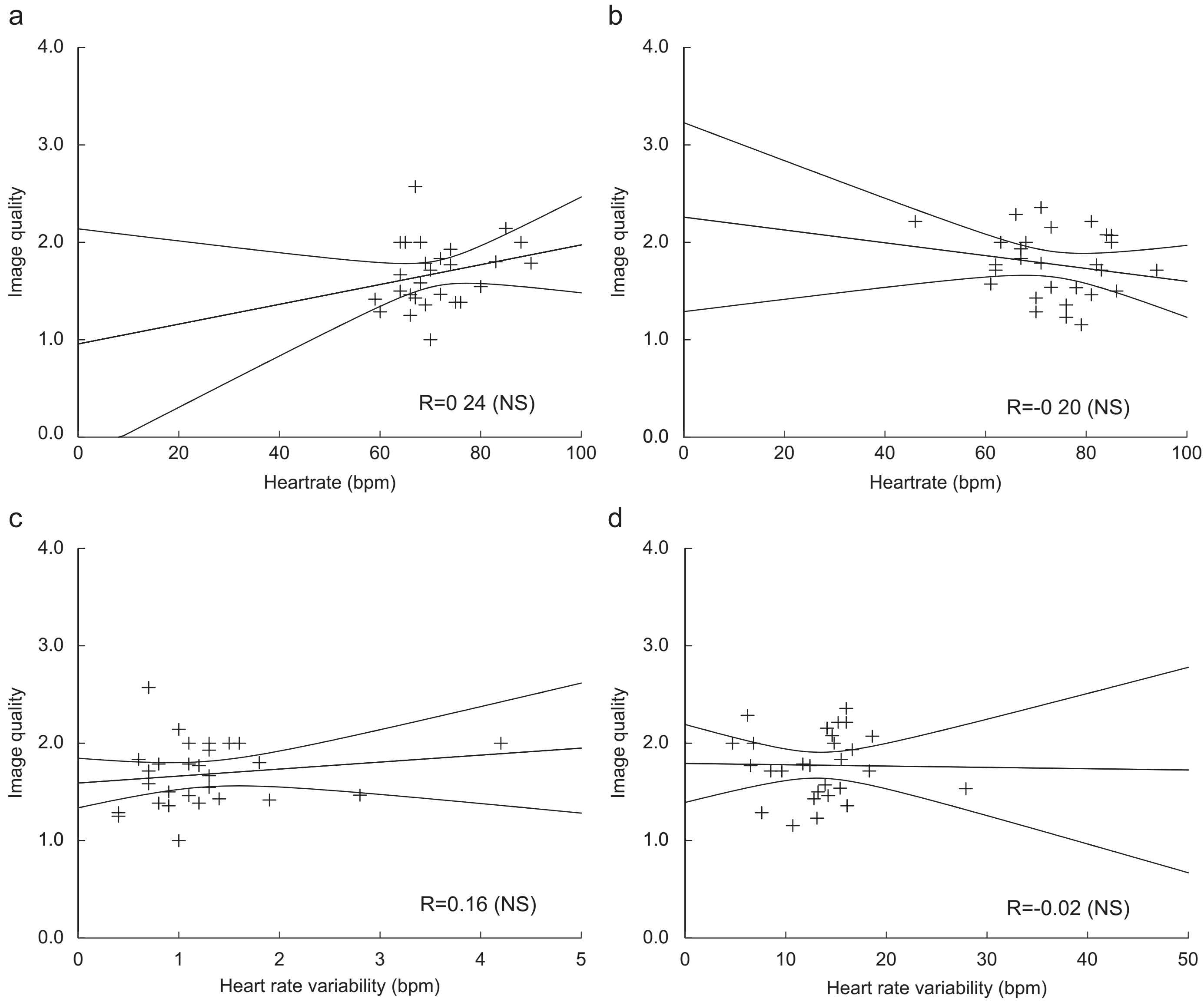

Fig. 1. Linear regression plots show mean image quality score over all segments per patient against mean HR for patients (a) in sinus rhythm and (b) with atrial fibrillation, and against HRV for patients (c) in sinus rhythm, and (d) with atrial fibrillation. Curves represent 95% confidence intervals.

Table 2
Overall image quality scores of patients with atrial fibrillation in low and high HR groups.

Characteristic	Low HR	High HR	*p* value
No. of patients	13	15	–
No. of segments	177	204	–
Average heart rate (bpm)	64.9 ± 6.7	81.1 ± 5.5	< 0.001
Heart rate variability (bpm)	12.8 ± 4.2	13.6 ± 5.3	NS
Overall image quality score	1.9 ± 0.3	1.7 ± 0.3	NS
Score 1 (%)[a]	27.7 (49/177)	35.8 (73/204)	–
Score 2 (%)	59.3 (105/177)	58.3 (119/204)	–
Score 3 (%)	12.4 (22/177)	5.9 (12/204)	–
Score 4 (%)	0.6 (1/177)	0.0 (0/204)	–

[a] Data in parentheses are numbers of segments used to calculate the percentages.

Table 2. There was no significant difference between the low and high HR groups in image quality and HRV. For patients in sinus rhythm with HR lower than 72 bpm, the best image quality was found in diastolic reconstruction in 146 of the 226 coronary segments (Fig. 2a). For those belong to high HR group, diastolic reconstruction intervals provided the best image quality in 68 of the 144 coronary segments (Fig. 2b). In patients with atrial fibrillation, the best image quality was seen during diastole in 142 of the 175 coronary segments and in 97 of the 202 coronary segments for low HR group (Fig. 2c) and high HR (Fig. 2d) group, respectively. Fig. 3 shows reconstructed images with a quality score of 1 (no motion artifact) for patients in sinus rhythm and with atrial fibrillation.

4. Discussion

We were able to show that 256-MDCT image of 99.7% and 100% of all segment were of sufficient quality for diagnostic assessment in atrial fibrillation and normal sinus rhythm, respectively. The overall mean quality score for all vessels was 1.8 (SD, ± 0.3) and 1.7 (SD, ± 0.3) in the presence of atrial fibrillation and regular sinus rhythm, respectively. With 256-MDCT, we noted no significant correlation with HR and the ability to obtain diagnostic quality images. Similar results were also obtained when evaluating the

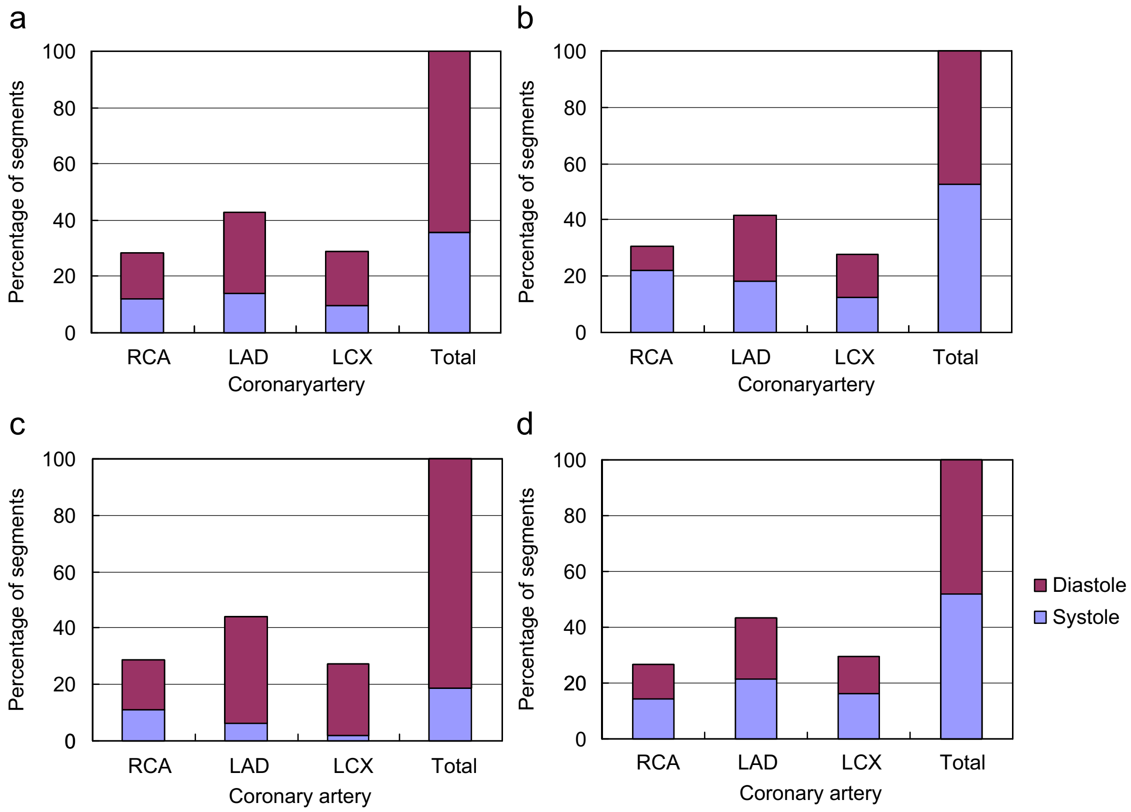

Fig. 2. Percentage of coronary segments with optimal reconstruction phase in systole and diastole for sinus rhythm patients belong to (a) low HR group and (b) high HR group, and for atrial fibrillation patients belong to (c) low HR group and (d) high HR group.

Fig. 3. Curved multi-planar reconstruction images show no motion artifact (arrow) of the RCA, reconstructed from diastolic data for patients in normal sinus rhythm with mean HR=64 bpm (a), systolic data for patient in normal sinus rhythm with mean HR=80 bpm (b), diastolic data for patient in atrial fibrillation with mean HR=62 bpm (c), and systolic data for patient in atrial fibrillation with mean HR=4 bpm (d).

relationship between HRV and image quality. Therefore, although the mean HR and HRV in the atrial fibrillation group were higher than those in patients with normal sinus rhythm, the mean diagnostic quality p value was not statistically different. These results suggested that this 256-MDCT is able to provide high diagnostic quality in patients with atiral fibrillation comparable to that of sinus rhythm patients.

The maximal coronary motion occurs at early to mid systole (ventricular contraction) and in early diastole (rapid filling). Coronary motion is relatively quiescent during the following phases, i.e. mid to late systole (slow filling) and mid diastole (isovolumric relaxation). In patients with sinus rhythm and low HR, mid diastolic data provide best image quality. However, in patients with higher HR, the motion-free time shortens more in mid diastole. Therefore, the optimal reconstruction phase is mostly located in systole for patient with sinus rhythm and high HR [15–17]. Based on our results, 64.6% coronary segments obtained the most optimal reconstructed image quality in diastole for patients in low HR group, while 52.8% coronary segments obtained their most optimal image quality in systole for patients in high HR group. These may explain the positive correlation observed in patients with sinus rhythm when evaluating relationship between HR and image quality, which indicates that image quality slightly degraded with increasing HR, although no significant correlation was observed.

Similarly, for patient with atrial fibrillation, 81.1% coronary segments obtained the most optimal image quality from diastolic reconstruction for atrial fibrillation patients in low HR group, while 52.0% coronary segments obtained their optimal image quality from systolic reconstruction for patients with atrial fibrillation and high HR. But a negative correlation between image quality and mean HR was seen for atrial fibrillation patients, though the result was not statistically significant. The R–R interval varies in each cardiac cycle in atrial fibrillation patients. The variation between end-diastole time to end-systolic time and the time of fast inflow phase in early diastole is small. On the contrary, the variation in the subsequent slow inflow phase (mid diastole) is large [18–20]. Thus, for patients with atrial fibrillation, image quality in diastolic reconstruction is decreased, while it is less affected in systolic reconstruction.

Several previous works had discussed the optimal reconstruction timing window for atrial fibrillation patients. Yang et al. [5] and Oncel et al. [7] reported that end-systolic phase reconstruction improves the quality of patients with atrial fibrillation. In these two studies, the mean HR were 83.7 ± 8.9 bpm and 90 ± 8.9 bpm. On the other hand, Matsumoto et al. [6] found that mid diastolic phase reconstruction images had better image quality than end systole phase reconstruction image in patients with atrial fibrillation. However, the mean HR during scanning was controlled to less than 70 bpm. In order to thoroughly investigate this issue, we enrolled 28 patients with atrial fibrillation having mean heart rate that ranges from 50 to 95 bpm and stratified them by the mean HR. Our results showed that the optimal reconstruction window depends on patient's HR, and the pattern is similar to that obtained from non-atrial fibrillation patients.

We acknowledge the following study limitations. First, we only performed subjective image assessment. No direct correlation with catheter angiography was performed. However, the good inter-observer agreement demonstrates that the study bias should be small. Furthermore, we included a relatively small group of only 56 patients. Further investigation of our preliminary results in larger patient population is thus needed to confirm the capability of 256-MDCT coronary angiography in order to broaden its clinical indication in population with sinus rhythm and atrial fibrillation as well.

In conclusion, our study is the first evaluation of image quality in patients with atrial fibrillation and shows the potential of using 256-MDCT coronary angiography in this patient group. Our results suggest that when appropriate reconstruction timing window is applied, patients with atrial fibrillation do not have to be excluded from MDCT coronary angiographic examinations.

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