Optimal systolic and diastolic reconstruction windows for coronary CT angiography using dynamic volume CT with 320-detector rows

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Purpose

Previous studies showed that the relationship between optimal phases of image reconstruction and heart rate at CT coronary angiography were different with temporal resolution. However, previous studies were based on slower gantry rotation speed or one/two segment reconstruction algorithm. 320-detector rows CT makes the application of multi-segment reconstruction more feasible. When heart rate>80bpm, three heart beats acquisition scan mode was used, which could improve the temporal resolution to 58.3 ms. Our hypothesis was that, the optimal reconstruction intervals in higher heart rate was different from previous CT.

This study was carried out to confirm the optimal reconstruction windows to reduce the radiation dose reliably whilst maintaining high diagnostic accuracy by taking heart rate into consideration.
Methods and Materials

Materials:
77 patients whose coronary vessel and cardiac function needed assessment were prospectively enrolled, including 41 males and 36 females with ages ranging from 34 to 73 years (mean age 63 ± 7.6 years). All CT examinations were performed with 320-detector rows CT (Aquilion ONE, Toshiba, Nasu, Japan) without complications.

Scanning protocol:
The scanning range was set from the level of the tracheal bifurcation to the diaphragm to cover the entire heart. A 40-60 mL bolus of Iohexol (Omnipaque 350, GE Healthcare, Shanghai, China; 40ml for <40 kg, 50ml for 40 to 50 kg, and 60 ml for >50 kg# was injected into an antecubital vein through an 18-gauge catheter with an injection rate of 4-6 mL/sec (4 mL/sec for <40 kg, 5 mL/sec for 40 to 50 kg, and 6 mL/sec for >50 kg# and followed by 50 mL of saline solution (5 mL/sec). The enhancement scan was controlled by bolus tracking software (SUREStart, Toshiba). The trigger threshold was set at 180 HU in the descending aorta at the same level as the aortic root.

All data acquisition was performed with the use of tube current modulation. The full tube current was set at 20-90% of the R-R interval. Outside the ECG-gating window, the tube current was reduced to 30% of the full current. For heart rate between 70 and 80 bpm, 2 heart beat acquisition was used. For heart rate >80 bpm, 3 heart beats acquisition was necessary to increase temporal resolution. Scanning parameters were: detector collimation, 320 × 0.5 mm; gantry rotation time, 350 milliseconds; tube current, 350-500 mA; tube potential, 100-120 kV.

Image post-processing:
A soft-tissue algorithm was used for image reconstruction. The field of view was adjusted to encompass the heart in the axial plane: depending on the heart size, the field of view was adjusted between 180×180 mm to 240×240 mm. The parameters for image reconstruction were set at a slice thickness of 0.5 mm with increments of 0.25 mm. Using the relative timing method, 10 groups of volume data sets were reconstructed in 10% steps throughout the entire scanned R-R interval. Reconstructed data sets were selected and transferred to the Vitrea FX image processing workstation. Cardiovascular post-processing software was applied to display images of multi-planar reconstruction (MPR), curve planar reconstruction (CPR), and volume rendering (VR).

Image assessment:
Using the 15-segment model recommended by the American Heart Association (AHA), the quality of each of the 10 differently phased groups of images was analyzed dynamically in correlation with the heart rate and reconstruction windows. Coronary image quality was graded at 4 levels: Grade 1 (scored as 1), vessels were displayed well with clear edges and no motion artifacts; Grade 2 (scored as 2), vessels were displayed with fuzzy edges and mild artifacts; Grade 3 (scored as 3), vessels were displayed with moderate artifacts and moderate blurring, but images were acceptable for diagnosis; Grade 4 (scored as 4), due to severe artifacts, the images were not assessable for diagnosis. As the tube current modulation was used, image noise was increased in images reconstructed in sections of the R-R interval where the tube current was reduced. So the image quality in our study was only evaluated by motion aircrafts. Based on the score of the segment with the worst image quality, the image quality of the right coronary artery (RCA), left anterior descending artery (LAD), and left circumflex artery (LCX) was determined.

By continuously observing the double-oblique parallel planes through the aortic annulus at different phases, the proportion of systole (vs. diastole) was determined based on the open/closed status of the aortic valve. For cases with poor image quality, images were reconstructed in 5% steps before and after the phase where a relatively good image was shown. The images with the best quality were selected for assessment to determine the relationship between the optimal reconstruction windows and heart rate. All images were interactively assessed by two independent assessors (S. G. and L. G.) with 7 and 6 years of experience in cardiovascular radiology, respectively. The two assessors were blinded to the results of heart rate and clinical information. Conclusions were made based on discussion and consensus.
Results

Image quality and heart rate

The average quality score for the optimal systolic reconstruction was 2.3 ± 0.6 for RCA, 1.7 ± 0.6 for LAD, and 2.1 ± 0.4 for LCX. The difference of image quality among the three vessels was significant by Friedman test ($P < 0.001$). The average quality of the optimal systolic reconstruction for the three major coronary arteries was significantly decreased with higher heart rate ($r = 0.39$, $P < 0.001$). The average image quality score for the optimal diastolic reconstructions was 1.6 ± 0.7 for RCA, 1.4 ± 0.6 for LAD, and 1.4 ± 0.6 for LCX. The image quality among the three vessels was statistically different by Friedman test ($P = 0.004$). The average image quality of the optimal diastolic reconstructions for the three major coronary vessels also deteriorated significantly with higher heart rate ($r = 0.82$, $P < 0.001$) (Fig. 1, 2 on page 6,3 on page 7).

Optimal systolic and diastolic reconstruction windows

Inter-observer agreement for the judgment of the open and closed phases of the aortic valve was high (Kappa = 0.81). All 77 patients had open aortic valves at the 0% (100%) window. With increasing heart rate, the proportion of diastole gradually decreased while the proportion of systole was positively correlated with the heart rate ($r=0.78$, $P<0.001$) (Fig. 4 on page 8). With increasing heart rate, the optimal systolic and diastolic reconstruction windows for the three coronary arteries shifted to later intervals (Fig. 5 on page 9).

With the increase of heart rate, the image quality for the three coronary vessels gradually decreased in both systole and diastole (except for the LCX in the systolic reconstruction). However, the image quality of the optimal reconstruction in systole deteriorated slower than that in diastole. At a slow heart rate, the image quality in diastole was better than that in systole. With the increase of heart rate, however, the image quality in diastole decreased significantly (systole: $y=1.39+0.009x$, $P<0.001$; diastole: $y=-0.97+0.035x$, $P<0.001$). When the heart rate was higher than 90.8bpm, the image quality for these vessels were poorer in diastole than that in systole.
Fig. 0: Frequency distribution of the image quality scores for the optimal systolic and diastolic reconstructions in the RCA (Group A: HR < 60 bpm, Group B: 60 # HR < 70 bpm, Group C: 70 # HR < 80 bpm, Group D: HR # 80 bpm).

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Fig. 0: Frequency distribution of the image quality scores for the optimal systolic and diastolic reconstructions in the LAD (Group A: HR < 60 bpm, Group B: 60 < HR < 70 bpm, Group C: 70 < HR < 80 bpm, Group D: HR > 80 bpm).

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Fig. 0: Frequency distribution of the image quality scores for the optimal systolic and diastolic reconstructions in the LCX (Group A: HR < 60 bpm, Group B: 60 # HR < 70 bpm, Group C: 70 # HR < 80 bpm, Group D: HR # 80 bpm).

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Fig. 0: Frequency distribution of the proportion of systole among groups with different heart rates. As heart rate increased, the proportion of systole increased gradually.

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**Fig. 0:** The relationship between optimal systolic/diastolic reconstruction windows and heart rate. With increasing heart rate, the optimal systolic reconstruction windows for the three coronary vessels increased linearly.

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Conclusion

1. 320-detector rows CT provides good diagnostic image quality within a wide range of heart rate. In patients with a low heart rate, the optimal coronary reconstruction window is in mid-late diastole. As HR increases, systolic reconstruction often yields superior image quality compared to diastolic reconstruction. The cut off heart rates at which optimal reconstruction intervals turned from diastole to systole was 90.8 bpm.

2. On the basis of the analysis of the regulation of image quality score in different heart rate groups, the optimal exposure phases were determined as followed: when heart rate <70bpm, the exposure windows should be preset at 65-80%; if 70 to 80bpm, 70-85%; if 80 to 90bpm, 70-90%; if heart rate >90bpm, 35-50%.
References


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