

# Evaluation of optimal match between gantry rotation time and cardiac cycle on multislice spiral CT coronary angiography imaging

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**Abstract. – OBJECTIVE:** To evaluate the relationship between gantry rotation time, heart rate and image quality during multislice spiral CT coronary angiography (MSCTCA).

**PATIENTS AND METHODS:** Data of 83 patients who underwent MSCTCA were reviewed. Based on the ratio between cardiac cycle and gantry rotation time, the patients were divided into two groups. Patients whose heart rates fell in the resonance frequency (the cardiac cycle / gantry rotational time ratio of 1.5, 2 or 2.5)  $\pm$  2 bpm were classified as synchronous (25 cases), while the remaining 58 patients (included a subgroup of 34 cases in whom heart rates were the same as in synchronous group but who had a different gantry rotation time). comprised the asynchronous group. Image qualities were compared between both groups.

**RESULTS:** In the synchronous group, most (199/287; 69.33%) images were poor. When gantry rotation time was changed in the subgroup of the asynchronous group, the majority (423/442 or 95.70%) of images improved. There was a significant difference ( $p < 0.001$ ) in the image quality among these patients. In 58 patients from asynchronous group, 757 segments of coronary arteries were evaluated, and 716 segments were of best quality (716/757; 94.58%).

**CONCLUSIONS:** When heart rate and gantry rotation time correlate and synchronous, the so-called frequency harmonics, coronary artery image quality is poor. However, by changing gantry rotation time to avoid the harmonic helps to improve the image quality on MSCTCA.

Based on the patient's heart rate, appropriate gantry rotation time can be selected in order to avoid resonance and obtain high quality images.

## Key Words:

X-ray, Computed tomography, Coronary artery, Gantry rotation, Temporal resolution, Multisector reconstruction, Cardiac cycle.

## Introduction

Multi-segment reconstruction technique is often utilized in reconstruction by multislice spiral

CT coronary angiography (MSCTCA) at a heart rate of  $> 65$  beats per minute (bpm). Although this technique can effectively improve temporal resolution of coronary image for certain range of heart rate, resonance occurs when cardiac cycle and gantry rotational period at a ratio of 1.5, 2, or 2.5. That is gantry rotation time synchronizes with the heart rate. For example, when the gantry rotation period is 350 ms, if the cardiac cycle is 525 ms (with a ratio between cardiac cycle and gantry rotational period of 1.5), or 700 ms (with a ratio of 2), or 875 ms (with a ratio of 2.5), resonance will occur, which leads to the imaging temporal resolution of only half of the gantry rotational time and occurrences of aliasing artifacts. This study aimed to develop a simple but effective method to counter the resonance in order to increase the temporal resolution for a large range of heart rate and to improve the quality of MSCTCA imaging.

## Patients and Methods

### Patients

We reviewed the data from 83 patients who underwent CT coronary imaging in our Hospital from 2007 to 2012. These patients comprised 47 male and 36 female patients whose age ranged from 30 to 80 years (median age of 60.3 years). Heart rates ranged from 67 to 115 bpm (mean average heart rate of  $81.57 \pm 9.35$  bpm). Exclusion criteria were absolute tachyarrhythmia, heart rate variation of more than 4 bpm, renal failure, allergy to contrast agent, pregnancy, and inability to consistently hold breath after training.

Based on gantry rotation period and heart rate in data acquisition, the patients were divided into synchronous and asynchronous groups. Patients whose heart rates fell in the resonance frequency (the ratio between cardiac cycle and gantry rotational period of 1.5, 2 or 2.5)  $\pm$  2 bpm were classified as synchro-

nous (25 cases). For gantry rotational times of 420, 375 (500), or 350 ms, the corresponding resonance heart rate ranged, respectively, from 70 to 74 bpm, (resonance cardiac cycle 840 ms), 78 to 82 bpm (resonance cardiac cycle 750 ms), 67 to 71 bpm (resonance cardiac cycle 875ms) and 83-87 bpm (resonance cardiac cycle 700 ms).

The remaining 58 patients were classified as asynchronous group. These patients included a subgroup of 34 cases in whom heart rates were the same as in synchronous group but who had a different gantry rotation time. These patients are referred to as the synchronous/different gantry rotation time group.

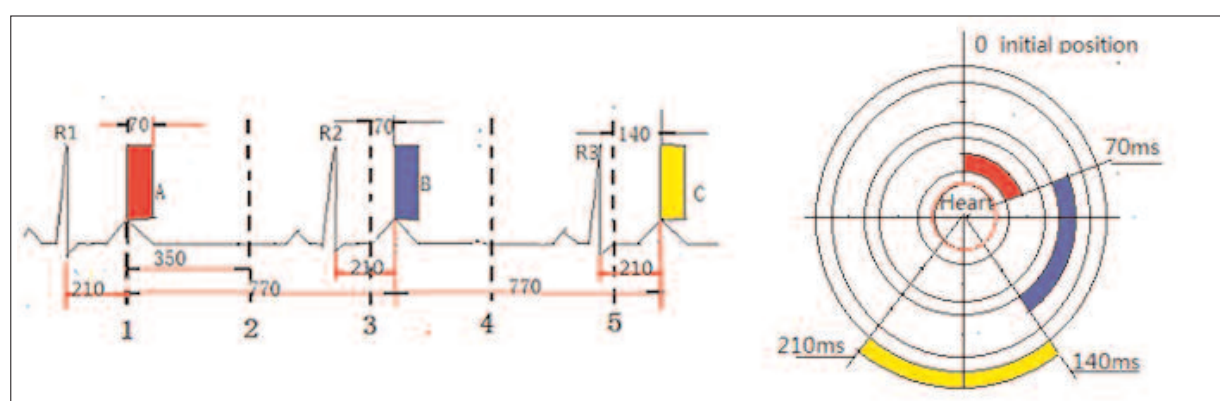
### Image Acquisition

A 64-detector row spiral CT scanner (Brilliance Philips Medical System, Best, The Netherlands) was used from January 2007 to May 2010. A 320-detector row spiral CT (Acquilion One Tsx-301A, Toshiba Medical System, Tokyo, Japan) was used from June 2010 to December 2012. Parameters for the 64-detector row CT scanning were the following: tube voltage 120-140 kV, current 320-400 mA, collimation 64 x 0.625 mm, pitch 0.2-0.3, gantry rotational time 420 or 500 ms. The scanning time varied between 6 and 9 sec. Parameters for the 320-detector row CT scanning were the following: tube voltage 120 kV, current 350-450 mA, 320 x 0.5 mm collimation, gantry rotational time 350, 375, or 400 ms, mean scanning time 2.5 sec (range: 2-2.8 sec). The X-ray exposure time was 40- 80% of the R-R interval.

Images were obtained using the three-segment reconstruction algorithm. Patient lied on the bed with supine position. When instructed, patients made a shallow inhalation, and held their breath and stayed still. CT-CA was performed from 2 cm below the level of the tracheal bifurcation to the diaphragm. Scans were acquired in the craniocaudal direction. Seventy ml of Iohexol (Omnipaque 350, 350 mgI/ml; Ge Pharmaceutical, Shanghai, China) were injected at a flow rate of 5 ml/sec followed by 40 ml of saline. Bolus-tracking was controlled with a region of interest in the descending aorta, and image acquisition was automatically performed when signal attenuation reached a predefined threshold of 150 HU.

### Image Reconstruction

Images were reconstructed using the standard software package for heart imaging supplied with the CT scanner. The lowest heart rate was 67 bpm and the highest heart rate 115 bpm. Retrospective ECG gating and three-segment reconstruction algorithm (Figure 1) were used with the reconstruction gating windows centered at 45% of the R-R period which was referred to as end-systolic. If the obtained image was not satisfactory, we searched for the best reconstruction window within 40-80% of R-R period using 5-ms increments. Parameters for the reconstruction were 180-240 mm field of view, 0.9 mm effective section thickness, 0.4 mm increment, and 0.5 mm effective section thickness when using 64-detector row spiral



**Figure 1.** Dashed line represents the initial position of the heart. The time between 2 dashed lines is the period of gantry rotation (350 ms). The period of the heart beat is 770 ms. When a 3 segment reconstruction algorithm is used, three data sets are in the same phase. Assuming that it is 210 ms apart from the previous R wave, the data set A (red) is 0 ms away, the data set B (blue) is 70 ms away, and the data set C (yellow) is 140 ms away from initial position. To reconstruct the heart image, time window of the data set must be greater than 70 ms. Three data sets correspond to three positions of the heart (red: 0-70 ms; blue: 70-140 ms; yellow: 140-210 ms). The reconstruction window then lasts from 0 to 210 ms (span of 210 ms), which is more than the required half scan reconstruction window of 175 ms. Temporal resolution is 70 ms.

**Table I.** Image quality of synchronous and asynchronous groups.

Image quality score	Coronary artery segments															Total
	RCA				LAD					LCX						
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
Synchronous group	25 patients															
Assessable segments	25	25	25	15	25	25	25	20	20	9	23	19	17	10	4	287
Score 1	2	1	1	1	6	6				1	3	3	1			27
Score 2	6	1	2	1	12	12	6	2	7		6	4	1		1	61
Score 3	17	23	22	13	7	7	19	18	11	8	14	12	15	10	3	199
Asynchronous group	58 patients															
Assessable segments	58	58	58	56	58	58	58	57	54	34	58	50	54	18	28	757
Score 1	58	48	53	49	57	56	57	55	53	32	57	49	53	15	24	716
Score 2		7	3	5	1	2	1	1	1	1	1	1	1	2	3	30
Score 3		3	2	2				1		1				1	1	11

Z = 27.19, p = 0,001

CT, and 0.25 mm increment for 320-detector row spiral CT.

**Post-processing and Analysis**

Data sets were post-processed at the workstation. Image analysis was performed using the CT data transverse image, volume rendering, multiplanar reformatting, maximum intensity projection, and curved multilane reformation (MPR) techniques. Each coronary artery segment was assessed according to guidelines of the American College of Cardiology and the American Heart Association<sup>1</sup>. The coronary arteries were divided into 15 segments which corresponded to the right coronary artery (segments 1-4), left main artery (segment 5), left anterior descending artery (segments 6-10), and left circumflex artery (segments 11-15). Segments with artery diameter greater than 1.5 mm were evaluated.

The quality of coronary imaging was ranked as follows. First grade was defined as excellent image quality with no motion artifacts, the second grade images had minor blurring of the vessel wall, while third grade images were of non-diagnostic images quality due to severe blurring or doubling of the vessel wall. All reconstructed images were evaluated by two independent readers with over 10 years of experience in radiology. If the scores differed between the readers, the final evaluation was discussed jointly by the readers.

**Statistical Analysis**

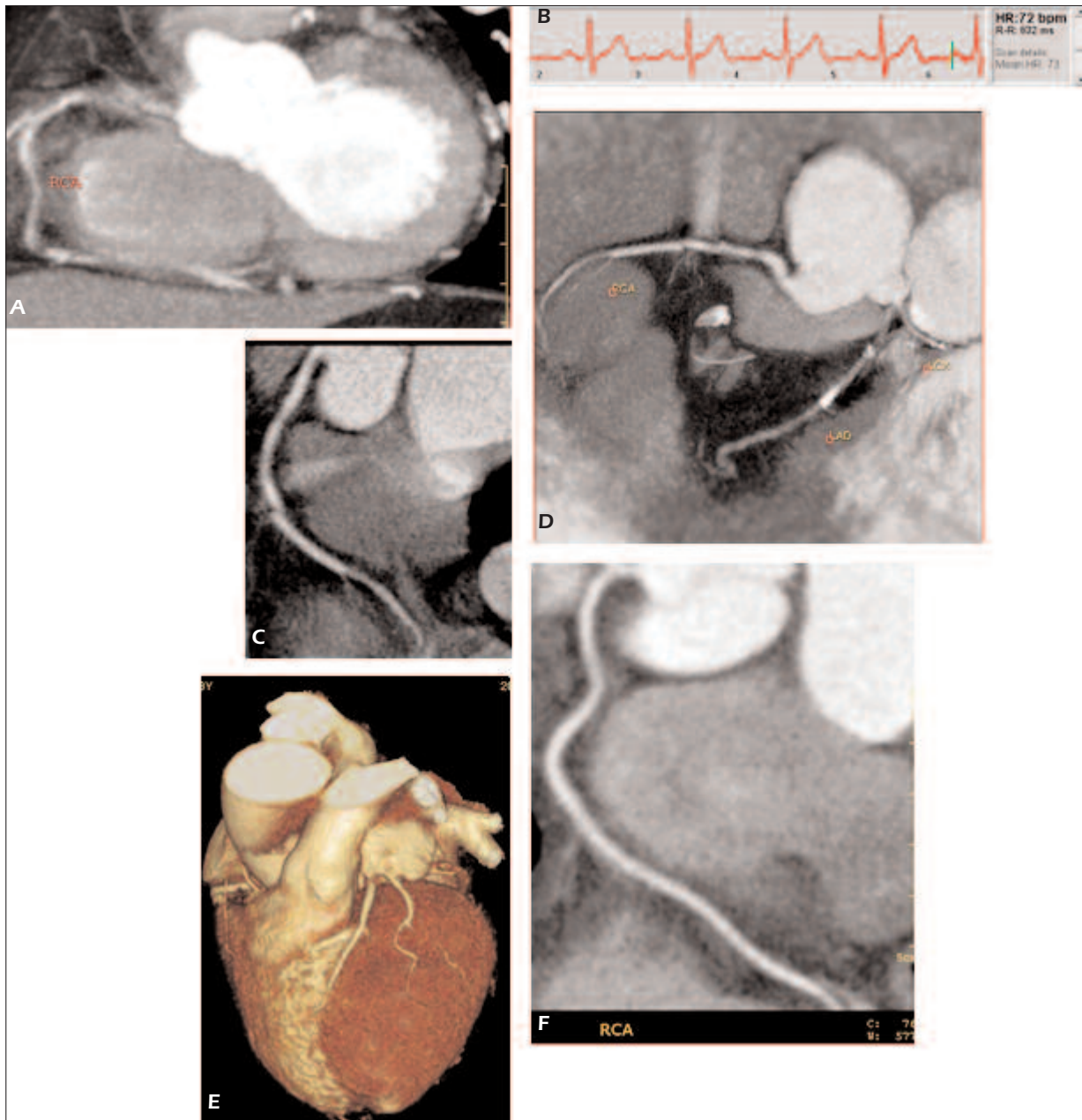
Statistical software package SPSS version 16.0 (SPSS, Chicago, IL, USA) was used for

statistical analysis. The Wilcoxon Mann-Whitney test was used to compare the image quality for study groups. The Kruskal-Wallis H test was used to evaluate image quality of patients of asynchronous group with different heart rates. The Spearman correction test was used to explore potential correlations between the image quality and the heart rate. The p value of < 0.05 was considered statistically significant.

**Results**

The inter-observer agreement for image quality rating with clustered data was good. Immediate agreement between both observers was achieved in 912 of the coronary augments (1044). In the remaining 132 segments, consensus reading was required to discriminate between image quality grades of 1 and 2.

In all 25 patients of synchronous group, resonance occurred because of synchronization of gantry rotational time and cardiac cycle. The patients had well-controlled breathing with no motion artifacts and stable heart rate. Forty-nine segments were excluded due to deformation and diameter of less than 1.5 mm, while 39 segments could not be differentiated because of extremely severe motion artifact and blurred structure. There were 287 segments suitable for evaluation. Of these, 27 (9.42%) segments were ranked as first grade, 61 (21.25%) segments as second grade, and 199 (69.33%) segments as third grade (Table I, Figure 2a-d, and Figure 3).

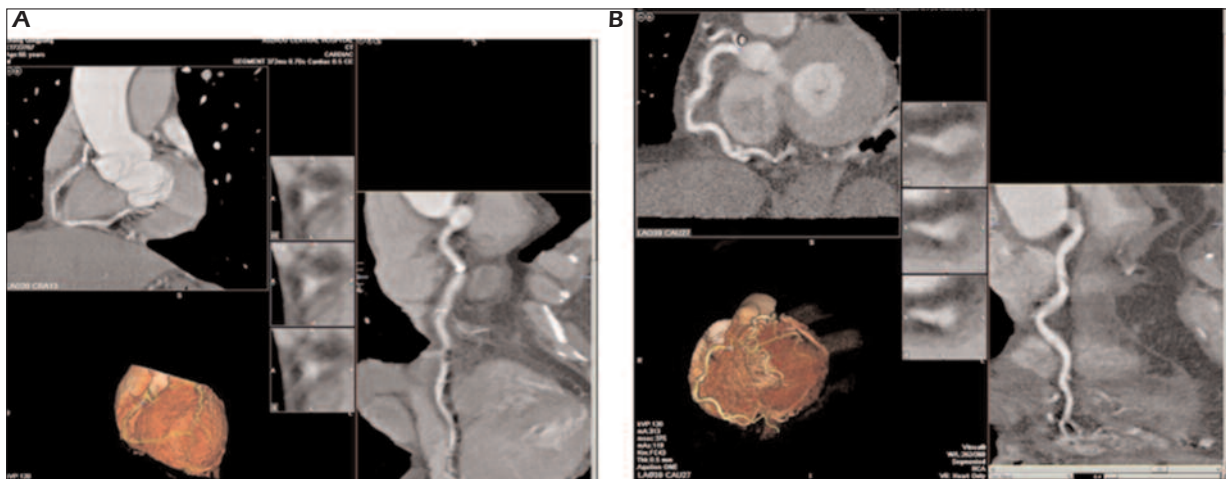


**Figure 2.** Images from three patients captured by the 64-detector row spiral CT. (a) The maximal intensity projection reformatting of RCA image in one patient of synchronous group with gantry speed of 0.42 s/rev, heart rate of 72 bpm (cardiac cycle to gantry period ratio was 2) shows that the structure is blurred due to an aliasing artifact and falls into grade 3. (b) ECG of the above patient. (c) Curved multiplanar reformatting of RCA image in another patient from synchronous group whose heart rate was also 72 bpm. The image shows severe motion artifact (grade 3 with discontinuity with the middle segments of the RCA resulting in non-diagnostic image quality). (d) Same patient as in panel (c); the map of coronary artery shows that structures of LAD and LCX are not clear (grade 3 image). (e) A volume rendering image of patient from asynchronous group with gantry speed of 0.5 s/rev and heart rate of 72 bpm. The image shows clear blood vessel structure. (f) Same patient as panel (e); curved multiplanar reformatting of RCA image shows no motion artifact (grade 1).

Thirty-four patients in the synchronous/different gantry rotation time group provided 442 segments, of which 423 (95.7%) were ranked as first grade (Figure 2e and f; Figure 4a-b), 13

(2.94%) as second grade, and 6 (1.36%) as third grade. The image quality in this group was significantly different from the images in synchronous group ( $p < 0.001$ ; Figures 2 to 4). For each





**Figure 3.** Images of right coronary artery of two patients from synchronous group captured by the 320-detector row spiral CT images. **A**, The volume rendering and maximum intensity projection reformatting image in a patient with cardiac cycle of 700 ms, heart rate of 85 bpm, and gantry speed of 0.35 s/rev shows a severe motion artifact (grade 3). **B**, The volume rendering and maximum intensity projection reformatting image in a patient with cardiac cycle of 730 ms and gantry speed of 0.375 s/rev also shows a severe motion artifact (grade 3).

resonance heart rate, different gantry rotation time showed a clear difference in image quality ( $p < 0.001$ ; Table II).

In the asynchronous group in general, there were 757 segments. All first, most second and third, and some fourth order branches could be clearly viewed. Seven hundred and sixteen (94.58%) segments were ranked as first grade, while 30 (3.96%) segments were ranked as second grade (Table III). There was no significant difference in image qualities between various heart rates. Furthermore, there was no correlation between image quality and heart rate. The image quality differed significantly between synchronous and asynchronous group ( $Z = 27.19, p < 0.001$ ).

## Discussion

### *Multi-sector Reconstruction Technique and Resonance*

Multislice spiral CT coronary angiography (MSCT-CA) reconstruction often uses multi-segment reconstruction technique in high heart beat in order to improve temporal resolution<sup>1-11</sup>. Multiple data sets taken at the same phase of the heart motion but in different heart positions in consecutive heart beats have to be linked in order for the total length of data window to be more than half of the gantry rotation (Figure 1). Yet, not all heart rates benefit from this. Previous studies reported that synchronization of gantry rotation time and heart beat (the so-called “fre-

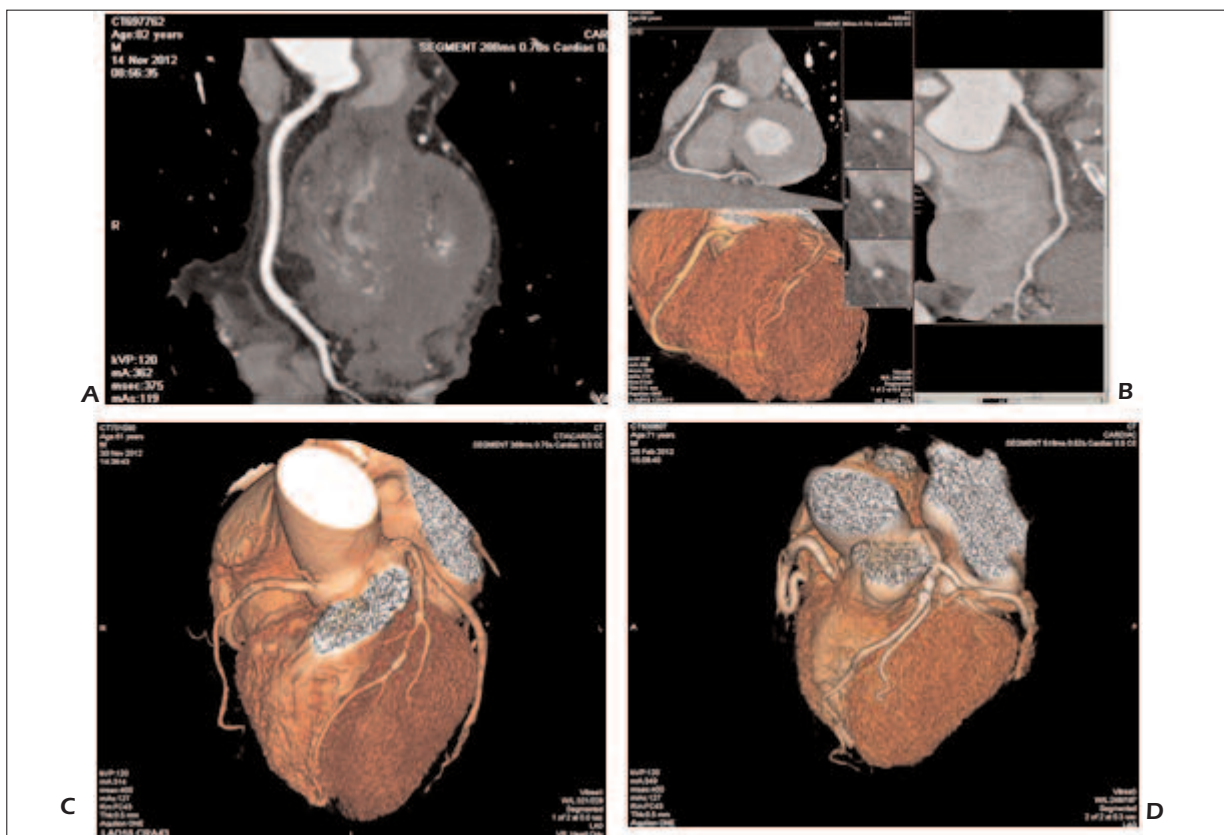
**Table II.** Comparison of image quality between synchronous group and a subgroup of asynchronous group with the same heart beat

Synchronous cycle (msec)	Synchronous group						Subgroup of asynchronous group						z	p
	Heart Rate bpm	Gantry rotation time ms	NO	Image quality Score			Gantry rotation time ms	NO	Image quality Score					
				1	2	3			1	2	3			
875	67-71	350	3	14	11	11	375	7	91	2	1	7.47	0.001	
750	78-82	375	3	4	17	21	350	7	89	2		9.89	0.001	
840	70-74	420	12	4	16	125	500	7	84	3	3	13.44	0.001	
750	78-82	500	5	0	5	33	420	6	71	2	2	17.15	0.001	
700	83-87	350	2	5	12	9	375	7	88	4		8.45	0.001	
total			25	27	61	199		34	423	13	6	23.18	0.001	

**Table III.** Image quality of different range of heart rate in asynchronous group.

Heart rate bpm	NO.	Image quality score			Mean rank	Chi-square	<i>p</i>
		1	2	3			
67-79	23	285	9	6	29.35	0.87	0.65
80-89	25	310	13	2	28.04		
90-115	10	121	8	3	33.50		

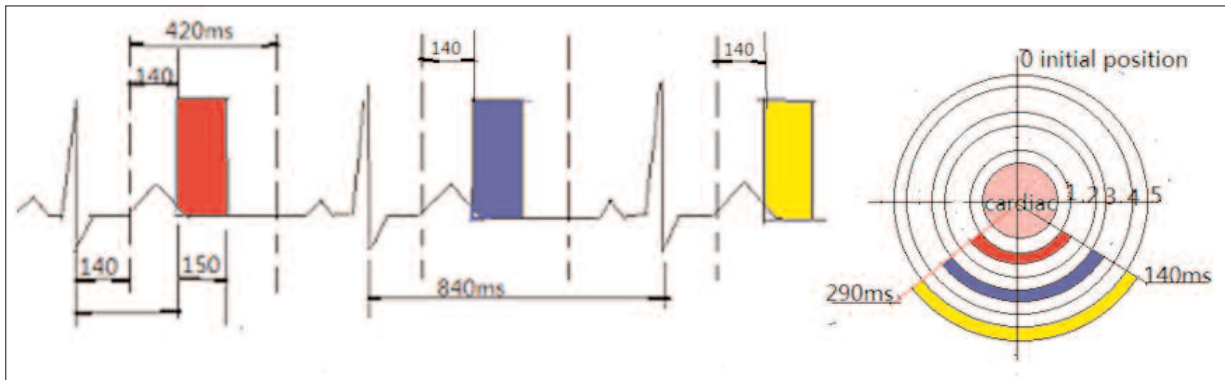
Footnote: Spearman correction test  $r = 0.163$ ,  $p = 0.221$



**Figure 4.** Four patients from asynchronous group evaluated by the 320-detector row spiral CT. **A**, Curved multiplanar reformatting of RCA image in a patient with gantry speed of 0.375 s/rev and cardiac cycle of 700 ms shows no motion artifact (grade 1) in all segments of RCA. **B**, Curved multiplanar reformatting of RCA image in a patient with gantry speed of 0.35 s/rev and cardiac cycle of 750 ms also shows no motion artifact (grade 1) in all segments of RCA. **C**, The volume rendering reformatting image of patient with gantry rotational period of 0.4 s/rev and cardiac cycle of 750 ms shows no motion artifact (grade 1). **D**, The volume rendering reformatting of patient with gantry rotational period of 0.40 s/rev and cardiac cycle of 520 ms shows no motion artifact (grade 1).

quency harmonics”), which leads to worse image quality<sup>12-17</sup>. We have found that when the ratio between cardiac cycle and gantry rotational time becomes 2 (Figure 5), heart beat and gantry rotational period are synchronized, and quality of

most images falls into grade 3. As shown in Figure 5, the gantry rotational speed is 420 ms/rev, and the cardiac cycle is 840 ms, the ratio between the cardiac cycle and the gantry rotational period is 2, then the data sets in consecutive heart



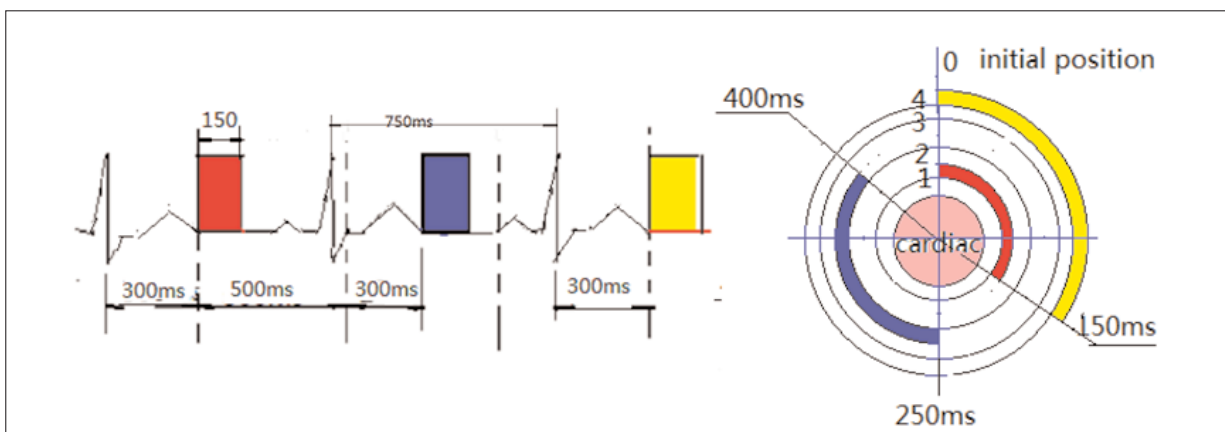
**Figure 5.** Heart beat period  $T = 840$  ms, gantry rotational speed of  $420$  ms/rev, and the ratio of heart period/gantry rotational period is  $2$ . Heart contraction was selected for image reconstruction. Each data set shares the same phase. Assuming it is  $280$  ms away from the previous R wave. red window is  $140$  ms away from the initial position. Similarly, blue window is also  $140$  ms away from the initial position. These two data sets correspond to the same position of the heart and are referred to as resonance. The only option for image reconstruction is to extend the length of the data set, which will introduce a significant motion artifact.

beat will correspond to the same position of the heart and therefore reconstruction is impossible. The only available solution is to extend the length of data window which results in a motion-related artifact. Similarly, if the cardiac cycle is  $1.5$  or  $2.5$  times of the gantry rotational time, the data sets of adjacent two beat respectively correspond to a  $0^\circ$  and  $180^\circ$  positions of the heart, and data collection from opposite directions is ineffective for the same heart position. Thus, data sets still overlap and reconstruction does not produce any clear image (Figure 6). When resonance occurs, the reconstructed image exhibits obvious aliasing. The resonance phenomenon is typical

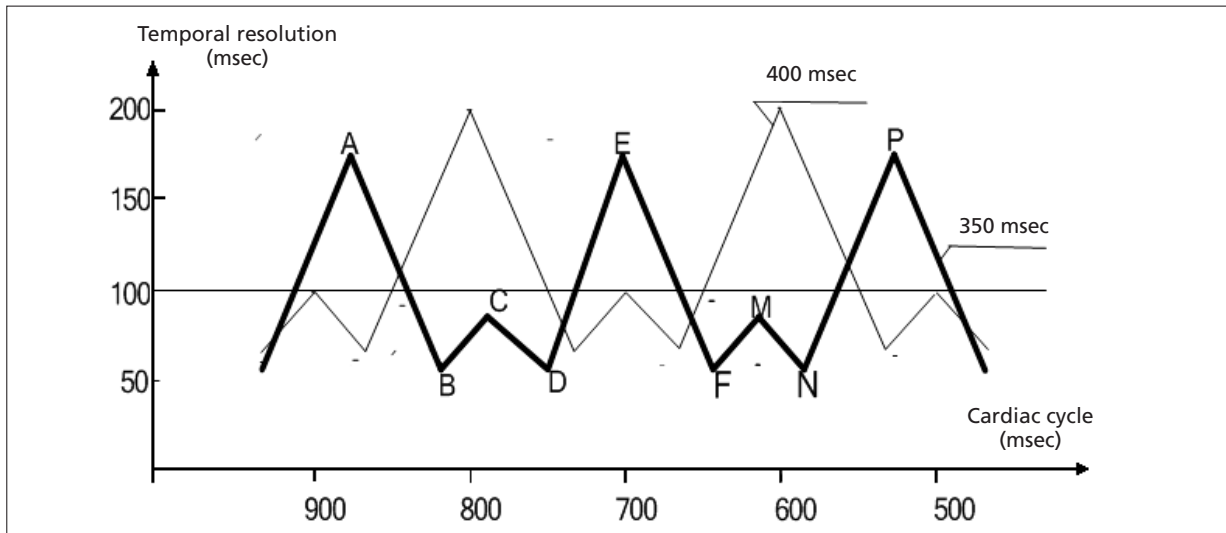
for multi-sector reconstructed images using CT scan, and this is an intrinsic flaw of the multi-sector reconstruction algorithm.

#### Removal of Resonance Phenomenon

The most important finding of our study is that the use of single gantry speed for a large range of heart rate<sup>18-26</sup> inevitably leads to significant discrepancies of image quality in coronary artery CT scan. As Table II showed two groups where the heart rates are the same but with different gantry rotational speeds, the image quality differ significantly ( $p < 0.001$ ). To find appropriate range of heart rate corresponding to gantry rotational



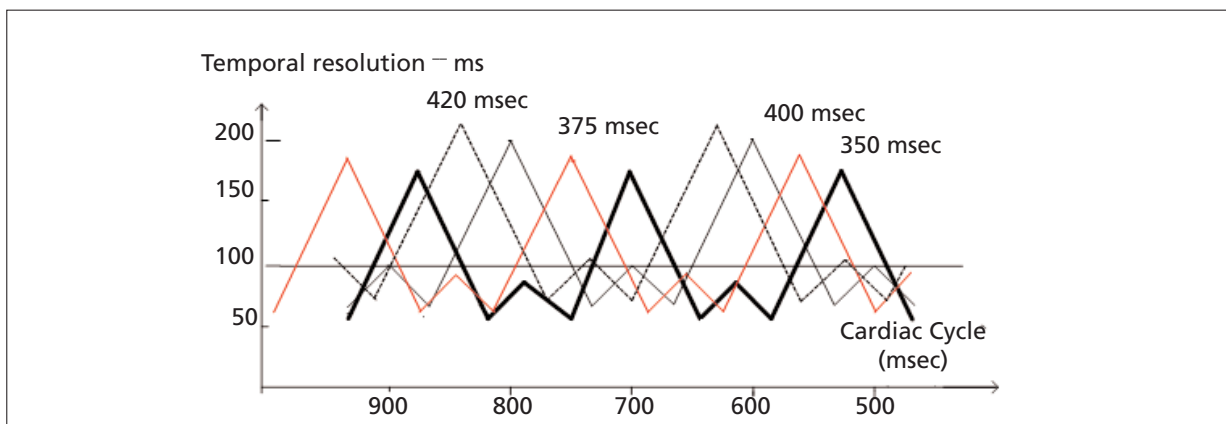
**Figure 6.** Cardiac cycle is  $750$  ms, gantry rotational speed  $500$  ms/rev, and the ratio of heart period/gantry rotational period is  $1.5$ . Heart contraction was selected for image reconstruction. Each data set shares the same phase. Assuming it is  $300$  ms away from the previous R wave. red window is  $0$  ms, blue window is  $250$  ms, and yellow window is  $0$  ms away from the initial position. The red and blue data sets are  $250$  ms apart but correspond to the same position of the heart, only in opposing directions. The only option for image reconstruction is to extend the length of the data set which will introduce a significant motion artifact.



**Figure 7.** Gantry rotational period of 350 ms (*thick line*) and 400 ms (*thin line*). The curve shows the 3-sector reconstruction temporal resolution as a function of heart period. These two curves are in counterphase: when one curve is at its peak (low temporal resolution of 100-175/200 ms), the other one is at its deepest point (high temporal resolution 58/67-100 ms), which enables excellent temporal resolution.

speed, we can plot the temporal resolution against cardiac cycle using 10 ms interval. At the turning point, the sampling time can be reduced to 1 or 0.5 ms, and all of the turning points A, B, C, D, E, F, M, N, P can be precisely calculated. By connecting all the points, we obtain a curve that shows variation of temporal resolution as a function of cardiac cycle (Figure 7). This curve consists of piecewise linear segments and is periodic with a period of half of the gantry rotational time. This is different from the curve offered in previous research where temporal resolution varied against heart rate<sup>14,16</sup>. That they used heart rate as the X-

axial make curves have obvious non-linear, which makes it complicated to know and master the law. As shown in Figure 7, due to the complementary nature between the curve of 350 ms/rev and 400 ms/rev, resonance can be completely removed. if the curves of gantry rotation times of 375 msec and 420 msec are plotted. As shown in Figure 8, temporal resolution ranged from 58.33 to 100 msec in a large range of heart rate (65-150 bpm). Asynchronous cases are obtained using the above approach, With a well controlled breathing and precise reconstruction phasing, high quality images can always be obtained.



**Figure 8.** For 3-sector reconstruction algorithm, various gantry speeds and matching heart rate. The y axis represents temporal resolution, while x axis shows cardiac cycle. Four gantry rotational speeds are plotted: 350 ms (*thick line*), 375 ms (*red line*), 400 ms (*thin line*), and 420 ms (*dashed line*).



Our study did not analyze the influence of heart rate on diagnostic accuracy, and we didn't include the coronary artery stenosis detection.

### Conclusions

The quality of the coronary artery CT scan image depends on the relationship between gantry rotational time and heart rate<sup>12</sup>. So before being scanned, the patient is trained how to breathe and his heart beat is measured again and again, based on the measured heart rate, appropriate gantry rotational time can always be selected in order to avoid resonance and obtain high quality images.

### Conflict of Interest

The Authors declare that they have no conflict of interests.

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