Study of 320-detector rows CT coronary: no influence of heart rate variability on image quality, diagnostic accuracy and radiation exposure

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Purpose

Since the clinical application of 4-detector CT to scan the coronary arteries by a noninvasive procedure, CT coronary angiography has emerged as an attractive, diagnostic modality for detecting coronary artery disease. However, the small diameter of the coronary arteries, their complex three-dimensional geometry, and their rapid movement throughout the cardiac cycle represent the major challenges for artifact-free coronary CT angiography. 'Step artifacts' and 'blurring artifacts' are two kinds of motion artifacts influencing the quality of coronary artery image. Dual-source CT (DSCT), with two x-ray sources and a temporal resolution of 83 ms, has resolved 'blurring artifacts' caused by high heart rate (HR)[1-3]. Nevertheless, 'step artifacts' caused by heart rate variability (HRv) is still an inverse factor influencing the image quality [1-2].

Just as the improved temporal resolution to resolve the problem of high HR, the longitudinal coverage of the detector should be expanded further to resolve the influence of HRv [4-7]. 320-detector rows dynamic volume CT (DVCT) can cover the whole heart within one-heart beat, which enables DVCT having the potential to resolve the impact of HRv. the studied beforey based on low HRof heart rate. can.val.tion fraction was calculat

The aim of the study was to evaluate the effects of HR and HRv on image quality, radiation dose and diagnostic accuracy in patients undergoing DVCT.
Methods and Materials

CT scanning protocol

All CT examinations were performed with a 320-detector rows CT (Aquilion ONE, Toshiba, Nasu, Japan) without any complications. We administered 0.4mg nitroglycerin two minutes before scanning in absence of contraindications (hypotension, current use of nitrate medications, migraine sensitive to nitrates). A breath hold trial was performed by simulating scanning with a single 5-second breath-hold command to adjust scanner settings to individual patients [9]. The scanning range positioned from the level of the tracheal bifurcation to the diaphragm to cover the entire heart (scanning range coverage was 12-14cm).

A 60ml bolus of iohexol (Omnipaque 350, Amersham Health#now GE Healthcare#Shanghai, China) was injected into an antecubital vein through an 18 gauge catheter at an injection rate of 5 mL/sec, followed by a 50 ml saline solution continuously. According to bolus tracking technique (SUREStart, Toshiba), a threshold was set at 180 HU in the descending aorta. The scanning parameters were: collimation 320×0.5 mm, gantry rotation time of 350 ms, tube voltage and the tube current of 100 kV and 350 mA for BMI < 18, 100 kV and 400 mA for BMI from 19 to 24, 120 kV and 450 mA for BMI >24. A prospective electrocardiographic (ECG)-gating was used in all cases. The exposure window was manually adjusted to 60%-85% of the cardiac cycle in patients with HR < 70 bpm, 30%-80% in patients with HR more than 70 bpm, respectively.

For HR <70 bpm at time of breath hold trial, one heart beat scan acquisition mode was used. For HR between 70-80 bpm, two heart beats acquisition mode was used. For HR >80 bpm, three heart beats acquisition mode was necessary to improve temporal resolution. Using multi-segments algorithm, the temporal resolution was able to reach 87.5 to 58.3 ms. If HRv changes 20% more than heart rate at time of breath hold trial, the scanner would hold on scanning and the system would attempt to capture one normal beat until the maximum exposure time was reached.

Data analysis

Image reconstruction was performed using a section thickness of 0.5mm and an increment of 0.25mm. The field of view (FOV) for the images was adjusted to exactly encompass the heart (180 mm-240 mm). Images were firstly reconstructed at preset 75% of the R-R interval. When the image quality was poor in patients with a stable heart rate, we determined which image from the automatically generated data stack at 75% of the R-R interval had the worst image quality. At this fixed level we then undertook further reconstructions at 2% steps through the available reconstruction window to determine
the optimal reconstruction interval. For patients with unstable heart rate, we used an absolute timing approach and reconstructed transverse images with a 10ms step from peak R-wave. In both cases, when the interval with least motion artifact was determined, the whole heart data was reconstructed.

All images were transferred to the workstation (Vitrea II fX, VitalImages, Minnetonka, MN). Curve planar reconstruction (CPR) and volume rendering (VR) were used to assess the image quality and coronary artery stenosis by two experts and blinded readers with 7 and 6 years of experience in cardiovascular radiology. Decisions were reached with a consensus. Coronary arteries were subdivided according to the 15-segment model proposed by the American Heart Association. All segments with diameter < 1.5 mm were excluded.

Quality score was measured by using the following four-point scale as follows: 1, excellent (no motion artifacts and clear delineation of the segment); 2, good (minor artifacts and mild blurring of the segment); 3, adequate, (moderate artifacts and moderate blurring without structure discontinuity); 4, non-evaluable (doubling or discontinuity in the course of the segment preventing evaluation or vessel structures not differentiable severe artifacts). Stenosis were visually classified as significant (#50% lumen diameter reduction) or non-significant (<50% lumen diameter reduction).

**Evaluation of radiation dose of CT coronary angiography**

The dose length product (DLP) displayed on the dose report on the CT scanner was recorded. An effective dose (E) was obtained using the equation: $E = k \times DLP \ (k = 0.029 \text{ mSv} \times \text{mGy}^{-1} \times \text{cm}^{-1})$, which was calculated specifically for DVCT[12].

**Invasive coronary angiography**

For 43 patients who were scheduled clinically-indicated invasive coronary angiography (ICA), ICA was performed with the conventional Judkin technique. Four views of the left coronary artery (LCA) and two views of the right coronary artery (RCA) were analyzed in consensus by two cardiologists with eleven years of experience. They were unaware of the CT results during the analysis. Coronary artery segments were defined according to the same guidelines mentioned above[10]. Lesions with a stenosis 50% or more in diameter were considered to be significant.

**Statistical analysis**
Statistical analysis was performed with statistic software (SPSS, version 16 for Windows; SPSS, Chicago, Ill). A \( p \)-value of less than 0.05 indicated a statistically significant difference.

Quantitative variables were expressed as a mean ± standard deviation, and categorical variables as frequencies or percentages. The inter-observer agreement for the determination of the image quality readout and assessment of significant coronary artery stenosis was calculated with Kappa statistics.

In a sub-analysis, patients were subdivided into three groups according to mean HR (group A: HR< 70bpm, group B: 70 ≤ HR <80bpm, group C: HR ≥ 80 bpm). Bivariate data were tested by Pearson correlation. Multivariate regression analysis was performed to test for mutual effects of the mean HR and HRv on the mean image quality score and diagnostic accuracy. The diagnostic performance of DVCT for the detection of a significant stenosis was calculated using the following parameters for measurement: sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV).
Results

Among the 94 patients, there were 47 patients whose heart rate can't be controlled under HR of 70bpm. The average HR of 94 patients during scanning was 74.2 ± 11.2 bpm (range, 54-114.3bpm) and the average SD of HRv was 3.7 ± 4.6 (range, 0-18.1). Of the 94 patients, 1317 out of potentially 1410 segments were available for evaluation. 93 segments were non-accessible because of either variation in coronary anatomy or vessels possessing a diameter < 1.5 mm at their origin.

Effect of HR and HRv on image quality

A significant correlation was found between mean the HR and mean image quality ($r = 0.63$, $p<0.001$) (Fig. 1 on page 8). Among the 47 patients whose HR<70bpm during breath hold trial, there were 43 patients scanned by one heart beat scan acquisition mode. 4 patients were scanned with two or three heart beats scan acquisition as premature beat happened. After the eliminating the data of short R-R intervals, images were constructed using one R-R interval. Thus, there was no variability of heart rate for patients with HR<70bpm during breath hold trial. For 47 patients with HR>70bpm during breath hold trial, two or three R-R intervals were needed for to improve temporal resolution. No significant correlation was found between HRv and the overall image quality ($r = 0.16\#p = 0.27$) (Fig. 2 on page 8).

Multivariate regression analysis to consider the co-effect of mean HR and HRv on image quality showed that HR was the single factor of significant influence ($p < 0.001$), while HRv had no significant effect on image quality ($p = 0.16\#$).

Effects of HR and HRv on radiation dose

The mean estimated effective dose was 14.8 ± 9.8 mSv. In patients with a HR<70 bpm, the mean radiation exposure of coronary CT angiography was 7.1±7.0 mSv. With higher HR, effective dose increased significantly ($p<0.001$), while there was no significant influence of HRv regarding an effective dose ($p=0.47$).

Effect of mean HR and HRv on diagnostic accuracy

The kappa value for coronary artery stenosis detection was 0.82. Significant coronary artery stenosis was presented in 38 segments of the 43 patients who underwent ICA. On the basis of a per-segment analysis, overall sensitivity was 97.4% #37/38#, specificity was 99.4%#351/353#, PPV was 94.9% (37/39), and NPV was 99.7% (351/352).
According to multivariate logistic regression analysis, HR and HRv showed no influence on the accuracy of lesion detection ($p = 0.17\#0.12$, respectively).
Images for this section:

**Fig. 0:** A linear regression plot of the image quality score (y-axis) against HR (x-axis). Dashed lines = 95% confidence limits.

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**Fig. 0:** A linear regression plot of the image quality score (y-axis) against HRv (x-axis). Dashed lines = 95% confidence limits.

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Conclusion

1. For DVCT, when heart rate<70bpm, the whole coronary artery can be imaged with one heart beat. In patients with higher heart rates when better temporal resolution is desired, multi-segments reconstruction is necessary and two or more heart beats are needed to improve temporal resolution. Compared with one heart beat scanning mode, multi-heart beats scanning mode can't always avoid the variability of different R-R intervals. Thus, the 'blurring' artifact can't be avoided completely. Compared with image quality in HR<70bpm, the image quality is degraded by higher HR.

2. If HR<70bpm, the whole coronary artery can be imaged within one R-R interval. Thus, HRv is 0. If HR>70bpm, multi-segments algorithm is required to improve temporal resolution. The degree of HRv, however, does not influence the image quality significantly. The main reason is the expanded longitudinal coverage of detectors. As the acquisition of the entire cardiac volume in a single gantry rotation allows the contrast bolus to be imaged at a single time point, there is no difference of R-R intervals along the Z-axis. Thus, the 'step artifacts' can be eliminated greatly. In addition, if HRv>20%, the scanner will hold on and exposes a similar R-R interval. HRv can be controlled within 20%. Therefore, the misalignment of images from the variation in R-R intervals is not statistically affected by the degree of HRv.

3. For DVCT, the whole heart is scanned by volume mode, which images the coronary artery with a pitch of 0. If a severe HRv is detected by DVCT, the scanner would hold on scanning of the short R-R intervals, which eliminates the influence of HRv significantly. On the other hand, as multi-segments reconstruction is required in high HR, the exposure time increases significantly with HR. Therefore, HR is still an inverse factor for radiation dose.

4. With high HR and severe HRv enrolled in this study, the accuracy of DVCT was still high. Therefore, no effect of HR and HRv on diagnostic accuracy was found.
References


Personal Information

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