Sixteen-detector Row CT Coronary Angiography: Investigating and Analyzing Reconstructed Images

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To investigate and analyze reconstructed images of retrospective ECG gating 16–detector row computed tomography for each of the major coronary arteries during the cardiac cycle under 65 heartbeats per minute.

16–detector row coronary artery CT angiographies obtained in 97 patients (63 men, 34 women; mean age, 56 years ±13; age range, 30-82 years) were reconstructed at 35%–85% of the cardiac cycle in increments of 10%. Two independent reviewers who specialize in cardiac radiology assessed the image quality, obtained with three-dimensional post-processing for segments 1–3 (right coronary artery), segments 5–8 (left main and left anterior descending coronary arteries), and segments 11 and 13 (left circumflex artery). Segments were defined according to the textbook of de Feyter PJ. The grades were assigned: 1, excellent; 2, good; 3, fair; 4, poor; and 5, very poor.

The three-dimensional reconstructed image score data were statistically analyzed with SPSS software version 10.0. The authors analyzed 97 patients’ data with 2-way ANOVA and found the left anterior descending artery, left circumflex artery and right coronary artery all best visualized at 75% of the cardiac cycle (p < .05).

Our results demonstrated that the reconstructed images of coronary arteries usually performed optimally during mid-to-late diastole when patients’ heart rate is under 65 bpm. 75% of the cardiac phase was the best visualization phase for all coronary arteries in this study.

Key words: Cardiac cycle, Multi-detector row CT, Reconstruction

Coronary artery disease is one of the leading causes of death. Almost half of these patients die without prior symptoms [1]. Conventional invasive coronary angiography constitutes the clinical gold standard for detection of coronary artery stenosis. However, the risk of potentially serious adverse effects and the associated costs have led to an intensive search for noninvasive alternatives [2]. Windecker et al reported that in Europe in 1995, diagnostic coronary angiography was performed in more than 1 million patients; only 28% subsequently underwent percutaneous transluminal coronary angioplasty [3]. Therefore, to detect the coronary artery disease by noninvasive imaging tools are needed. Contrast-enhanced multi-detector row computed tomography (MDCT) is a promising noninvasive technique for the detection, visualization, and characterization of stenotic coronary artery disease [4-7].

Retrospectively ECG-gated MDCT offers the possibility of reconstructing images at different points of the R-R interval from the same raw data set [8]. An inverse relation between heart rate and image quality was reported previously [9, 10]. Sixty-five beats per minute was defined as the upper heart rate threshold with which it is possible to achieve motion-free image
quality [11]. It is therefore common practice to use β-blocking agents to maintain heart rates at a level below that threshold during image acquisition.

The purpose of this study was to investigate the 3D reconstruction images of coronary arteries and statistically analyze the optimized phase images in cardiac cycle when the heart rate was under 65 beats per minute (bpm).

**MATERIALS AND METHODS**

A total of 97 patients (63 men, 34 women; mean age, 56 years ±13; age range, 30-82 years) whose heart rate are lower than 65 bpm, undergoing CT angiography of the coronary arteries were enrolled in this study. The mean heart rate was 58±5 bpm (range, 41-65 beats/min). All patients gave written informed consent, and all examinations were performed with a 16-detector row CT scanner (Lightspeed 16; GE Medical Systems). The following scanning protocol was used: 16 x 0.625 mm collimation; 500-msec rotation time; 120 kV, 400 mA. To establish the scanning delay for main angiographic bolus [12-16], a test bolus of 20 mL of contrast material (Visipaque 320mgI/ml; Amersham Health) was used. Acquisition of the scans began 5 seconds after the beginning of the injection of contrast material with scanning every 2 seconds in the ascending aorta. With use of a power injector (Medrad Stellant), a 100 mL bolus of contrast material was injected via an 18-gauge catheter into an antecubital vein with 4 mL/sec flow rate. To reduce the heart rate, a β-blocker (10 mg of propranolol) was administered orally 40 minutes to 1 hour before the examination and a single-sector algorithm was used. To determine the optimal position of the image reconstruction window relative to the cardiac cycle, six sets of reconstructions—at 35%, 45%, 55%, 65%, 75%, and 85% of the cardiac cycle—were performed for each raw data file. The concept of 35%–85% reconstruction refers to the percentage of the cardiac cycle retrospectively defined for reconstruction. The reconstructed section thickness was 1.25 mm, and the image increment was 1.25 mm. The image data from each of these reconstructions were transferred to a computer workstation for three-dimensional volume-rendered post-processing. Two independent reviewers visually assessed these three-dimensional volume-rendered images interactively on the workstation. The image quality with each data set was graded as follows, in terms of artifacts and visibility: 1, excellent; 2, good; 3, fair; 4, poor; 5, very poor. For image analysis, we used the coronary segments as defined in the textbook from de Feyter PJ [17]. Each reviewer assessed segments 1–3 (right coronary artery), segment 5 (left main coronary artery), segments 6–8 (left anterior descending coronary artery), and segments 11 and 13 (left circumflex coronary artery) (Fig. 1). Overall, each reviewer assessed 9 segments of coronary arteries per patient in one phase. Statistical analysis was performed with 2-way ANOVA software (SPSS, version 10.0).

**RESULT**

Each of the two reviewers evaluated 873 segments in the 97 patients. The results of mean grade and standard deviation which composed of two reviewers’ score are listed in Table 1 and Fig. 2. Segment 5 (left main coronary artery) could be clearly visualized at almost all time points in the cardiac cycle [Table 1]. For most patients, the left

<p>| Table 1. The mean grade and standard deviation of each segment between two reviewers |
|---------------------------------|-----|-----|-----|-----|-----|-----|-----|-----|</p>
<table>
<thead>
<tr>
<th>Segment</th>
<th>Reader1</th>
<th>Reader2</th>
<th>Reader1</th>
<th>Reader2</th>
<th>Reader1</th>
<th>Reader2</th>
<th>Reader1</th>
<th>Reader2</th>
</tr>
</thead>
<tbody>
<tr>
<td>RCA1</td>
<td>3.2±1.1</td>
<td>2.9±1.0</td>
<td>3.6±1.2</td>
<td>3.6±1.1</td>
<td>3.9±1.1</td>
<td>4.0±1.0</td>
<td>2.8±1.2</td>
<td>2.6±1.1</td>
</tr>
<tr>
<td>RCA2</td>
<td>3.8±1.0</td>
<td>3.7±0.8</td>
<td>4.1±1.1</td>
<td>3.9±1.0</td>
<td>4.6±0.8</td>
<td>4.6±0.7</td>
<td>3.4±1.4</td>
<td>3.3±1.1</td>
</tr>
<tr>
<td>RCA3</td>
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<td>3.5±1.0</td>
<td>4.1±1.0</td>
<td>3.7±1.1</td>
<td>4.6±0.8</td>
<td>4.2±0.9</td>
<td>3.5±1.3</td>
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<tr>
<td>LMC5</td>
<td>2.5±1.0</td>
<td>2.3±0.9</td>
<td>2.9±1.0</td>
<td>2.9±1.0</td>
<td>3.1±1.0</td>
<td>3.1±1.0</td>
<td>2.1±0.9</td>
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<tr>
<td>LAD6</td>
<td>2.5±0.9</td>
<td>2.5±0.8</td>
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<td>3.3±1.0</td>
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<td>3.3±1.0</td>
<td>2.1±1.0</td>
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<tr>
<td>LAD7</td>
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<tr>
<td>LAD8</td>
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<td>3.6±0.9</td>
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<td>LCX11</td>
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<tr>
<td>LCX12</td>
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</tbody>
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anterior descending artery (segments 6-8) was best visualized in mid-diastole at 75% of the cardiac cycle (Fig. 3). The time point for best image quality of the right coronary artery (segments 1-3) locates at middle to late in diastole at 75% of the cardiac cycle (Fig. 3). The left circumflex artery (segments 11 and 13) showed optimal image quality at 75% of the cardiac cycle (Fig. 3). The results of 2 reviewers for each coronary artery were analyzed by 2-way ANOVA, with a p value < 0.05 considered statistically significant. The 3D images show the reconstruction window from 35% to 85% of the cardiac cycle. At 75% of the cardiac cycle, we can gain the best image quality of all coronary arteries (Fig. 4, 5). There was a good agreement (k=0.61) between the two reviewers.

**DISCUSSION**

Prior reports [4, 5, 18] that indicate ECG-gated MDCT are highly accurate for the detection of coronary artery stenosis if the image quality is sufficient. An inverse relation between heart rate and image quality was reported previously [9, 10]. A patient’s heart rate during MDCT scanning had a significant influence on phase of the cardiac cycle in order to obtain the clearest image of the coronary arteries. Therefore, a useful approach might be to limit the use of MDCT for coronary artery visualization to patients with lower heart rates or to use pharmacologic interventions (e.g., β-blocker) during the scanning to enhance image quality and accuracy in the identification of coronary stenosis. Sixty-five beats per minute were defined as the upper heart rate threshold with which it was possible to achieve motion-free image quality [9, 10, 11].

In our study, we selected patients which heart rate lower than 65 bpm and reconstructed coronary artery 3D images. Multiple reconstructions were performed in different cardiac phases for optimal image quality of individual vessels. The coronary arteries (RCA, LMC, LAD, and LCX) were read and scored by two radiologists who specialize in cardio-radiology. The results showed excellent images of all segments, which fell in 75% of cardiac cycle (Fig. 3). Following this result, we can reconstruct 3D images directly in 75% cardiac cycle in most cases. This will gain better image quality in a short period. We analyzed the mean values between two reviewers [Table 1]. Left main coronary artery was visualized in all phases, and 75% of cardiac cycle presented the best visualization. Right coronary artery, left ante-
MDCT coronary angiography images analyze anterior descending and left circumflex coronary arteries were also best visualized in 75% of cardiac cycle. At 65% of cardiac cycle provide the second best visualization for all three coronary arteries.

According to Giesler's study [2], the mid-to-late diastole cardiac phase frequently yielded the best image quality of the left main, left anterior descending and left circumflex arteries; the optimal position to clearly visualize the right coronary artery was more evenly distributed over late systole, early diastole, and mid-to-late diastole. The heart rate significantly influenced the optimal cardiac phase. The best imaging window in patients with a heart rate of 70 beats per minute or less was usually during mid to late diastole [2]. Because of the shorter duration of diastolic relaxation, the optimal cardiac phase to visualize the coronary arteries in patients with a heart rate more than 70 beats/min was more frequently during late systole and early diastole. There is a different finding in Andreas F.K.’s study [19]. The left anterior descending artery was best visualized in mid-diastole at 60-70% of the cardiac cycle, and the left circumflex artery was best visualized at 50%. The optimal reconstruction window for the right coronary artery was at 40%.

Giesler and Andreas use Somatom Volume Zoom scanner (Siemens, Forchheim, Germany) to perform their studies. The scanning protocol used in

Figure 4. Right coronary artery 3D images were reconstructed at 35% to 85% of the cardiac cycle in increments of 10% with 16-detector row CT coronary angiography. A, 35% of the cardiac cycle. B, 45%. C, 55%. D, 65%. E, 75%. F, 85%. Fig. 3D possesses the best image quality of RCA (white arrow) was seen in the mid-diastolic phase (75%) of the cardiac cycle. The poorest visualization was seen in systolic phase (45%).
the two studies were similar: Collimation 4×1mm; gantry rotation time 500msec; infusion rate 4ml/sec; reconstruction window from 20% to 80% and increment is 10%. The mean heart rate was 65bpm ±10 in Andreas’s study and 69bpm±13 in Giesler’s study. In Giesler’s study, the heart rate were divided into 4 groups namely 60bpm or less, 61-70bpm, 71-80bpm and 81bpm or more. The optimal position of data reconstruction window located at 70% of cardiac cycle in Giesler’s study when the heart rates lower than 70bpm. As for the Andreas’s study, there was no more description for optimal position of reconstruction window.

In our study, the optimal reconstruction window for each coronary artery is at 75%. This result is similar to Giesler’s study; the mid-to-late diastolic cardiac phase frequently yielded the best image quality when the heart rate is less than 70 beats/min. There was a good agreement (k=0.61) between the two reviewers in our study.

Although MDCT, to examine the coronary arteries, is still undergoing rigorous clinical validation, it is hoped that MDCT will eventually be used instead of angiography for routine assessment of the coronary arteries. The procedure can be performed more quickly than angiography, and requires less skill to perform than cardiac catheterization. Catheter-related risks, including bleeding at punc-
ture site, are also eliminated, and no hospitalization or close monitoring post-study is required. In the future, additional technical developments, such as decreased gantry rotation time and the simultaneous acquisition of more than sixteen parallel slices, may further improve image quality and diagnostic accuracy.

CONCLUSION

MDCT with retrospective ECG gating permits the detection of coronary artery stenosis with high accuracy if image quality is sufficient. Our results demonstrated that the reconstructed images of coronary arteries usually performed optimally during mid-to-late diastole when patients’ heart rate is under 65 bpm. 75% of cardiac phase is the best visualization phase for all coronary arteries in this study.

REFERENCES

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十六切面電腦斷層冠狀動脈檢查及重組影像偵測分析

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國立清華大學 生醫工程與環境科學系博士班2
中台科技大学 放射科学研究所3
長榮大学 呼吸照護系4

以16切面電腦斷層搭配回顧式心電圖偵測分析心跳低於65下患者重組影像在心週期的最佳影像。

97位病患（男性63位，女性34位；平均年齡56 ± 13歲；年齡範圍由30歲至82歲）。在接受16切面電腦斷層冠狀動脈檢查，其影像重組由心週期35% 至85%，間隔10%。重組影像分段依de Feyter PJ所著冠狀動脈電腦斷層一書之分段標準評估右冠狀動脈（第1~3段）、左主冠狀動脈（第5段）、左前降枝（第6~8段）及左迴旋枝（第11、13段）。重組完之影像品質評分標準由很好到很差分別由1分到5分分佈。1分表示很好，5分表示很差，影像由兩位心臟放射線專科醫師判讀評分。

97位心跳低於65下病患之3D重組影像以SPSS ANOVA軟體分析出各冠狀動脈皆在75%心週期有最佳影像品質（p < 0.05）。

心跳率低於65bpm患者之冠狀動脈重組影像最佳品質在心舒張期中末段有最佳品質。在此研究中，75%心週期為重組最佳影像。

關鍵詞：心週期；多切面電腦斷層；重組