Although conventional angiography is still considered the gold standard for the detection and diagnosis of coronary artery disease (CAD), it is a highly invasive procedure. Multi-detector computed tomography (MDCT) for imaging the heart is a promising noninvasive technique in terms of its ability to visualize the coronary arteries (1-6). However, it is well known that the image quality is highly dependent on the heart rate, and the cardiac motion artifacts caused by higher heart rates (HRs) remain a major cause of image degradation in MDCT coronary angiography (7-9). Some recent papers have reported that motion-free coronary angiograms can be consistently obtained when the HR is less than 80 bpm (10) and 64-slice MDCT provides diagnostic-quality images of the coronary arteries within a wide range of...

The Influence of Heart Rate and its Variations on Image Quality: A Comparative Study of 16- and 64-Slice Multidetector Row Computed Tomography

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Purpose: We wanted to investigate the influence of heart rate (HR) and its variations on the CT angiography (CTA) image quality with using 16- and 64-slice multidetector CT (MDCT).

Materials and Methods: Of the 200 recruited patients, 100 underwent 16-slice MDCT (M:F = 74:26, median age: 55.2 ± 12.8 years) and 100 underwent 64-slice MDCT (M:F = 68:32, median age: 58.4 ± 11.6 years). We evaluated the image quality with respect to the HR and the variations in the HR. The images were graded in terms of the quality of vessel depiction with using a four-point scoring system from 1 to 4, where 4 represented the best image quality. In addition, we analyzed the 16- and 64-slice MDCT images in terms of the presence and frequency of stair-step artifacts.

Results: The mean HR variation was significantly lower on 64-slice MDCT than that on 16-slice MDCT (5.48 ± 4.20 bpm vs. 10.31 ± 5.90 bpm, respectively, p < 0.05). The mean image quality score of 64-slice MDCT was significantly greater than that of 16-slice MDCT (3.40 ± 0.36 vs. 2.75 ± 0.43, respectively, p < 0.05). The frequency of stair-step artifacts was markedly greater for 16-slice MDCT (2.4 ± 3.2 vs. 0.5 ± 1.04, respectively, p < 0.05).

Conclusion: 64-slice MDCT provides better image quality because it reduces the scan times and minimizes the HR variations.

Index words: Tomography, X-ray
Heart rate
Coronary artery disease
heart rates (38–102 bpm) [11], yet higher HRs and variations in the HR significantly degrade the image quality of the whole coronary tree. Because the HR increases or it is highly variable in most patients during CT scanning, and even within short breath-hold durations [9–13] HR responsive scanning or premedications such as β-blockers that lower and stabilize HR may increase the image quality by minimizing the influence of HR variations [9, 14].

To the best of our knowledge, the effect of HR and its variations on the image quality of 16- and 64-slice MDCTs, which are commonly used in current practice, have not yet been investigated and reported on in Korea. Therefore, we investigated the influence of HR and its variations on the image quality of the coronary CT angiograms obtained with using 16- and 64-slice MDCTs.

Materials and Methods

Patients

This retrospective study was conducted on 200 patients who had undergone coronary CT angiography. One hundred of them had undergone cardiac CT using a 16-slice MDCT from January 2006 to July 2006 (men:women = 74:26, mean age: 55.2 ± 12.8 years), and the other 100 had undergone cardiac CT using a 64-slice MDCT from May 2007 to June 2007 (men:women = 68:32, mean age: 58.4 ± 11.6 years). The HRs were checked before and during the CT scans for all the patients. To analyze the effects of HR on image quality, the patients were classified according to HR as follows: (1) < 60 bpm, (2) 61–70 bpm, (3) 71–80 bpm, (4) 81–90 bpm, (5) 91–100 bpm and (6) >100 bpm. Variations in HR were defined as the difference between the highest and lowest HR, and these variations were classified as: (1) 0–5 bpm, (2) 6–10 bpm, (3) 11–15 bpm, (4) 16–20 bpm and (5) > 20 bpm. No β-blocker was administered to any patient prior to coronary CTA. The patients with a severe calcification in a coronary artery, a stent or who had undergone coronary bypass grafting were also excluded.

MDCT Exam

Coronary CT angiography was performed with the use of a 16- slice MDCT scanner with a 0.42-s rotation time (Mx8000 IDT; Philips Medical Systems, Best, The Netherlands) and a 64-slice MDCT scanner with a 0.42-s rotation time (Brilliance 64, Philips Medical Systems, Best, The Netherlands) with retrospective ECG gating. A standard scanning protocol was applied, with 16 × 0.75-mm and 64 × 0.625-mm section collimation, a gantry rotation time of 420-msec, a tube energy of 120 kV and an effective tube current of 500/800 mAs. A bolus of 100–120 mL (16-slice MDCT) or 75–85 ml (64-slice MDCT) contrast media (Ioprov; Intravist 370; Schering, Berlin, Germany) was intravenously injected (4 mL/sec). By using a Bolus Pro Ultra (BPU), a region of interest was placed in the ascending aorta (16-slice MDCT)/descending thoracic aorta (64-slice MDCT) and the scan was automatically initiated once a selected threshold (150 HU) was reached. The ECG of the patient was saved concurrently with the acquisitions. The mean scan duration was 18 ± 3 seconds (range: 15 to 24 sec) for the 16-slice MDCT and 11 ± 3 seconds (range: 8 to 14 sec) for the 64-slice MDCT. The various scan parameters are shown in Table 1.

Image Reconstruction and Analysis

After acquisition of the raw helical CT data, retrospec-

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Table 1. A Four-point Grade Scale of Image Quality

<table>
<thead>
<tr>
<th></th>
<th>16-Slice MDCT</th>
<th>64-Slice MDCT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collimation</td>
<td>16 × 0.75 mm</td>
<td>64 × 0.625 mm</td>
</tr>
<tr>
<td>Thickness/Increment</td>
<td>0.8 / 0.4 mm</td>
<td>0.67 / 0.33 mm</td>
</tr>
<tr>
<td>Pitch</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>Rotation time</td>
<td>420 msec</td>
<td>420 msec</td>
</tr>
<tr>
<td>Temporal resolution</td>
<td>53 msec</td>
<td>53 msec</td>
</tr>
<tr>
<td>kVp/mAs</td>
<td>120 / 500</td>
<td>120 / 800</td>
</tr>
<tr>
<td>Scan time</td>
<td>15–24 sec</td>
<td>8–14 sec</td>
</tr>
<tr>
<td>Threshold /delay time</td>
<td>200 HU / 5sec</td>
<td>150 HU / 6.5 sec</td>
</tr>
<tr>
<td>ROI</td>
<td>ascending aorta</td>
<td>descending aorta</td>
</tr>
<tr>
<td>Contrast media</td>
<td>100–120 ml (4 ml/sec)</td>
<td>75–85 ml (4 ml/sec)</td>
</tr>
<tr>
<td></td>
<td>+ 30 ml (3 ml/sec) saline</td>
<td>+ 60 ml (3.5 ml/sec) CM &amp; saline</td>
</tr>
</tbody>
</table>
tively ECG-synchronized sections were reconstructed using adaptive multi-cyclic reconstruction and a heart rate responsive gating algorithm. The projection data was collected to provide image data sets at the desired physiological phases during the cardiac cycle. All the data was processed using a dedicated workstation (Extended Brilliance Workspace; Philips Medical Systems, Best, The Netherlands) and the were displayed using visualization techniques such as source tomograms, thin-slab maximum intensity projections (MIPs), multi-planar reformation (MPR) and volume rendering. Subsequently, the curved MPR images were assessed for motion-free imaging (i.e., no tattered or ragged delineations) of the coronary branches. All three image post-processing modalities (source tomograms, thin-slab MIPs and curved MPRs) were used for the subjective

Fig. 1. Multiplanar reformations with a short axis view of the RCA in four patients, along with the semiquantitative four-point image quality scores.

A. An image with a quality score of 4 shows no motion artifacts (arrows) in all the proximal to mid segments of the three coronary arteries.

B. An image with a quality score of 3 shows no/minimal motion artifacts and it is assessable in the proximal to mid segments of two coronary arteries (arrows).

C. An image with a quality score of 2 is assessable in all the proximal segments of three coronary arteries. There is an obscure middle segment of the RCA (arrow).

D. An image with a quality score of 1 is assessable in the proximal segments of one or two coronary arteries. Although the RCA cannot be assessed (arrows), the proximal segment of the LAD is seen clearly (arrowhead).
evaluations. Three investigators (DHK, EJC, and SIC, with 4, 2, and 5 years of coronary CT angiography experience, respectively) assessed the coronary artery segments according to the guidelines of the American College of Cardiology and the American Heart Association (15). The image quality was evaluated by investigators who were kept “blind” to the HRs and the variations in the HRs. Decisions concerning image quality were achieved by consensus. The images were graded with respect to vessel depiction with using a four-point scoring system (1 to 4), where 4 represented best image quality (Fig. 1). Image scores between 3 and 4 were considered adequate for coronary assessments, and those with scores of 1 or 2 were considered inadequate. The scores were defined as shown in Table 2. In addition, high quality images were chosen by selecting an optimized HR window. Banding artifacts, including stair-step and acceleration artifacts caused by changes in HR, were evaluated on the 16-slice and 64-slice MDCT scans (Fig. 2). The artifacts were registered as present or not.

### Statistical Analysis

Descriptive statistics were stratified according to the image quality scores into four image quality groups. Continuous variables are expressed as means ± standard deviations. *P* values < 0.05 indicated statistical significance. The Kruskal-Wallis test was used to evaluate the quantitative parameters (HR and its variations), which were stratified by the four image quality scores. The two-sample *t*-test was used to compare the means of the image quality scores of the MDCTs. All the statistical analyses were performed with SPSS, version 12.0.

### Results

The numbers of the patients in each HR range (16-slice MDCT: 64-slice MDCT) before the scans were as follows: 1) < 60 bpm (*n* = 25:22), 2) 61–70 bpm (*n* = 32:30), 3) 71–80 bpm (*n* = 23:29), 4) 81–90 bpm (*n* = 13:15), 5) 91–100 bpm (*n* = 5:3) and 6) >100 bpm (*n* = 2:1) (Table 3). The mean HRs were 68.45 beats per minute ± 15.42 in the patients before undergoing 16-slice MDCT scanning and 68.90 beats per minute ±

<table>
<thead>
<tr>
<th>Scores</th>
<th>Image Quality</th>
<th>Image Situation</th>
</tr>
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<tbody>
<tr>
<td>4</td>
<td>When all the proximal to mid coronary arteries were assessable</td>
<td>Excellent</td>
</tr>
<tr>
<td>3</td>
<td>When two proximal to mid coronary arteries were assessable</td>
<td>Good</td>
</tr>
<tr>
<td>2</td>
<td>When all the proximal coronary arteries were assessable</td>
<td>Fair</td>
</tr>
<tr>
<td>1</td>
<td>When one or two proximal coronary arteries were assessable</td>
<td>Bad</td>
</tr>
</tbody>
</table>

Fig. 2. Stair-step and acceleration artifacts.
A. Stair-step like motion artifacts are seen on the right coronary artery (arrowheads).
B. Prominent acceleration artifacts (arrows) are seen below the inferior wall of the LV.
14.25 in the patients before undergoing 64-slice MDCT scanning. The mean HRs of the patients who underwent cardiac CT with a 16-slice or 64-slice MDCT were 71.04 beats per minute ± 13.52 and 69.31 beats per minute ± 14.71, respectively. A high HR variation was found to be associated with poor image quality (the mean score for 16-slice MDCT vs. that for 64-slice MDCT: 3.17 vs. 3.63 at 0–5 bpm, 2.06 vs. 2.25 in 16–20 bpm, \( p < 0.05 \)) (Table 4). 64-slice MDCT was found to have a higher mean image quality score (3.41 ± 0.97 vs. 2.84 ± 0.53, respectively, \( p < 0.05 \) and less occurrence of artifact (0.5 ± 1.04 vs. 2.4 ± 3.2, respectively, \( p < 0.05 \)) (Table 5). In particular, the acceleration artifacts occurred more often in the 16-slice MDCT scans (\( n = 11 \) vs. \( n = 1 \)).

### Discussion

The overall diagnostic quality of noninvasive CT coronary angiography is largely dependent on the spatial resolution, the HR during the examination, an appropriate reconstruction time point within the cardiac cycle and the contrast enhancement \( [2] \). The present study shows that greater HR variations and higher HRs deteriorate the image quality. Furthermore, our study shows that HR variations importantly affect the 16- and 64-slice MDCT image quality, which concurs with the findings of Lee et al. \( [16] \). In that previous report, the coronary CT angiography image quality was found to be more affected by variations in the HR than by a high HR, and the selection of an optimized reconstruction window for good image quality was found to be most affected by the HR when 4-detector row CT without multicyclic reconstruction and a HR responsive gating algorithm were used. Our study also showed the same result that HR variation affected the image quality rather than the HR. Hoffmann et al. \( [10] \) suggested that any strategy to optimize the temporal resolution based on a single fixed HR would fail because of the highly variable nature of HRs even for a short breath-hold duration. In addition, they suggested that the initial HR be reduced to less than 75
bpm to include a safety margin and to optimize the image quality because the HR in most patients increases slightly during scanning.

So then, how do we overcome this problem? Fortunately, there have been several recent developments that minimize image degradations due to higher HRs and HR variations. First, adaptive multi-cycle reconstruction algorithms are available over a wider range of HRs up to 80–100 bpm for 16-slice or 64-slice scanners. These algorithms automatically adjust the system as the HR varies during spiral acquisition. Second, specific cardiac phases or intervals can be determined based on the R waves of the ECG signals. This approach uses either a fixed offset or a fixed percentage delay during the R-R interval to determine a particular phase of the cardiac cycle (17). However, this method requires that the operator directly select the ideal phase for imaging, and it does not account for the variable diastolic phase of the heart (18, 19). Third, a delay algorithm can be used to automatically compensate for the non-linearities during the systolic and diastolic portions of the cardiac cycle that are caused by HR variations to ensure that a desired physiological phase is captured and reconstructed. However, the images produced with using this algorithm are often poor. Finally, premedication, such as with a beta-blocker, can be used to reduce the heart rate and arrhythmia.

In addition to examining the effect of HR and its variations on image quality, we also found that the image quality score was higher and the frequency of artifacts was lower for 64-slice MDCT (3.41 ± 0.97, 0.5 ± 1.04) than for 16-slice MDCT (2.84 ± 0.53, 2.4 ± 3.2). In particular, motion artifacts such as acceleration or stair-step artifacts occurred more frequently on the 16-slice MDCT scans than on the 64-slice MDCT scans (n=11 vs. n=1). These results were probably due to the narrower coverage (16 × 0.75 mm) and the slower scan time (18 ± 3 seconds) of 16-slice MDCT than those for 64-slice MDCT (64 × 0.625 mm, 11 ± 3 seconds).

In conclusion, we suggest that 64-slice MDCT produces better image quality than that of 16-slice MDCT by minimizing the HR variations, reducing the scan times and improving the spatial and temporal resolutions.

References

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16열-과 64열-다절편 전산화단층촬영의 비교 연구

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2부산대학교병원 영상의학과
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김동훈·최상일·전은주·박재형

목적: 16열과 64열 다절편 전산화단층촬영(이하 MDCT라 함)을 이용하여 CT관상동맥 영상 질에 미치는 심박수와 심박수 변화에 대하여 연구하고자 하였다.

대상과 방법: 200명을 대상으로 하였으며, 100명(남: 여=74명: 26명, 55.2 ± 12.8 세)은 16열 MDCT를, 다른 100명(남: 여=68명: 32명, 58.4 ± 11.6 세)은 64열 MDCT를 활용하였다. 저자들은 심박수와 심박수 변화에 따른 영상질을 검사하였다. 영상은 1점에서 4점까지 혈관 분석으로 하였으며 4점이 가장 좋은 영상을 의미한다. 덧붙여, 16열 및 64열 MDCT에서 계단상 허상(stair-step artifacts)을 분석하였다.

결과: 평균 심박수 변화는 64열 MDCT에서 16열 MDCT보다 의미 있게 빠르게 변화(5.48 ± 4.20 회/분과 10.31 ± 5.90 회/분, p < 0.05). 평균 영상 질 수치는 64열 MDCT에서 16열 MDCT보다 의미 있게 높았다 (3.40 ± 0.36 점과 2.75 ± 0.43점, p < 0.05). 계단상의 허상은 16열 MDCT에서 64열 MDCT보다 더 많이 발생하였고 (2.4 ± 3.2회/검사와 0.5 ± 1.0회/검사, p < 0.05).

결론: 64열 MDCT는 스캔시간을 줄이고 심박수 변화가 최소화되기 때문에 더 나은 영상을 제공한다.