Circulatory progress has recently been achieved in the field of noninvasive imaging of the coronary arteries by computed tomography (CT). Multidector-row CT (MDCT) scanners are equipped with thinner detectors and have a shorter rotation time, which enables considerably faster volume coverage with a thinner slice width during a single breath hold. The entire heart volume can be covered with nearly isotropic spatial resolution. By using the retrospective ECG gating technique, cardiac CT imaging can be obtained during an arbitrary cardiac period with a data acquisition window that is shorter than the rotation time of the scanner. However, taking into consideration that the inherent cardiac motion is rather large and complicated, this data acquisition window is not sufficiently short. Therefore, it is not always possible to obtain an adequate quality image, irrespective of which phase of the cardiac cycle the image is reconstructed in.

Several methods have been attempted to determine the optimal phase for image reconstruction. In patients with lower heart rates (HRs), some researchers recommend image reconstruction in the slow filling period, and adequate image quality for evaluation of stenoses and plaques can be obtained. A similar phenomenon of better image quality for clinical use occurs in patients with lower HRs or those using β-blockers. However, β-blockers are contraindicated in cases of congestive heart failure, atrioventricular block, or bronchial asthma, and the adverse reactions of contrast media can be severe in those using β-blockers.

It is difficult to determine the appropriate phase for image reconstruction in patients with higher HRs, and occasionally multiple image series at different reconstruction phases have to be obtained for adequate quality image. The purpose of this study was to optimize the image reconstruction phase of MDCT coronary angiography with reference to the HR by retrospectively analyzing CT and ECG data.

Methods

Study Population

The Institutional Review Board of Shiga University of Medical Science did not require approval or informed patient consent for this study, which was based on a retrospective analysis of CT images obtained in routine clinical practice during a 15-month period from January 2003 to March 2004. During this period, 58 sequential patients with suspected obstructive coronary artery disease underwent 8-row cardiac MDCT (Aquilion 8, Toshiba, Japan) for coronary angiography. The average age was 65.1 years (age range: 45–81 years) and their mean HR during the examination was 64.9 beats/min (range: 45–84 beats/min). Written informed consent for CT evaluation with contrast medium had been given by all patients. The exclusion criteria included severe arrhythmia, renal dysfunction, and known allergic reactions to the contrast medium.
The center of the mid diastolic period and avoided atrial contraction (Fig 2).

Data Acquisition

A standardized scanning protocol was used, with a detector collimation of 8×1 mm, table feed per rotation of 2–2.4 mm, and rotation time of 0.5 s. A bolus of 80–100 ml of non-ionic contrast medium (320 mg/ml, 370 mg/ml iodine) was injected intravenously at a flow rate of 3.0 ml/s via a 20G catheter in a cubital vein. A post-contrast saline injection was not used. As soon as the density level in the ascending aorta at the level of carina, which was monitored at 1-s intervals, reached a predefined threshold of 200 Hounsfield units (HU), the patient was automatically instructed to maintain a single inspiratory breath hold (20–30 s) during data acquisition. The ECG data were recorded simultaneously. The scan direction was cranio-caudal, covering an area from the level of the right main pulmonary artery to the lower end of the heart.

Image Reconstruction

Following acquisition, the scan data were subsequently reconstructed for 10 different types of phases using the retrospective ECG-gating technique. The multi-segmental reconstruction algorithm was used in all the cases, with a temporal resolution that varied theoretically from 50 to 250 ms. The reconstruction parameters were 160–180 mm FOV, 1-mm slice thickness, and 0.5-mm increments.

The 10 reconstruction phases were as follows.

1. Method Tp, Method Tm, and Method Te Image reconstructions were performed antegrade in relation to the previous R wave. The image reconstruction phase was centered on the peak of the T wave in Method Tp, at the midpoint of the descending curve of the T wave in Method Tm, and at the end of the T wave in Method Te, aiming for image reconstruction that corresponded to the late systolic period (Fig 1).

2. Method P Image reconstruction was performed retrograde in relation to the next R wave, and the end of the reconstruction phase was positioned on the peak of the P wave, aiming for reconstruction that corresponded to the mid diastolic period and avoided atrial contraction (Fig 2).

3. Method RR30, Method RR40, Method RR50, Method RR60, Method RR70, and Method RR80 The center of the reconstruction phases was positioned at the relative points referred to between 30% and 80% of the RR interval with an increment of 10% (30%, 40%, 50%, 60%, 70%, and 80%). In the RR30, RR40, and RR50 methods, the center of the reconstruction phases was positioned at the relative points referred to between 30% and 50% of the RR interval with an increment of 10% (30%, 40%, and 50%), aiming for image reconstruction that corresponded to the late systolic phase. In the RR60, RR70, and RR80 methods, the center of the reconstruction phases was positioned at the relative points referred to between 60% and 80% of the RR interval with an increment of 10% (60%, 70%, and 80%), aiming for image reconstruction that corresponded to the mid diastolic period.

Since the image reconstructions were performed at a constant interval from the R-peak in the Tp, Tm, Te, and P methods, these methods were defined as the “absolute reconstruction methods”, whereas in the RR30, RR40, RR50, RR60, RR70, and RR80 methods, the image reconstructions were performed at points with an indefinite duration from the R peak, which can change with the HR, and hence were defined as the “relative reconstruction methods”.

Image Evaluation

All the image data that were reconstructed by the 10 methods were transferred to a computer workstation for post-processing (ZAIO M900, Zaiosoft, Tokyo, Japan). Evaluation of the coronary arteries was performed on this workstation by thin-slab maximum intensity projection and sagittal or coronal multi-planer reformation images, in 7 portion as follows: 2 portions in the right coronary artery (RCA: proximal and distal portion), left main coronary artery (LMCA), 2 portions in the left anterior descending artery (LAD: proximal portion and 1st diagonal branch) and 2 portions in the left circumflex artery (LCX: proximal portion and obtuse marginal artery). The proximal portion of the RCA, distal portion of the RCA, proximal portion of the LAD and proximal portion of the LCX were defined as segments #1 and #2, #3 and #4PD, #6 and #7, and #11 and #13, respectively, in accordance with the classification used by the American Heart Association. When the coronary arteries were calcified or stented, a higher window center (500–650 HU) and greater width (1,100–1,400 HU) were also used.

Using a 5-point grading scale, 2 board-certified radiologists who were unaware of the patients’ clinical histories,
Fig 3. A 44-year-old man with old myocardial infarction. A metallic stent has been placed in segment #2. Significant stenosis can be seen in segment #6 on coronary angiography. Average heart rate during data acquisition was 59.5 beats/min. Volume rendering (A) by Method P shows excellent image quality in the proximal and distal portions of the right coronary artery (RCA). Volume rendering (C) by Method RR 70 shows poor image quality in the proximal portion of the RCA and fair image quality in the distal portion of the RCA. Volume rendering by both Method P (B) and Method RR 70 (D) show excellent image quality in the proximal portion of the left anterior descending artery, 1st diagonal branch and obtuse marginal artery.

Fig 4. A 63-year-old woman with old myocardial infarction. A metallic stent can be seen in segment #2. Average heart rate during data acquisition was 74.5 beats/min. Volume rendering (A) and oblique sagittal MIP (Minimum Intensity Projection) (B) by Method Tm show excellent image quality in the proximal portions of the RCA. Volume rendering (C) and oblique sagittal MIP (D) by Method RR70 show good quality images in the proximal portion of the RCA.
evaluated the images and scored each of the 7 portions of the coronary arteries in terms of continuity and visibility of the vascular lumen as follows: 4=Excellent image quality without any discontinuity or vague borders of the vessel; 3=Good image quality with 1 discontinuity or 1 vague border of the vessel; 2=Fair image quality with 1 discontinuity and 1 vague border of the vessel; 1=Poor image quality with more than 2 discontinuity or more than 2 vague borders of the vessel; 0=Very poor image quality with more than 2 discontinuity and more than 2 vague borders of the vessel (Figs 3A–D, 4A–D).

When the coronary arteries were calcified or stented, continuity and visibility of the vessel walls instead of the vascular lumen were evaluated. In the case of any discrepancy, the images were reviewed until a consensus was reached.

Analysis

Comparison of the 10 Image Reconstruction Methods Used for the RCA, LAD, LCX and LMCA

The patients were divided into 4 groups according to their average HR (beats/min) (<55 (n=9), ≥55 but <65 (n=15), ≥65 but <75 (n=13), and ≥75 (n=21)). The average HR in each case was defined as the average for the total cardiac cycle during data acquisition. A vessel with a score of 3 or more in 2 portions in the RCA, LAD and LCX was defined as an assessable vessel. The number of assessable vessels was compared between the 10 different reconstruction methods in the RCA, LAD and LCX separately in each group. The number of LMCA with a score of 3 or more was also compared between the 10 different reconstruction methods. Kruskal-Wallis and Tukey-Kramer tests were performed for statistical analysis in order to define the most appropriate reconstruction method in each group.

Comparison of the Relationship Between Image Quality and HR in the Mid Diastolic and Late Systolic Periods

As previously mentioned, Methods RR60, RR70, RR80 and P were aimed for image reconstruction that corresponded to the mid diastolic period. In these 4 methods, the best of the summed scores in all 7 portions was defined as the best score in the mid diastolic period. Methods RR30, RR40, RR50, Tp, Tm and Te were aimed for image reconstruction that corresponded to the late systolic period. In these 6 methods, the best of the summed scores in all 7 portions was defined as the best score in the late systolic period. The best score in the mid diastolic period was compared with that in the late systolic period in each patient. To investigate whether average HR influenced the best scores in the late systolic period or that in the mid diastolic period, correlation coefficient and single regression analyses were performed.

Comparison of the Relationship Between Image Quality and Variation in HR During Data Acquisition by Absolute Reconstruction Methods and Relative Reconstruction

Methods

The 10 methods can be divided into 2 groups according to whether they aim for image reconstruction that corresponds to the late systolic period or the mid diastolic period. Comparison and analyses were performed in these 2 groups separately. The best of the summed scores in all 7 portions was defined as the best score separately in the absolute reconstruction methods and relative reconstruction methods. The best score in the absolute reconstruction methods was compared with that in the relative reconstruction methods in each patient. Correlation coefficient and simple regression analyses were performed to assess the relationship between the best score and variation in HR during data acquisition.

Comparison of the Relative Reconstruction Methods and Absolute Reconstruction Methods According to ECG-Based Analysis

In order to clarify the temporal relationships between the relative reconstruction methods and absolute reconstruction methods and to eliminate the influence of the HR on the duration of each cardiac period, 2 ECG-based evaluations were added.

(1) The proportion of the interval between the peak of the R wave and the center of the image reconstruction phase determined by the absolute reconstruction methods to the RR interval was used to evaluate the relationship of the R-Tp/RR, R-Tm/RR, and R-Te/RR ratios with the change in HR.

(2) The diastolic and systolic periods approximately correspond to the TR and RT intervals, respectively. In the absolute reconstruction methods, image reconstructions were performed on the basis of the duration between the peak of the R wave and the end of the T wave and the peak of the P wave and the peak of the R wave. Because the R-Te, Te-Pp, and Pp-P intervals may correlate with image quality in the 10 reconstruction methods, including the absolute reconstruction methods, the influence of HR on the R-Te, Te-Pp, and Pp-P intervals was evaluated. The R-Te was previously measured, as described in (1). The Te-Pp, and Pp-P intervals were newly defined as the duration from the end of the T wave and the peak of the P wave, and from the peak of the P wave and the peak of the R wave, respectively, and measured on the ECG record.

Results

The patient characteristics are summarized in Table 1. Interobserver agreement for evaluation of image quality was moderate (Kappa =0.6). Six portions in 5 patients were not visible because the arteries were absent or totally occluded as documented by invasive coronary angiography.

In another 6 portions in 5 patients, it was very difficult to identify the vascular lumen because of the small size of the arteries or severe calcification. These 12 portions in 10 patients were excluded from the analysis. (Segment #3: 1

Table 1 Patient Characteristics

<table>
<thead>
<tr>
<th></th>
<th>HR &lt;55 (n=9)</th>
<th>55 ≤ HR &lt;65 (n=15)</th>
<th>65 ≤ HR &lt;75 (n=13)</th>
<th>75 ≤ HR (n=21)</th>
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<tr>
<td>Gender (M/F)</td>
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<td>13/2</td>
<td>12/1</td>
<td>15/6</td>
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<tr>
<td>Age (years)</td>
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<td>62.0±3.4</td>
<td>61.0±6.6</td>
<td>66.0±7.2</td>
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<td>Diabetes (%)</td>
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<td>4 (27)</td>
<td>3 (23)</td>
<td>6 (29)</td>
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<tr>
<td>Hypertension (%)</td>
<td>3 (33)</td>
<td>10 (67)</td>
<td>8 (62)</td>
<td>13 (62)</td>
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<tr>
<td>Hypercholesterolemia (%)</td>
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<td>7 (46)</td>
<td>6 (46)</td>
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<tr>
<td>Smoking (%)</td>
<td>4 (44)</td>
<td>9 (60)</td>
<td>7 (54)</td>
<td>14 (67)</td>
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</table>

HR, heart rate.
artery, #4PD: 1 artery, #7: 1 artery, #9: 3 arteries, #12: 4 arteries and #13: 2 arteries.) Correlation coefficient and simple regression analyses between the best score and average HR and between the best score and variation in HR were performed in 48 patients.

Comparison of the 10 Image Reconstruction Methods Used for the RCA, LAD, LCX and LMCA

Significant difference in the number of LMCA with a score of 3 or more was not found between the 10 methods. Table 2 shows the number of assessable vessels in the RCA, LAD, and LCX. The number of assessable vessels were counted in 4 groups separately, which was classified on the basis of average HR during data acquisition.

RCA, right coronary artery; LAD, left anterior descending artery; LCX, left circumflex artery. Other abbreviation see in Table 1.

Comparison of the Relationship Between Image Quality and HR in the Mid Diastolic and Late Systolic Periods

The best score in the mid diastolic period was obtained by the absolute method in 35 patients and by the relative methods in 32 patients. In 9 patients, it was obtained by both methods.

Group With HR ≥65 beats/min Method Tm yielded the greatest number of assessable vessels in the RCA, LAD and LCX, except in the LCX for patients with HR ≥75 beats/min. No significant difference between Method Tm and the 4 methods used for the mid diastolic period was observed.

Group With HR <65 beats/min As shown in Table 2, Method P enabled assessable visualization of the RCA, LAD and LCX in the most cases, but no significant differences were observed when compared with the image quality produced by Method RR70 and RR80. In the RCA, Method P yielded significantly more assessable vessels than the other 9 methods in patients with HR ≥55 and <65 beats/min. In the LCX, Method P yielded significantly more assessable vessels than the 6 methods used in the late systolic period in patients with HR <65 beats/min. No significant difference in the number of assessable vessels in the LAD was observed among Methods P, Tp and Tm.

Table 2 Number of Assessable Vessels in the RCA, LAD and LCX

<table>
<thead>
<tr>
<th>HR (beats/min)</th>
<th>Tp</th>
<th>Tm</th>
<th>Te</th>
<th>P</th>
<th>R30</th>
<th>R40</th>
<th>R50</th>
<th>R60</th>
<th>R70</th>
<th>R80</th>
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<tr>
<td>RCA</td>
<td></td>
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<td></td>
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<td></td>
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<tr>
<td>≤54</td>
<td>1/8</td>
<td>1/8</td>
<td>7/8</td>
<td>0/8</td>
<td>4/8</td>
<td>4/8</td>
<td>7/8</td>
<td>6/8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>64–74</td>
<td>2/14</td>
<td>0/14</td>
<td>10/14</td>
<td>3/14</td>
<td>0/14</td>
<td>0/14</td>
<td>7/14</td>
<td>2/14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>≥75</td>
<td>5/13</td>
<td>4/13</td>
<td>3/13</td>
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<td>1/13</td>
<td>0/13</td>
<td>3/13</td>
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<tr>
<td>LAD</td>
<td></td>
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<td></td>
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<tr>
<td>≤54</td>
<td>3/8</td>
<td>3/8</td>
<td>2/8</td>
<td>1/8</td>
<td>0/8</td>
<td>4/8</td>
<td>6/8</td>
<td>6/8</td>
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<tr>
<td>LCX</td>
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<tr>
<td>≤54</td>
<td>1/8</td>
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<tr>
<td>64–74</td>
<td>5/14</td>
<td>5/14</td>
<td>14/14</td>
<td>0/14</td>
<td>3/14</td>
<td>7/14</td>
<td>11/14</td>
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</table>

The best score in the mid diastolic period correlated with average heart rate (R²=0.53, p<0.01). The best score was obtained by the absolute method in 35 patients and by the relative methods in 32 patients. In 9 patients, it was obtained by both methods.

Table 2 Number of Assessable Vessels in the RCA, LAD and LCX

Fig 5. Scatter plot of the best scores in the mid diastolic period vs average heart rate during data acquisition.
R²=0.53, p<0.01. These mean values were distributed about a straight line given by y =–0.42x+48.92. However, the best score in the late systolic period did not correlate with average HR during data acquisition (R²=0.004, p=0.69) (Fig 6).

Comparison of the Relationship Between Image Quality and Variation in HR During Data Acquisition by the Absolute Reconstruction Methods and Relative Reconstruction Methods

In the late systolic period, the best score in the absolute

Fig 6. Scatter plot of the best scores in the late systolic period vs average heart rate during data acquisition. The best score in the late systolic period did not correlate with average heart rate (R²=0.004, p=0.69). The best score was obtained by the absolute method in 48 patients and by the relative methods in 17 patients. In 7 patients, it was obtained by both methods.

Fig 7. Scatter plot of the best scores in the absolute reconstruction methods in the late systolic period vs variation in heart rate during data acquisition. These mean values were distributed about a straight line given by y =–0.6x+21.19.

Fig 8. Scatter plot of the best scores in the relative reconstruction methods in the late systolic period vs variation in heart rate during data acquisition. These mean values were distributed about a straight line given by y =–0.46x+19.32.
Comparison of the Relative Reconstruction Methods and Absolute Reconstruction Methods According to ECG-Based Analysis

Proportion of the Interval Between the Peak of the R Wave and the Center of the Image Reconstruction Phase Determined by the Absolute Reconstruction Methods to the RR Interval The R-Tp/RR, R-Tm/RR and R-Te/RR ratios varied from 28% to 39% (average: 31.8%), from 33% to 46% (average: 36.7%) and from 38% to 52% (average: 41.2%), respectively, in the group with HR \( \geq 65 \) and <75 beats/min. In the group with HR \( \geq 75 \) beats/min, they varied from 28% to 43% (average: 35.1%), from 34% to 50% (average: 41.6%) and from 41% to 58% (average: 48.2%), respectively. Similarly, some variance was demonstrated in the ratios in the group with HR <65 beats/min (Fig 11).

Influence of HR on the R-Te, Te-Pp, and Pp-R Intervals Although there was a slight decrease in the R-Te and Pp-R intervals, despite the elevation of HR, the Te-Pp interval showed an obvious decrease. The average R-Te interval also decreased slightly from 444 ms in the group with HR <55 beats/min to 358 ms in the group with HR \( \geq 75 \) beats/min, and the average Pp-R interval was almost equal in all 4 groups, varying from 155 ms to 172 ms. However, the average Te-Pp interval showed a marked decrease from 831 ms.
in the group with HR <55 beats/min to 439 ms in the group with HR ≥75 beats/min.

Discussion

Cardiac imaging needs to be acquired during the phase of least motion. Because the image reconstruction phase can be chosen retrospectively when using the ECG-gated technique, in clinical practice it is crucial to obtain images during periods of less motion. However, HR varies markedly among the patient population, so fixed methods cannot be applied to all patients? The purpose of this study was to obtain the optimal reconstruction phase for MDCT coronary angiography according to changes in the HR.

This study demonstrated that the best image reconstruction phase was achieved by using Method P when the HR was low (<65 beats/min). This reconstruction phase almost corresponded to the mid diastole and avoided the atrial contraction period. In the atrial contraction, the atrium contracts abruptly in order to transfer blood to the ventricle that expands reflectively. Image quality in the mid diastolic period decreased as average HR increased. In contrast, image quality in the late systolic period was almost constant, despite changes in the average HR. Six methods used in the late systolic period, especially Method Tm, achieved assessable image quality in some patients with HR >65 beats/min.14 A similar result has been reported previously, wherein the optimal reconstruction phase corresponded to the mid diastole in patients with HR <60 beats/min or to late systole when HR exceeded 65 beats/min.15 To explain this phenomenon, it is necessary to know the physiological change in the length of each cardiac phase occurring with changes in HR. In other words, it is necessary to identify the phase that tends to be influenced or remains uninfluenced by changes in HR.

Mao et al demonstrated the influence of HR on the RT, TP, and PR intervals.16 In their study, the RT, TP, and PR intervals were defined as the interval from the peak of the R wave to the end of the T wave, from the end of the T wave to the beginning of the P wave, and from the beginning of the P wave to the peak of the R wave, respectively. The average value of the TP interval was reported to decrease from 695 ms to 184 ms (73% decrease) when the HR increased from 40 beats/min to 90 beats/min; however, the average values of the RT and PR intervals decreased from 408 ms to 335 ms (only 18% decrease) and from 227 ms to 186 ms (only 22% decrease), respectively. The RT, TP, and PR intervals in that study almost correspond to the respective R-Te, Te-Pp, and Pp-R intervals used in the present study. Our study also demonstrated a slight decrease in the R-Te and Pp-R intervals despite increased HR, whereas the Te-Pp interval showed an obvious decrease. As previously described, the diastolic and systolic periods approximately correspond to the TR and RT intervals, respectively.16 Therefore, the diastolic period tends to shorten with increasing HR, whereas the systolic period does not.

The diastolic period can be roughly divided into 4 periods in close order after the previous R wave: isovolumic relaxation, rapid filling, slow filling, and atrial contraction.17 Slow motion of the ventricular wall is observed in both the isovolumic relaxation and slow filling periods, and the slowest motion is observed in the latter period. In contrast, rapid motion of the ventricular wall is observed in the rapid filling and atrial contraction periods. In our study, Method P was designed to perform image reconstruction during the slow filling period, avoiding the atrial contraction period. As described previously, the diastolic period shortens with increasing HR, particularly the slow filling period, as reported by cardiac ultrasound observation. Therefore, in cases with lower HR, the phase determined by Method P contains not only the slow filling period but also the preceding rapid filling period. This is probably the main reason why Method P cannot create good image quality in cases with higher HR.

The isovolumic relaxation period in early diastole and the reduced ejection period in late systole are usually considered to be associated with less motion of the ventricle, similar to the slow filling period.17 Systole does not shorten significantly even with increasing HR. The reduced ejection period is also not significantly short in cases with higher HR. As described previously, the slow filling period strongly contributes to the large reduction in the diastolic period in cases with higher HR; hence, the other 3 cardiac periods in the diastolic phase are considered to shorten slightly, despite the elevation of HR. Therefore, even in cases with higher HR, the ejection period and the following isovolumic relaxation period are sufficiently long, and as a result, the reconstruction phase that contains these periods can provide better quality images. In our study, Method Tm yielded the greatest number of assessable vessels with HR >65 beats/min, and this may be attributed to the image reconstruction phase being contained within these 2 cardiac periods in most cases. The reduced ejection and isovolumic relaxation periods do not decrease significantly despite the change in HR. However, in comparison with the duration of the slow filling period in cases with lower HR, the duration of these periods in the cases with higher HR is not sufficient long. Because the temporal resolution varied from
50 ms to 250 ms, even if the reconstruction phase determined by Method Tm could correspond precisely with the reduced ejection and isovolemic relaxation periods, they inherently would contain the rapid filling period or the contraction period in cases with large temporal resolutions. In this study, we adopted a multi-segmental reconstruction technique for the image reconstruction. In this reconstruction technique, it is generally acknowledged that temporal resolution changes in a complex manner as the HR or helical pitch changes. Moreover, variation in HR has a great impact on temporal resolution. Therefore, it is very difficult to analyze the correlation between temporal resolution and image quality. However, when the HR is strictly 80 beats/min, temporal resolution theoretically becomes 250 ms. In this study, when the average HR was approximately 80 beats/min, poor quality images were obtained. We consider that a large temporal resolution is one of the main causes of poor image quality achieved with Method Tm in some cases with higher HR. Our result in which the best scores did not change remarkably, despite changes in the average HR by using methods designed for the late systolic period, indicates that image quality in the late systolic period can be improved in cases with a high HR if the temporal resolution of the CT scanner is reduced in the future.

Methods RR70 and RR80 produced an image quality that was worse than that produced by Method P in our study (Table 2), which was attributable to the fluctuation in the patients’ HR during data acquisition. Actually, in our study, the average PP-R interval was almost equal, despite the elevation of HR, and image quality achieved with the absolute reconstruction method in the mid-diastolic period did not change so much, despite the large variation in HR during data acquisition, as compared with the relative reconstruction methods used in the mid-diastolic period.

Sato et al. previously reported a similar result in cases with lower HR. They reported that the image reconstruction phase determined by Method P could consistently avoid the atrial contraction period in each cardiac cycle and could provide much better image quality than the method in which the beginning of the image reconstruction phase was positioned at the mid-peak of the RR intervals of the cardiac cycle.10,20

As previously described, the point at which the reduced ejection period changes into the isovolemic relaxation period is supposed to be near the end point of the T wave. The ventricular movement is expected to be larger at the beginning of the rapid filling period than at the end of the contraction period. Therefore, we presumed that the center of the image reconstruction phase should be positioned antegrade before the end of the T wave in order to contain both the reduced ejection period and the isovolemic relaxation period, which generally means less motion of the ventricle, and avoid the rapid filling period. Based on this hypothesis, the center of reconstruction phases in the present study was positioned on the peak of the T wave, at the midpoint of the descending curve of the T wave, and at the end of the T wave.

The absolute reconstruction methods produced better quality images than the relative reconstruction methods in the late systolic period in most cases. The proportions of the R-Tp, R-Tm, and R-Te intervals to RR interval varied significantly in the group with HR >65 beats/min, which indicates that the image reconstruction phase determined by the relative reconstruction methods may correspond to different cardiac cycles and is probably the reason why Method RR40 is inferior to Method Tm. However, in the late systolic period, the superiority of the absolute reconstruction methods was not demonstrated in cases with large variation in HR during data acquisition, as compared with the relative reconstruction methods, although the average R-Te interval decreased slightly despite the elevation of HR. These results indicate that the absolute reconstruction method in the late systolic period could not contain these 2 phases in every cardiac cycle during scanning in some cases with large variation in HR, and it is not sufficient for prediction of the late systolic period to rely on the length of the R-Te interval without considering the configuration of the T-wave. Actually, the interval between the Tp and Te showed a marked variation from 50 ms to 120 ms, and it was impossible to perform theoretical analysis. Further examination is necessary to evaluate the period in late systole that is suitable for obtaining sufficient image quality in patients with higher HR.

Study Limitation
Analysis using curved multi-planner reformation technique was not available on our workstation. Therefore, we could not accurately measure the intra-luminal volume of the coronary arteries in order to investigate whether or not the coronary arteries actually collapse in the late systolic period and whether this collapse has a great influence on the analysis of the degree of stenosis in the coronary arteries.

Conclusion
The best quality images were obtained when the end of the image reconstruction phase was positioned at the peak of the P wave in patients with HR <65 beats/min. In some patients with HR >65 beats/min the optimal image reconstruction phases were obtained when the image reconstruction phase was centered at the mid-peak of the descending curve of the T wave. Therefore, if HR is naturally high and pre-medication with β-blocker is contraindicated or very difficult, image reconstruction in late systole is worth performing. However, even image reconstruction in the late systolic period is not adequate in cases with large temporal resolution. It is recommended to try to decrease the HR of patients before data acquisition by whatever means possible, such as taking a deep breath to increase circulating blood volume, and perform data acquisition when the HR is <65 beats/min.

References


