Applicability of ECG-Gated Multislice Helical CT to Patients With Atrial Fibrillation

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Background Multislice computed tomography coronary angiography (CTCA) is reconstructed by ECG gating and consequently it is difficult to obtain coronary artery images from patients with arrhythmias, such as atrial fibrillation (AF), by the conventional method.

Methods and Results Eleven patients with AF (9 males, 2 females; mean age: 62.5 years) underwent CTCA using a slice thickness of 0.5 mm, gantry rotation of 0.4 or 0.5 s/rot and pitch of 3.2–4.0. A segmented reconstruction method was used to construct CTCA images at the conventional relative 70–75% (mid-diastolic phase) and 30–35% (end-systolic phase) of the R-R interval and furthermore, the absolute mid-diastolic phase and end-systolic phase from the R wave. Three investigators, who were unaware of the coronary angiography results, independently evaluated the curved multiplanar reconstruction (MPR) images. In both the relative and absolute phase reconstruction, there were motion artifacts in the mid-diastolic than in the end-systolic phase. The absolute phase images had less motion artifacts than the conventional relative phase images. Optimal curved MPR images were obtained in the absolute end-systolic phase. The quality and motion artifacts of those optimal images from AF patients were similar to those from patients in sinus rhythm.

Conclusion The absolute end-systolic phase is the best time to get optimal CTCA images in AF patients.

Key Words: Absolute end-systolic phase; Atrial fibrillation; Coronary angiography; Multislice helical CT

The recent development of ECG-gated multislice computed tomography (MSCT)-1-5 has made it possible to visualize both the coronary arteries6-8 and plaque9,10 However, this method still suffers from a number of limitations. Specifically, it can be difficult to evaluate coronary artery stenosis. In patients with severe tachycardia11 or extensive calcification of the coronary artery walls, it is difficult to depict the vascular lumen12 and in patients with arrhythmia, visualization of the coronary arteries is difficult. Atrial fibrillation (AF), which is a frequently observed arrhythmia, is more common with advancing age and is said to have a prevalence rate of approximately 10% in people aged 80 years or older.13 Moreover, there is increasing concern regarding this arrhythmia because the number of elderly patients is increasing every year.13

With the conventional ECG-gated reconstruction method, it is recommended that reconstruction be performed at around 70–75% of the R-R interval, which corresponds to the slow-filling phase in which cardiac motion is slowest. This method is effective for the examination of patients with sinus rhythm (SR), but in patients with AF, the R-R interval varies in each cardiac cycle. The degree of variation corresponds to the length of the slow-filling phase in almost all cases, while the length of both the ejection phase and the rapid filling phase remains relatively constant.14 Therefore, the reconstruction at around 70–75% of the R-R interval is not suitable for the examination of patients with AF. Moreover, at end-systole, cardiac motion reverses from contraction to expansion, and is therefore relatively small near end-systole (approximately ±50 ms). We have developed the “end-systolic absolute phase reconstruction method” in which these factors are taken into consideration in order to determine the absolute time between the R wave of the ECG and end-systole and in which reconstruction is performed during this absolute end-systolic phase. We used this method to examine the patients with AF in order to evaluate its clinical applicability.

Methods

Subjects The subjects were 11 patients with AF (9 men, 2 women; mean age, 66.5±8.1 years) who underwent ECG-gated MSCT studies during the period from May 2000 to February 2004 (Table 1). Six of them had been taking β-blockers for a long time to control their heart rate and the other 5 patients were given β-blocker at 2 h prior to the MSCT scan to reduce their heart rate. Five patients underwent conventional coronary angiography (CAG), which was compared with the MSCT findings. As control subjects, we enrolled 89 patients with SR (68 men, 21 women; mean age, 63.1±11.3 years) who underwent ECG-gated MSCT studies from March 2001 to September 2002. They were also given β-blocker 2 h before the MSCT examination. Four subjects who could not keep breathhold
were excluded, leaving a total control group of 85 patients with SR.

**Computed Tomography (CT) System**

The CT scanner employed was a 16-slice MSCT scanner (Aquilion 16 system, Toshiba Medical Systems Corporation, Japan) equipped with an ECG synchronization unit, and 16-slice simultaneous scanning was performed with a slice thickness of 0.5 mm. Using a wireless 3-point electrode monitor (Fukuda Electron, Japan), images were acquired by helical scanning with simultaneous recording of the ECG signal.

**Scanning Method**

The gantry rotation speed was either 0.4 or 0.5 s/rot, whichever provided the highest temporal resolution. In order to permit the entire heart to be scanned during a single breath-hold, the helical pitch was set at the time of...
scanning so that scanning could be completed within 30s and the highest possible temporal resolution was obtained.

In order to minimize the severe artifacts that can be generated by the flow of high-concentration contrast medium into the right atrium from the superior vena cava, the scanning direction was from the feet to the head.

**Contrast Enhancement Method**

A contrast medium injector was used to administer approximately 100ml of nonionic iodinated contrast medium via the left antecubital vein by 2-speed injection method (first injection: 60ml injected at a rate of 3.6ml/s, second injection: 40ml injected at a rate of 1.8ml/s). Scanning was started at the optimal timing by confirming in real time that the contrast medium had reached the left ventricle.

**Reconstruction Method**

We used an ECG-gated segmented reconstruction method for MSCT to produce 3-dimensional (D) images and curved multiplanar reconstruction (MPR) images.

**Patients With SR** Reconstruction was performed in the mid-diastolic phase (absolute time from R wave) exhibiting minimal cardiac motion at which coronary artery movement was stopped and the mitral valve was clearly depicted.

**Patients With AF** Four methods were used for reconstruction (Fig 1).

**Mid-Diastole Relative Phase Reconstruction Method** Reconstruction was performed at 50ms to 40ms before and after the time phase 70–75% from the R wave in each R-R interval.

**Mid-Diastole Absolute Phase Reconstruction Method** Reconstruction was performed at the absolute time (approximately ±50ms) set approximately 650ms from the R wave in each patient.

**End-Systole Relative Phase Reconstruction Method** Reconstruction was performed 50ms to 40ms before and after the time phase 30–40% from the R wave in each R-R interval.

Fig 2. Visualization methods and cardiac phases for reconstructed images (3-dimensional images). (A) End-systolic image obtained using the image selection method based on the relative phase. (B) Mid-diastolic image obtained using the image selection method based on the absolute phase. (C) End-systolic image obtained using the image selection method based on the absolute phase. (D) Mid-diastolic image obtained using the image selection method based on the absolute phase. Compared with the end-systolic images, the mid-diastolic images contain many artifacts and are not continuous. In addition, the images reconstructed using the conventional image selection method based on the relative phase (%) at end-systole show more artifacts and poor continuity compared with the images reconstructed using the image selection method based on the absolute phase (ms). Therefore, end-systolic images based on the absolute phase are judged to have the highest image quality.
Fig 3. Curved multiplanar reconstruction (MPR) images of a 73-year-old man with atrial fibrillation, old myocardial infarction, and coronary artery bypass grafting. Satisfactory images with good continuity are obtained by the absolute end-systolic phase reconstruction. (A) Curved MPR image showing the anatomy from the main left coronary artery to the left anterior descending branch. Total occlusion of the main segment (#5) of the left coronary artery and many lesions of calcification in the left anterior descending branch are seen. (B) Curved MPR image of the right coronary artery. Many lesions of calcification are seen in the right coronary artery. (C) Curved MPR image showing the anatomy from the main left coronary artery to the left circumflex branch. Total occlusion of the main segment (#5) of the left coronary artery and many lesions of calcification in the left circumflex branch are seen. (D) Curved MPR image showing the anatomy from the coronary artery bypass graft (great saphenous vein) to the left anterior descending branch. The anastomoses of the coronary artery bypass graft, the presence of soft plaque, and stenosis in that area are seen.

Fig 4. Comparison of the results of visual evaluation with regard to the continuity of curved multiplanar reconstruction images between absolute end-systolic phase computed tomography coronary angiography (CTCA) in patients with atrial fibrillation and absolute mid-diastolic phase CTCA in patients with sinus rhythm. Af, atrial fibrillation; RCA, right coronary artery; LAD, left anterior descending; LCX, left circumflex.

End-Systole Absolute Phase Reconstruction Method
Reconstruction was performed at the absolute time (approximately ±50 ms) set approximately 350 ms from the R wave in each patient.

Evaluation of Image Quality
The images were visually evaluated by 3 investigators who were unaware of the results of CAG. The continuity of the coronary arteries (right coronary artery (RCA), left anterior descending branch (LAD), and left circumflex branch (LCX)) in the curved MPR images was graded using a 4-grade scale: 3 (excellent) no discontinuities in the coronary artery walls; 2 (good) 1 or 2 discontinuities of 1 mm or more; 1 (fair) 3 to 5 discontinuities of 1 mm or more; 0 (poor) 6 or more discontinuities of 1 mm or more and evaluation is almost impossible. The continuity score
Table 2 Comparison of Coronary Stenosis Detection Between CTCA and CAG in Patients With Atrial Fibrillation

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CTCA, computed tomography coronary angiography; CAG, coronary angiography.

was determined by the mean of scores for each of the coronary artery on patient with AF and SR respectively.

Statistical Analysis

Continuity scores were expressed as mean ± SD. Statistical analysis was conducted using the unpaired t-test for analysis of significance between the different values. Statistical significance was established at values of p<0.05.

Results

Compared with the end-systolic images, the mid-diastolic images contained many artifacts and were not continuous. In addition, at both end-systole and mid-diastole, images obtained using the image selection method based on the relative phase contained more severe artifacts and showed poorer continuity than those obtained using the image selection method based on the absolute phase (ms). Each continuity score was 0±0 (n=11) in the mid-diastolic relative phase, 0.7±0.9 (n=11) in the mid-diastolic absolute phase, 0.2±0.4 (n=11) in the end-systolic relative phase, and 2.2±0.7 (n=11) in the end-systolic absolute phase in AF patients. Therefore, the end-diastolic images from the absolute phase showed the best continuity and highest image quality for the RCA, LAD, and LCX (Fig 2). For patients with AF of 60 beats/min or less, the images obtained using the ECG-gated half reconstruction method included more severe artifacts and showed poorer continuity than those obtained using the ECG-gated segmented reconstruction method. When the generation of curved MPR images was attempted at end-systole, satisfactory images with excellent continuity were obtained, permitting visualization of coronary artery stenosis or occlusion, the anastomoses of coronary artery bypass grafts, calcification, and soft plaque (Fig 3). Therefore, we conclude that it is possible to evaluate coronary artery stenosis even in patients with AF by using curved MPR images in addition to the 3-D images.

The continuity scores of the curved MPR images were as follows: 1.9±0.9 (n=11) for the RCA, 2.5±0.5 (n=11) for the LAD, and 2.2±0.4 (n=11) for the LCX (Fig 4). The scores for the curved MPR images of the 85 patients with SR that were generated using the conventional method (segmental reconstruction in mid-diastole) were 2.3±0.9, 2.6±0.7, and 2.5±0.7, respectively. Although the scores for the patients with AF tended to be lower than those for the patients with SR, the differences were not statistically significant and the images obtained in the 2 groups were comparable.

We tested the ability of end-systolic absolute phase CT coronary angiography imaging in AF patients to detect the coronary stenosis (>50%) in comparison with CAG. The overall sensitivity of MSCT was 85.7%, specificity was 94.4%, positive predictive value was 66.7% and negative predictive value was 98.1% (Table 2).

Discussion

In the present study, the continuity of images reconstructed at end-systole in patients with AF was superior to that of images reconstructed in mid-diastole (which are generally employed). A possible reason for this finding is that although the R-R interval varies in each cardiac cycle in patients with AF, the variation in the time from end-diastole to end-systole and in the fast-inflow phase in early diastole is small, whereas the variation in the subsequent slow-inflow phase is large. Therefore, in the slow-inflow phase, the temporal variation differs significantly from cardiac cycle to cardiac cycle. Thus, when data sets for 2–4 cardiac cycles are reconstructed, the images obtained exhibit significant discontinuity because data sets acquired at markedly different phases are used for the image reconstruction. On the other hand, at end-systole, the temporal variation in each cardiac cycle is small and therefore, even when data sets from 2–4 cardiac cycles are used for reconstruction, the images show excellent continuity. In addition, the continuity of the reconstructed images selected by the absolute phase was superior to that of the reconstructed images selected by the relative phase (conventional method) for the following reason. In patients with AF, if data sets from 2–4 cardiac cycles located at 70% (or 75%) of the R-R interval are simply used for reconstruction, even though the variation in the time from end-diastole to the fast-inflow phase is small and the variation of the R-R interval depends on the subsequent slow-inflow phase, reconstruction is performed using data sets acquired at different phases. This is also true for end-systole (30–40%). Specifically, the phase shift becomes larger as the variation in the R-R interval increases. Therefore, the method in which the absolute phase is used to extract the data sets in the range from end-diastole to end-systole (R-R interval: 0%) to the cardiac phase in which motion is slowest is superior for acquiring data sets in phases that match most closely. Note that in mid-diastole, there is a shift in cardiac phase depending on the change in the rate of expansion. Moreover, there are cardiac cycles in which contraction starts before this cardiac phase is reached. At end-systole, it is possible to acquire data sets at cardiac phases that match closely because the change in the rate of contraction in each cardiac cycle is small.

However, even when this method is employed, it is difficult to evaluate the coronary arteries in AF patients with tachycardia. In addition, we have encountered patients in whom evaluation was more difficult for the RCA than for the LCA, because the RCA moves more than the left one.

Study Limitations

The major limitations of this study are that the number of patients with AF was small, and that CAG was performed in only 5 of them. This study did not include AF patients with tachycardia, because heart rate was controlled by β-blocker.

Conclusion

Even in patients with AF, high-quality images with ex-
cellent continuity can be obtained by reconstructing end-systolic images selected by the absolute phase, making it possible to evaluate the coronary arteries with the combined use of 3-D and curved MPR images.

References