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ECG-Edit Function in Multidetector-Row Computed Tomography Coronary Arteriography for Patients With Arrhythmias

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Background  ECG-gating is necessary for cardiac computed tomography, but is not suitable for arrhythmias, so the aim of this study was to evaluate the usefulness of the ECG-edit function for this purpose.

Methods and Results  Of 1,221 patients undergoing 64-row multidetector-row computed tomography coronary angiography (coronary MDCT), 123 patients (28 atrial fibrillation (Af), 39 premature atrial contractions (PAC), 42 premature ventricular contractions (PVC), 3 PAC+PVC, 10 sinus arrhythmias (SA), and a second-degree atrioventricular block (2°AVB)) had arrhythmias necessitating the ECG-edit function. Short R-R interval was deleted and mid-diastolic phases were selected from the long R-R intervals using the “R+absolute time” method. In the present study, the reconstructed images were evaluated using a triple-grade scale A–C, representing excellent, acceptable, and unacceptable image quality. Image quality, categorized as A, B and C, respectively, was 50%, 36% and 14% for the 28 patients with Af; 56%, 36% and 8% for the 39 PAC patients, and 65%, 33% and 2% in the 42 PVC patients. None of the scans of the PAC+PVC, SA, and 2°AVB patients was ranked as C.

Conclusions  The ECG-edit function is useful for reconstructing coronary MDCT images in many arrhythmias, and provides clinically acceptable images in most cases. (Circ J 2008; 72: 1071–1078)

Key Words: Arrhythmia; Coronary artery; ECG-edit function; Multidetector-row computed tomography (MDCT)

Remarkable progress has been made in recent years in ECG-gated multidetector-row computed tomography (MDCT), making it possible to accurately define the extent of coronary artery stenosis and calcification, and address the composition of atherosclerotic plaque in some cases. Although MDCT angiography is becoming an integral part of clinical practice, it suffers from some important drawbacks that limit its wider clinical application: (1) the radiation exposure is high for a screening test, (2) the contrast medium and its adverse effects are no different from standard invasive coronary angiography (CAG), (3) breath-holding becomes a problem in some patients, (4) it is difficult to evaluate stenosis in the presence of severe calcification or an implanted stent, and (5) it is difficult to obtain images of an acceptable quality in patients with rapid heart rate or arrhythmia. Arrhythmias are frequently observed in patients with cardiovascular disease and are commonly associated with ischemic heart disease. This imposes an unavoidable problem for coronary MDCT. In fact, up to 10% of patients undergoing coronary MDCT are found to have arrhythmias during the examination. Only a few previous studies have reported countermeasures against arrhythmias, and effective algorithms not yet developed.

In the present study, we evaluated the usefulness of the ECG-edit function in image reconstruction after coronary MDCT for use with patients with arrhythmias. We also determined how best to employ the ECG-edit function to obtain clinically acceptable images.

Methods

Patients

ECG-gated coronary MDCT examinations were performed in a total of 1,285 patients between June 2006 and March 2007. Of these, 60 patients were unable to hold their breath and 4 patients with an inappropriate scan range were excluded in order to eliminate factors other than arrhythmias that might adversely affect image quality. Therefore, 1,221 patients (687 men, 534 women) were enrolled. The average age of the patients in the study group was 66±11 years.

The presence of an irregular cardiac rhythm for which image reconstruction was required was defined as arrhythmia for this study; as such, abnormal heart rates not associated with an irregular cardiac rhythm, such as bradycardia, tachycardia, first-degree atrioventricular block, the presence of a pacemaker, complete right bundle branch block, and complete left bundle branch block, were included as regular rhythm. Therefore, 1,098 of 1,221 patients (male:female...
were classified as having normal rhythm and were excluded from analysis. ECG-edit function evaluation was performed for the remaining 123 patients (age: 70±11 years, males 74, females 49). The arrhythmias in these patients included atrial fibrillation (Af, n=28), premature atrial contractions (PAC, n=39), premature ventricular contractions (PVC, n=42), PAC+PVC (n=3), sinus arrhythmia (SA, n=10), and second-degree atrioventricular block (2°AVB, n=1).

**Imaging Protocol**

The contrast medium injection time was fixed and the injection rate and injection volume were determined according to the patient’s weight. Stellant Dual Flow (Nihon Medrad K.K., Osaka, Japan) was administered via an antecubital vein using a 3-phase injection method: contrast medium, a 50:50 mixture of contrast medium and saline solution, and then saline solution. In the MDCT scanner, the plane for the bolus-tracking method was set to the 4-chamber view, and injection was then started. After 8 s, bolus tracking was performed and scanning was started when arrival of the contrast medium in the left ventricle was visually confirmed. At the same time, a voice message instructing the patient to hold his or her breath was played back (for 3 s), a delay time of 5 s after the voice message (total 8 s) was provided to permit the variation in heart rate to decrease, and MDCT cardiac scanning was then performed from the feet to the head. The volume of contrast medium administered was 60–80 ml. Scanning was performed at a tube voltage of 120 kV (for patients <70 kg) or 135 kV (for patients ≥70 kg), a tube current of 400–600 mA, a tube rotation speed of 0.35, 0.375, 0.4, or 0.45 s/rot, a helical pitch of 8.0 to 11.2 (blood pressure: 0.125–0.175), a scan slice thickness of 0.5 mm×64 rows, an image slice thickness of 0.5 mm, and a reconstructed interval of 0.3 mm. For patients with a heart rate of 70 beats/min or higher, 25 mg of atenolol was administered orally on the night before the examination, unless contraindicated. Alternatively, 2–10 mg of propranolol was injected intravenously immediately before scanning.

**ECG-Edit Function**

In the ECG-edit function, the R wave trigger can be manually set and specified cardiac cycles can be deleted. Using this function, the optimal cardiac phase with minimal motion is selected and coronary MDCT images are reconstructed. Of the various available methods, such as R+absolute time, R–absolute time and relative phase (%R-R), to specify the cardiac phase for image reconstruction, the most suitable method was selected according to the individual case. However, generally, short R-R intervals were deleted and images were reconstructed in the mid-diastolic phases selected using the R+absolute time method. If the data were still unsuitable, end-systolic phases were selected and image reconstruction performed.

**Image Assessment Criteria**

Image assessment was conducted as shown in Fig 1 using a 3-grade semi-quantitative scale: excellent images were ranked A, when the blood vessel walls were clearly depicted in the curved planer reconstruction (CPR) image without blurring is obtained. Rank B: Acceptable. The image is acceptable, but not excellent. The CPR image shows some blurring. Axle-shaped motion artifacts are seen in the coronary artery short-axis slices (arrows). Rank C: Unacceptable. There are 1 or more segments measuring 3 mm or longer that cannot be assessed. In this case, the temporal resolution is insufficient for evaluation of the left circumflex branch because of the mismatch between the heart rate and the gantry rotation speed (arrow). RCA, right coronary artery.

**Result**

**Case Studies**

In a 70-year-old man, cardiac MDCT was performed to
identify the cause of sudden loss of consciousness (Figs 2a, b). The ECG obtained during scanning showed interpolated PVCs (R5, R9, R12, and R15). The time interval from the immediately preceding R wave to the PVC (coupling interval) was shorter than the normal R-R interval. Because these were interpolated extrasystoles, the next R wave appeared at the expected time after the PVC and the time interval from the extrasystole to the next R wave (R5 to R6, R9 to R10, and R12 to R13) was shorter than the normal R-R interval. The slow filling phase was absent in these cardiac cycles. At first, end-systolic reconstruction was performed without ECG-edit function (Fig 2a). Moderate motion artifacts were observed in segments #1 (proximal) and #2 (middle) of the right coronary artery (RCA), and image quality was rank B. Therefore, R4 to R6, R8 to R10, R11 to R13, and R14 to R16 were deleted, the remaining cardiac cycles with a slow filling phase were specified using R+720 ms, and image reconstruction was then performed (Fig 2b). As a result, acceptable (rank A) images were obtained.

A 69-year-old man with Af and rapid ventricular response, and QS pattern in leads III and aVF underwent cardiac MDCT to rule out ischemic heart disease. The patient's heart rate was 122 beats/min when he entered the CT room and was reduced to 92 beats/min after intravenous injection of 50 mg of verapamil. At first, end-systolic segmental reconstruction was performed without ECG-edit function and image quality was rank C, because there were severe motion artifacts in RCA segments #1 (proximal) and #3 (distal) and #13 (distal) in the left circumflex artery (Fig 3a). Secondly, using the ECG-edit function, cardiac cycles with short R-R intervals (700 ms or less) were excluded, long R-R intervals were selected using R–50 ms, and segmental reconstruction was performed. As a result, good images (Rank A) were obtained (Fig 3b). Because the long R-R intervals were suitably distributed, it was possible...
to reconstruct mid-diastolic images.

In a 67-year-old woman with SA (Figs 4a–c), cardiac MDCT was performed after she complained of chest pain typical for coronary artery disease. At first, the mid-diastolic image was automatically reconstructed at R+694 ms according to the “Phase Navi” software provided by Toshiba Medical Systems (Fig 4a) without the ECG-edit function. Image quality was rank C, because motion artifacts meant we could not evaluate coronary stenosis in RCA #1 (proximal) and RCA #3 (distal). Secondly, we manually set the reconstruction timing at R –240 ms without the ECG-edit function (Fig 4b), but image quality was still rank C, because motion artifacts again prevented evaluation of coronary stenosis in RCA #1 (proximal) and RCA #3 (distal). Finally, cardiac cycles with short R-R intervals were excluded using the ECG-edit function, those with relatively long R-R intervals were selected, and the diastolic reconstruction method was applied with R +800 ms (Fig 4c). As a result, acceptable images (Rank A) were obtained.

**Image Reconstruction With ECG Gating**

Image reconstruction was performed using the ECG-edit function in patients with various types of arrhythmias, and the images obtained were then evaluated. As shown in Fig 5, of the 28 patients with Af, images for 14 (50.0%) of them were classified as rank A, 10 (35.7%) as rank B, and 4 (14.3%) were rank C. Of the 39 patients with PAC, 22 (56.4%) were A, 14 (35.9%) were B, and 3 (7.7%) were rank C. Of the 42 patients with PVC, 27 (64.3%) were rank A, 14 (33.3%) were rank B, and 1 (2.4%) was rank C. Of the 3 patients with PAC+PVC, 2 (66.7%) were rank A and 1 (33.3%) was rank B. Of the 10 patients with SA, 4 (40.0%) were rank A and 6 (60.0%) were rank B. The 1 patient with 2°AVB was rank A (100%).

Rank C images in patients with Af were obtained when cardiac cycles with short R-R intervals occurred in succes-
Fig 4. Multidetector-row computed tomography coronary angiography in a 67-year-old female patient with sinus arrhythmia. Mean heart rate (HR) 65 beats/min. Scanning was performed at a tube rotation speed of 0.35 s/rot. (a) Mid-diastolic reconstruction without ECG-edit function with R+694 ms. Motion artifacts were seen in right coronary artery (RCA) #1 (proximal) and RCA #3 (distal), because of atrial kick. Image quality was rank C. (b) Mid-diastolic reconstruction without ECG-edit function with R-240 ms in the same patient. Motion artifacts were also observed in RCA #1 (proximal) and RCA #3 (distal) and image quality was rank C. (c) Mid-diastolic reconstruction with ECG-edit function with R+800 ms in the same patient. At first, short R-R less than 910 ms were deleted by the ECG-edit function, and then mid-diastolic segmental reconstruction with R+800 ms was performed. Although banding artifacts were seen, continuity was good and no motion artifacts were observed. Image quality was rank A. LAD, left anterior descending artery; LCX, left circumflex artery.
sion during scanning and image reconstruction therefore needed to be performed at end-systole. Otherwise, the amount of data would have been insufficient if an excessive number of R-R intervals were deleted. The reason for rank C images in patients with PAC+PVC was that PACs or PVCs occurred suddenly during scanning, even though arrhythmic beats had not been observed during practice breath-holding. Because scanning was performed at the standard helical pitch, the amount of data acquired was insufficient for the ECG-edit function and the images therefore needed to be reconstructed at end-systole.

Comparing the image quality for patients with regular rhythm against that for patients with arrhythmias, of the 1,098 patients with regular rhythm, 821 (74.8%) were rank A, 232 (21.1%) were rank B, and 45 (4.1%) were rank C. Of the 123 patients with arrhythmias, 70 (56.9%) were rank A, 45 (36.6%) were rank B, and 8 (6.5%) were rank C (Fig 6). A significant difference in the distribution of image ranking between the 2 groups was observed by $\chi^2$ test ($p<0.0001$). However, the ratio of rank A+B images to all images was 95.9% in the regular rhythm group and 93.4% in the arrhythmia group, which was not a significant difference.

**Discussion**

**ECG-Gated Scanning and the ECG-Edit Function**

Because of the suboptimal temporal resolution of MDCT scanners, ECG-gated scanning needs to be performed using 1 of the 2 ECG-gated scanning methods available: prospective or retrospective gating. The retrospective gating method is more commonly used in current clinical practice. Data are acquired for the entire scan time and images are then reconstructed from the data obtained in phases with minimal cardiac motion using the ECG signals that are recorded simultaneously. In patients with regular rhythm and a heart rate less than 65 beats/min, cardiac motion is minimal during the mid-diastolic phase (slow filling phase), which is therefore used for image reconstruction. However, in patients with a heart rate higher than 70 beats/min, the mid-diastolic phase becomes shorter, and end-systole is considered the optimal phase for image reconstruction. If arrhythmias occur during scanning, the same cardiac phases cannot simply be selected using the information provided by the ECG. To address this issue, an ECG-editing function is used. In the present study of a group of 1,285 consecutive patients,
ECG editing was required in 123 or 10% of patients. The largest groups were the PVC and PAC groups, followed by the Af group. The use of the ECG-edit function allowed clinically useful coronary MDCT images to be obtained in more than 93% of patients, regardless of the type of arrhythmia.

**Types of Arrhythmia and the ECG-Edit Function**

Interpolated or compensatory PVCs are commonly encountered during CT angiography. Because the next R wave in interpolated extrasystoles appears at the expected time after the PVC and the time interval from the extrasystole to the next R wave is shorter than the normal R-R interval, the slow filling phase is absent in those cardiac cycles. Therefore, the remaining cardiac cycles with a slow filling phase are specified using R+absolute R-R, and image reconstruction is performed. In compensatory PVCs, long compensatory phases occur after the extrasystole. For compensatory PVCs with bigeminy, it is possible to reconstruct images using the long compensatory phases. However, the amount of data may be insufficient if the cardiac cycles used for reconstruction do not follow a regular pattern. Based on our experience, the amount of data will be insufficient if consecutive data for 2 s or more is deleted. In such cases, image reconstruction must be performed using the data acquired at end-systole without using the ECG-edit function and often leads to less than optimum image quality.

From a study of patients with Af, using ECG, phonocardiogram, and M-mode echocardiography in over 300 cardiac cycles, it was reported that variation in the R-R intervals occurs prominently (77±200 ms), but not in systole (R-S2: 377±19 ms) or the rapid filling phase (163±26 ms). The variation in the slow filling phase is similar to the R-R interval (245±210 ms). As such, the slow filling phase becomes longer in parallel with the increase in the R-R interval and systole and the rapid filling phase do not show significant changes. Based on that report, coronary MDCT was performed in patients with Af using a 16-slice MDCT scanner without the benefit of the ECG-edit function. The images were reconstructed at end-systole and at mid-diastole using the relative-phase method (%R-R) and the absolute-phase method (R+absolute time) using data for the entire cardiac cycle and then compared with the reconstructed images. Those authors concluded that the optimal phase with minimal movement was end-systole. A subsequent study agreed with those findings and reported that the best image quality was obtained by reconstructing the data obtained at end-systole (R+absolute time). Cademartiri et al reported that the ECG-edit function is particularly useful in patients with mild arrhythmias. They performed CAG in patients with extrasystoles (heart rate <70 beats/min), bradycardia with Af, R wave mistriggering, and arrhythmias (heart rate <40 beats/min). However, the details are unclear for Af because no case was presented.

In general, image quality at end-systole is inferior to that at mid-diastole, and if possible, images should be reconstructed at mid-diastole, even in patients with Af. As illustrated by case 2 (Figs 3a,b), it is possible to reconstruct images at mid-diastole in most cases using the ECG-edit function, even in patients with Af with rapid ventricular response. Cardiac cycles with short R-R intervals are deleted, those with long R-R intervals are selected, and the mid-diastolic phase is specified as R+absolute time or R−absolute time (just before the next R wave), not as 75% of R-R. In patients with Af, P waves are absent, there is no effective atrial contraction, and the slow filling phase continues to immediately before the next R wave. It is therefore possible to specify the phase for image reconstruction as the phase immediately before the next R wave. In patients with regular rhythm (with P waves) and a heart rate of 70 beats/min (R-R interval: 857 ms), the optimal cardiac phase with minimal motion is normally end-systole, but the mid-diastolic phase is often best in patients with Af, even at a heart rate of 80 beats/min (R-R interval: 750 ms). In this situation, however, the long R-R intervals must follow a regular pattern to ensure that a sufficient amount of data is obtained. To avoid the problem of insufficient data, it is necessary to set the helical pitch thinner than that used for routine scanning. In addition, the use of the ECG-edit function may frequently cause adjacent data to be lost, resulting in lower temporal resolution. It is therefore necessary to select the fastest gantry rotation speed.

SA, which is generally of minimal clinical significance, is one of the most difficult arrhythmias for image reconstruction by MDCT. Because the R-R interval varies and the presence of a P wave results in atrial contraction, the data up to immediately before the next R wave cannot be used for image reconstruction, unlike for Af. In that situation, relatively short R-R intervals are deleted, relatively long R-R intervals of similar length are selected, and the data up to immediately before the next P wave is acquired using R+ absolute time. Acceptable images in the mid-diastolic phase can then be reconstructed.

**Study Limitations**

In this study, image quality scoring might have been influenced by a subjective bias, even if multiple experienced cardiologists and radiological technicians carefully assessed coronary MDCT. The diagnostic accuracy of the edited coronary MDCT compared with invasive CAG was not evaluated. Although almost patients with arrhythmias underwent coronary MDCT for evaluation of coronary artery disease in this study, only a small number of patients with arrhythmias underwent invasive CAG because of negative findings on coronary MDCT. Further investigation is necessary to evaluate the diagnostic accuracy of edited coronary MDCT compared with invasive CAG. Occasionally in image reconstruction using ECG-edit function, the amount of data may be insufficient. To avoid this problem, the helical pitch needs to be set thinner than that used routinely. If scanning is performed with a thinner pitch and the amount of data is insufficient after image reconstruction, images should be reconstructed at the end-systolic phase. However, if ECG dose modulation is used, the S/N of the end-systolic images is degraded because of insufficient dose. Taking these issues into consideration, we performed scanning without using ECG dose modulation. As a result, the exposure dose was generally higher in patients with arrhythmias than in patients with regular rhythm. To overcome this problem, the development of CT scanners with higher temporal resolution that also support prospective gating is necessary.

**Conclusions**

The ECG-edit function is useful for reconstruction of coronary MDCT images in many patients with arrhythmias, providing clinically acceptable images in more than 93% of instances.
References


