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# Reduced artifacts and improved diagnostic value of 640-slice computed tomography in patients with cardiac pacemakers

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## Abstract

**Objective:** The aim of this study was to compare the feasibility of 640-slice with 64-slice computed tomography (CT) coronary angiography for diagnosing coronary lesions in patients with pacemakers.

**Methods:** Forty-five and 50 patients with pacemakers and with suspected or known coronary artery disease underwent 64-slice (64 group) and 640-slice (640 group) CT scans, respectively. All segments of the vessels were evaluated according to the 15-segment model recommended by the American Heart Association.

**Results:** The incidence of moderate or severe artifacts was significantly lower (7.27% vs. 32.17%) and the diagnosable rate for coronary lesions was higher (98.91% vs. 94.19%) in the 640 compared with the 64 group. In the 64 group, the incidence of artifacts in patients with a heart rate >65 bpm (20.98%) was higher than in those with a heart rate <65 bpm (15.67%), although the difference was not significant, while the incidence of artifacts was significantly higher in patients with heart arrhythmia (21.40%) compared with in those with normal heart rhythm (15.09%).

**Conclusions:** Among patients with pacemakers and a higher heart rate or heart arrhythmia, 640-slice CT may be more effective than 64-slice CT for diagnosing coronary lesions, by reducing moderate and severe artifacts.

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## Introduction

Coronary artery disease (CAD), also known as ischemic heart disease, is a type of cardiomyopathy (atherosclerosis or dynamic vasospasm) caused by myocardial ischemia and hypoxia or myocardial necrosis.[1] CAD is a common disease, particularly among patients aged between 40 and 50 years. Coronary angiography (CAG) can reveal the location, extent, severity, and coronary collateral circulation in patients with coronary artery stenosis or obstructive lesions, and has been considered as the gold standard for diagnosing coronary heart disease.[2,3] However, although CAG can assess vascular stenosis accurately, it cannot determine vascular wall lesions or show the size and character of the lesion accurately.[4] In addition, CAG is a traumatic examination technique that may cause arrhythmia in approximately 3% of patients, leading to acute myocardial infarction, arterial embolism, or other serious complications.[5] Magnetic resonance coronary angiography of the proximal sections of the coronary artery can provide a reliable assessment of coronary artery stenosis and can be used to screen the coronary artery near the middle of the stenosis.[6] However, the resolution of this technique is not high, and its application to distal sections and small branches of the coronary artery is therefore limited.[7] Moreover, magnetic resonance imaging has some contraindications, for example in patients who suffer from claustrophobia, or have an intracranial aneurysm clip, or other metal implants, pacemakers, or artificial valves.[8]

The recent rapid development of arrhythmia interventions in China has contributed to an increasing clinical use of cardiac pacemakers, implantable cardioverter defibrillators, and cardiac resynchronization therapy. Researchers showed that approximately 35% of patients with cardiac pacemaker implants had been diagnosed with CAD.[9,10] Approximately 75% of patients with CAD were above 60 years old, and the risk was higher among this age group.[9,10] It is therefore necessary to develop effective noninvasive arteriography designed for patients with coronary heart disease and cardiac pacemakers.

The most common indications for using multi-slice computed tomography (CT) in patients with cardiac pacemakers are suspicious myocardial ischemic disease (coronary heart disease) and electrode perforation.[9,10] However, prior to the advent of 64-slice CT, CT coronary angiography could not be performed extensively in patients with pacemakers because of undetectable electrocardiogram (ECG) signaling.[10] Although 64-slice CT has improved the use of noninvasive coronary angiography in patients with pacemaker implants, metallic artifacts and consequent degradation of image quality still have a significant impact on the diagnostic value of this technique.[9,11]

Equipment and inspection technologies for multi-slice spiral CT (MSCT) have continued to develop over recent years, leading to substantial improvements in time and spatial resolution. MSCT coronary angiography is currently recognized as a preferred noninvasive method for the diagnosis of coronary heart disease. The aim of this study was to explore the feasibility of a new generation of 640-slice dynamic volume CT coronary angiography for the diagnosis of coronary artery lesions in patients with cardiac pacemaker implants, and to compare the advantages of 640-slice with 64-slice CT.

## Methods

This study was approved by the Ethics Committee of The First Affiliated Hospital of Wenzhou Medical University. All patients enrolled in the study provided written informed consent.

### *Patients*

A total of 95 patients with pacemakers from multiple centers were enrolled in this study. There were 49 men and 46 women, mean age 65 ± 11 years (range 49 to 87 years), with a mean body mass index (BMI) of 23.39 (range 19.43 to 30.81). All patients were clinically diagnosed with definite or possible coronary heart disease. Forty-five and 50 patients underwent 64-slice (LightSpeed 64 VCT, GE Healthcare, Piscataway, NJ, USA) (64 group) and 640-slice (Aquilion ONE, Toshiba, Otawara, Japan) (640 group) CT coronary scans, respectively. No patients had severe renal insufficiency or a history of iodine allergy, and none were taking metoprolol to control their heart rate. Patients in both groups were divided into low and high heart rate groups, with 65 beats per minute (bpm) as the cut-off point according to the recommended collection scheme, because of the time slice resolution (175 ms) limitation of the device. Patients were also divided into normal pacing and arrhythmia groups, according to the pacing ECG.

### *Image acquisition*

Patients underwent breath-hold training before scanning. Scanning covered the area from the trachea bifurcation to the diaphragmatic surface of the heart.

For 64-slice CT coronary scanning, a retrospective ECG-gated spiral scan was performed using the GE LightSpeed 64 VCT. Contrast agent (20 mL iodopamine, 370 mgI/mL) was injected via the elbow vein at a flow rate of 5.0 mL/s using a dual-tube high-pressure syringe. Dynamic scanning of the same layer was then performed to acquire a time-density curve for the ascending aortic root layer and to calculate the optimal scan delay time. Subsequently, 60 to 70 mL of contrast agent and 30 mL of saline were injected at the same flow rate and the scan was performed after an optimal delay. The scan parameters were 129 kV, 750 mA, and a scan time of 5. 6 ± 1.0 s.

For 640-slice CT coronary scan, a modulated cardiac CTA/CFA dynamic volume scan was performed using an Aquilion ONE. The scan was triggered using a prospective ECG gating technique and the automatic Sure Start contrast agent tracing technique. The trigger point was scheduled to scan the descending aorta at the central level of the scan, using a trigger threshold of >250 HU or individualized manual triggering. The scanning parameters were 120 kV, tube current 300 to 550 mA, rack speed 350 ms/round, and scanning time 0.35 to 2.476 s. The acquisition phase for patients with a heart rate <65 bpm was 70% to 80% of the R – R interval, and one beat was collected, that for patients with a heart rate of 65 to 79 bpm was 30% to 80% of the R – R interval, and two beats were collected, and that for patients with a heart rate ≥80 bpm was 30% to 80% of the

R – R interval, and three or four beats were collected. A volume of 45 to 60 mL of contrast agent (iodopamine, 370 mgI/mL) was injected into the antecubital vein at a flow rate of 4.0 to 5.5 mL/s, using a high-pressure syringe (Stellant; Medrad, Indianola, PA, USA), followed by the injection of 30 mL of physiological saline at the same flow rate.

### Image processing

Images were post-processed using a Vitrea3 workstation (Vitrea; Vital Images Inc., Minnetonka, MN, USA) for reorganization. The recombination methods included maximum density projection, volume reproduction, multiplanar recombination, and surface recombination.

### Image evaluation

The image quality was assessed independently by two experienced professional physicians, and consensus was reached by discussion between two technicians. The images were analyzed with reference to the 15-segment method recommended by the American Heart Association, and the 15 segments comprise proximal, middle and distal segments of the right coronary artery (S1 to S4), left main coronary artery (S5), proximal, middle, and distal segments of the left anterior descending coronary artery (S6 to S8), the first and second diagonal branch (S9, S10), left circumflex branch proximal segment (S11), obtuse marginal branch (S12), the distal segment of the left circumflex artery (S13), posterior branch of the left ventricle (S14), and the left main coronary artery (S15). Coronary artery segments with a diameter $<1.5$ mm were not assessed. Image quality scores for the coronary artery were divided into four grades: 1 (3 points), blood vessels with good and clear edges and with no artifacts; 2 (2 points), blood vessels with continuous and blurred edges and with mild artifacts; 3 (1 point), blood vessels with continuous edges and moderate artifacts but suitable for diagnosis; and 4 (0 points), serious artifacts such that the blood vessels cannot be diagnosed. Artifacts affecting the coronary arteries, including motion artifacts, step artifacts, metal artifacts, and data loss, were scored and classified as mild or moderate/severe.

### Statistical analysis

Quantitative data were expressed as mean $\pm$ standard deviation and categorical data were expressed as frequencies and percentages. The effects of age, sex, BMI, heart rate, and heart rhythm on image quality were evaluated by $t$-tests and $\chi^2$ tests. A value of $P < 0.05$ was considered significant.

## Results

### Information and scanning parameters

Background information and scanning parameters for the patients receiving 64-slice or 640-slice CT are shown in Table 1. There were no significant differences in terms of age, sex, BMI, heart rate, or heart rhythm between the two groups.

### Image artifacts

Artifacts affecting the image quality of coronary arteries include motion artifacts, metal artifacts, stair-stepped artifacts, and missing data-induced artifacts. Pacemaker electrode-induced metal artifacts can degrade the image quality scores, and severe metal artifacts can make the images unevaluable. Metal artifacts induced by pacemaker electrodes may affect the image quality of the right coronary (S1, S2), distal (S3), posterior descending (S4), and left anterior descending branch (S8), especially in segments S1 and S2. Figure 1a and Figure 1b show stair-stepped artifacts and

**Table 1.** Information and characteristics of patients.

| | 64 (n = 45) | 640 (n = 50) | *P* |
|---|---|---|---|
| Age | 73.58±11.29 | 73.46±11.52 | 0.959 |
| Sex | | | 0.931 |
| Male | 23 | 26 | |
| Female | 22 | 24 | |
| BMI | 22.4±4.76 | 22.6±4.95 | 0.842 |
| Heart rate (bpm) | | | 0.879 |
| ≥65 | 20 | 23 | |
| <65 | 25 | 27 | |
| Heart rhythm | | | 0.897 |
| Normal | 24 | 26 | |
| Arrhythmia | 21 | 24 | |

BMI: body mass index, bpm: beats per minute.
Values given as mean ± standard deviation.

missing data-induced artifacts on 64-slice CT coronary artery imaging in a patient with cardiac pacemaker implantation. Figure 2a shows reduced image quality of S2 segments on 640-slice CT coronary artery imaging in a patient with a cardiac pacemaker due to pacemaker electrode metal artifacts, but the image quality was improved after adjustment during reconstruction (Figure 2b).

## *Image quality and score*

Totals of 637 and 735 segments from the 64 and 640 groups, respectively, were available for analysis, and 38 and 15 segments were invisible or had an initial diameter

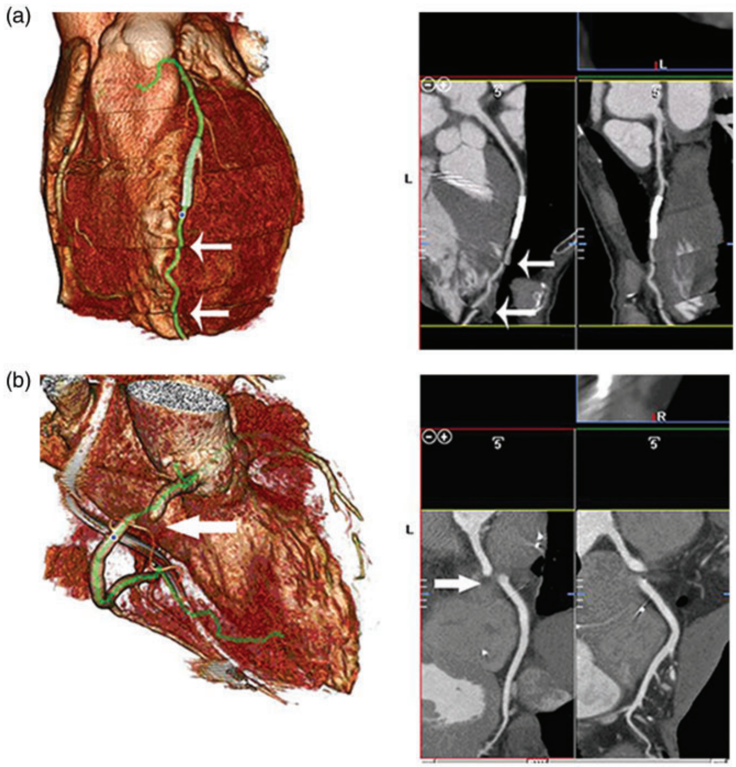


**Figure 1.** Artifacts affect quality of 64-slice CT images. (a) Stair-stepped artifacts (arrows) in coronary artery imaging in patient with a cardiac pacemaker. (b) Missing data-induced artifacts (arrows) in coronary artery imaging in patient with a cardiac pacemaker.

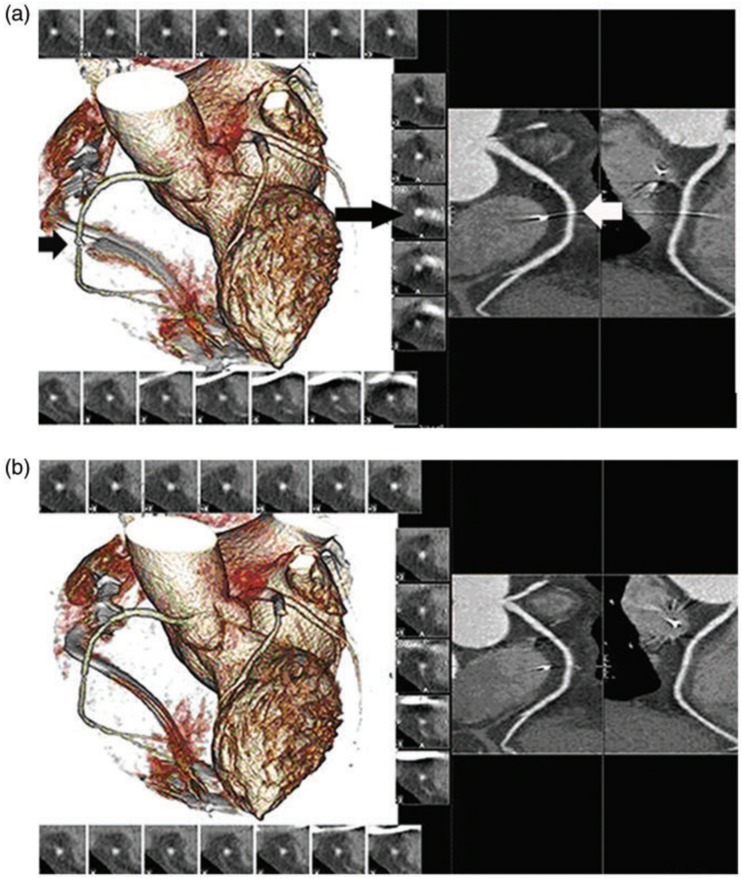

**Figure 2.** Pacemaker electrode-induced metal artifacts removed by reconstruction during 640-slice CT coronary artery imaging in patient with a cardiac pacemaker. (a) Pacemaker electrode metal artifacts (arrows) reduced the image quality of coronary artery S2 segments. (b) Reconstruction phase (ECG cycle from 80% to 72%) significantly removed artifacts.

<1.5 mm. There were significant differences in the numbers of various artifacts between the two groups (Table 2). Most coronary artery image artifacts in the 640 group were mild (92.73%, 102/110), with few moderate or severe artifacts (7.27%, 8/110). Among the eight segments with moderate or severe artifacts, three were severe metal artifacts, one was a moderate metal artifact, and four were moderate motion artifacts. In contrast, the incidence of moderate or severe artifacts was significantly higher in the 64 group (32.17%, 37/115, $P < 0.001$), comprising 20 moderate artifacts (8 metal artifacts, 12 stair-stepped artifacts, and 2 missing data-induced artifacts) and 17 severe artifacts (6 metal artifacts, 3 stair-stepped artifacts, and 8 missing data-induced artifacts).

The reconstruction phase can reduce the effect of metal artifacts in coronary segments caused by pacemaker electrodes. The segments affected by metal artifacts in the 640 group comprised 17, 16, 4, 6, and 8 in S1, S2, S3, S4, and S8, respectively. After reconstruction, the affected segments

**Table 2.** Numbers of segments with different artifacts in patients undergoing 64- and 640-slice computed tomography.

| | 64 (n = 45) | 640 (n = 50) | *P* |
|---|---|---|---|
| All segments | 637 | 735 | <0.001 |
| All segments with artifacts | 115 | 110 | 0.123 |
| Segments with mild artifacts | 78 | 102 | 0.372 |
| Segments with moderate or severe artifacts | 37 | 8 | <0.001 |
| Motion artifacts | 8 | 93 | <0.001 |
| Metal artifacts | 42 | 17 | 0.004 |
| Stair-stepped artifacts | 55 | 0 | <0.001 |
| Missing data-induced artifacts | 10 | 0 | <0.001 |

were reduced to five, six, two, three, and one case(s), respectively. The image quality scored also increased in segments without complete removal of metal artifacts, with 13 of 17 improving to grade 2. The final image quality scores in the 64 and 640 groups are listed in Table 3. There were no significant differences in the numbers of grade 1 or grade 2 artifacts (both diagnosable) between the two groups, but the 640 group had significantly fewer grade 3 and grade 4 artifacts (not diagnosable) (both $P < 0.001$), but significantly more grade 1 + grade 2 artifacts ($P < 0.001$). In terms of diagnostic ratios, 640-slice CT was more effective than 64-slice CT (98.91% vs. 94.19%).

**Table 3.** Numbers of segments with different image scores in patients undergoing 64- and 640-slice computed tomography.

| | 64 (n = 45) | 640 (n = 50) | *P* |
|---|---|---|---|
| All segments | 637 | 735 | <0.001 |
| Grade 1 | 522 | 625 | 0.123 |
| Grade 2 | 78 | 102 | 0.372 |
| Grade 3 | 20 | 5 | <0.001 |
| Grade 4 | 17 | 3 | <0.001 |
| Grade 1 + 2 | 600 | 727 | <0.001 |

## *Factors affecting image artifacts and quality*

The effects of age, sex, BMI, heart rate, and heart rhythm on image artifacts are shown in Table 4. There were no significant differences in the incidences of image artifacts in either group in relation to age, sex, BMI, or heart rate. However, the incidence of artifacts in the 64 group was higher in patients with a heart rate >65 bpm (20.98%, 60/286) than in those with a heart rate <65 bpm (15.67%, 55/351), though the difference was not significant. As expected, heart rhythm had a significant effect on image artifacts, and the incidence of artifacts was significantly higher in patients with heart arrhythmia (21.40%, 64/299) than in those with normal heart rhythm (15.09%, 51/338) ($P = 0.039$) in the 64 group. Although similar high image artifact incidences were observed in patients with a heart rate >65 bpm and with heart arrhythmia in the 640 group, the differences were not significant.

We further analyzed the impacts of heart rate and heart rhythm on the occurrence of moderate and severe image artifacts. Higher heart rate and the presence of arrhythmias increased the proportion of moderate and severe artifacts compared with all artifacts in the 64 group, as shown in Table 5 ($P = 0.083$ vs. $P = 0.067$; $P = 0.039$ vs. $P = 0.010$).

## Discussion

This study aimed to provide up-to-date application data for 640-slice CT in patients

**Table 4.** Effects of age, sex, body mass index, heart rate, and heart rhythm on image artifacts in all segments in patients undergoing 64- and 640-slice computed tomography.

| | 64 (n = 45) | | *P* | 640 (n = 50) | | *P* |
|---|---|---|---|---|---|---|
| Segments | 637 | 115 | | 735 | 110 | |
| Age (years) | | | 0.898 | | | 0.956 |
| ≥73 | 21 (297) | 53 | | 23 (339) | 51 | |
| <73 | 24 (340) | 62 | | 27 (396) | 59 | |
| Sex | | | 0.919 | | | 0.428 |
| Male | 23 (324) | 58 | | 26 (382) | 61 | |
| Female | 22 (313) | 57 | | 24 (353) | 49 | |
| BMI | | | 0.955 | | | 0.348 |
| ≥22 | 20 (284) | 51 | | 22 (354) | 53 | |
| <22 | 25 (353) | 64 | | 28 (381) | 57 | |
| Heart rate (bpm) | | | 0.083 | | | 0.261 |
| ≥65 | 20 (286) | 60 | | 23 (338) | 56 | |
| <65 | 25 (351) | 55 | | 27 (397) | 54 | |
| Heart rhythm | | | 0.039 | | | 0.299 |
| Normal | 24 (338) | 51 | | 26 (281) | 52 | |
| Arrhythmia | 21 (299) | 64 | | 24 (254) | 58 | |

BMI: body mass index, bpm: beats per minute. Values given as no. patients (no. segments).

**Table 5.** Impacts of heart rate and heart rhythm on moderate and severe image artifacts in patients undergoing 64- and 640-slice computed tomography.

| | 64 (n = 45) | | *P* | 640 (n = 50) | | *P* |
|---|---|---|---|---|---|---|
| Segments | 637 | 37 | | 735 | 8 | |
| Heart rate (bpm) | | | 0.067 | | | 0.346 |
| ≥65 | 20 (286) | 22 | | 23 (338) | 5 | |
| <65 | 25 (351) | 15 | | 27 (397) | 3 | |
| Heart rhythm | | | 0.010 | | | 0.116 |
| Normal | 24 (338) | 12 | | 26 (281) | 2 | |
| Arrhythmia | 21 (299) | 25 | | 24 (254) | 6 | |

Values given as no. patients (no. segments).

with cardiac pacemaker implants, and to compare the data with the results for 64-slice CT. Few studies have performed noninvasive CT coronary angiography in patients with pacemakers because of the occurrence of pacemaker electrode-induced metal artifacts, arrhythmias, and undetectable ECG signals by ECG gating.[12,13] However, technological advances in 640-slice CT image acquisition mean that CT coronary angiography can now be conducted in these patients. The current results showed that 640-slice CT significantly reduced image artifacts and increased the incidence of diagnosable images in these patients compared with 64-slice CT.

Pacemaker electrode-induced metal artifacts can degrade the image quality in coronary arteries, while severe metal artifacts can result in unevaluable images.[14–16] Pacemaker electrodes can cause complex metal artifacts, including partial volumetric effects and ray hardening artifacts.[14–16] However, 640-slice CT uses a quadrature sampling technique and an image optimization system (BOOST[30]), allowing a thinner image reconstruction interval to be applied to reduce the partial volume effect. BOOST[30] can effectively minimize pacemaker electrode-induced metal artifacts by reducing ray hardening artifacts. The current results showed that artifacts induced by pacemaker electrodes in 640-slice CT could reduce the image quality of the adjacent coronary artery S1, S2, S4, and S8 segments, especially S1 and S2 segments, in which image quality was reduced by 1 to 2 points. In addition to metal-induced artifacts, other severe artifacts can also lead to difficulty in assessing coronary artery segments because of blurred images. Previous studies reported that 3.3% to 14.7% of coronary segments were not evaluable using 64-slice CT.[9] Similarly, our results showed that 5.8% of coronary segments had moderate or severe artifacts. Although artifacts on 64-slice CT can be improved by ECG editing and phase adjustment techniques, there remains a problem with data pairing and matching of data for multi-cardiac cycles, caused by the narrow range of detectors restricting the adjustment scope, potentially resulting in a relatively high proportion of moderate and severe artifacts.[14–19] Thus 37 of the 637 segments acquired from 45 patients using 64-slice CT exhibited moderate or severe artifacts. Among patients who underwent 640-slice CT, 110 segment artifacts were identified in 735 coronary arteries from 50 patients, including three segments with severe and one with moderate metal artifacts, and four segments with moderate motion artifacts. Because 640-slice CT involves 16 cm full-heart imaging, there were no stair-stepped artifacts or missing data-induced artifacts. Furthermore, 640-slice CT adopts a cross-sectional volume scanning method and the scanning bed thus remains stationary during the data acquisition, allowing complete volume data to be obtained for each scan. Multi-sector reorganization is thus not required because of the continuous nature of the data, and the data can be merged and reconstructed more reliably. At the same time, the application of advanced cardiac reconstruction technology also minimizes the amplitudes of coronary motion and metal artifacts. In line with improvements in image artifacts, the current study showed that 640-slice CT produced a higher proportion of diagnosable images than 64-slice CT (98.91% vs. 94.19%).

Heart rate, bed movement, and helical scan splicing all affect the quality of cardiac arterial imaging using 64-slice CT.[18–21] However, 640-slice CT can completely cover all cardiac arteries with only one cycle of fixed bed scanning, thus improving the time resolution by avoiding overlapping reconstruction and multiple heartbeats, helical delusion artifacts, and inconsistent enhancement phases caused by spiral 64-slice CT scans.[18–21] In addition, ECGs are complicated in patients with permanent pacemakers, including normal pacing, pacing dysfunctions (Figure 3), and their own arrhythmias. Many patients show arrhythmias on dynamic ECG, including ventricular premature beats, atrial premature beats, atrial fibrillation, short array of atrial tachycardia, and short ventricular paroxysmal tachycardia.[14–19] However, the improved time resolution (35.0 to 175.0 ms) of 640-slice CT can greatly reduce the probability of capturing arrhythmias by ECG gating. Even in the event of frequent arrhythmias, 640-slice CT anti-arrhythmia software can reject ECGs and acquire similar cardiac cycles by a series of adjustments, ensuring relatively stable cardiac cycle acquisition in arrhythmia patients with pacemakers and allowing satisfactory image reconstruction. In the present study, the incidence of artifacts in patients with

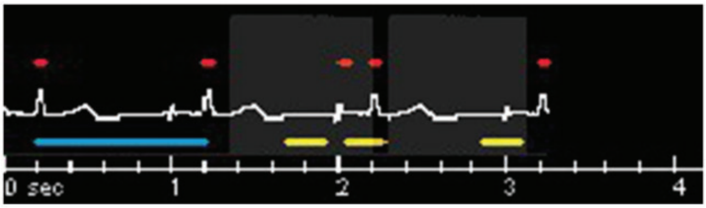


**Figure 3.** Misidentification by ECG gating. Pacing stimulation signal was misidentified as a heartbeat signal by ECG gating.

pacemakers undergoing 64-slice CT coronary angiography was higher among those with a heart rate >65 bpm (20.98%) than in those with a heart rate <65 bpm (15.67%), although the difference was not significant, while patients with heart arrhythmia had significantly more artifacts than those with normal heart rhythm (15.09% vs. 21.40%, $P = 0.039$). Moreover, these factors had greater impacts on moderate and severe image artifacts. However, the associations between image artifacts and heart rate or heart rhythm were weaker in patients who received 640-slice CT. These results demonstrated that 640-slice CT was an effective technique for CT coronary angiography in patients with implanted pacemakers and arrhythmias.

This study had several limitations. There were no endpoints for stenosis detection or quantification, and further studies using selective coronary angiography as the gold standard are needed to evaluate the accuracy of multi-slice CT for the diagnosis of coronary stenosis in these patients. In addition, more information, such as Agatston score to quantify artery plaque burden, should be included to clarify the differences between 64- and 640-slice CT in patients with pacemakers.

In summary, 640-slice CT provides better coronary artery image quality than 64-slice CT in patients with pacemaker implants. Furthermore, 640-slice CT is associated with a higher ratio of diagnosable images, greater stability, and fewer artifacts than 64-slice CT, and may be particularly beneficial for reducing moderate and severe image artifacts in patients with heart rhythm disturbances.

## Declaration of conflicting interest

The authors declare that there is no conflict of interest.

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