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ORIGINAL ARTICLE

Computed tomography in patients with cardiac pacemakers: difficulties and solutions

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Abstract The presence of cardiac pacemaker systems may significantly limit interpretation of multi-slice computed tomography (MSCT) images. In 80 patients (45 men; aged 69.5 ± 13.4) with previously implanted anti-arrhythmic devices, a 64-slice CT (Aquilion-64) was performed. In 61 patients (76.3%), ECG gating was used (coronaries visualization) and in 19 patients (23.7%) without ECG gating (not coronaries visualization). In all 19 patients without ECG gating MSCT images were diagnostic. In 37 (60.6%) patients of 61, there was no problem with gating process and image quality was diagnostic. In 24 (39.4%) with visible spikes in the ECG-gating group, there were difficulties in differentiating the R spike from an artificial spike (unipolar pacing) by MSCT software. In 15 patients (24.6%) after reprogramming, it was possible to obtain good quality images. In nine (14.7%) patients, it was not possible to reprogram devices due to old unipolar leads, but in two cases (3.3%), ECG gating was corrected manually and good image quality was obtained. In seven (11.5%) patients, it was not possible to perform ECG gating. The ECG gating process was identified as the main cause of the imaging problems. Bipolar leads working as bipolar pacing seem to be necessary to perform MSCT with ECG gating. A unipolar system lead may cause serious problems with reconstructions.

Keywords Multi-slice computed tomography · Pacemaker · ICD · Lead · Programming of the devices

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Introduction

Severe heart rhythm disorders, including malignant ventricular arrhythmias, and advanced heart failure are clinical entities for which potential method of treatment can be implantation of pacemaker, implantable cardioverter-defibrillator (ICD), or cardiac resynchronization therapy (CRT) devices (according to indications) [1]. As a result, the number of patients with implanted endocardial leads (atrial, right ventricle, left ventricle) is still increasing. This trend is strictly connected with the growing number of complaints and co-morbidities which have to be diagnosed in these patients. Unfortunately, the presence of metal elements, which are a part of the leads and devices themselves, in some diagnostic methods (e.g., magnetic resonance imaging) cause that those methods are contraindicated [2–4]. Use of other methods (e.g., multi-slice computed tomography, MSCT) faces with some unexplained problems during examination in patients with previously implanted pacemakers and ICDs [5, 6]. Meanwhile, significance, indications, and availability of MSCT scanners are increasing [7–9]. In this specific group of patients, the most important in this context is evaluation of ischemic heart disease and recognition of myocardium perforation by the lead [10, 11]. The actual question is whether the MSCT can be a diagnostic method for all patients with anti-arrhythmic devices.

The purpose of this study was to evaluate the factors determining certain difficulties in performing of MSCT in patients with implanted cardiac pacemakers or ICDs, and to find the solutions that allow to avoid potential problems with examination.

Methods

Eighty consecutive patients (45 males, 35 females, mean age 69.5 ± 13.4 years) with previously implanted anti-arrhythmic devices were included into the study. In all, a 64-slice CT using Aquilion 64-MSCT scanner (Toshiba, Japan) was performed after obtaining a stable rhythm. Subjects were divided into two subgroups according to necessity to use MSCT gating process.

The first group included 61 patients (76.3%) in whom ECG-gating had been used. In this group, only patients with suspected coronary artery disease (CAD) were included, and the main purpose of MSCT was coronary arteries comprehensive analysis. A suspicion of CAD was based on clinical symptoms such as chest pain, shortness of breath when exercising or during other vigorous activities, and other typical/atypical symptoms coexisting. Atypical ECG changes and positive results of exercise testing was also a basis for performing MSCT.

The second group included 19 patients (23.7%) who had MSCT examination based on non-EGC gating protocol and the main purpose of MSCT was chest structure analysis like suspicion of lead perforation, suspicion of pulmonary embolism, or aorta aneurysm visualization. In this group, we did not perform analysis of coronaries.

Patients were excluded from the study if they presented with the following clinical features: frequent cardiac extrasystoles, renal insufficiency (serum creatinine >1.3 mg/dl), hyperthyreosis, and known allergy to non-ionic contrast agents. The presence of permanent or persistent atrial fibrillation with a slow ventricular rate (<75 bpm) was accepted. In each case, informed consent was obtained. The study protocol was approved by the local ethical committee. A scheme of the study is presented in Fig. 1. The characteristics of the groups are presented in Table 1.

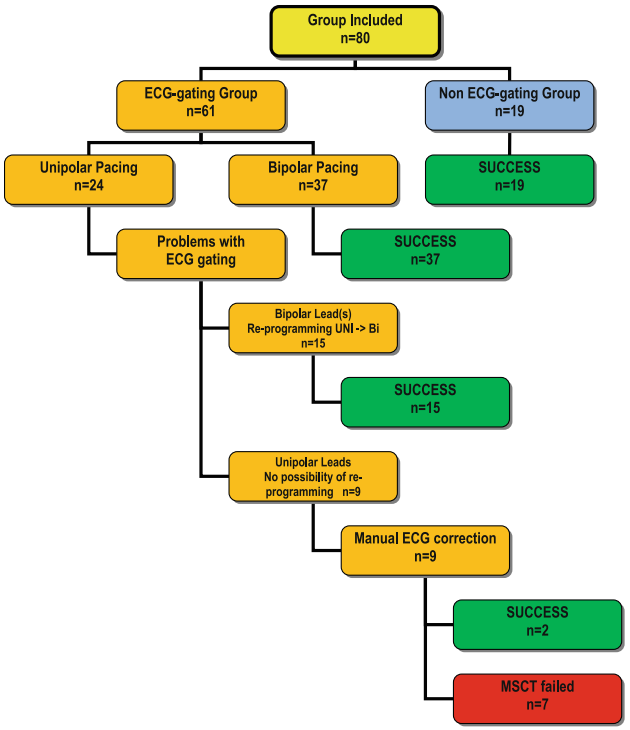

Fig. 1 Graphic scheme of the research

MSCT protocol in the ECG gating group

Scanning with a retrospective ECG gating was performed using a 64-slice scan with a collimated slice thickness of 0.5 mm during a breath-hold. The helical pitch was 12.8 (best mode) and rotation time was 0.4 s. Average tube voltage was 135 kV at 380 mA, being strictly dependent on the individual's body mass index (BMI). A pre-selected region of interest was used in all. In each case, the start of the scan was like routine arterial imaging. The cut-off for heart rate (HR) was set at 65 beats per min. If the HR was higher, metoprolol succinate (Betaloc, Astra Zeneca, Sweden) at a dose of 5–10 mg was administered intravenously, if not contraindicated. If the expected HR slowing was not achieved, the patient was excluded from the study. In those subjects who were pacemaker-dependent, the paced rates were reduced instead of using metoprolol. On average, 100 ml of non-ionic contrast agent (Iopromidum, Ultravist 370, Schering, Germany) was given to each patient during the examination at an average rate of 5 ml/s. Contrast was given in three phases: 90 ml of contrast agent (average), then 24 ml of contrast agent, and 16 ml of saline flush (60/40%), and finally 30 ml of saline. Full examination, including coronary artery calcium, function of the heart and coronary arteries comprehensive analysis, was performed.

MSCT protocol in the no-ECG gating group

Scanning was performed using 64 slices with a collimated slice thickness of 1.0 mm during a breath-hold. The helical pitch was 15 and the rotation time was 0.5 s. Average tube voltage was 120 kV at automatic current calibration. Contrast agents (the same as in the former group) were given in two phases: 70 ml contrast agent (average), and 20 ml of saline.

Table 1 Characteristics of the examined groups

	ECG gating group	Control group (without gating)
Number of patients included	61	19
Sex (men)	40/60 (66.6%)	5/19 (26.3%)
Average age ($x \pm$ SD)	68.6 ± 11.9	68.3 ± 17.9
Average period from implantation	3.11 ± 3.45	1.21 ± 3.49
Cause of MSCT examination		
CAD suspicion	61 (100%)	0
Lead perforation	0	5 (26.3%)
Pulmonary embolism	0	19 (52.6%)
Aorta aneurysm	0	3 (15.8%)
Before ablation	0	1 (5.3%)
Type of pacing (programmed)		
AAI (R)	3 (4.9%)	0
VVI (R)	14 (22.9%)	5 (26.3%)
DDD (R)	42 (68.9%)	14 (73.7%)
VDD (R)	2 (3.3%)	0
Producers of pacemakers examined		
Medtronic	42 (68.9%)	14 (54.3%)
Biotronik	6 (9.8%)	3 (15.8%)
St. Jude Medical	6 (9.8%)	0
Ela Medical	2 (3.3%)	2 (10.5%)
Guidant	2 (3.3%)	0
Vitatron	3 (4.9%)	0
Main cause of pacemaker implantation		
Sinus node dysfunction	38 (62.3%)	11 (57.9%)
AV blocks	14 (22.9%)	6 (9.9%)
AF with bradycardia	3 (4.9%)	2 (10.5%)
VT/VF	6 (9.8%)	0
Atrial fibrillation		
Paroxysmal AF	14 (22.9%)	4 (21.1%)
Permanent AF	10 (16.4)	2 (10.5%)

Post-processing

Post-processing of the images was performed on Vitrea 2 (software version 3.9.0.0) workstations (Vital Images, USA). In each case, 3D volume rendering (VR) reconstructions, and multi-planar reformatting (MPR) were created. All data were evaluated by two experienced MSCT investigators.

Image evaluation

Images were evaluated based on diagnostic possibility to the performed examination. As the "diagnostic" was treated images where main purpose of examination was achieved, e.g., when the main aim of MSCT was coronary artery visualization due to CAD suspicion, proper visualization, and possibility of evaluation of main coronary arteries were treated as diagnostic.

Device programming

The actual programs of implanted devices were read before the examination using an adequate programmer. If there was a need, in some cases the devices were reprogrammed on the time of examination. The main purpose of the programming process was to obtain stable artificial pacing or a native rhythm of the patient. For safety reasons, all tests, such as amplitudes, thresholds, and resistance of the system on all leads, were performed directly after examination. All before-examination parameters were programmed repetitively after examination. The ECG gating test was always performed to confirm the possibility of gating during scanning.

Results

In 37 (60.6%) out of 61 patients from the ECG gated group, there was no problem with gating process and images were diagnostic. In 24 (39.4%) patients with visible spikes on the ECG, there were difficulties in differentiating the R spike from an artificial spike (when working as unipolar pacing) by MSCT gating software. Because artificial spikes have similar for R spikes characteristic including high voltage, gating software cannot properly different both spikes. During single RR cycle, two (native and artificial) high spikes are visible and are double counted (double R counting). In 15 patients (24.6%), after reprogramming it was possible to obtain diagnostic quality images. In nine (14.7%) patients it was not possible to reprogram devices due to old unipolar leads, but in two cases (3.3%), the ECG gating was corrected manually and diagnostic image quality was obtained. In the remaining seven (11.5%) patients, it was not possible to perform ECG gating as well as MSCT itself (Fig. 2).

In all patients with bipolar leads we were able to visualize coronary arteries that's mean to obtain fully diagnostic image quality. Most of the artifacts were visible only close to metal active elements; silicon-insulated wires were well visible. Examples of a patient's vessel analysis are presented in Figs. 3 and 4. In the non-ECG gating group, in

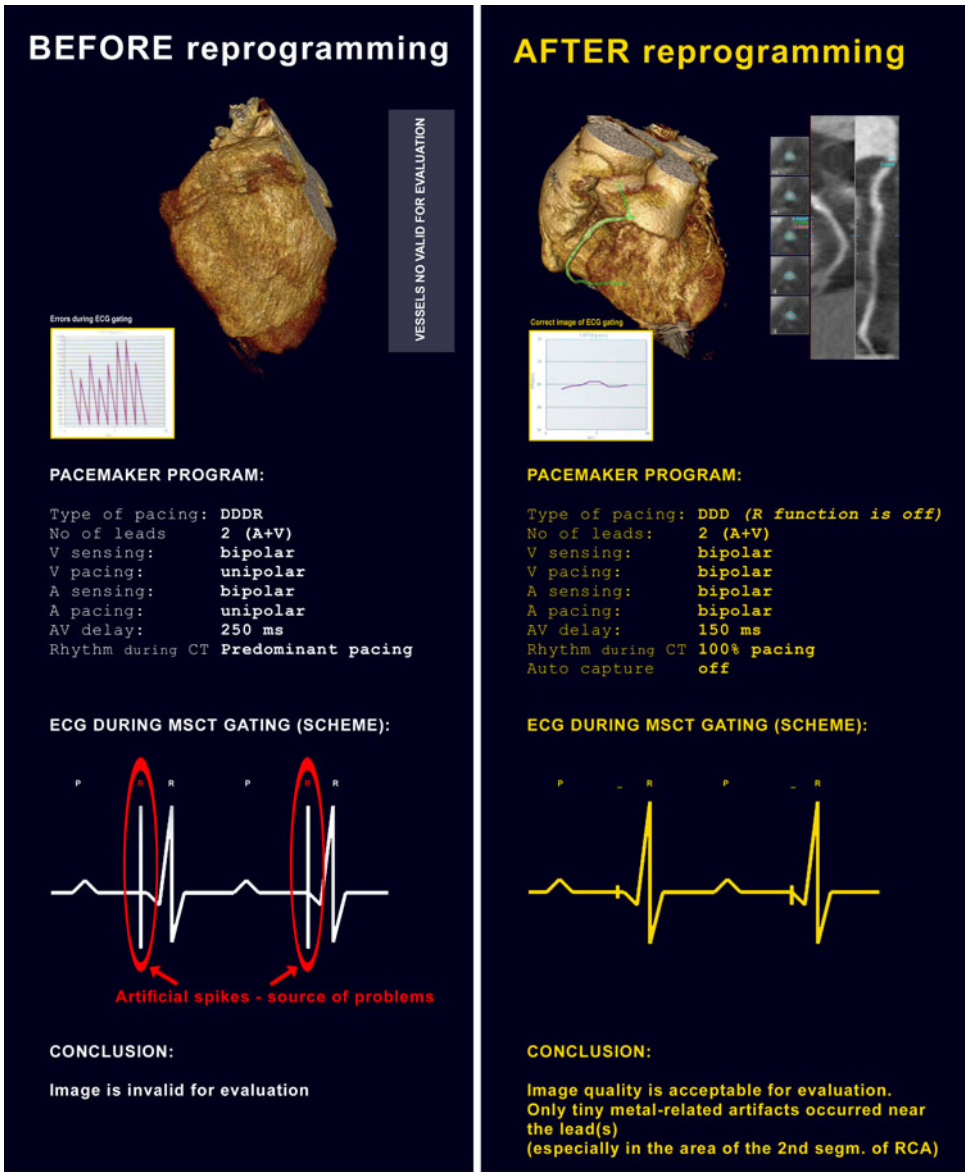

Fig. 2 Comparison of ECG, programming, and reconstruction in two types of programming—unipolar versus bipolar pacing. On the *left*, errors during reconstructions are visible (double R counting)

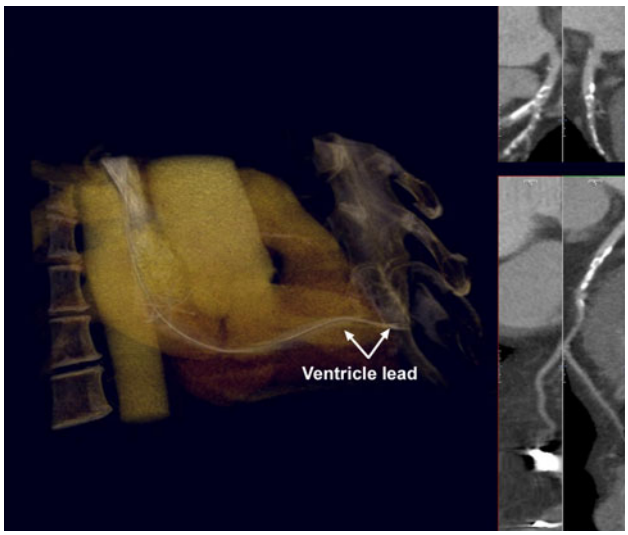

Fig. 3 Advanced ischemic heart disease in a patient with an implanted VVI pacemaker. On the left visible ventricle, bipolar, screw-in lead, on the right diagnostic quality of coronary arteries despite presence endocardial lead

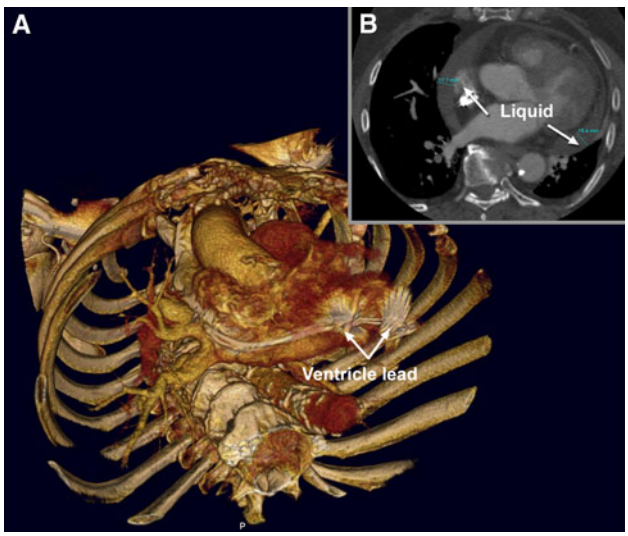

Fig. 4 Endocardial lead visualization in patients with suspicion of perforation (layer of liquid surrounding the heart). **a** 3D reconstruction. **b** Multi-planar reformatting (MPR) reconstruction

all 19 patients there was no problem with performing of MSCT and image quality was diagnostic.

Recommended programming

The parameters of devices that gave optimal results in 52 patients (65%) were:

- bipolar pacing on each lead (sensing can be programmed both bipolar or unipolar),
- rate-responsive function should be switch off,
- to avoid unexpected working of the implanted devices threshold capture function should be also switch off,
- A-V delay should be programmed in each case independently to obtain stable artificial pacing.
- We did not observe any electromagnetic interferences in the ICD group, so we think that in the ICD group detection and therapies can be turned on.

Discussion

Popularity of MSCT as well as number of patients with implanted anti-arrhythmic devices increased. Sometimes there is a need of performing MSCT in those patients. The most common indication for MSCT is suspicion of ischemic heart disease [7].

However, sometimes unexplained problems in implanted patients can occur. A key element for reconstruction of the heart for most CT scanners is the ECG gating allowing for the scanning in the same phase of cardiac cycle (R–R interval) [12]. Finally, those partial data are connected during digital reconstruction. In modern anti-arrhythmic systems, there is a possibility of programming one of the two modes of pacing according to the lead configuration: unipolar or bipolar. As can be seen in Fig. 2, the main difference in ECG for both is the amplitude of artificial spikes. On the left part of Fig. 2, ventricle spikes were identified by computer software in the MSCT scanner as an R spike, which could provoke serious problems with reconstruction, and in most cases made it impossible. In our study, a bipolar pacing was identified as crucial for optimal image quality. Unfortunately, for the patients with old unipolar leads, bipolar pacing could not be programmed due to lead technical construction. For these patients, there was an option as a correction of ECG gating manually, however, the results were unsatisfactory. We cannot explain why exact manual reduction R markers from artificial spikes on ECG gating curve do not resolve problem in all. Only in two patients it was possible. In the rest (seven patients), the images were hazy and not "diagnostic". We would rather conclude that in those patients MSCT should not be performed. Some issues regarding programming HR also seemed important. In most patients it was possible to program a lower HR. Thus (if possible) a re-programming HR into a value lower than 60 beats per min could be recommended. It seems also plausible to switch off the rate-responsive function, especially in patients with double-sensor rate-responsive pacemakers [13].

In a few papers, the opportunity of performing a MSCT was reported, despite that some kinds of problems showed that it was not always reliable. In the last few years, only a

few reports have been published evaluating mostly its efficacy for visualization of leads perforation. In a large group of patients, Hirschl et al. [10] showed that it was possible to perform MSCT. A similar statement was concluded in a study by Henrikson et al. [11]. Thus, our results do extend these observations. Unfortunately, we were unable to find studies in which evaluation of coronary arteries had been an objective of the study in such patients. We found that in most patients with bipolar system leads it was possible to perform a reliable MSCT evaluation of the coronaries. However, taking into account the X-ray exposure related to 64-MSCT examination with a retrospective ECG gating and unfair results in patients with unipolar leads, indications for MSCT should be cautioned. The results of our study speak for a use of unipolar configuration of pacing and bipolar sensing in patients with a bipolar system of the lead(s). On the other hand, a type of sensing has not been found important from the point of view of the MSCT examination.

In a few cases, when the scanning could be considered successful, a reliable evaluation of coronary arteries could not be performed. We previously reported that the presence of endocardial leads may limit applicability of coronary CT angiography, especially in the right coronary artery area [14]. Artifacts that are visible from metal elements can cause many problems with interpretation of images and clinical conclusions.

Study limitations

As a clinically based study, a double-blind random comparison between different programming was not possible, either because of a relatively high dose of radiation or the amount of the contrast agent for ethical reasons. Therefore, an unavoidable selection bias may weaken the power of the results of our study. We did not analyze the influence of the presence of metal parts of endocardial leads in this paper; however, we did in our previously published research [14]. Also, a limited number of examined patients does not allow for conclusions to be generalized. However, the importance of the problem (in terms of increasing population of patients with pacemakers) does seem to allow the observational studies to be recognized.

Conclusions

A reliable performance of MSCT coronary arteries evaluation is possible in most patients with implanted antiarrhythmic devices. Difficulties related to distinguishing the R-wave are common. Bipolar leads working as bipolar pacing seem to be necessary to perform MSCT with ECG gating. A unipolar system lead may cause serious problems with reconstructions. Adequate pacemaker programming could overcome these difficulties in the majority of cases.

Conflict of interest None.

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