Original Investigation

Magic Angle in Cardiac CT: Eliminating Clinically Relevant Metal Artifacts in Pacemaker Leads with a Lead-Tip/Gantry Angle of ≤70°

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Rationale and Objective: To identify the influence of various parameters for reducing artifacts in computed tomography (CT) of commonly used pacemakers or implantable cardioverter-defibrillator (ICD) lead tips.

Materials and Methods: This ex vivo phantom study compared two CT techniques (Dual-Energy CT [DECT] vs. Dual-Source CT [DSCT]), as well as the influence of incremental alterations of current-time product and pacemaker lead-tip angle with respect to the gantry plane. Four pacemaker leads and one ICD lead were evaluated. The images were assessed visually on a five-point Likert scale (1 = artifact free to 5 = massive artifacts). Likert values 1–3 represent clinically relevant, diagnostic image quality.

Results: 344 of 400 total images were rated with diagnostic image quality. The DECT and dual-source DSCT technique each scored 86% diagnostic image quality. Statistically, DECT images showed significantly improved image quality ($P < .05$). Concerning the current-time product, no statistically significant change was found. Regarding lead-tip positioning, an angle of ≤70° yielded 100% diagnostic image quality. Pacemaker and ICD leads were assessed to have statistically significant differences.

Conclusions: Surprisingly, the lead-tip angle of 70° has been established as the key angle under which diagnostic image quality is always ensured, regardless of the imaging technique. Thus, we call 70° the "Magic angle" in CT pacemaker imaging.

Key Words: Pacemakers; implantable cardioverter-defibrillator (ICD); metal artifact reduction; dual-energy CT; dual-source CT.

INTRODUCTION

Patients with implanted metallic devices are a common sight in clinical practice using computed tomography (CT). In particular, more than one million cardiovascular implantable electronic devices such as pacemakers (PMs) and implantable cardioverter-defibrillators (ICDs) are being implanted in patients with cardiovascular diseases every year, and this number is rising (1).

These devices are usually implanted in an infraclavicular subcutaneous or submuscular pocket with a transvenous lead. Most ventricular leads are placed in the apex of the right ventricle (RV), and most atrial leads are implanted in the right atrial appendage. There is a 4.4% incidence of a lead dislodgement or malfunctioning (~44,000 patients) 1 year after implantation (2) from which approximately 10,000 patients are suffering from possible lead perforation.

Because of the stiffness of the lead and the relative thin wall of the right ventricle (usually <5 to 7 mm), lead protrusion or perforation is a clinical occurring problem. If a lead completely perforates the wall, there is a loss of ventricular pacing capture. Diagnosis is mostly confirmed by PM interrogation, conventional chest X-ray in two planes, or echocardiography. Diagnosing an incomplete perforation (so called protrusion) is more challenging because PM performs within normal boundaries. This state cannot be evaluated in echocardiography, X-ray, or Magnetic resonance imaging (MRI). Therefore pertinent guidelines stipulate an Electrocardiography-synchronized CT of the heart (3). However metal artifacts often hamper the proper visualization of the lead tip in the right ventricular myocardium, which is crucial to safely avoid thoracotomy.

Besides movement-induced artifacts, which are potentially eliminated by ECG-synchronized examinations, in the "vast majority of cases," (4) non-motion artifacts like beam hardening and photon starvation can affect image quality.

Consequently, to reduce metal artifacts, this ex vivo phantom study aims to compare the two CT techniques (Dual-Energy CT [DECT] and Dual-Source CT [DSCT]) as well as the influence of incremental alterations of

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current-time product and PM lead-tip angle with respect to the gantry plane.

MATERIALS AND METHODS

CT Data Acquisition and Experimental Setup

All examinations were conducted with a DSCT (Somatom Definition Flash, Forchheim, Siemens Medical Healthcare). Technical parameters were collimation: 2 × 2 × 64 and a temporal resolution of 75 ms. We examined four commonly used right ventricular PM leads and one ICD lead. For further information, please refer to supplemental 1. The PM leads were fastened on top of a flat device to achieve a straight plane on the curved radiographic table. The angle of the lead tip on top of the device was increased by 10° increments with regard to the gantry plane, ranging from 0° to 90°. An angle of 0° was defined as being parallel to the z-axis (ie, patient's z-axis) of the CT scanner, and 90° was defined as being parallel to the CT gantry plane or X-ray beam (Fig 1). The gantry-centered position of the device was ensured by scanning two orthotopic topograms.

In each angle, the DECT and DSCT examinations were conducted with a stepwise increase in the current time product. For DSCT, the respective current time product was increased from 150 to 370 mAs (150, 200, 250, 300, and 370 mAs). For DECT, these values were 65, 125, and 185 mAs using 100/140 kV as voltages.

Image Post-Processing or Evaluation

All examinations were reconstructed with a slice thickness of 1 mm + 0.8 mm increment, a field of view of 220 × 220 mm, and a convolution kernel of B26f.

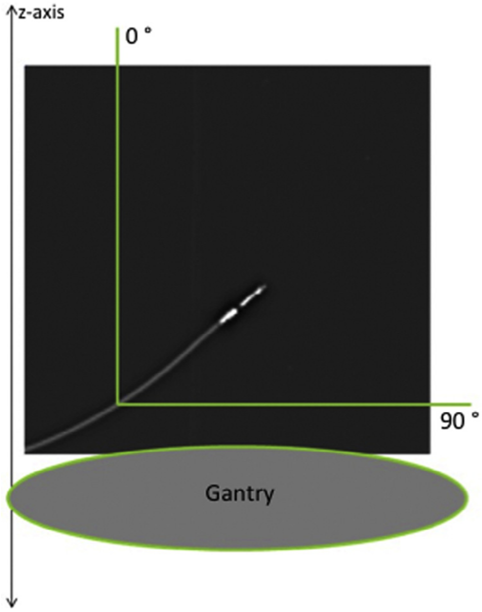

Figure 1. Experimental setup: positioning of the lead tip with regard to the gantry plane.

From DECT examinations, images with the two different spectra (100 and 140 kV) were reconstructed and post-processed by calculating virtual monoenergetic images (VMC) on a dedicated workstation (MMWP; Siemens Health care; Forchheim; Germany) and Syngo.via (Basic Client 1.1.0.18; Siemens Healthcare). VMCs were manually synthesized by selecting voltage levels with the visually evaluated highest artifact reduction.

The images were arranged in three different reformations with regard to the lead tip for evaluating artifact burden (coronal, sagittal, and axial).

The acquired data were assessed by two observers (experience of 1.5 years and 7 years). The artifact burden was visually quantified on a 5-point Likert scale (1 = no artifacts, 2 = few artifacts, 3 = moderate artifacts, 4 = many artifacts, 5 = massive artifacts).

Images with Likert values of 1–3 were defined as having diagnostic image quality, whereas those with Likert values of 4 and 5 were assessed to have nondiagnostic image quality. Each observer made an individual assessment of the respective image quality. In the case of a scoring divergence, both observers decided on a final Likert value in consensus.

Statistics

Statistical analysis was performed using SPSS Statistics 22 (IBM Corporation, Armonk, NY). Categorical variables were expressed as counts and percentages. For continuous data, mean ± standard deviation was expressed. For comparison of continuous variables, a paired t test was used. To compare categorical variables, we conducted the two factorial non-parametric Friedman test with an analysis of variance. An intraclass correlation coefficient was calculated to detect an interobserver bias. A *P* value <.05 was defined as statistically significant for every test.

RESULT

A total of 320 image acquisitions from four ventricular PM leads were examined as well as 80 image acquisitions from the investigated ICD lead, resulting in a total of 400 reconstructions evaluated.

A total of 344 (86%) image acquisitions were rated as having diagnostic image quality, whereas the remainder were rated as having nondiagnostic image quality (14%). A Likert value of "1" was given 112 times, whereas a Likert score of "2" was accorded 131 times, a score of "3" was granted 101 times, a score of "4" was assessed 48 times, and, finally, a score of "5" was given eight times.

Technique or Protocol

Evaluation DECT versus DSCT

In acquisitions with the DSCT, 86% of the reconstructions were deemed as showing diagnostic image quality, just like