Cardiac Magnetic Resonance with a Conditional Pacemaker at Three Tesla Field Strength

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Cardiovascular magnetic resonance at 3-tesla (3T) has inherent technical challenges that are increasingly being overcome. Recently, some pacemakers and leads have been approved for 3T conditional use. The purpose of this report is to review B_{1+RMS} , a new, more accurate parameter used to define energy deposition during magnetic resonance imaging, as well as to present the imaging protocol and procedure utilized to rule out causes of heart block in a patient with a pacemaker *in-situ*. This case demonstrates that high quality, diagnostic images can be obtained at 3T with conditional pacemakers *in situ*.

Key words Artificial cardiac pacemaker · Magnetic resonance imaging · Equipment safety · Cardiac imaging techniques.

INTRODUCTION

Growth of cardiovascular magnetic resonance (CMR) has been paralleled by expanding indications and employment of cardiac implanted electronic devices (CIEDs). First-generation magnetic resonance imaging (MRI) conditional devices were limited to 1.5-tesla (1.5T) field strength. Recently, a small number of devices were designated “MRI conditional” status at 3-tesla (3T). Extra-thoracic MRI at 3T in patients with magnetic resonance (MR)-conditional CIEDs has been previously described [1,2]. However, to our knowledge, no CMR of patients with CIED *in-situ* (i.e., directly within the field) at 3T have been reported in the literature. The purpose of this case study is to review B_{1+RMS} [derived from the ten-second, time-averaged field strength or root mean square (RMS) of the flip angle (B_{1+})], a new parameter used to define energy deposition during MRI, as well as to present the imaging protocol and procedure utilized in a case of idiopathic, complete heart block.

CASE REPORT

A 39-year-old male presented with a 5-day history of lethargy, dyspnea, coryzal symptoms, and no previous medical history. Electrocardiogram (ECG) demonstrated complete atrio-ventricular conduction block. Echocardiogram, biochemical, and haematologic investigations were normal. Informed consent was obtained.

Access to urgent CMR was limited, and insertion of an Ensura SureScan DR dual-chamber pacemaker with CapsureSense leads (Medtronic, Minneapolis, MN, USA) was performed (Fig. 1). Pacing mode was DDD (dual-chamber, dual-sensing pacing with triggering and inhibiting functionality). CMR at six weeks was used to investigate secondary causes of heart block.

CMR protocol

Safety protocols were observed, and the pacemaker was switched to MR-conditional mode-DOO (dual-chamber paced, no sense, no response) at 80 beats-per-minute. Scanning was performed with the patient in a supine position, head first with MRI-safe ClearTrace 2 electrodes (CONMED, Utica, NY, USA) for ECG capture. A MAGNETOM Skyra 3T MRI and PERU monitoring device (Siemens, Erlangen, Germany) were used for

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CMR acquisitions: gradient-recalled echo cine sequences were substituted for balanced steady-state free precession series to reduce the B_{1+RMS} and CIED-related artifact. T1-weighted, T2-

Fig. 1. Chest radiograph with dual-lead pacemaker confirming MR-conditional symbol (---); see inset (curved white arrow).

weighted, fat saturated, first-pass perfusion, and late gadolinium-enhanced (LGE) sequences were obtained (Fig. 2A-C). The predicted specific absorption rate (SAR) was <1.7 W/kg for each sequence. All sequences fell well below the $2.8 \mu\text{T}$ B_{1+RMS} threshold.

Case findings

CMR did not demonstrate myocardial oedema or pathological late-gadolinium enhancement. Ventricular size and function were normal. Minimal CIED-related artifacts occurred, and high-quality images were obtained with excellent ventricular blood-to-myocardial contrast ratio (BMCR) and contrast-to-noise ratio (CNR) [3] for the short-axis cine (BMCR 2.64; CNR 23.75) and LGE (BCMR 24.93; CNR 29.84) sequences.

The patient remained asymptomatic throughout the study. Subsequent interrogations confirmed that CIED parameters were unchanged post-MRI, and that the patient was pacemaker dependent, supporting the diagnosis of idiopathic complete heart block.

DISCUSSION

CMR did not demonstrate evidence of myocarditis or infil-

Fig. 2. A 39-year-old male with idiopathic, third degree atrioventricular-conduction block. Cardiovascular magnetic resonance (A) T2 fat-saturated sequence demonstrated no myocardial oedema (white arrow), (B) 4-chamber and 2-chamber gradient-recalled echo cine sequences demonstrate normal structure and function with excellent spatial resolution, minimal artefact related to pacemaker leads (white arrowheads), (C) short axis first-pass perfusion and late gadolinium-enhanced sequences excluded resting perfusion deficits and myocardial scar (white arrows), and (D) B_{1+RMS} prediction displayed in the specific absorption rate Monitor Operating Mode window of a Siemens Skyra MRI system.

Table 1. Techniques to reduce B_{1+RMS}

Increased RF pulse duration
Use of ‘Low SAR mode’
Increased TR without reducing slice number
Reduced slices for set TR
Reduced ETL
Reduced refocusing angle (FSE sequences)
Reduced flip angle (GRE sequences)
Use GRE sequences instead of SE or FSE

Adapted from Faulkner. Signal 2016;5(1). RF: Radiofrequency, SAR: specific absorption rate, TR: repetition time, ETL: echo train length, FSE: fast spin echo, GRE: gradient recalled echo, SE: spin echo

trative myocardial disease as a cause for heart block. This case highlights the efficacy and safety of CMR at 3T to investigate causes of heart block in patients with an MR conditional pacemaker *in situ*.

Potential safety concerns exist when imaging patients with CIEDs. These include induced currents, heating, torque, and antenna effects related to radio-frequency (RF) energy deposition.

Specific absorption rate

SAR is the traditional metric for calculating RF power absorbed per unit of mass. It varies between patients and cannot be directly measured during MRI acquisitions. SAR has no universal standard, varies between MRI systems, and is a poor predictor of implant temperature changes. Thus, its use to guide safe imaging is unreliable and potentially dangerous [4].

B_{1+RMS}

B_{1+RMS} is a parameter available on 3T MRI scanners built af-

ter 2013. It provides more accurate indications of energy absorption than SAR with *in-situ* CIEDs and is independent of patient factors. Adjusting parameters to reduce SAR also typically reduces B_{1+RMS} ; examples are listed in Table 1 [5].

Energy deposition thresholds vary between manufacturers, as will the location of the B_{1+RMS} display on scanner consoles (Fig. 2D). SureScan CIEDs have a maximum B_{1+RMS} threshold of 2.8 μ T for thoracic imaging at 3T.

Summary

This case demonstrates that high-quality diagnostic images can be obtained safely in patients with MR conditional CIEDs *in situ* at 3T field strength (traditionally limited to 1.5T). Strict adherence to safety protocols and vendor MR conditions is required.

Conflicts of Interest

The authors declare that they have no conflict of interest.

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