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Cardiovascular Magnetic Resonance at 0.5T in Five Patients with Permanent Pacemakers

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ABSTRACT

Background: **Cardiovascular magnetic resonance (CMR) yields important clinical information which often cannot be obtained from other imaging modalities. Cardiac pacemakers have conventionally been considered a contraindication to CMR, and relatively few data exist on CMR in such patients.** ***Methods and results:*** **We present 5 patients who underwent 6 CMR scans in a 0.5 Tesla scanner. The patients were non-pacemaker dependent, and the pacemakers were reprogrammed prior to scanning to have sub-threshold output. Spin echo, gradient echo and real-time sequences were used with specific absorption rates of up to 0.1 W/kg. A cardiologist was present during each scan, and the patient had continuous electrocardiographic and non-invasive monitoring of vital signs. Five of the scans were carried out without incident providing useful diagnostic information, which was not compromised by obvious artifact from the pacemaker box. In one case, the pacemaker began pacing at maximum voltage at a fixed rate of 100. This patient was removed from the magnet, and there were no clinical sequelae. The mean pre- and post-scan ventricular lead voltage threshold was the same (2.28 V vs 2.28 V).** ***Conclusion:*** **Our experience is that CMR at 0.5T in non-pacemaker dependent patents can be performed in closely supervised circumstances where the benefit-risk assessment is considered positive.**

INTRODUCTION

The presence of a cardiac pacemaker has conventionally been regarded as a contraindication to undertaking magnetic resonance (MR) of any part of the body (1). This is reinforced by at least 11 reports in the literature of death in patients who were scanned with a pacemaker (2–4). The details of those patients who died are not fully characterized in terms of magnetic field strength, imaging sequences, pacemaker type and pacemaker dependency of the patient. In addition, the cause of death was not clearly identified. Importantly, there have been no reported deaths in pacemaker patients who underwent MR scanning in a planned fashion under the direct supervision of a physician.

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There are several theoretical problems which may arise from scanning a patient in a CMR scanner (1). The static element of the magnetic field may cause motion or displacement of the pacemaker generator or leads. The static or pulsed elements of the magnetic field may cause heating, rapid atrial or ventricular pacing (and thereby induce arrhythmias), asynchronous pacing, reed switch malfunction, inhibition of pacemaker output and may interfere with the programmed parameters. Of these issues, heating of the pacemaker lead may be the main problem (5).

Recently, a significant number of patients with pacemakers have undergone CMR scanning without incident, where there was a clear clinical need for the information from the scan or in the context of a planned clinical trial. Most of the reports in the literature refer to patients with pacemakers undergoing non-cardiac magnetic resonance scans (6–16). There remain rather limited data on the performance of CMR in the heart and vessels in patients with pacemakers, which has relevance because of the different location of the pacemaker relative to the isocentre, which may have bearing on the effects of the procedure on the pacemaker (17). There is also the issue of possible interference with interpretation of the cardiovascular structures which are in proximity to the pacemaker and which for CMR are the focus of diagnostic attention. A limited number of patients with a permanent pacemaker have been reported as safely completing a CMR scan. A series of 51 MR imaging examinations at 0.5 Tesla reported by Sommer et al. included

Table 1. Patient indications and CMR sequences used

	Indication	CMR sequences	MR scanner reported Peak SAR (W/kg)
Patient 1	Multiple ventricular fibrillation arrests with no identified cause	Spin echo Gradient echo cine	0.1 0.002
Patient 2 (Scan 1)	Heterotopic cardiac transplantation, new heart failure, echocardiography unable to visualize cardiac function	Spin echo Gradient echo cine	0.1 0.002
Patient 2 (Scan 2)	As above, repeated because of gating problems with 2 superimposed ECG traces on surface recording	Real time echo planar imaging	0.0008
Patient 3	Congenital transposition of the great arteries, echocardiography unable to determine function of the pulmonary valve	Spin echo Gradient echo cine	0.1 0.002
Patient 4	Aortic and mitral mechanical valve replacements, clinical aortic regurgitation, but none found on echocardiography	Spin echo Gradient echo cine	0.1 0.002
Patient 5	History of ventricular arrhythmias controlled with multiple anti-arrythmic drugs, possible arrhythmogenic right ventricular cardiomyopathy	Spin echo Gradient echo cine	0.1 0.002

The spin echo sequence was a non-breathold multi-slice sequence with echo time of 40 ms, 2 repeats of 128 phase encodes, and scan duration of approximately 4 minutes. The gradient echo cine was a field even echo rephasing sequence with an echo time of 14 ms, flip angle 30 degrees, a repeat time of 50 ms, 2 repeats of 128 phase encoding steps, and a scan duration of approximately 4 minutes. The real-time single-shot gradient echo- echo planar sequence used an echo time of 15 ms, flip angle of 50 degrees, with 5 frames per second ungated.

8 MR scans which were safely completed (6). Martin et al. include 3 CMR scans in a series of 62 general CMR examinations safely completed at 1.5 Tesla (7). We, therefore, report our experience of undertaking CMR in non-pacemaker dependent patients.

METHODS

We attempted 6 CMR scans in 5 patients with permanent pacemakers, none of whom were pacemaker dependent. In all patients, the clinical scenario was such that the benefit-risk ratio was felt to be clearly in favor of undertaking CMR. This was explained in detail to the patient and written informed consent was obtained in all cases. All scans were undertaken on a 0.5 Tesla Picker Vista scanner, with the 6B operating system, and with a customized body RF coil of 55 cm width and 55 cm length. The imaging sequences and their peak specific absorption rates, as reported by the scanner, are shown in Table 1. Patients had continuous ECG and non-invasive blood pressure monitoring, resuscitation equipment was available, and an experienced cardiologist was present throughout. Each patient was slowly introduced into the scanner as a conservative measure to allow continuous ECG recording and monitoring of cardiac rhythm. CMR sequences were used initially with lowest specific absorption rates and then increasing as a conservative measure. Patient questioning was performed after each sequence, and these were separated by a 2 minute non-scan period, which was instituted to promote cooling from any induced wire heating. In each case we chose the strategy recommended by Gimbel et al. of reprogramming the pacemaker prior to CMR to prevent ventricular capture (18) by programming the pacemaker to off (OOO mode) or by setting sub-threshold levels of output voltage (minimum) and pulse width (narrowest possible) before entering the scanner. All leads were set to bipolar. Table 2 presents the pacemaker settings used during the scanning.

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Five of the 6 CMR scans were completed without complication. In these 5 patients, there were no significant symptoms reported at the time of the scan. Analysis of the ECG during the scan did not reveal any evidence of cardiac dysrhythmias or inappropriate pacing. No significant changes to pacemaker threshold was noted in any of the atrial or ventricular (2.28 V vs 2.28 V) pacing wires implanted following CMR (Table 2). The scan of patient 3 was abandoned as a precautionary measure when the pacemaker box began pacing at maximum voltage at a fixed rate of 100/min when the patient was introduced into the magnetic field. The patient was removed from the magnet and the scan was not pursued because of the unexpected pacemaker behavior.

The pacemaker box and leads caused a sizeable artifact on the CMR images (Fig. 1). This was greater for gradient echo than spin echo images. In our cases, however, these pacemaker box artifacts did not interfere with the interpretation. CMR added valuable clinical information in these patients which had not been otherwise available, and this had a direct impact on their clinical management. In the case of patient one, his CMR scan suggested a diagnosis of cardiac sarcoidosis (Fig. 2) which was later supported with a positive Kveim test. At the first CMR scan for patient two, it was not possible to gate to the ECG from the donor heart because of the dominant electrical signal from the native heart, and so only information relating to the very poor

Table 2. Pacemaker settings before, during and after CMR

	Pacemaker Model		Output pulse width (msec)	Output voltage (V)	Mode	Polarity
Patient 1	Medtronic	Pre-CMR	Na	Na		
	Minix	During CMR	Na	Na		
	8340	Post-CMR	Na	Na		
Patient 2	Medtronic	Pre-CMR		(A-lead)	DDD	bipolar
(Scan 1)	Minuet		0.42	2.5 (V-lead)		
	7108	During CMR	0	0 (A-lead)	VVI	bipolar
			0.06	0.8 (V-lead)		
		Post-CMR		(A-lead)	DDD	bipolar
			0.42	2.5 (V-lead)		
Patient 2	Medtronic	Pre-CMR		(A-lead)	DDD	bipolar
(Scan 2)	Minuet		0.42	2.5 (V-lead)		
	7108	During CMR	0	0 (A-lead)	VVI	bipolar
			0.06	0.8 (V-lead)		
		Post-CMR		(A-lead)	DDD	bipolar
			0.42	2.5 (V-lead)		
Patient 3	Pacesetter	Pre-CMR	0.49	2.4	VVIR	bipolar
	Regency	During CMR	0.03	0.3	VVI	bipolar
	SR	Post-CMR	0.49	2.4	VVIR	bipolar
Patient 4	Biotronik	Pre-CMR	0.5	2.0	VVI	bipolar
	Pikos VVI	During CMR	0.25	0.1	VVI	bipolar
		Post-CMR	0.5	2.0	VVI	bipolar
Patient 5	Pacesetter	Pre-CMR	0.4	2.0 (A-lead)	DDD	bipolar
			0.4	2.0 (V-lead)		
	Trilogy	During CMR	0	0 (A-lead)	000	
			0	0 (V-lead)		
	DR+	Post-CMR	0.4	2.0 (A-lead)	DDD	bipolar
			0.4	2.0 (V-lead)		

function of the native heart was obtained. The scan was repeated on a second occasion using real-time imaging sequence which obviated the need for gating, and information was the donor heart was shown to be functioning well without evidence for rejection but with a stroke volume that was insufficient to support an adult systemic circulation following deterioration in native heart function. In patient 4, CMR demonstrated impaired occluder closure of the monostrut valve and severe aortic regurgitation, which echocardiography had been unable to demonstrate. In patient 5, CMR scanning did not support the diagnosis of arrhythmogenic right ventricular cardiomyopathy and a diagnosis of dilated cardiomyopathy was made.

DISCUSSION

Magnetic resonance is becoming increasingly important in clinical practice and the lifetime likelihood of having a MR scan of any body part is considered to be in the region of 70%. Likewise, CMR has rapidly increasing indications (19), and many more cardiac patients are now receiving

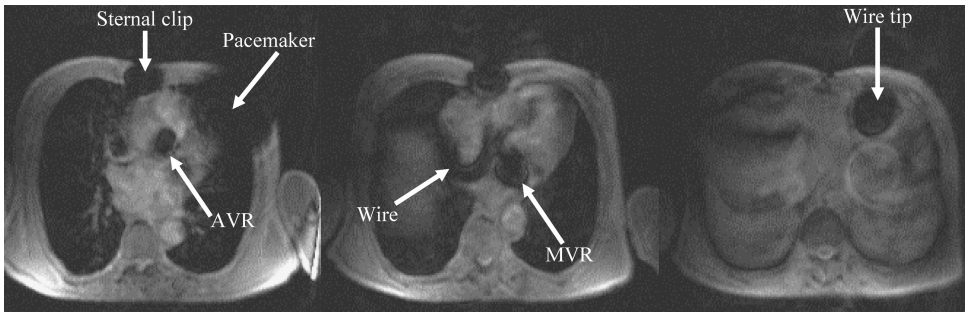

Figure 1. Example of CMR artifacts during cardiac scanning of patient 4 using gradient echo cines at the level of the aortic valve (left), mitral valve (middle) and inferior right ventricle (right). Artifacts are identified with arrows from the pacemaker box, pacemaker lead, sternal wires, the aortic valve replacement (AVR) and the mitral valve replacement (MVR). None of the artifacts prevented identification and quantification of the severe aortic regurgitation and moderate pulmonary regurgitation which were not identifiable by echocardiography in this case.

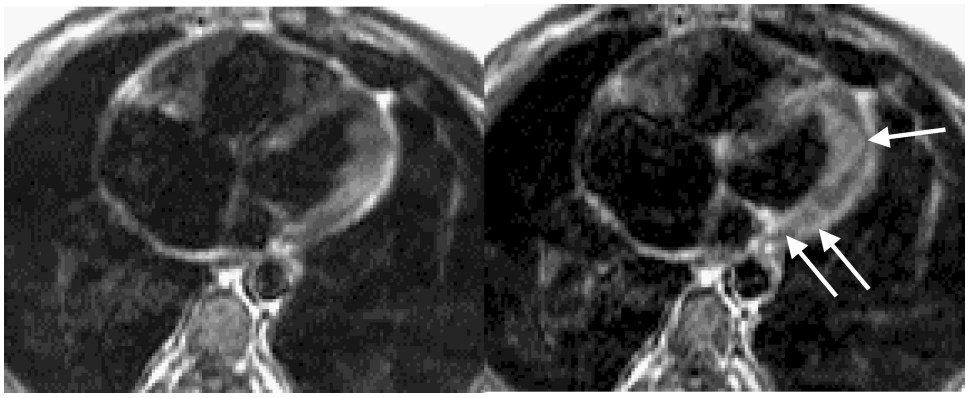

Figure 2. Example of spin echo CMR in patient 1 who presented with recurrent malignant ventricular arrhythmias and normal coronary arteries. Gradient echo cines showed mildly impaired left ventricular function and hypokinesia of the lateral wall. The spin echo images are taken prior to (left) and after (right) injection of gadolinium-DTPA. There is obvious enhancement of the lateral wall (arrowed). A diagnosis of sarcoidosis was made, and this was subsequently confirmed by a Kveim test and skin rash biopsy. The arrhythmias responded to treatment with steroids.

pacemakers for indication such as resynchronization therapy. Conventionally, patients with permanent cardiac pacemakers have been excluded from MR scanning because of the theoretical risk of causing these patients harm from lead heating of by modifying the action of their pacemakers while in the magnetic field. Pacemaker patient deaths have been recorded during CMR, although details of the cause of deaths are scant (2–4), and these events were sustained with older-type pacemakers (20).

There have been a number of publications ranging from case reports (8–10), to prospective trials describing the safety of undertaking MR examinations in patients with permanent pacemakers in magnetic fields between 0.5 and 1.5 Tesla (6, 7). These all involved studying patients who were not pacemaker dependent (although at least one pacemaker dependent patient was inadvertently studied). Special strategies for pacemaker scanning were usually employed (21), and these varied with programming the pacemaker to asynchronous mode, programming the parameters to be sub-threshold and making no changes to programming. It would appear that there is no documented case of death during MR with appropriate pacemaker preparations and vital sign monitoring during MR. Almost all of the patients described, however, underwent non-cardiac magnetic resonance.

Sommer et al. described a total of 8 CMR scans in 6 patients being successfully carried out in a 0.5 Tesla scanner (6). These were part of a study of totaling 51 MR examinations in 44 patients. None of these patients were pacemaker dependent. Pacemakers were programmed to bipolar asynchronous pacing. ECG, blood pressure and pulse oximetry were monitored non-invasively, and an observer was with the patient in the scanner room throughout. The scans were carried out without incident, and there was no significant change in lead threshold, although this information was not provided separately for the cardiac scans.

In the largest of the reported series, a total of 62 MR studies in 47 patients were undertaken at 1.5T (7). Only 3 of these were heart scans, the remainder being a typical mixture of other indications for MR. The pacemakers were not re-programmed to asynchronous mode or sub-threshold for ventricular capture, the ECG was monitored, and voice contact maintained throughout. There was no pacing dysfunction during the scan. One patient did describe feeling his pacemaker move during a spiral k-space coronary artery acquisition. These 3 patients had dual chamber pacemakers. In the 3 (out of 6) leads where threshold data was recorded, there was an increase in threshold following MR. In the first patient, there was no data available as the pacemaker was at end of life. In the second patient, the atrial lead threshold rose from 1.0 V to 1.5 V after scanning, but the ventricular lead thresholds were not recorded. In the third patient, the atrial threshold rose from 1.1 to 1.5 V and ventricular threshold rose from 0.9 to 1.1 V. For all patients overall, only 9.4% of leads had an increase in threshold >0.1 V.

Our experience of scanning non-pacemaker dependent patients is very similar. Five of our scans in these patients were carried out without incident. In the case of patient 3, continuous ECG monitoring showed unexpected pacemaker malfunction in the magnetic field, and we were able to remove this patient from the magnetic field with no adverse effect. Information from the scan in the other 4 cases proved clinically important. Following this initial experience, we will continue to consider further requests from referring physicians for CMR in patients with pacemakers, providing the benefit-risk ratio appears favorable.

Limitations

Only 5 patients were studied, which reflects the relatively uncommon clinical request for CMR in patients with pacemakers due to good physician awareness of this contraindication. Studies were performed at 0.5T, which has theoretical advantages in pacemaker patients over 1.5T because lower RF power in the imaging sequences and other factors might suggest less

lead heating effects. Therefore, our results cannot be assumed to reflect safety at other field strengths.

CONCLUSIONS

CMR scans were undertaken safely at 0.5T using a strategy of choosing non-pacemaker dependent patients and programming their pacemakers to sub-threshold output, with bipolar lead configuration. Our experience that CMR can be safely undertaken at 0.5T extends and is in accord with other limited reports involving MR scans of the cardiovascular system. Further studies are warranted as to the safety of CMR at 1.5 Tesla in patients with permanent pacemakers, whether strategies to scan pacemaker dependent patients may also be developed and whether pacemaker design can be improved for CMR.

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