MRI in patients with implantable cardiac devices

Over the last decade there has been a considerable increase in both the number of patients referred for magnetic resonance imaging (MRI), and in the number of patients requiring implantable cardiac devices. An estimated 50-75% of patients with implanted cardiac devices may require an MRI during the lifetime of their device. Traditionally, cardiac pacemakers have been a contraindication for MRI due to the interaction between the magnetic field and the ferromagnetic components of the device, and radiofrequency field interactions with the device and leads. The advent of MR conditional implantable loop recorders (ILR), MR conditional pacemakers (PPM), and more recently MR conditional implanted cardioverter defibrillators (ICD), (Biotronik, Berlin, Germany; Medtronic, Inc., Minneapolis, MN; St Jude Medical, St Paul, MN) now permits the safe scanning of patients with these devices when performed under vendor specified conditions.

The term 'MR conditional' describes "an item with demonstrated safety in the MR environment within defined conditions". Most reported MRI adverse events are believed to be due to deficiencies in screening methods, therefore it is essential that a robust and comprehensive strategy is established to enable the safe scanning of patients with MR conditional implanted cardiac devices. It is paramount that the referring and MRI staff are familiar with the risks of scanning patients with implanted cardiac devices and remain up-to-date with safety protocols and device specific imaging conditions and restrictions. It is beneficial to liaise with vendor representatives, and essential to know how to access implant details. These may be available through an internal database and/or on the manufacturer's website. It is important not to rely on anything but official statements of MR conditionality from the device manufacturer. The patient with an MR conditional PPM or ICD must not enter the MR environment until the device has been programmed to scanning mode by a cardiac physiologist, and the implant manufacturer defined conditions for safe operation are met. Risks and safe scanning conditions are device and vendor specific. Manufacturers provide information on device specific conditions relating to factors affecting risk including, but not limited to:

- Static magnetic field strength
- Gradient magnetic field – maximum gradient strength
- Type of coil (receive only or transmit/receive)
- Spatial gradient (rate at which the static magnetic field changes with distance)
- Specific absorption rate (SAR W/kg) relating to radiofrequency energy deposition. Maximum limits for this radiofrequency energy deposition are usually specified for whole body SAR and head SAR
- Scan duration
- Scan exclusion zones
- Time after implantation – usually at least six weeks as leads are more prone to dislodgement prior to this. Some manufacturers have a built-in safety mechanism which does not allow the device to be programmed into its safe scanning mode until six weeks post implantation.

There is a theoretical risk that data stored on an ILR may be adversely affected by electromagnetic fields produced during an MRI scan. Any data stored on the device should therefore be downloaded prior to the MRI scan; in most cases this can be performed remotely by the patient. The device should be cleared following the scan as interrogation of devices following MRI has revealed ECG alterations and arrhythmias believed to be artifacts due to magnetohydrodynamic effects during the scan.

It is recommended that a local policy is developed for the identification, documentation, imaging and provision of any aftercare for patients with implantable devices undergoing an MR examination. Imaging of the patient with an MR conditional implanted PPM or ICD demands a well-coordinated, multi-disciplinary team approach (figure 1). It is essential to ensure that all staff involved are aware of the risks and scanning conditions and are satisfied that it is safe to proceed before the patient enters the MR environment. The roles and responsibilities of radiology and cardiology staff to address and reduce the risk involved in scanning patients with MR conditional pacemakers and ICDs are outlined below:

- Upon receiving the referral for MRI of a patient with an MR conditional pacemaker (as identified by the referrer) the first priority is to ensure that both the device and the leads are MR conditional. The booking radiographer confirms the device make, model and implantation date from implantation documentation (or annual pacemaker check-up information) and/or the patient’s implant card. Specific imaging conditions are then confirmed from manufacturer documentation.
- A recent chest x-ray should be reviewed by the consultant radiologist (in conjunction with cardiothoracic colleagues if required) to confirm any radiopaque device markings (if these are present for the device), to ascertain device position (pectoral region), and to ensure that there are no fractured or abandoned leads present. Some leads will have radiopaque markings to identify them as MR conditional. However, it is important to note that existing lead models which have been retrospectively approved as MR conditional will not have radiopaque markings, so not all leads will be identifiable in this way. Good product knowledge, comprehensive implant information and liaison with manufacturer representatives will help make this less of a concern.
- Immediately prior to the scan a cardiac physiologist interrogates the device, confirms the make and model of the device and leads (which should match the information obtained by the booking radiographer), and programs the device to ‘scan mode on’ from which point the patient is monitored by ECG and/or pulse oximetry.
- The scanning radiographer also confirms that the device is MR conditional from the documentation, and checks device scanning conditions before the patient enters the

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scan room. The scan is performed in ‘normal SAR mode’ and the patient monitored (by ECG and/or pulse oximetry) throughout for any deviations in pulse rate/haemodynamic function. A crash trolley and defibrillator with pacing capabilities must be immediately available in the MR controlled access area.

- Immediately following the scan the cardiac physiologist reprograms the device to ‘scan mode off’ and checks the device to ensure normal function.
- Checks at each stage of the process are documented on a standardised form and signed by the relevant healthcare professional, and this documentation should be recorded on the radiology information system.

Image quality is largely unaffected by the presence of cardiac devices with the exception of thoracic imaging in the region of the implant. Image distortions and signal voids associated with magnetic susceptibility artifacts will result when the field of view is near to, or includes, the device (figure 2). Further, magnetic field inhomogeneity caused by the presence of the implant poses a challenge for fat suppression imaging. Imaging in the region of ILRs is not significantly degraded by artifact (figure 3), however PPMs and ICDs can cause substantial artifacts. Susceptibility artifacts are more problematic with inversion recovery imaging and steady state free precession (SSFP) sequences used in cardiac MRI. Various techniques to minimise susceptibility artifacts when imaging the heart in these patients have been suggested:

- Scanning on arrested inspiration which moves the heart inferiorly with the diaphragm and away from the position of the device.
- Using a cardiac shim or frequency adjust over the heart.
- Switching the phase and frequency encoding direction. This may project the artifact away from the area of interest as susceptibility artifacts are more pronounced in the frequency encoding direction.
- Increasing the receiver bandwidth, although this incurs an increase in image noise.
- Spin echo sequences are less susceptible to artifacts than gradient echo sequences.
- Susceptibility artifacts are less apparent on spoiled gradient echo sequences compared to steady state imaging, although there is a compromise in terms of image contrast (figure 4).

**Conclusion**

In conclusion, it is possible to safely image patients with implanted cardiac devices in MRI. The device and leads must be identified as MR conditional, following which a coordinated multidisciplinary approach should be employed to further confirm that the device is safe, is programmed into ‘scan mode on’, and imaging conditions specified by the manufacturer are adhered to. The patient must be monitored by ECG and/or pulse oximetry, and a crash trolley and defibrillator with external pacing capabilities should be immediately available in the department. It is essential that all staff involved in the imaging process are fully informed of the device (and lead) details, risks and scan conditions. Good communication between referrers, radiology and the cardiac physiology team will achieve a safe and efficient scan procedure.

**References**


**Figure 1**
Flow chart depicting a multidisciplinary approach to ensure safe imaging of MR conditional pacemakers.

**Figure 2**
Magnetic susceptibility artifact from MR conditional pacemaker in the left pectoral region.

**Figure 3**
Minimal susceptibility artifact from insertable loop recorder present at the border of the right ventricle.

**Figure 4**
Susceptibility artifact present in the left ventricle on SSFP 4 chamber view (A). Spoiled gradient echo four-chamber view (B) eliminates artifact but has poor image contrast.