A guide to improving and testing the MR compatibility of external devices

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Purpose

In research applications, it is sometimes the case that a normally non-MR-compatible item of equipment needs to be used near or within the bore of the MRI scanner during simultaneous MR imaging. Examples include cameras, tracking systems, feedback devices in fMRI, tools in interventional MRI, moving platforms to simulate cardiac or respiratory motion, and many others. The aim of this educational e-poster is to clearly explain the interactions between external devices and the scanner that can be expected, how to modify the device to avoid these interactions, and how to test if a modified device is truly MR-compatible. Although a wealth of information exists concerning MR safety, less information is available regarding other aspects of MR compatibility. In this educational review, we provide a practical guide to help address this issue. This work is a compilation of basic physics, well-known engineering techniques, and examples from our own work.

Outline of Content

In this review we divide scanner-device interactions into three main categories, relating to the three main fields in question: the B0 field; switching gradient fields; and the RF field. In all three cases interactions are possible in both directions: not only can the scanner adversely affect the device, but the device can adversely affect MR data quality. In all cases, there are device modifications that should be made in order to avoid problems, as well as tests that can be performed to assess MR compatibility. Here we list some of the main points that will be discussed:

B0 field

Probably the most well-known compatibility issue is the force or torque that results if ferromagnetic objects are placed near the main magnetic field. In this case, standards exist for external devices [1, 2], but these are mainly based on MR safety considerations. In this review, we focus on smaller effects, such as local deformations of the B0 field, which occur even when a device easily meets safety requirements. Selection of materials based on careful consideration of magnetic susceptibility is particularly important [3]. Field mapping can be used to test unknown materials or to assess the impact of the device as a whole (Fig. 2). If the item under consideration is electronic, then saturation of inductors with ferrite cores can lead to non-linear behaviour of the inductor and failure of the device (the magnetic saturation level of inductor cores is often on the order of 0.1 T). This is a particular problem for switched-mode power supplies. Air core inductors can solve this problem. Field-effect transistors (FETs) also behave differently depending on their orientation to the main magnetic field, due to the Hall effect [4]. Magnetic storage devices and magnetic switches are likely to malfunction at typical B0 fields used in MRI.

Switching gradient fields

The rapid switching of the gradient fields (often known as dB/dt) can induce eddy currents in any conductive material in a device. These eddy currents can have a number of undesirable effects, including heating, mechanical vibrations (due to interaction with the B0 field) and corruption of the MR images (e.g. image distortions, ghosting in EPI). Eliminating conductive material is the best solution to this problem. High dB/dt can also generate noise in cables used to transfer data to or from the device. A related issue is mechanical vibrations of the scanner, caused by gradient switching. These can reduce the precision of tracking devices.

RF field

RF energy from the scanner can cause heating in wire loops and interfere with electronic equipment. Shielding can solve these problems. Copper is a useful material for this, since it has a magnetic susceptibility close to that of tissue, but is highly conductive. A maximum SAR pulse sequence with trains of RF pulses (e.g. TSE) can be used to 'stress-test' the device. The reciprocal problem also occurs: external devices can introduce noise into MR images. Any cable running through the Faraday cage can act like an antenna. Ideally, optical fibre should be used for data transfer; if this is not possible, then shielded cable, grounded to the Faraday cage can suffice, particularly if combined with RF traps or filters.

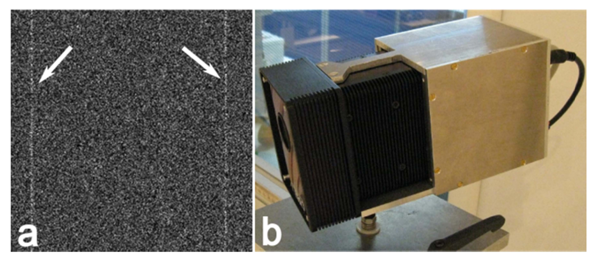

Figure 1: RF testing by disabling signal excitation is a sensitive means to detect interference from external devices: (a) noise from a camera system; (b) good shielding can prevent this problem.

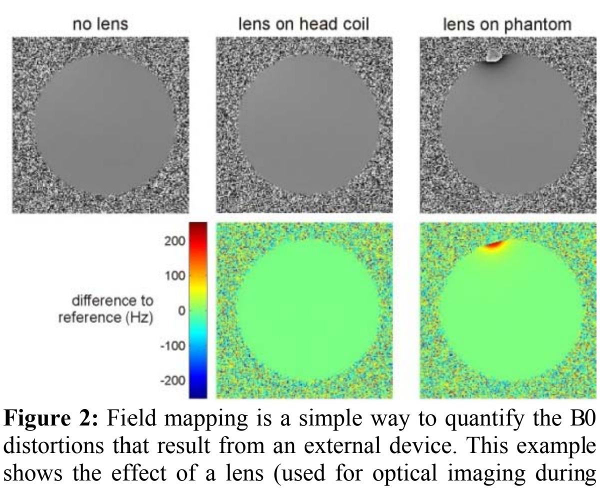

Figure 2: Field mapping is a simple way to quantify the B0 distortions that result from an external device. This example shows the effect of a lens (used for optical imaging during MRI) on the B0 field in a water phantom at 1.5 T [5].

Summary

Even when a product is considered 'MR safe', it may not be truly MR compatible. There are a number of effects unrelated to safety to consider when using an electronic device in the MR environment. This review provides a practical guide to help those undertaking this task.

References

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Acknowledgements: This work is a part of the INUMAC project supported by the German Federal Ministry of Education and Research, grant #01EQ0605.