

**Static Magnetic Fields: Bioeffects, Regulation and Management**  
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Ultrahigh field MRI (>3T) offers many opportunities in clinical practice and biomedical research. However it also poses some definite risks to patients or volunteers and to staff, that can be minimized by careful management. Furthermore, ultrahigh field MRI will generally expose staff and volunteers to static fields greater than the exposure limits recommended by international bodies in order to avoid potential, currently ill-defined hazards to health. In fact most MRI risks exposing staff to switched gradient fields in excess of advised exposure limits doubt [1]. The issues requiring special consideration at ultrahigh field generally relate to the static magnetic field, although RF heating also becomes a more serious issue.

**Regulation of magnetic field exposure for staff, patient and volunteers**

The international body that provides exposure guidelines in this area is the International Commission for Non Ionizing Radiation Protection (ICNIRP), which is recognized as the expert body in this area by the World Health Organization. ICNIRP is currently reviewing its guidelines for exposure to magnetic field [2]. However its 1998 guidelines [3] set a ceiling limit for occupational exposure to static magnetic fields of 5 T for limbs, 2 T for whole body, with 200 mT time weighted average over a working day. These exposure limits are generally designed to avoid acute effects (in particular dizziness) rather than any long-term risks to health from exposure to the various magnetic fields associated. Most countries also have local committees of scientific advisers who also provide exposure guidelines in this area [4, 5]. In general different bodies are then responsible for implementing the scientific guidelines to produce exposure limits for the protection of staff and patients involved with MRI, and these vary between different countries [4, 6, 7]. In many jurisdictions staff exposure to ultrahigh field could exceed static field exposure limits, although the legal weight of these limits varies. Volunteers can usually be exposed to any field strength provided that the study is carried out with local IRB/ethics committee approval [2, 8].

Irrespective of any exposure limits, it is clearly sensible to devise working practices to minimize unnecessary staff exposure. For instance patient handling systems should be designed to enable subject positioning in a region of low magnetic field. Furthermore local rules should be written to record and control staff exposure, although staff exposure can only be monitored approximately since no static field meter operating above 2 T is currently commercially available.

Any exposure to a static field must inevitably involve moving into that field, which must lead to additional exposure to time varying fields (dB/dt) and hence induced currents, and indeed to a gradient fields (dB/dz). No limits on field gradient exist, but limits do exist on induced current densities (10 -40 mA/m<sup>2</sup> at these frequencies [3]). The available theoretical [9] and empirical evidence suggests that such normal occupational movements around 3T and 7T magnets may well exceed dB/dt or current density exposure limits.

It should be noted that there is remarkably little data available on which the regulatory bodies can base their limits, and since the regulatory bodies generally reach their conclusions using the precautionary principle this tends to lead to exposure limits which are based on extrapolation of results from beyond the region of the original data, and which seem surprisingly low to the MRI community [1]. People working in high field MRI should consider conducting careful, published safety studies- for instance there is virtually no data available on the typical exposures to magnetic fields experienced by staff working in MRI, so

the regulatory bodies have no idea how their exposure limits are likely to impact on MRI workers.

### **Interactions with the human body**

There are a variety of potential mechanisms for interactions between the human body and magnetic fields [10, 11]. However, so far none of these have been shown to have clinically significant, long-term or short-term, deleterious effects at currently achievable field strengths, although further research is necessary in some areas. For some time it was thought that the magnetohydrodynamic effect on blood flow in the aorta and hence on blood pressure, would constrain imaging at currently achievable field strengths, but now the evidence [12, 13] suggests that this will not be relevant until field strengths reach approximately 15T.

The most significant observed interaction with the human body is the 'vertigo effect', which is thought to be due to an interaction between the magnetic field, and the vestibular system of the inner ear that is responsible for balance. To avoid excessive vertigo, subjects must be moved slowly into the magnet (for instance moving from 3 T to 8 T in 3-4 minutes [13]). Although most people do not find the vertigo effect to be more than a minor nuisance, it does limit the time that people are willing to work inside the bore of ultrahigh field magnets. Furthermore risk assessments should be carried out to take account of this effect when people are performing critical tasks in the vicinity of the magnet.

### **Siting issues**

For an unshielded 7 T magnet, the 0.5 mT isofield line would occur at more than 20 m axially from the centre of the magnet. Therefore ultrahigh field magnets are sited within an iron box (of approximately 150 tonnes) to provide sufficient passive shielding to restrain the stray field and thus make siting requirements feasible. The mass of the magnets themselves is approximately 40 tonnes, so the underlying geology of the site, and the ability to crane the magnet must be considered.

Some of the spectrometer control equipment will not be able to operate at significant stray fields, but cable lengths need to be minimized. Therefore the site should also be designed with space allocated for ancillary equipment at an appropriate location. Since the stray field extends further axially, this is likely to be next to the magnet.

Room plans must also consider safety in event of a quench, which is particularly important for ultrahigh field magnets which store a larger volume of cryogenic gases. Following a quench, the pressure in the magnet hall will increase greatly, so, for instance, outward opening doors must always be provided.

### **Management of MR unit**

The most significant danger from MRI is the 'projectile effect'. The force on a ferromagnetic object is proportional to the product of the static field strength and the field gradient. This means that the forces experienced around a magnet will depend on the exact field profile and the nature of the magnet shielding, including any passive shielding. It is extremely important that best practise in MR room design is followed at ultrahigh field [14, 15]. Furthermore access controls must be instigated to prevent magnetic objects inadvertently being brought into the magnet hall, and to avoid exposing members of the general public with sensitive implanted medical devices and other metal fragments in their body to fields of greater than 0.5 mT. In particular the magnet room door should be kept locked unless there is a subject in the magnet, and the operator should have a clear view of the magnet room door.

### **Acoustic Noise**

Acoustic noise will generally increase with field strength, depending on the design of the gradient coils. Sufficient acoustic insulation must be installed to avoid exposing the scanner operators to high noise levels for long periods of the day. Similarly the materials lining the magnet hall should be chosen to damp the reflection of sound within the room. Adequate ear protection must be provided for volunteers or patients.

### **RF power deposition**

Clearly the SAR deposited by a given pulse sequence will go up with field strength, although in practice this is always controlled by the scanner software, and so in normal use it will not be an issue for the user except in that it may limit the use of some sequences at high field. However at high field the RF deposition becomes less uniform, leading to hotspots, which must be borne in mind particularly when using local (surface) or home built transmit RF coils, or when scanning regions with limited heat dissipation mechanisms such as the eye.

### **Implants and conductors on the surface of the skin**

Probably the most important practical effect of RF heating at high field is the potential interaction between the RF field and implants in the body or conductors attached to the surface of the skin (such as ECG electrodes) [16]. Lists of devices and implants that have been tested can be found in the literature [17]. It is very important to recognise that the interaction between the electric fields and these objects depends on the SAR but also on the relative size of the object compared to the wavelength of the electric field. Therefore although in general the heating effect will go up with field strength, in particular circumstances the object may be 'tuned' to the electric field at a particular RF frequency, giving greater heating at lower field. [18]. Furthermore the electric fields produced will depend on the exact configuration of the RF coils, and therefore the heating effect will depend on field strength, exact model of scanner, and even on the position of the object within the coils. Therefore if an object is listed as apparently being safe to use in an MR scanner it is important to check exactly in which configuration it was tested. Many implants have not been tested at ultrahigh field, and the ASTM International have designed internationally agreed methods for testing the MR compatibility of implants in terms of both heating [19] and displacement [20].

### **Conclusion**

Ultrahigh field MRI can be performed with no apparent ill effects for staff or subjects, provided careful management procedures are followed.

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