Intraoperative MRI: Safety

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KEYWORDS

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- Neurosurgery • Intraoperative imaging

MRI safety has been a central component of the diagnostic MRI industry. There are more than 10 million diagnostic magnetic resonance (MR) procedures performed safely each year in the United States. The American College of Radiology guidelines for diagnostic MRI facilities have ensured a very good safety record since the late 1970s. The successful incorporation of MR into the operating room requires similar adherence to strict safety guidelines and an understanding and respect for the powerful (and dangerous) physical forces of MRI. Moreover, the use of MRI during surgery creates a unique set of safety concerns for the patient including MRI interpretation and infection control challenges.

PHYSICAL FORCES OF MRI

There are three major physical forces used in MRI that can generate a safety risk for patients and staff: the static magnetic field (B_0), the gradient magnetic field (dB/dt), and the radiofrequency (RF) electromagnetic field. The major risks in the MR environment related to these forces are projectiles, burns, dislodged ferromagnetic implants, and medical device malfunction or failure.

The B_0 is the main magnetic field of the MR scanner. It is always "on." Its primary function is the alignment of protons. There is substantial literature on the potential biophysical risks of large magnetic fields including extensive study on animals and human exposure in industrial settings.[1,2] To date, there have been no firmly established adverse effects of magnetic fields of up to 3T. The mechanical effects of B_0, however, are extremely dangerous. The magnetic field is highest at the magnet and decays over distance from the magnet (spatial gradient). The MR safe line is defined at 5 G (1T = 10,000 G). Thus, all MR installations have a unique gauss plot to define the area around the device (**Fig. 1**). The implication for safety is critical. Ferromagnetic objects brought within the magnetic field will be accelerated across the spatial gradient (drawn from lower to higher magnetic force) until impact at the magnet. The heavier the object, the faster the acceleration and higher the potential energy delivery to health care workers or the patient near the intraoperative MRI (iMRI) (**Fig. 2**). Diagnostic MR facility safety programs are very sensitive to the dangers of the static magnetic field. iMR centers must also recognize the dangers of rotational forces exerted on objects in the static field. All surgical tools used in iMRI must be cleared for potential ferromagnetic content. Tools with little or no ferromagnetic content can be considered "MR compatible" and used within the magnet during imaging. Other tools can be considered "MR safe" if the ferromagnetic content is too small to become projectiles in the static field, but high enough to degrade the quality and spatial accuracy of acquired images. These tools may be

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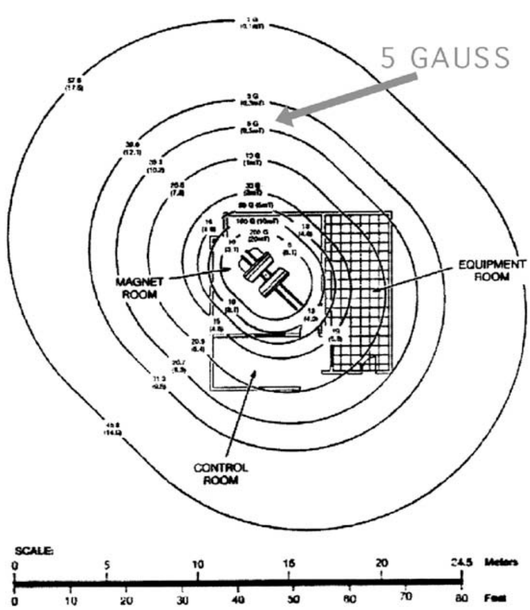

Fig. 1. Gauss plot.

useful during surgery, but must be respected for their likelihood of rotating within the field to align with B_0.

The second major physical force in MR is the dB/dt. During image acquisition, a smaller magnetic field is applied across the main field at varying angles and times to create perturbations of B_0. This permits the localization of protons. The safety concerns of the gradient field include the induction of voltage or current in tissues or implants (Faraday's law: changing magnetic field induces current). It has the potential to induce neural or muscular activation and create heat within tissues. It is the major source of noise in the MR environment. The gradient field can cause induced voltage in conductive objects (eg, pacemaker), instrument movement or failure, and spatial artifacts in the images. To limit the risks of the gradient field, all scanners are optimized to function at low dB/dt (time rate of change of gradient magnetic field<20T/s).

Fig. 2. This photograph taken in a diagnostic MR suite illustrates the risk of violating the spatial magnetic field with an anesthesia cart.

The third physical force in MRI is the RF electromagnetic field (B_1) which induces the excitation of protons. The main risk of the RF field is heating. The energy generated by B_1 is quantified in watts or kilograms and referred to as the specific absorption rate. It is one thousand times stronger than dB/dt and can cause burns, interfere with powered instruments (eg, anesthesia equipment), and induce currents in looped conductors (eg, a Bovie electrocautery wire). The danger of RF is addressed by limiting the specific absorption rate, avoiding looped wires near the patient or staff, and individually screening equipment for compatibility with the RF field in the ranges used for iMRI cases.

PHYSICAL SAFETY STANDARDS

iMRI suites and their designated perioperative areas follow implemented safety guidelines and practices that were set forth by the American College of Radiology for diagnostic MRI facilities. An additional set of practices unique to those facilities involved in interventional procedures is also necessary for staff, patient, and physician safety. Standard physical safety protocols at Norton Hospital (Louisville, Kentucky) for the 0.5T "double-doughnut" General Electric Medical Systems, are referenced as general guidelines for safe surgical intervention in this article.[3–5]

THE IMRI SUITE AND ZONE RESTRICTIONS

MRI suites are sectioned into zones based on the level of physical risk from the magnet and are designed to prevent injuries to patients, staff, and property (**Fig. 3**). A protocol for creating and maintaining four zones is now followed for such purposes. Zone I is open to all staff, patients, and the general public as a transition zone for entrance into the MRI suites' functional areas. No specific level of training is needed for staff access. zone II is the gateway from an area of no magnetic danger (zone I) to an area that may be included in the 5-G line perimeter (zones III or IV).[3,4] A potentially dangerous amount of static magnetic field is assumed to be within the 5-G line, which can cause harm to ferromagnetic substances, equipment in the area, and persons. Static magnetic fields cause objects to become missiles. Therefore, all patients are monitored in zone II and are