Anesthetic concerns for pediatric patients in an intraoperative MRI suite

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Current Opinion in Anesthesiology 2011, 24:480–486

Purpose of review
Intraoperative magnetic resonance imaging (iMRI) is an evolving technology used to provide precise intraoperative navigation during a variety of neurosurgical and other types of surgical procedures. Anesthesiologists need to be aware of the unique challenges created by this environment. Failure to recognize the differences between the diagnostic MRI environment and the iMRI environment can compromise the safety of the patient and operating room staff and present logistical problems.

Recent findings
Recent surgical reports herald the uses and benefits of iMRI. However, there are a few in the anesthesia literature addressing the significant benefits and the anesthesia-specific issues this technology creates. We will review recent reports describing anesthetic care of patients in this environment as well as examine the recent surgical and radiologic literature as they relate to issues faced by anesthesiologists.

Summary
We describe the design of different iMRI suites as well as provide a breakdown of both patient and equipment issues encountered by anesthesiologists practicing in this environment. Finally, we offer our ongoing experience in this environment and provide suggestions to optimize patient outcomes.

Keywords
intraoperative magnetic resonance imaging, pediatric anesthesia, pediatric neurosurgery

Curr Opin Anesthesiol 24:480–486

0952-7907

Introduction

Advances in multimodal imaging approaches in neurosurgery provide precise guidance for the resection of tumors and other lesions. Intraoperative magnetic resonance imaging (iMRI) is an evolving technology that combines the imaging capabilities of MRI with an operative suite [1,2]. This technology has been most useful during neurosurgical procedures [3–6], but has applications in other operative settings in which precise location of a surgical lesion and its margins are essential [7]. Given the potential benefits and hazards posed by the introduction of an MRI in an operating room environment, this review will discuss the aspects of designing and staffing a safe environment for the anesthetic management of patients undergoing iMRI-guided neurosurgery.

History

iMRI grew out of an effort to improve intraoperative navigation and resections during neurosurgical procedures [8]. Prior to the development of the iMRI, stereotactic navigational tools had been utilized to facilitate localization of lesions and improve precision of resection. These systems employed frame-based or frameless systems. Frame-based systems present special problems in children, including the need for general anesthesia for frame placement as well as image acquisition [9]. There are concerns regarding the access to the patient's airway and ability to manage an inadvertent loss of airway while a frame is in place on a child's head. Frameless systems were developed to alleviate these issues. The advantages of frameless systems include elimination of the need for general anesthesia for frame placement in children and access to the patient's airway without a metal frame held in place by pins secured to the patient's skull. A frameless system still allows for precise localization of lesions in deep brain structures or near eloquent cortex and facilitates surgical exposure during resection.

The problem with both frame-based and frameless systems is their reliance on images acquired preoperatively. The dependence upon images acquired prior to any surgical positioning and/or manipulation can be confounded by brain shift. Brain shift is a term that describes the movement of anatomical structures intraoperatively

[10]. Brain shift can result from position changes, anesthetic effects, egress of cerebral spinal fluid (CSF), and mass resection [11]. The amount of brain shift varies with the lesion's tissue type, patient positioning, size of the craniotomy, CSF loss, degree of hyperventilation, and volume of the lesion resected. Furthermore, the amount of brain shift increases with the duration of surgery. Thus, the accuracy of these systems diminishes during the case. Intraoperative imaging should reveal the extent of brain shift and the evolving anatomy during the course of a surgical procedure [11].

Collaboration between the Brigham and Women's Hospital in Boston and General Electric resulted in the world's first iMRI system in 1994 [8]. This 0.5 Tesla magnet had surgical access pods on each side of the magnet (Fig. 1). This space allowed a surgeon to operate on a patient who was physically in the bore of the magnet for the duration of the case.

Types

There are currently three main types of iMRI systems commercially available. There are some subtle variations upon them, particularly with the recent proliferation of multimodal imaging surgical suites [computed tomography (CT), PET, functional MRI (fMRI)]. Each group has its own set of advantages and disadvantages.

The original 'open' system at the Brigham and Women's Hospital had a stationary magnet (0.5 T) and a stationary patient. The main advantage of such a system is its ability to obtain frequent 'real-time' images. Despite this advantage, there are several significant disadvantages. First, there is extremely limited access to the patient for both surgeons and anesthesiologists creating profound difficulty in managing intraoperative misadventures such as uncontrolled bleeding or loss of airway. Second, because the procedure occurs within the bore of the magnet, it is necessary for all equipment to be MRI safe, including all surgical instruments. Although tools exist, their quality often is inferior to conventional instruments. Furthermore, some equipment, such as electroencephalographic leads and monitors is not at all compatible with the magnetic resonance (MR) environment. Thus, these systems are less common than newer models.

Figure 1 The first intraoperative MRI system

The first intraoperative magnetic resonance imaging (iMRI) system was operational at the Brigham and Women's Hospital (Boston, Massachusetts) in 1994. Note the double 'donut' configuration of this system that provides narrow access pods to the surgical site.

Key points

- iMRI technology is becoming more common as it is believed to facilitate a better patient outcome, particularly for neurosurgical procedures.
- There are several types of systems that will inform the specific anesthetic concerns.
- Anesthetic management of patients in this environment encompasses many extra challenges compared to a conventional operating room.
- Anesthesiologists should be involved from the outset to aid in designing the room and developing policy to ensure optimal patient outcome and safety.

Systems utilizing a mobile magnet and stationary patient have become more popular, as they offer significant advantages over 'open' configurations (Fig. 2a and b) [12]. However, one disadvantage is that intraoperative image acquisition can only occur after the patient has been placed within the magnet, which requires additional time [13]. If this process is initiated with an open cranium, maintenance of the sterile field is imperative. This can be accomplished by encapsulating the patient and the open cranium in sterile drapes. Also, in order to account for MRI unsafe instruments and equipment, extra instrument counts must be performed prior to moving the magnet into position. However, these systems have some advantages. First, the suite can be configured to essentially be a normal operating room (Fig. 3). Thus, surgical access to the patient is less impaired. Normal surgical instruments can be utilized – regular microscopes, drills, retractors, and so on. Further, intraoperative imaging can be combined with updatable navigation technology, which can account for the aforementioned brain shift. The cost of such a suite can be prohibitive, as these systems require rooms with specialized MRI shielding because of the associated high magnetic fields. Systems can utilize small, lower field strength magnets in an existing operating room at a much lower cost [14]. The main disadvantage to a lower field strength system is its inferior resolution.

Figure 2 Intraoperative magnetic resonance imaging acquisition

In a mobile magnet and stationary patient configuration, (a) the patient is covered with a plastic drape to preserve sterility. (b) The magnet is then moved in position with the patient's head inside the bore of the magnet.

The advantages and disadvantages of a stationary magnet and movable patient system are similar to those for a movable magnet and stationary patient. One difference with having a movable patient platform is the opportunity to include several different imaging modalities such as positron emission tomography and biplanar fluoroscopy within an operative suite. The disadvantages relate largely to the docking of the anesthetized patient, intraoperative monitors, and anesthesia machine into the specific imaging system. Nevertheless, some centers are using these systems with great success [15•].

Anesthetic considerations in an intraoperative magnetic resonance imaging suite

Safe and effective anesthesia in an MRI environment is fraught with challenges [16]. The American Society of Anesthesiologists (ASA) has recently published practice guidelines on care in MR environments [17]. It is likely to be necessary to have even more stringent safety mechanisms in place for iMRI given the added complexities of caring for a patient undergoing a surgical procedure in such an environment (as opposed to purely diagnostic imaging). Special issues for anesthesia providers in this environment can be broken down into several categories.

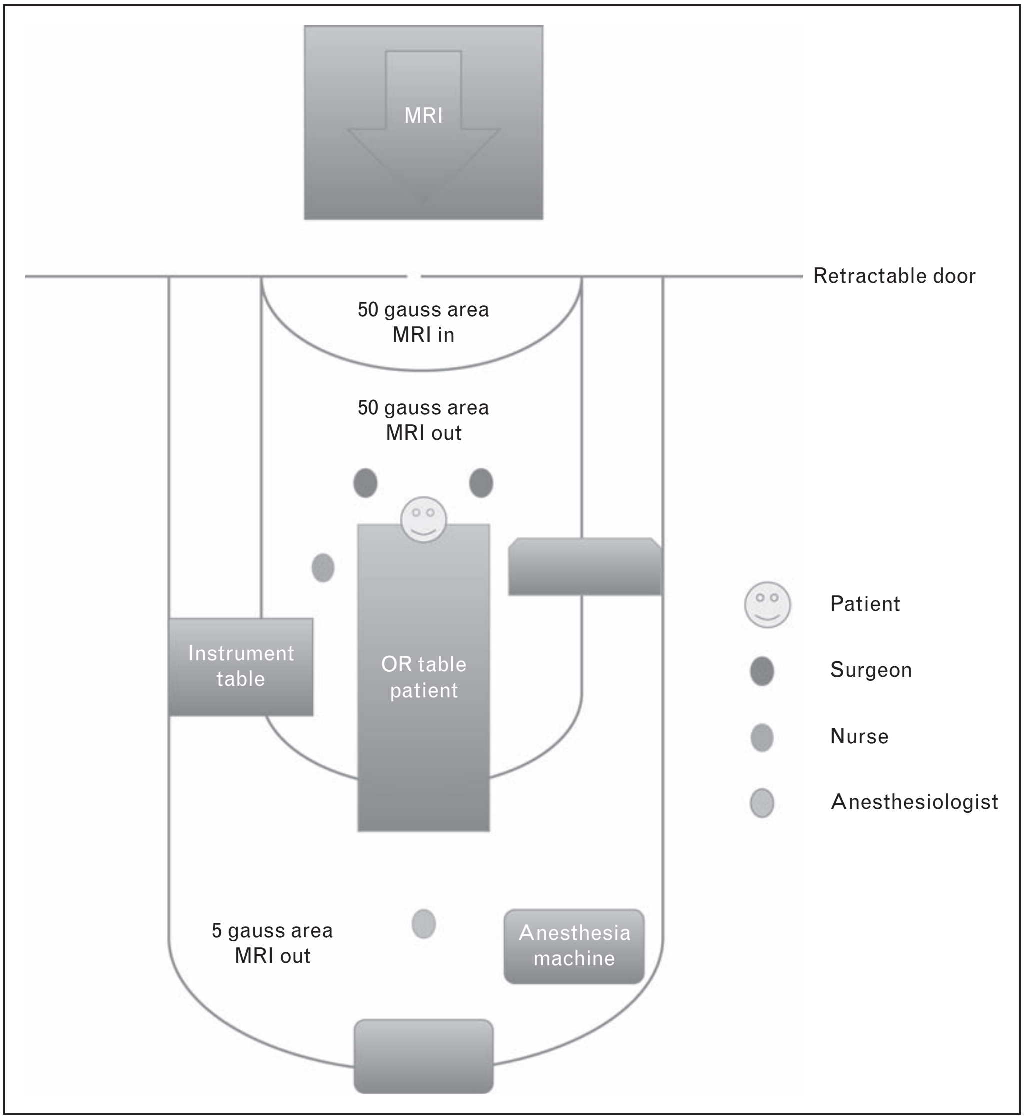
Equipment issues

When describing implantable devices and medical equipment, specific terminology has been established to describe their relative safety in an MRI environment. MRI safe means that the item poses no risk in such an environment. MRI unsafe means that the item poses a hazard in all MRI environments. MRI conditional refers to items that have been demonstrated to pose no known hazards in a specified MRI environment with specified conditions of use. An example of this would be an MRI conditional anesthesia machine that is conditional to 100 Gauss in a 1.5 T magnet. Beyond that field strength, the item may be unsafe [18].

Newer iMRI systems that allow movement of either the patient or the magnet will enable MRI unsafe surgical instruments to be used intraoperatively, as long as these instruments and equipment are removed during imaging. However, the patient still needs to be anesthetized and carefully monitored. This necessitates the use of MRI safe or conditional anesthesia equipment, including the anesthesia machine, physiologic monitors, and infusion pumps. Other anesthesia equipment that is MRI unsafe can be moved outside the 5 Gauss line during scanning. This allows the use of normal airway equipment (such as a difficult airway cart) and other useful devices such as ultrasound units.

There are a variety of commercially available MRI conditional anesthesia machines. It is essential that these machines be incorporated in an iMRI environment. Additionally, several MRI conditional monitoring systems are available and should be utilized. The ASA practice advisory falls short of recommending the use of such anesthesia machines and monitors for patient care at all times in an MR environment. However, iMRI presents a different and potentially more complicated set of challenges for the anesthesiologist. Namely, in addition to the imaging portion of the procedure, the patient still needs to be kept safe and anesthetized for the surgical component and patients undergoing neurosurgical procedures generally require more extensive monitoring than those solely undergoing diagnostic scans. It is not acceptable to have a conventional anesthesia machine or infusion pumps outside the 5 Gauss line as some practitioners employ in some diagnostic imaging because of the risks of ferrous equipment becoming projectiles

Figure 3 Layout of intraoperative magnetic resonance imaging setting



The relative positions of the operating room staff and equipment are shown in this diagram. OR, operating room.

(Fig. 3). Given the significant expense of the development of an iMRI suite, the expense of special anesthesia equipment does not significantly increase the overall cost. However, the safety benefits from utilizing MRI conditional equipment in this environment are legion.

Positioning/patient access

Positioning of the patient and the consequent access the anesthesiologist will have to the patient will be dictated by a number of factors. First, the type of iMRI system employed will come into play. Movable magnet/stationary patient systems have tables fixed in a particular location in the operating room. Most often, the patient's head will be 180 degrees away from the anesthesiologist during the procedure. The actual distance may be 10–15 feet from the anesthesia workstation, limiting access to the patient. In this scenario, with an anesthetized patient located far away, emergent airway management may be particularly complicated, especially with a prone patient secured in a head frame. This situation can be further complicated by the presence of the necessary radiofrequency head coil, further obscuring access to the airway. Consequently, meticulous attention must be taken to ensure the endotracheal tube is well secured prior to patient positioning and turning of the bed (Fig. 4). Many practitioners will employ nasotracheal intubation in this situation, as it might offer a more secure method than an

Figure 4 Close up view of a prone patient's head prior to draping

Note the extremely limited access to the airway due to the presence of the head pinning system and receiving coil. Because of these additional concerns in the intraoperative magnetic resonance imaging (iMRI) suite, meticulous attention should be paid to ensuring a secure airway prior to covering patient with sterile drapes, proceeding with the surgical procedure, and placing the patient within the bore of the magnet.

Figure 5 A view of the anesthesiologist's work area

The anesthetic management of neurosurgical patients requires specialized monitors and infusion pumps. Given the limited access to the patient, all catheters (intravenous, intraarterial, bladder, etc.) must be secured and readily accessible under the surgical drapes.

orotracheal airway. In addition, all catheters (intravenous, intra-arterial, bladder, etc.) must be secured and accessed under the drapes. In our institution, we have jointly developed protocols for positioning and draping of the patient in conjunction with the nurses, neurosurgeons, and MR technologists. This allows us to have limited access to the patient relative to the situation in conventional operating rooms (Fig. 5).

Special training

The American College of Radiologists has developed practice guidelines for personnel working in an MRI environment [19]. These guidelines extend to nurses, surgeons, and anesthesia providers in an iMRI setting. A component of these guidelines is the designation of an MRI safety officer, often an MR technologist. It is advisable that anesthesiologists, nurses, and surgeons work with this safety officer to develop specific training and orientation modules to ensure practitioners in such an environment have undergone proper education to maximize safety. This training/orientation should be specifically designed to encompass not only the standard safety consideration of working in an MR environment, but also the special considerations and safety concerns of iMRI.

This should include all the basic information for working in any MRI environment. Additionally, the individual must understand the unique challenges in working in an environment in which the magnetic field is a moving entity. Thus, a greater degree of vigilance is required to ensure that no ferromagnetic objects are unaccounted for when moving the patient into the magnet or moving the magnet over the patient. It is highly recommended that groups working in such an environment work together to develop protocols for ensuring safety of both patients and staff in this environment that are tailored toward the specifics of the individual institution.

Limitations

Although iMRI can offer tremendous advantages to patients undergoing a variety of surgical procedures, there are significant limitations to these systems. These limitations can be divided into those that are presented by the equipment, patient, and environment.

Equipment issues

Although there exist several MRI conditional versions of common equipment needed for modern anesthetic care such as anesthesia machines, monitors, infusion pump, endotracheal stylets, and so on, there are a number of pieces of critical and necessary equipment that do not have MRI conditional counterparts [17,20]. These include defibrillators, fluid-warming devices, forced air warming devices, Doppler ultrasound machines, peripheral nerve stimulators, and core temperature probes. Obviously, few would want to initiate a case in such a high-tech environment without many of these items. The challenge then becomes how to use them or have them immediately available without compromising the safety of the patient or caregivers. Once again, a collaborative approach works well in this situation when designing checklists and protocols to allow ease of use concomitantly with good safety practices. Our institution routinely employs such MRI unsafe equipment during the nonimaging portions of the case, when the MRI unit is safely garaged. We then remove all MRI unsafe components such as the precordial Doppler and peripheral nerve stimulator prior to bringing the magnet into position. There is a systematic method of accounting for removal of such devices as well as a standardized checklist that is reviewed prior to bringing the magnet into position. The checklist includes all items and issues that affect anesthesiologists, surgeons, and nurses. Finally, we have tethered a number of MRI unsafe pieces of equipment in the suite to the wall with cables to prevent them from ever being inadvertently moved within the 5 Gauss line.

The ability to perform various types of neuromonitoring is greatly compromised in this suite. For example, needle electrodes used in motor and sensory evoked potential monitoring create an array of potential hazards if they are inadvertently left in place during imaging [21]. They can be used in this room as long as this is done before the magnet enters the operating room. A checklist is used to assure all MRI unsafe items are counted and moved beyond the 5 Gauss line.

In addition to limitations on MRI unsafe equipment, there are issues with the room itself that is designated MRI safe. For example, special head pinning systems are employed with iMRI systems. However, there have been problems with these including poor mobility of the device at its various joints, difficulties with proper pin placement, difficulties with proper pin seating in the skull, and device durability issues. Also, placement of radiofrequency head coils to facilitate image acquisition creates a number of challenges for the anesthesiologist, particularly as these challenges may further limit access to the patient's airway.

Patient issues

There are certain patients who should not enter the MR environment because they could potentially suffer injury or death. These patients include individuals with implanted defibrillators or pacemakers [22,23]. Other implanted devices are more controversial such as vagal nerve stimulators [24] and cochlear implants [25]. It is important to have conversations with the institutional MRI safety officer prior to scheduling patients with implantable devices in an iMRI suite.

Environmental issues

The physical environment that exists in an iMRI suite is different from other operating room suites. For example, because of the need to keep the magnet supercooled with liquid helium or nitrogen in an effort to maintain a pristine magnetic field, the operating room suite itself possesses a limited ability to alter room temperature. For many adult patients, this may be a minor inconvenience [13]. However, this can significantly adversely affect care of small children, especially neonates [26]. Small babies have an extremely limited ability to self-regulate temperature. Thus, exposure to a cold environment can result in significant hypothermia and its consequences. Active heating with forced hot air warmers is essential in maintaining proper patient temperature during the nonimaging phases of the procedure. Covering the patient with impermeable sterile drapes during the imaging phase prevents most radiant heat loss by the patient.

In addition, there are patients who are too large to undergo intraoperative imaging. The size of the bore of the magnet will be the limiting factor. It should be noted that although a patient may be a tight fit in a diagnostic setting, the same patient may not necessarily fit into the iMRI magnet due to the additional burden of drapes to maintain sterility as well as surgical positioning issues. Pressure sores and localized ischemic tissue injury can result from direct skin contact with the operating room table, other equipment such as imaging coils, and the inner bore of the magnet. Judicious padding and adjustment of the patient's position should be carefully performed before the operative and imaging phases.

Conclusion

Intraoperative navigation technology for neurosurgical procedures has advanced significantly over the past two decades since its original development. iMRI is the latest in the progression of intraoperative navigation techniques. Surgeons and radiologists are aware of the benefits that these technologies offer [27,28•,29–31,32••], but anesthesiologists must be cognizant of the challenges that these technologies present regarding safe patient care. There are numerous challenges in caring for an anesthetized patient in this environment. With appropriate understanding of the issues, proper planning, and good communication, safe and effective procedures can be performed in this environment to facilitate the best possible outcome.

Acknowledgements

Conflict of interest

There are no conflicts of interest.

References and recommended reading

Papers of particular interest, published within the annual period of review, have been highlighted as:

- • of special interest
- •• of outstanding interest

Additional references related to this topic can also be found in the Current World Literature section in this issue (p. 592).

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This article is particularly important as it describes one center's experience with a suite designed for both intraoperative imaging and purely diagnostic imaging. A system designed as such can significantly improve the cost-effectiveness of iMRI.