CHAPTER 17

HYBRID OPERATING ROOMS

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Checklist

- Using an intraoperative magnetic resonance imaging (IMRI) suite
- Isolating radiofrequency using the Faraday cage
- Restricting access
- Managing fixed and mobile anesthesia equipment
- Marking Gauss lines

The hybrid operating room (OR) is an interesting concept, marrying two areas with distinct and different problems and concerns. Under this category would be the IMRI suite and angiography operating suite. The considerations for hazardous areas as described in Chapter 16 apply to these hybrid areas as well.

Intraoperative Magnetic Resonance Imaging

IMRI is an emerging concept marrying operative interventions, most commonly intracranial neurosurgical procedures, with MRI for immediate intraoperative evaluation of cerebral interventions and resections. The ability to obtain an accurate MRI during an operative intervention allows for further resections and additional interventions without transporting the patient from the sterile OR environment. Working in a magnetic field requires significantly increased safety precautions. The OR environment is not always easily adapted to the safety required to work in the magnetic environment of a strong-field MRI required for cranial imaging. Thus, OR design must incorporate changes to allow surgical interventions and MRI examinations to take place in the same environment.

There are two approaches currently used to adapt space for use IMRI suites. The first approach entails movement of the patient from the OR to the MRI scanner (fixed); the second design is for the scanner to be moved to the patient (mobile). Both approaches require careful planning and involvement of all team members, especially anesthesiology, at the earliest stages prior to construction.

Design Considerations

The initial phases of implementation of an IMRI neurosurgical program involve the planning and consideration of space and money for construction. The initial design decision must be whether the patient will be intraoperatively moved to the MRI scanner or whether a suite will be designed with enough room to allow for construction of an OR capable of having an MRI scanner moved into it. The design of an OR without accommodating an MRI scanner is relatively straightforward. The OR should be designed according to accepted standards and located as close to the MRI scanner as possible. Systems can then be purchased that allow the patient to be transported to the MRI scanner either while on the operating table or via a wheeled transport cart. This is analogous to what presently occurs when a patient requires a postoperative MRI scan. The patients are transported, awake or under controlled ventilation, to the MRI scanner, and imaging is accomplished. As this design does not involve alterations to normal OR specifications and construction, it will not be discussed further. This design does allow access from more than one operating suite, providing more flexibility and possibly more use.

Design of an IMRI suite usually entails design of two component areas: an OR suite and a diagnostic imaging suite. This design allows maximum benefit from the MRI scanner and maximal use of a high-cost capital equipment item. The business plan may incorporate a diagnostic imaging area to allow for continued use of the MRI system when not required for operative use (Figure 1). This entails a design that allows patients from outside of the OR to access the imaging system but protects the cleanliness of the operative environment. As a result, placing the unit on the outside of the complex near elevators and stairs is important. From a safety perspective, a patient staging area is usually required immediately outside the scanner so that the proper screening for ferrous metals can occur prior to taking the patient into the scanner room. In an emergency, this area can also be used as a resuscitation space for the MRI patient, since resuscitation inside the room is dangerous for both the staff and patient.

Figure 1

Example of an intraoperative magnetic resonance imaging suite design incorporating an operative suite (yellow area), diagnostic scanning area (red area), and a common control area (purple area).

The design of an MRI room must consider the specific requirements in obtaining an adequate MRI scan: medical imaging in a high magnetic field and isolation from radiofrequency artifact. The former, the safe conduct of imaging in a high-Gauss magnetic field, usually receives the bulk of consideration from the medical personnel. The latter, radiofrequency isolation, is possibly the more difficult task and receives priority from physicists involved within the project and is merely assumed by most personnel not familiar with the process of obtaining an MRI. The need for radiofrequency isolation is due to the signals produced by MRI examination and converted to images. MRI involves no radiation exposure and, thus, requires no special protective equipment for patients or for medical personnel. However, the rapidly changing magnetic field fluctuations produce substantial noise, necessitating the use of protective devices (i.e., ear plugs or earphones) to preserve patient and personnel hearing. The MRI produces small variations in radiofrequency emissions as the magnetic fields vary in location and orientation, as atomic reorientation occurs with changes in the magnetic fields. The radiofrequency emitted by atoms as they "relax" to their normal state is detected by radiofrequency coils placed close to the body area of examination, with these radiofrequency emanations then being interpreted by computerized programs to yield a high-definition image of the patient's anatomy. The presence of metallic objects (e.g., implants) within the patient's body or the presence of radiofrequency interference will significantly degrade the images obtained.

Understanding these caveats of MRI is crucial when designing an OR to be functional as an IMRI examination room. Firstly, in order to eliminate extraneous sources of radiofrequency interference, a Faraday cage must be constructed to isolate the entire OR from radiofrequency interference. It is common to make the entire room a Faraday cage (Figure 2) to isolate radiofrequency. However, the Faraday cage must be "violated" of necessity to have the appropriate medical gasses and electrical outlets available for anesthesia and surgical equipment. It is important for meetings to take place prior to approving final design plans in order that the Faraday cage is constructed to allow the minimum amount of outside access to pierce the cage and be available within the OR area (Figure 2).

Figure 2

Copper lining within the walls of an intraoperative magnetic resonance imaging suite make a Faraday cage inside the suite to isolate the area from radiofrequency interference.

Much is made of MRI safety in the context of ferromagnetic items being drawn into the magnetic bore and causing considerable damage and, rarely, patient harm. The crucial aspect of design of an IMRI is to allow enough square footage for ferromagnetic instruments to be safely removed from the magnetic field. This involves a large, relatively square room design to allow such surgical instruments as operating microscopes, imaging adjuncts (e.g., image-linked operative guidance systems), and ferrous surgical instruments to be removed from the magnetic field, typically to areas of the IMRI suite that experience less than 5-Gauss magnetic field strength. Even with a sufficiently large room, however, it is prudent to allow for the placement of tethering bars around the periphery of the room to physically restrain larger items (e.g., operative light booms, operating microscopes, surgical instrument tables, etc.) with tethering cords (Figure 3). It is also helpful to mark the Gauss lines on the floor (50, 5, and 0) and to color code each line. When the mobile magnet is brought into the operating suite, all unsafe material is located behind the 0 line. When the mobile magnet is not in the room, it can be housed in a hangar with shielded doors. It is important to mark the Gauss lines around the hangar when the doors are closed, as the magnetic field will still likely extend into the room in front of the doors.

Figure 3

A blue tethering strap anchors the anesthesia machine to a tethering bar during a clinical intraoperative magnetic resonance imaging case.

Equipment Considerations

After the design phase of the IMRI suite has been finalized, the next consideration for the anesthesia service is obtaining appropriate equipment to safely administer anesthesia for procedures performed in the suite. Intracranial operations comprise the bulk of the procedures currently performed. The ability to have standard monitoring devices along with invasive monitors, such as intra-arterial pressure monitoring and central venous pressure monitoring, is essential. The caveat is that these monitors, while initially placed in the absence of a magnetic field, would then need to be functional when the MRI phase of the procedure is required. Of note, the MRI is generally performed at the conclusion of the surgical procedure, but, on occasion, further operation is performed and a second MRI would be obtained. Thus, one cannot assume that the monitors could be discontinued or not actively displayed during the MRI phase, as this may not be the conclusion of the surgical procedure. Secondly, as inferred above, the monitoring devices themselves should be MRI safe or conditional. Most equipment has ferrous elements or gives off radiofrequency interference such that it is not suitable in the IMRI area. For instance, commonly used displays for monitoring devices have significant radiofrequency emanations that would preclude obtaining a high-resolution MRI scan. Thus, specialized radiofrequency-isolated displays are required to allow for adequate scans.

Much of the equipment in a normal anesthesia supply cart needs to be carefully examined, and replacement nonmagnetic counterparts found. For example, it is common to need a flashlight during the MRI scan (even fluorescent lights are significantly “radiofrequency dirty”), yet trying to obtain a nonferromagnetic, battery-powered flashlight is extremely difficult. Many MRI-

compatible pieces of equipment can be found online at an increased cost as compared to ferromagnetic counterparts. Some equipment cannot be replaced or manufactured as "magnetically neutral" and, thus, must be placed as far away from the magnetic bore and as close to the minimal magnetic field area as possible. An example is a common vaporizer. The vaporizer cannot be manufactured without significant ferromagnetic components, and it must remain securely attached to the (otherwise nonmagnetic) anesthesia machine. No auxiliary vaporizers are allowed in the room, for changing the vaporizer (thus, unlocking a vaporizer from the anesthesia machine) could create a projectile when the MRI scanner enters the IMRI suite.

During the MRI, power will be shut off to all nonessential equipment. It is very important to consult with the engineers during the design stage so that they understand that anesthesia equipment must be powered at all times.

Lastly, as much as possible, ferromagnetic anesthesia disposable supplies should be eliminated in the stock of the IMRI suite. All needles, guide wires, and neuromuscular monitoring devices should be counted and securely stored outside of the 5-Gauss magnetic field prior to every MRI phase of the procedure. We utilize a defined stock of anesthesia supplies that are counted immediately prior to the patient entering the IMRI suite and recounted prior to every MRI scan to ensure that no unaccounted supplies are potentially present in the IMRI suite.

Pagers, cell phones, personal digital assistants, calculators, computers, watches, telephones, and signaling systems are necessarily turned off to eliminate radiofrequency noise and interference. An appropriate, secured area should be identified in close proximity to the IMRI suite to not only accommodate MRI staff personal items but also those items that are brought in by the OR staff. The lack of a means of direct communication with the OR personnel (e.g., surgeon, anesthesiologist, and OR crew) should also be discussed and a protocol for communication be designed. Thus, the design of the IMRI suite should also take into account these factors when designing the coverage and anesthesia commitment to the project.

Access to the IMRI rooms is restricted at all times to personnel who have been screened and trained. This means that doors remain locked and only credentialed staff have access with key cards or other mechanisms.

Angiography Operating Rooms

Angiography ORs are used when the surgeon wishes to see vascular anatomy during the course of the procedure. They may be used for coronary, peripheral, or cerebral vascular procedures.

Angiography suites require lead shielding of the walls, floor, and ceiling. These ORs need added length (at least 8 ft) in the long axis to accommodate the anesthesia machine and other equipment at the head end of the table, with the x-ray machines and viewers at the foot end. Retrofitted angiography operating suites can end up with low ceilings because of the conflict between ceiling height requirements of ceiling-hung C-arms and surgical lights and booms. This will result in booms for operating lights and lower viewing screens, risking head injuries to

personnel and hampering access to the patient. It is better to design an intraoperative angiography suite de novo than to retrofit one. Intraoperative angiography suites require control rooms adjacent to the ORs. With biplane fluoroscopy for the coiling of cerebral aneurysms and arteriovenous malformations (AVMs), the anesthesia machine is usually placed behind the fluoroscopy tube and out of range of its turning radius. There needs to be a 4-ft clearance around the radius of rotation of the fixed-based biplane fluoroscopy to avoid hitting the anesthesia equipment.

Challenges

One of the challenges that anesthesia providers are facing is the increasing use of remote locations that request the use of anesthesia for either patient safety or to obtain higher quality imaging. Our surgical colleagues continue to expand their skill sets, striving to improve patient outcomes by reducing complications related to large incisions, prolonged recovery, and lengthy hospital stays. They are increasingly moving away from larger procedures in favor of more minimally invasive techniques. Endovascular repair of aneurysms throughout the body are one such example. Like those procedures performed by surgeons, other procedures, such as transjugular intrahepatic portosystemic shunts, thrombectomies, and embolectomies, just to name a few, are being performed on a more regular basis by our colleagues in radiology. As hospitals are moving toward supporting more minimally invasive techniques, the input of anesthesiologists in designing these remote locations and hybrid ORs is becoming more frequently requested. What are some things that one must take into consideration when aiding in the design of these areas?

Patient Safety

First and foremost is patient safety. Prior to the administration of any anesthetic and during the design of any remote location (with the potential to administer anesthesia) or a hybrid OR, a series of questions must be addressed:

- What does one need to safely administer anesthesia?
- What resources would one need for an emergency situation?
- Is the patient being kept safe from radiation hazards?
- Is there a way to emergently terminate the procedure being performed?

By surveying the area in which one will be working prior to administering the anesthetic, one can anticipate any potential problems, such as lack of supplies or necessary equipment. When it comes to protecting the patient from the untoward effects of ionizing radiation, it is important to understand what type of procedure is being performed. Procedures that use general angiography or fluoroscopy tend to have more scatter of gamma radiation, thus exposing not only the patient, but also the anesthesia provider and other staff, to its effects. More directed therapy, such as computed tomography–guided procedures, which will not be discussed further, have less scatter.

It is important to have the ability to emergently stop the procedure, whether this is through direct communication with our surgical or radiology colleagues or via a mechanical device that inhibits the ionizing radiation. While many of the mechanical stop functions are located at a control desk, it is important to consider placement of the anesthesia provider's area during design of an angiography suite.

Anesthesia Provider Safety

Similar to being vigilant towards the safety of the patient, one must also be vigilant toward the safety of the anesthesia care provider. Is he/she adequately protected from radiation exposure? Will he/she be able to safely perform his/her job?

It was noted that as the introduction of electrophysiologic (EP) laboratories was made, the exposure to radiation for the anesthesia care providers was doubled at that institution.1 The article mentions that lead aprons protecting the thyroid, gonads, and sternum cover only 82% of the active bone marrow. The use of lead screens does protect somewhat; however, they do little to protect against scatter. Distancing oneself from the source of ionizing radiation provides the greatest protection, with the optimum distance to minimize one's exposure to radiation being 36 in. However, with many remote locations being already cramped sites, it is often difficult to find those 36 in necessary to decrease one's exposure to ionizing radiation. As mentioned in the Handbook of Ambulatory Anesthesia, a distance of 6 ft from the source of ionizing radiation is the equivalent of wearing five lead aprons. Wearable lead shields, however, only protect against 80% to 90% of ionizing radiation, with the rest penetrating.2 The International Atomic Energy Agency has published guidelines in what is known as "the White Paper" about what is considered an appropriately safe level of radiation exposure; for further information, please refer to this easily accessible piece of information.

One should be mindful of the above distances, however, when designing hybrid ORs or remote locations, such as angiography suites or EP labs. If possible, the anesthesia personnel should be, at minimum, 3 ft from the source of the ionizing radiation. If this cannot be done, or if the safety of the patient is jeopardized by this, the anesthesia care provider should request not only lead aprons that cover both front and back, but also lead screens to be placed in front of the source of the ionizing radiation. This will help deflect scatter and further decrease the exposure to the anesthesia care provider.

Access to Patient

In keeping with the idea of protection by distance, some areas have developed the use of an observation area while "runs" of angiography are being performed. During this time, the anesthesia care provider, as well as other members in the remote location or hybrid OR, are asked to relocate to a protected area. If this will be part of the daily function, one must be reasonably sure that the patient's vital signs are displayed on a dedicated monitor either in the observation room or on a boom facing the observation room.

The anesthesia care provider must also have unobstructed access to the patient from the observation room (i.e., no operating tables, lead screens, or other obstacles to impede access to the patient).

Some procedures allow the anesthesia provider to be directly near the patient with appropriate shielding. If this is the case, or if this is the primary function of the room being designed, the above protection recommendations apply. Again, though, one must be reasonably certain that the anesthesia provider has easy access to the patient's airway in an emergency.

Given the fact that many angiography tables are long and mechanically driven, as well as that many of the sources of the ionizing radiation are mobile, it is prudent to do a trial run prior to starting the procedure. Once the airway and patient are secure, cables, intravenous tubing, and the anesthesia circuit should be arranged in a manner that does not obstruct the image while, at the same time, being free to move with the patient. Once this is performed, the table is moved in a manner that simulates motions that will be done during the procedure itself. By taking 5 minutes at the beginning of the case, much hassle can be avoided at a later point.

Access to Anesthesia Provider

Just as important as being able to safely and quickly access the patient in the event of an emergency, access to the anesthesia provider in the event of an emergency is tantamount. Many times, anesthesia equipment is relegated to a corner, often with the angiography equipment obstructing access. It is recommended that during construction of hybrid ORs or angiography suites, the anesthesia provider's area be placed either directly in front or to the side of the entry door or at a reasonable distance from the door that allows both other providers and anesthesia technicians quick and efficient access. Having the appropriate protection capabilities (i.e., lead aprons and lead screens) available outside the area or upon entry is also important.

Traffic Control

Remote locations have typically been designed without input from anesthesiologists about space requirement. The space is routinely smaller than that to which one may be accustomed. Maintaining an efficient and fluent traffic pattern becomes a must. When designing a remote location where anesthesia may be provided, the patient areas that are often taken for granted must be included in the design. If one is not in the "designing" stage, but rather in the "providing" stage, the following must be properly accounted for before continuing with providing the anesthetic. These include:

- Patient receiving area
- Anesthesia prescreening area
- Patient induction area
- Transportation to procedure room/area from induction area
- Recovery area
- Discharge area

Adequate nursing staff must be available for the preprocedure/preoperative area as well as the recovery area.

A model that is frequently used in outpatient surgery involves utilizing the same nursing staff for both the prescreening area and the recovery area. Some institutions are beginning to construct hybrid ORs that are roughly 900 to 1000 sq ft. This is to accommodate the large monitors and imaging arms that are used in cases that involve diagnostic and therapeutic imaging modalities, such as angiography, EP laboratories, and interventional radiology. However, this can become somewhat inefficient in that circulators are required to take additional steps to the central core to retrieve various items. A routine OR size is roughly 600 sq ft. However, this does not always take into consideration the need for anesthesia equipment or supplies. One cannot simply measure the size of the anesthesia machine and backstand and add it to the overall size; rather, one must also factor into the design the ability to safely access the patient as well as for others to safely access the anesthesia staff.3

Minimum Requirements

Prior to any procedure, whether in a newly designed remote location or hybrid OR designed with input from members of the anesthesia field, a survey of the site is required. The following items should be confirmed as being on hand before performing any anesthetic in a remote location or hybrid OR:

- Space
- Electrical outlets (eight to ten for the team)
- Communications system
- Personnel
- Lighting
- Piped gases
- Suction (one or two outlets)
- Gas scavenging
- Traffic control and radiation hazard control

If any of the above is missing, or if there are questions regarding the adequacy of the equipment, consult the hospital's biomedical engineering department. Often, storage of anesthesia machines and equipment and supplies becomes an issue. Many institutions have taken to storing the anesthesia equipment behind the scanner gantry, retrieving it if necessary.

References

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