IRM PEROPÉRATOIRE : LES DÉFIS POUR OFFRIR UN ENVIRONNEMENT SÉCURITAIRE POUR LES PATIENTS ET LE PERSONNEL

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Les normes de l'AIISOC relatives à cet article figurent dans la publication Normes de l'AIISOC pour la pratique des soins infirmiers périopératoires (11e édition) de l'Association des infirmiers et infirmières de salles d'opération du Canada (AIISOC) d'avril 2013, section 4, pp. 237 à 241, normes 4.6.

RÉSUMÉ :

L'imagerie par résonance magnétique peropératoire en temps réel (IRSp) offre d'énormes avantages pour les patients ayant à subir une chirurgie pour l'ablation d'une tumeur cérébrale. Cet article traitera de l'expérience du Winnipeg Health Sciences Centre lors de la mise en œuvre d'un nouveau programme d'IRSp dans un nouveau bloc de salles d'opération neurochirurgicale. Il passera en revue la technologie de l'IRM et abordera les mesures de sécurité à respecter pour les patients et le personnel.

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KEYWORDS: PATIENT SAFETY, CHECKLISTS, EDUCATION

INTRAOPERATIVE MRI: THE CHALLENGES OF PROVIDING A SAFE ENVIRONMENT FOR PATIENTS AND PERSONNEL

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ABSTRACT:

Real-time intraoperative magnetic resonance imaging (iMRI) provides a tremendous benefit to patients undergoing brain tumour surgery. This paper will discuss the Winnipeg Health Sciences Centre's experience implementing a new iMRI program in a new neurosurgery operating room suite. It will review MRI technology and discuss related safety considerations for patients and personnel.

INTRODUCTION:

The ability to offer high resolution intraoperative Magnetic Resonance Imaging (iMRI) at any time during a

The intraoperative MRI theatre with the shielded doors to the magnet storage area closed.

surgical procedure provides a great benefit to patients. In June 2013 Winnipeg's Health Sciences Centre began to offer iMRI procedures for patients undergoing surgery for brain tumours. Surgeons now have the ability to consult a real-time image during the surgical procedure and make decisions based on the findings of an iMRI. This technology will expand to include other types of surgery in the future.

While developing and implementing this new program, in a new operating room suite located in a new iMRI environment, the support and help from other experienced sites provided a tremendous boost.

Benefits of Intraoperative MRI:

Intraoperative MRI scans allow the surgeon to see the difference between healthy and diseased brain tissue during the surgical procedure. This enables them to more completely remove tumours. This ability to determine whether resection is complete is a great benefit in the resection on many types of primary or metastatic tumours. A randomized controlled trial demonstrated that patients undergoing surgery with intraoperative MRI had complete resection 96% of the time as compared to only 68% in the standard operative group. There was no increased risk of neurological problems associated with the more complete resection. The authors suggest that the extent of resection correlates with survival rates in glioma surgery.[1]

McGill University Health Centre reports that intraoperative MRI procedures, during tumour resection in children, are beneficial to reducing or eliminating epileptic seizures.[2]

Other advantages of intraoperative neurosurgical MRI include:

- Reliable imaging that reflects the situation in the surgical field in real time;
- The ability to identify bleeding in the brain, during surgery, beyond the field directly observed by the surgeon;
- Accurate anatomical identification of brain structures and avoidance of damage to them; and
- At the end of surgery a final MRI scan can determine if all the aims of surgery were achieved.[3]

Our Experience:

As the surgical team began to plan, along with the MRI technologist, the iMRI manufacturer representatives, and with consultation with other sites, it was quickly determined that there are many safety considerations associated with bringing an extremely powerful MRI magnet into an operating room.[4] Patient and personnel safety depended on the establishment of clear departmental and procedural regulations that met national safety standards, along with consistent and firm enforcement of the resulting policies, practice guidelines and standards of care. Clinical practice standards were developed specific to our physical environment and resources.

The MRI safety program was established with comprehensive preliminary education and training of champions that included:

- Educational sessions from the new iMRI scanner's manufacturer;
- An MRI safety video;
- Review of the site's iMRI Clinical Practice Standards;

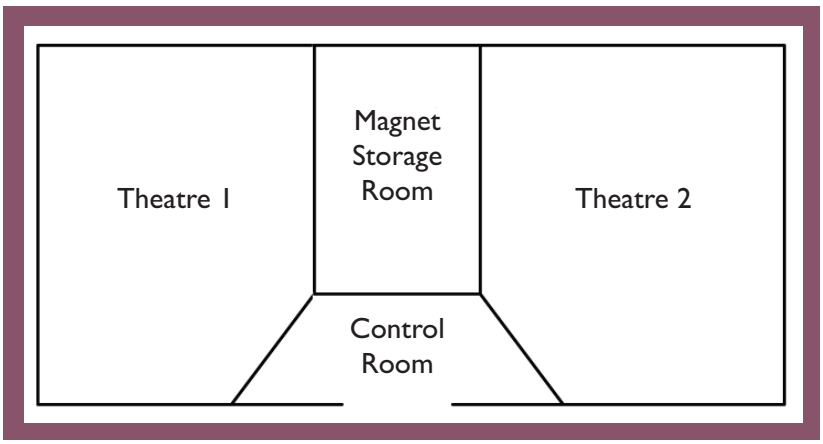
- Completion of MRI environment and personal screening for all personnel which included screening for ferromagnetic objects and/or implants that may be affected by the magnetic force;
- Orientation to the MRI theatre and surrounding physical space;
- Repeated simulations, with the complete surgical team, that included every step of the neurosurgical procedure from the pre-operative assessment to the transfer of the patient to the recovery area; and
- Simulation of an intraoperative cardiac arrest.

Safety checklists were developed, tested, and revised as necessary. These checklists are consistently utilized by the surgical team so that no safety precaution is missed at any time, thus ensuring the safety of the patient and of theatre personnel. Safety checklists are completed, with pause, by the entire surgical team and are performed:

- Pre-operatively, before the patient enters the theatre;
- Immediately prior to draping; and
- Immediately prior to each time the MRI magnet advances into the theatre.

Surgical counts are also conducted by nursing and anaesthesia personnel immediately prior to each magnet entry and immediately following its exit from the theatre.

Figure 1: Basic Floor plan of MRI suite at this site



MRI Technology:

In order to expand on the safety issues involved MRI technology, the access zones, and MRI fields have been briefly outlined below.

During an iMRI the patient is positioned in the central opening of a large electromagnet and is exposed to bursts of alternating radiofrequency energy waves. This, essentially, stimulates the magnetic nuclei of hydrogen atoms in the water of body cells thus altering their state of equilibrium. The nuclei, as they return to their original state of equilibrium, emit radiofrequency signals that are converted into three-dimensional color images.[5]

The ultra-powerful MRI magnet is contained within the protective walls of the machine's bore. At Winnipeg Health Sciences Centre the MRI scanner is stored in a secure storage area, between 2 ORs, and enters into each theatre via shielded metal double doors on the OR walls. See Figure 1 for the basic floor plan. The doors slide open to each side and the magnet advances into each theatre and retracts back into the storage area using ceiling-mounted tracks. Operation of the MRI magnet is controlled by technologists who are located in a control room adjacent to both theatres. The control room has windows into each theatre and into the central magnet storage room. There is also a shielded doorway into the magnet storage room from the control room. **The magnet is always on**… even when it is not in use. When the shielded metal doors are securely closed there are no risks posed by the magnet to the inside of the theatre.

Strengths of the magnetic fields are designated in units of tesla (T) for ultra-powerful magnetic fields, and units of gauss (G) for less powerful magnetic fields. The strength of the magnetic field within the magnet's bore at this site is 3T.[6] 1T = 10,000G.

A 3T MRI magnet, such as the one at this site, is 60,000 times the force of the earth's magnetic field.[7]

Theatre shielded doors are open to reveal the MRI magnet in its storage area.

Different coloured circular flooring patterns around the MRI scanner allow personnel to easily identify the following fields:

- The 5 gauss line identifies the perimeter surrounding an MRI scanner within which the static magnetic fields are higher than 5 gauss;
- 5 gauss and below are considered safe levels of static magnetic field exposure for the general public; and
- Electromagnetic and ferromagnetic items outside the 5 gauss line are not affected by the magnet

The circular inner (closest to the magnet) 50 and outer 5 gauss lines on the floor of the MRI theatre demonstrate that the magnetic intensity diminishes with greater distance from the magnet.

Access Zones:

Health care facilities may restrict access to MRI suites by establishing four conceptual zones around the MRI scanner. Each zone, as recommended by the Joint Commission that accredits and certifies US health care facilities, is described in relation to its purpose and distance from the MRI scanner.[8,9] In brief they are:

- ***Zone 1*** is open to the public and offers the least exposure to magnetic fields;
- ***Zone 2*** should be restricted from public access. Ferromagnetic objects are safe in this zone, but must remain here and not be taken into zone 3;
- ***Zone 3*** at Winnipeg Health Sciences Centre this zone is inside the MRI theatre. Entrance is restricted to personnel who have been orientated and screened for access to this area. Warning signage is clearly posted; and
- ***Zone 4*** is located within the 5 gauss line immediately surrounding the MRI scanner in all directions. During an intraoperative MRI the patient remains in zone 4 on a non-ferromagnetic OR bed and the magnet advances toward the patient. The MRI technologist and theatre personnel also enter zone 4 to position the anaesthetized patient safely in the scanner's opening. The anaesthetic machine is not MRI safe and, therefore, has long tubing extensions so that it can remain outside zone 4 at all times. Once the magnet storage room doors are opened, into the theatre, any ferromagnetic object in zone 4 may be pulled into the magnet with tremendous velocity resulting in injury to the patient or any person in its path of travel or damage the MRI scanner itself.

The MRI-safe OR bed remains, within the MRI theatre, in a fixed location within the 50 gauss perimeter line. During anaesthesia induction the bed is positioned so that the patient's head is closest to the anaesthetic machine. The bed is turned on a swivel, just prior to prepping and draping, so that the patient's head faces in the opposite direction (toward the closed MRI doors). This allows room for the surgical team and their equipment and also aligns the patient for entry into the magnet once the shielded doors are opened and the magnet advances into the theatre.

The patient often has the first intraoperative MRI scan following the anesthetic induction and positioning. Because of this, the sterile surgical equipment is set up in the periphery of the theatre outside the 5 gauss line.

INTRAOPERATIVE MRI (cont.)

After draping is completed, the sterile equipment is moved inside the 50 gauss line and positioned beside the operative field at the patient's head. This equipment is moved back outside the 5 gauss line prior to each subsequent magnet entry into the theatre and remains there until the magnet retreats and the shielded doors are closed. With this process no ferromagnetic surgical instruments or equipment are affected by the magnet.

MRI Fields:

MRI technology uses three types of magnetic fields to create images. They are the very strong static field, smaller time variant magnetic fields called "gradients", and a radio frequency electromagnetic field:[10]

- The **static field** is an ultra strong magnetic field created by the superconducting coils and is measured in units of Tesla. The static field does not vary and is **always on**. When the doors to the magnet storage area are opened, the static field extends into the theatre. The main safety risks in this field are from ferromagnetic objects accelerating into the bore as projectiles and from movement, or malfunction, of implanted ferromagnetic medical devices and metal debris.
  The best method to eliminate this risk is to conduct a comprehensive screening of all patients and personnel for ferromagnetic objects such as pagers, some pens, some eyewear, etc on their person and implants within their bodies prior to their entry into the magnet room. Constant vigilance is required.
- **Smaller time variant gradient magnetic fields** are constantly turned on and off during scanning. The main safety risk

from these fields is from the generation of currents that may cause peripheral nerve stimulation and can disrupt the operation of implanted medical devices. Patients with implanted medical devices must be identified and may not be an iMRI candidate.

- **Radio frequency electromagnetic fields** can cause tissue heating and burns. In high-frequency electromagnetic fields the energy can be transmitted across open spaces and through insulators.

  Conductive materials such as wires and leads, could act as a radio frequency antenna, should not be looped or come into direct contact with the patient's skin as this may cause burns.

Accidents and Injuries in the MRI Suite:

The Joint Commission published a Sentinel Event Alert[8] reporting that the most common patient injuries in the MRI suite are burns and the most common objects to undergo significant heating are wires and leads. Projectiles, such as oxygen cylinders being pulled in to the MRI, have also been reported. This Alert also discussed a database developed, over a 10-year time, span by Jason Launders (a former medical physicist with the Emergency Care Research Institute) that monitors health care technology and patient safety. The US database revealed 389 reports of MRI-related events including nine deaths. Three of the deaths were related to pacemaker failure, two to insulin pump failure. More than 70% of the 389 reports were burns and 10% were projectile-related.[9]

Risk-Reduction Strategies:

Risk-reduction strategies to prevent accidents and injuries include the following:

1. Restricting access to the iMRI environment:

- Before entering the iMRI theatre, to assist with any aspect of a clinical procedure, all clinical team members and support staff must first have received the required education, orientation and pre-screening.

- No one may enter the iMRI theatre without approval from the MRI technologist. At Winnipeg Health Sciences Centre the technologist maintains a list of individuals who have been pre-screened and orientated to the iMRI theatre. S/he will remind personnel to perform a personal check for ferromagnetic objects prior to entry as those items have the potential to become projectiles when the magnet enters the theatre. These items include cell phones, stethoscopes, pens, watches, body jewellery, hairpins, some styles of glasses, etc. If any individual refuses to comply with the safety requirements, s/he will not be permitted to enter the theatre until after s/he has attended additional education and demonstrates compliance with safety regulations;

- When the door to the magnet is open the theatre doors will automatically lock to prevent theatre entry and exit through that door. Emergency entry and exit may be made via the door to the magnet storage room; and
- Brightly lit warning signs outside the theatre are clearly visible to anyone in the hallway.

The MRI technologist uses a remote controller to advance the magnet into the theatre towards the MRI-safe OR bed.

2. Providing as much MRI-safe equipment as possible:

- MRI-safe versions of equipment are available for fire extinguishers, oxygen tank, stretcher, anaesthesia monitors and cables, etc. However, many pieces of essential equipment are not MRI-safe. For easy identification, each item should be labelled by the health care facility with MRI hazard level symbols as defined by the American Society for Testing Materials (ASTM)[8] for MRI-safe, MRI-conditional and MRI-unsafe items.

- Caution is advised for supply carts. While non- ferromagnetic supply carts may be labelled as MRI-safe it is possible that ferromagnetic items may be stored on that cart. It would be prudent to not label the cart as MRI-safe in that situation.

- A hand-held magnet should be readily available to test items if it is not known whether they are ferromagnetic.

3. Taking precautions to prevent patient burns:

- Conductive materials, such as wire leads in a looped configuration, may absorb radiofrequency energy during the MRI which will focus the energy in a small area and cause a local burn if in direct contact with the patient's skin.[10] As a precaution it is important to always:
  a) Ensure wire leads are not looped; and
  b) Place padding between any wire leads and the patient's skin.

- Conductive loops may also be inadvertently created by the patient's limb placement.[10] This can be avoided by positioning the patient so his/her hands, legs or knees are not touching each other.

4. Providing hearing protection for all individuals:

- The MRI scan creates a high acoustic level of sound and so it is essential that hearing protection devices be provided for the patient and for any individuals who will remain inside the theatreduring the iMRI.

5. Simulating the management of emergency situations and providing readily-accessible guidelines for personnel in these situations:

- Simulation of emergency procedures provides an excellent learning opportunity for the surgical team and promotes evaluation of developed emergency processes;

- If the patient undergoes a **cardiac arrest**, during the iMRI scan, the MRI magnet retraction process is immediately initiated by the technologist in the control booth. It may, however, take a few minutes for the magnet to retract and the storage area shielded doors to completely

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close. Treatment, including cardio-pulmonary resuscitation, may begin immediately but the cardiac defibrillator is not MRI-safe and may not be brought into the theatre until the magnet is retracted, the shielded metal doors are closed, and the warning sign outside the door is no longer illuminated.

If the patient is to be in prone position during surgery an MRI-safe stretcher is placed in the magnet storage room, prior to surgery, so it is accessible during the procedure in order to reposition the patient into supine position for resuscitation.

Code blue posters with guidelines are easily accessible in the theatre.

- In the event of a **fire**, during an iMRI scan, the technologist in the control booth will immediately initiate retraction of the magnet from the room, activate the fire alarm, and call the code. External fire safety personnel should not enter the theatre until the magnet is retracted, the doors to its storage room are closed, and the warning sign outside the theatre door is no longer illuminated.

Theatre personnel should remove any burning material from the patient and ensure the patient and personnel are not in immediate danger. The theatre's MRI-safe fire extinguisher may be used until it is safe to evacuate and for fire-safety personnel to enter. Fire orders and building **evacuation** routes and plans should be clearly posted.

- MRI machines are cooled by liquid helium. In order to quickly de-energize the MRI magnet, in an extremely urgent situation, the helium may be quickly released into the atmosphere during an emergency process called **quenching**.[11]

Quenching may be necessary in a situation where a patient is experiencing severe injuries as a result of being pinned against the magnet by a ferromagnetic object. The decision to quench is made by the MRI technologist or the surgeon.

Once the quenching process has been initiated, the helium is vented from the machine (which takes about 20 seconds) before the patient can be moved. Quenching is an extremely expensive process as the magnet must later be restored, at a very high cost, but may be necessary in a life-threatening emergency.

6. Patient pre-screening:

- Patient pre-screening is essential to

Figure 2: Pre-Drape Patient Positioning Checklist:

- Patient's hearing protection in place and secured
- Head positioned with MRI-safe fixation devices
- Lower MRI coil in place
- Patient's arms secured at sides
- Skull clamp, coil arm and navigation attachment secured
- Padding to axilla, breast and scrotum as appropriate
- No skin-to-skin contact
- Wires, leads, cables and breathing circuits positioned apart and parallel and padded with no loops
- Leads, electrodes and temperature probes are MRI-safe
- Velcro safety belt is secured
- OR bed is locked and facing the MRI magnet entry

avoid inadvertent injury. Patients who are to have an intraoperative MRI are often pre-screened prior to their admission into hospital. Contra-indications to undergoing an MRI include, but are not limited to, patients who have pacemakers, insulin pumps, certain cranial aneurysm clips, and some implants.[12,13,14]

Transdermal patches may contain aluminum or other metals that can overheat during a scan. Ferro-magnetic debris, such as a piece of metal lodged in the eye, may move during the scan and cause further injury. Allergies to MRI contrast media are also assessed.

Comprehensive pre-hospital admission screening is performed by the MRI technologist and involves reviewing information on the screening form, as completed by the patient, a verbal interview to verify the accuracy and thoroughness of

Figure 3: Pre-Magnet Entry Checklist

- Wire removed from craniotomy drape
- Fluid collection pouch drained and no wet area under patient's head
- Anaesthesia counts are correct
- Anaesthesia machine brakes are on and it is outside the 50 gauss line
- Anaesthesia supply cart/blades/laryngoscope handle outside the 5 gauss line
- Vital signs monitor and infusion pumps outside the 5 gauss line
- Pressure bags are secured with tourniquets
- Nerve stimulator removed from patient and outside 5 gauss line
- Nursing counts are correct
- No ferromagnetic objects on the sterile field
- ESU grounding pad removed
- Pneumatic compression stockings disconnected
- All navigation accessories removed
- The following items are outside the 5 gauss line
    - Hair clipper
    - Patient warming devices
    - Microscope
    - Fluid warmer
    - All foot pedals
    - Ceiling booms and lights
    - Instrument tables
- Charting computer is positioned outside the 5 gauss line and turned off
- Top MRI coil secured in place over protective drape
- MRI-compatible stretcher available
- Anaesthetist has hearing protection
- Surgical team pocket check: no jewellery, hair pins or clips, wallets, keys, etc

ALL CLEAR declared by the surgical team

information on the form, and allowing time for discussion and clarification by the patient and technologist.

- The patient must also be assessed and screened immediately prior to admission to the theatre. The team must ensure there are no ferromagnetic items on the patient and no contra-indicated implants. The patient's hospital gown should have no metal snaps, hair accessories must be removed, and identification tags should not be pinned to the hospital gown. If the patient requires supplemental oxygen an MRI-safe oxygen tank must be used in the theatre. At Winnipeg Health Sciences Centre the immediate preoperative assessment and screening is completed in the pre-surgical waiting area and is performed together with the patient, perioperative nurse, anaesthetist and the MRI technologist.

7. Developing Safety Checklists:

- Checklists should reflect each unique environment. Safety check lists, conducted with pause by the entire surgical team, are critical to providing a safe environment for the patient and for the surgical team.

- The pre-operative checklist provides confirmation that pre-screening has been completed.[14]

- Following the induction of anaesthesia, and patient positioning for brain tumour surgery, and prior to covering the patient with surgical drapes, the team at Winnipeg Health Sciences Centre pauses to complete a pre-drape patient positioning safety checklist. Checklists are specific to each site. See Figure 2 for indicators that could be included in a Pre-drape Patient Positioning Checklist.

- Immediately prior to the entry of the MRI magnet all ferromagnetic equipment, instruments, etc. are moved to the 'safe zone' outside the 5 gauss line in the theatre. A pre-magnet

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entry "All Clear" checklist is conducted prior to the opening of the shielded doors and magnet entry. Counts are completed of every sterile surgical instrument and every anaesthesia item that remains on the top of the anaesthetic machine during the procedure. The counts are conducted outside the 5 gauss line, by two individuals, prior to magnet entry and immediately following magnet exit. See Figure 3 for indicators that may be included in the Pre-magnet Entry Checklist.

CONCLUSION:

The ability to provide real-time imaging, during the surgical procedure, supports the best possible surgical outcome for patients undergoing surgery for brain tumours. Providing a safe environment for patient and personnel, during these new and unique procedures, continues to provide ongoing challenges to the surgical team, and the range of surgical clinical applications for iMRI will only continue to expand. Specific perioperative nursing standards for intraoperative MRI procedures must be developed to provide a new and dynamic resource for the perioperative team.

ORNAC Standards pertaining to this article can be found in the Operating Room Nurses Association of Canada (ORNAC) (April 2013) *Standards, Guidelines, and Position Statements for Perioperative Registered Nursing Practice* (11th edition). Section 4, pg(s) 215-218, Standard 4.6.

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