Surgical briefings, checklists, and the creation of an environment of safety in the neurosurgical intraoperative magnetic resonance imaging suite

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Technological advances have made it possible to seamlessly integrate modern neuroimaging into the neurosurgical operative environment. This integration has introduced many new applications improving surgical treatments. One major addition to the neurosurgical armamentarium is intraoperative navigation and MRI, enabling real-time use during surgery. In the 1970s, the American College of Radiology issued safety guidelines for diagnostic MRI facilities. Until now, however, no such guidelines existed for the MRI-integrated operating room, which is a high-risk zone requiring standardized protocols to ensure the safety of both the patient and the operating room staff. The forces associated with the strong 1.5- and 3.0-T magnets used for MRI are potent and hazardous, creating distinct concerns regarding safety, infection control, and image interpretation. Authors of this paper provide an overview of the intraoperative MRI operating room, safety considerations, and a series of checklists and protocols for maintaining safety in this zero tolerance environment.

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KEY WORDS • operating room safety • checklist • intraoperative magnetic resonance imaging

THE modern OR contains a variable and complex array of equipment and personnel. Additionally, composite issues of staff coordination, time constraints, and communication cumulatively increase errors of commission and omission. In 2000, the Committee on Quality of Health Care in America published their book To Err is Human, leading to increased awareness of patient safety.22 The book estimated that in the US alone, medical errors cost more patient lives than either car accidents or breast cancer. The worldwide overall incidence of hospital adverse events approximates 10%,3 with the OR being the most common site for incidents in the hospital setting, and errors occurring in up to 14.6% of surgical patients.50 Looking at the data, it has been recognized that about 50% of these incidents are avoid-able.44 Following the report of Haynes et al.,11 the WHO launched its Surgical Safety Checklist in 2008 as well as their campaign Safe Surgery Saves Lives. Currently, the checklist is used by more than 300 organizations worldwide, becoming a fundamental component of patient care and safety.55 To respond to threats and ensure safety, 2 important factors were identified: communication between the various team members and an awareness of the surroundings in order to respond to emergencies. Health care has used these evidence-based practices to reduce the risk of errors, morbidity, and mortality.35 Haynes and colleagues11 identified the common occurrences of error through the surgical checklist and demonstrated its value as a safety tool.

The ioMRI-OR places the patient and staff in contact with a high magnetic field strength, creating a potentially hazardous environment with no room for error. Additionally, a number of other equipment-related safety considerations—such as the use of electrical equipment, flamma-
ble liquids, lasers with the potential to start fires, cautery, other equipment in a sterile field, and numerous cables and wires running across the OR—must be accounted for in creating a safe environment for patients. Patient safety also takes into account appropriate informed consent, patient identification, surgical site, surgical side, patient positioning, instrument counts, specimens, and medication safety. A variety of personnel from different backgrounds are involved in patient care in the ioMRI-OR, and communication and understanding need to be flawless for maximal patient safety, necessitating the creation of checklists, briefings, and protocols that can be followed by all. In the United Kingdom between 1990 and 2006, the Medicines and Healthcare Products Regulatory Agency received 163 user incident reports and 58 vigilance reports concerning MRI. The majority of incidents involved radiofrequency burns, followed by projectiles, and lower incidences of cryogen burns, altered device functions, foreign metal objects, noise, and physiological effects. The complexity and possible threat posed by the imaging equipment makes checklists and their explicit use by all team members essential.

At the Cleveland Clinic, the ioMRI-OR, established in 2010, utilizes checklists in the operating rooms to improve patient safety, avoid gaps in care, and promote effective communication among the various team members. This requires team leaders to promote and build a culture of safety, support staff members, cultivate effective communication with the patient and team members, and use lessons learned to enhance safety and advance ideas to further prevent errors. A modified WHO-based surgical checklist is used (Fig. 1) at various time points, from the patient’s entry into the OR environment to his or her exit into the PACU. Our program relies on respect (Appendix) and keeping patients first. The use of surgical checklists creates a zero tolerance environment for errors. To date, we have performed more than 120 cases involving a wide gamut of ioMRI-OR procedures without any reported incidents, and we attribute this to our commitment to using the checklist system. Our objective in the present paper was to describe the utilization of checklists to prevent errors and maintain a high degree of absolute safety in our ioMRI-ORs.

**Methods**

We describe our initial experience with cases in the ioMRI-OR between February 2010 and June 2012. The cases included tumor resections in adult and pediatric patients, laser thermal therapy for tumors with real-time ioMRI monitoring, deep brain stimulation, and epilepsy surgery. We detail our ioMRI-OR setup, the dangers created by the magnet and by operating in a high-magnetic-field area, as well as the safety considerations in zoning various regions in the ioMRI-OR. Additionally, we review anesthesiology workflow and safety considerations, equipment considerations, training of personnel, the surgical checklist protocol, and video clips showing its use at our institution.

**The ioMRI-OR Environment**

Various technologies that integrate MRI with the surgical OR are available. At the Cleveland Clinic, the IMRIS Neuro MRI magnet (IMRIS, Inc.) moves between 2 rooms separated by a movable wall: an operating room and an adjacent space that has been set up for use in routine imaging and where the 1.5-T magnet is docked when not in use. The MRI unit, a mobile 1.5-T platform, is hung on ceiling-mounted rails and has been used successfully by a number of surgeons at different locations. The unit can be moved into the OR when imaging is required while the patient table remains stationary; hence, significant movement of the patient or equipment is not required. In this respect, the ioMRI-OR functions like

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### Safety Checklist: Operating Room, ASC, and Procedure Room

**Checklist to be used for all procedures performed in the Operating Room, Ambulatory Surgery Center, and Procedure Room**

<table>
<thead>
<tr>
<th>Sign In: Surgery</th>
<th>Sign In: Procedure</th>
<th>Time Out</th>
<th>Sign Out</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interactive team discussion</td>
<td>Interactive team discussion</td>
<td>Involves interactive verbal communication</td>
<td>Verbal confirmation prior to team leaving the room</td>
</tr>
</tbody>
</table>

**Introduction of team**

- Pre-Procedure Checklist:
  - **Nursing**
    - Allergies
    - H&P
    - Informed Consent
    - Nursing Assessment
    - VTE Prophylaxis
    - Critical Information
  - **Anesthesia**
    - Anesthetic (Pre-Op)
    - Blood products
    - Pre-anesthesia assessment
    - Critical Information
  - **Surgeon**
    - Diagnostic test results available
    - Imaging available and properly labeled
    - Implants, devices, and/or special equipment
    - Site Marked (when applicable)
    - Critical Information

**Introduction of team**

- Pre-Procedure Checklist:
  - **Nursing**
    - Allergies
    - Anesthetic (Pre-Op)
    - H&P
    - Informed Consent
    - Nursing Assessment
    - VTE Prophylaxis
    - Critical Information
  - **Anesthesia/Proceduralist**
    - Blood products
    - Pre-anesthesia assessment
    - Critical Information
  - **Proceduralist**
    - Diagnostic test results available
    - Imaging available and properly labeled
    - Implants, devices, and/or special equipment
    - Site Marked (when applicable)
    - Critical Information

**Team agrees**

- Correct Patient
- Correct side and Site
- Correct Procedure
- Correct Position (if applicable)
- Affirmation of Time Out (if applicable)

**Surgeon**

- Are all items/issus resolved? Are we ready to start?

**Name of procedure recorded**

- Disposition of unused blood products discussed
- Counts Completed and Reconciled
- Specimen(s) labeled

**Equipment issues addressed**

**Team reviews**

- Key concerns for recovery and management of the patient

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![Fig. 1](image-url) Operating room, ambulatory surgical center (ASC), and perioperative surgical checklist used at the Cleveland Clinic, which was adapted from the WHO guidelines. H&P = History & Physical; VTE = venous thromboembolism.
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a conventional diagnostic MR suite with high-quality imaging. The arrangement is featured in Fig. 2. Alternative ioMRI-OR setups dock the magnet in the center of 2 ORs, effectively enabling 2 cases to take place at the same time (a detailed description of such a layout is available in the literature\textsuperscript{40,41}). Additionally, various other alternative ioMRI-OR system designs and platforms are available and have been used.\textsuperscript{1,18,24,31,32,39}

**Dangers and Magnetic Forces Associated With ioMRI-ORs**

The MRI unit generates 3 physical forces that can place patients and OR staff at risk: the static magnetic field, the gradient or time-varying (pulsed) magnetic field, and the radiofrequency field.

The static magnetic field is the main field of the MR unit, measured in teslas, and is constantly on and created by the superconducting coils. High-field magnets are considered to have strengths of 1.0, 1.5, and 3.0 T. Given that the earth’s gravitational pull is 0.05 mT or 0.5 G, a 1.5-T magnet is 30,000 times more powerful than gravity, and a 3.0-T magnet has about 60,000 times the pull of gravity.\textsuperscript{29} Although no adverse effects have been established in fields of up to 3.0 T, the mechanical effects can be devastating, with ferromagnetic objects accelerating across this gradient, making them missiles or projectiles and also causing a rotational force while within the bore.\textsuperscript{17,34,36,37} There have been instances of damage to equipment, injury, and even death that have been reported in the literature.\textsuperscript{4} Ferromagnetic aneurysm clips have been known to migrate, leading to a fatal hemorrhage during MRI, and implanted devices may fail as components become displaced by the magnetic field.\textsuperscript{21} To avoid the dangers of the static field, careful screening of patients undergoing an ioMRI procedure is recommended, and this counsel cannot be overstated. In fact, it should be an integral component of the checklist prior to entry into the preanesthesia area as well as during the anesthesia check and preoperative briefing (Figs. 3 and 4).

The gradient, or time-varying, magnetic field is a smaller field that, when applied, enables image slices of specific body segments. This magnetic field is intermittently on and off, causing the loud noises heard during scanning. The level of noise depends on the strength of the magnet, with permissible sound levels up to 99 dB.\textsuperscript{35} Exposure to high noise levels can lead to hearing loss, making hearing protection essential.\textsuperscript{19} To avoid damage due to high noise levels, the insertion of earplugs has been recommended even in patients under anesthesia, and careful screening for devices should be diligently performed.\textsuperscript{38} Ear plugs should also be worn by personnel inside the OR while scanning is being performed. Moreover, the gradient field can induce a current in tissues that can in turn cause neural or muscular stimulation and generate heat within tissues. Electrical current can also be generated by this field, and safety standards and recommendations have been published.\textsuperscript{35}

The radiofrequency field induces excitation in protons, and its main side effect is heating within tissues. This field can cause interference with electrical equipment and generate currents within looped instruments. Local thermal injury is avoided by measuring the specific absorp-

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**Fig. 2.** Artist’s representation of the ioMRI-OR setup at the Cleveland Clinic showing Zones I–IV demarcated for patient and staff safety. Zone I (light green) is the safe zone for patients, family members, and staff. Zone II (orange) is the anesthesia induction area in which the huddle and induction take place. Zone III (yellow) is restricted to ioMRI-OR personnel with training and access. A check for ferromagnetic objects occurs here prior to entry in the OR. Zone IV (red and pink) is the danger zone where caution must be exercised at all steps. The pink area is outside the 5-G line and is where the non–MRI compatible instruments and devices are placed. The red area lies within the 5-G line in our setup, and extreme care must be taken within this region when the magnet comes into the OR to scan the patient. Reprinted with permission, Cleveland Clinic Center for Medical Art & Photography © 2012. All rights reserved.
tion rates throughout imaging and is limited based on FDA guidelines. To avoid tissue overheating, the transdermal drug delivery patches containing metal backing should be removed unless they are essential. Moreover, avoid loops within monitoring wires and cautery cables, using only MRI-compatible leads, and avoid direct skin contact.

Because of the magnetic forces in this environment, the ioMRI-OR is typically separated into units or zones, depending on the level of physical risk and distance from the magnet, designed to prevent any risk or injury to the patient, personnel, or equipment (Fig. 2). At our institution there are 4 zones. Zone I is open to all individuals, family members, and patients with no need to fill out the MRI safety questionnaire. All personal items for those who intend to go beyond this point must be left in lockers. The preanesthesia interview is performed in Zone II, and the surgical sign-in and induction of anesthesia are performed in Zone III. The control room and the scrub area is comprised of Zone IV, which is closed to all personnel except for the patient, surgical team, and medical record number; NG = nasogastric; NPO = nothing by mouth; PCA = patient-controlled analgesia; PT = patient; Trach = tracheotomy.

**Fig. 3.** Preoperative MRI nursing checklist for use prior to transferring a patient to the ioMRI-OR. EEG = electroencephalography; EGFR = estimated glomerular filtration rate; ET = endotracheal tube; GFR = glomerular filtration rate; HCG = human chorionic gonadotropin; ICF = International Classification of Functioning, Disability and Health; MRN = medical record number; NG = nasogastric; NPO = nothing by mouth; PCA = patient-controlled analgesia; PT = patient; Trach = tracheotomy.
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**SAFETY SCREENING FORM FOR MRI PATIENTS**

<table>
<thead>
<tr>
<th>Date__/__/</th>
<th>Name___</th>
</tr>
</thead>
<tbody>
<tr>
<td>DOB_/_/</td>
<td>CCF #___</td>
</tr>
<tr>
<td>Indication for exam?</td>
<td>Last Name</td>
</tr>
<tr>
<td>YES/NO</td>
<td>Age ____</td>
</tr>
</tbody>
</table>

- Have you had an MRI in the past? If yes, describe reason.
- A surgical operation or procedure of any kind? If yes, list all prior surgeries and approximate dates:
- Prior injury by a metal object/foreign body (e.g., bullet, BB, shrapnel)? If yes, please describe
- Prior injury from a metal object in your eye (metal slivers, shavings, other metal objects)?
- If yes, did you seek medical attention?
- Kidney disease, diabetes, liver disease, asthma, or other allergic respiratory disease?
- Do you have acute or chronic renal failure? Dialysis Dependent? Yes/No
- Do you have any drug allergies? If yes, list drugs.
- Have you ever received a contrast agent/w/r dye used for MRI, CT, or other x-ray or study?
- Have you ever had a contrast agent allergic reaction?

**YES/NO**

- **Cardiac pacemaker/defibrillator**
- Any I.V. access port (e.g., Broviac, Port-a-Cath, Hickman, PICC line)
- Pulmonary Artery Catheter
- Medial patch (e.g., Nitroglycerine, nicotine)
- Any type of electronic, mechanical, or magnetic implant
- Any type of internal electrode(s) or wire(s)
- Any type of surgical clip or staple
- Aneurysm clip(s)
- Any implanted items (e.g., pins, rods, screws, nails, plates, wires)
- Implanted drug pump (e.g., Insulin, Biciflidan, chemotherapy, pain medicine)
- Neurostimulator/Biostimulator
- Halo vest
- Spinal fixation device/Spinal fusion procedure
- Shunt
- Radiation seeds (e.g., cancer treatment)
- Surgical mesh/Location
- Any type of collar, filter or stent
- Artificial heart valve
- Artificial limb or joint/what and where
- Hearing Aid/Cochlear implant/Ear implant
- Artificial eye/Eyelid spring/Eyelid weights
- Tissue expander (e.g., breast)
- Removable dentures, false teeth or partial plate
- Body piercing/location
- Wigs, hair implants
- Tattoos or tattooed eyeliner
- VAC Dressing

**Female Patient:**
- Are you pregnant or could you be pregnant? Date of last menstrual period
- Are you breast feeding?
- Diaphragm, MD, Pyewockey

**Male Patient:**
- Pacemaker implant

**OTHER**
- I attest that this information is correct to the best of my knowledge. I have read and understand the contents of this form and I have had the opportunity to ask questions regarding the information on this form.
- Signature of Patient/Relative/Spouse
- Radiology MD/RN/PRT
- Printed Name
- Date

Requesting MD (if applicable) Requesting MD (printed)

If patient/family member unavailable, requesting staff shall sign above & document in the paper/digital chart so no family member is available; above screening was completed by the requesting service. Based upon reasonable review, the benefits of the MRI exam outweigh any potential risk.

![Safety screening form for patients undergoing MRI](image)

**Fig. 4.** Safety screening form for patients undergoing MRI that the patient fills out and the nursing staff and physician verify. IUD = intrauterine device; VAC = vacuum assisted closure.

...connected to Zone IV through a corridor, which is under the strict control of MRI personnel. The patient and staff are screened for any metal implants using metal detectors located along the side entrance to the zonal area as well as a hand-held metal detection screen manipulated by a designated employee prior to entrance into Zone IV.

Once a ferromagnetic check has been performed, the patient enters the ioMRI-OR, or Zone IV, both the diagnostic and surgical areas. Although the entire OR is designated as Zone IV, a thick gray line delineates an area safe for placing ferromagnetic equipment. It is shaped in an oblong and circumferential manner surrounding the OR table. An inner line represents the region where the magnetic field is 50 G and higher, and the outer line is 5 G and lower. Any ferromagnetic object within this zone can be attracted to the magnet and act as a missile with devastating consequences.

**Anesthesia Considerations**

Historically, anesthesia services have played an integral role in setting up new services such as ambulatory surgical services, critical care, acute and chronic pain, and perioperative services. Anesthesiologists as the safety advocates for patients as well as OR personnel have an essential role in the ioMRI-OR. While the physical location of the ioMRI-OR is remote by necessity in a majority of cases, it is essential to conduct the anesthesia...
protocol away from the ioMRI-OR because of equipment limitations imposed by the magnet.

Anesthetic considerations in the ioMRI-OR have several subdivisions: transport, remote location anesthesia, strong electromagnetic field, use of only approved items, equipment counts, MRI periods, possible emergencies, and awake cases. The use of an induction room (Zone II) allows any necessary monitoring, as well as additional equipment that is not MRI safe but may be vital during the critical induction period, for example, ultrasound and difficult airway management cart, resuscitation equipment, and malignant hyperthermia cart.

After anesthesia is safely induced, there will be adequate time to change the monitors to MRI-safe ones and ensure that there are no ferromagnetic items left on the patient. Although controlled ventilation can be used during induction, transport through Zone III (ferromagnetic check) can delay patient ventilation—resulting in hypercapnia and an increase in intracranial pressure—manual ventilation with an Ambu bag should be used. Volatile anesthetics can be used after induction, but an intravenous anesthetic agent should be used during transport. The induction room can also serve as a safe environment distant from the magnet, where adequate equipment and an anesthesia machine can be kept ready in case there is a need to evacuate the OR or resuscitate with non-MRI safe equipment. Thus, the induction room is always kept ready and clean while the patient is within the ioMRI-OR and is not simultaneously used for any other patient. Additional nursing help, not necessarily screened to enter Zone III or IV, is stationed in this area and able to assist in cases of emergency. Anesthesia in the operating suite should be maintained with MRI-compatible equipment including MRI-compatible monitoring, anesthesia machine, intravenous fluid, medication pumps, and so forth. Some equipment that does have a ferromagnetic quality but is essential to patient care can be used within the OR but should be transferred far behind the OR and unplugged and secured before each scan.

Before starting a case, before each MR image, and at the end of the surgical procedure, all equipment is counted to confirm that all possible ferromagnetic equipment is stored behind the 5-G line. On completion of the case, anesthetic emergence and extubation can be done directly in the OR, in the induction room adjacent to the ioMRI-OR, or in the PACU. For patients who will be kept intubated during transport to the PACU or intensive care unit, ventilation is maintained using an Ambu bag or transport ventilators. Transport monitoring and emergency medications and sedation are provided en route. It is essential to communicate with the destination nursing staff and physician ahead of transport for a correct hand off and transfer-of-care process. Henrichs and Walsh16 have proposed these steps in a sequential manner, namely assessment of the patient prior to surgery, induction of anesthesia, positioning the patient, surgical procedure, postoperative MRI, closure and emergence from anesthesia, and finally recovery in the PACU.

**Equipment Considerations**

Equipment used in Zone IV is safe subject to strict guidelines for compatibility testing. The implementation of protocols for equipment safety and functioning requires collaboration among biomedical engineers, ioMRI-OR staff members, and risk management personnel. Presently, MRI-compatible anesthetic equipment is available in the marketplace for use in ioMRI-OR suites, including the anesthesia machine and physiological monitors with several channels for central venous pressure, arterial pressure, and intracranial pressure. The availability of 2-monitor screens (1 in the control room) enables the anesthesia team and MRI technologists to track a patient’s vital signs. Wireless electrocardiographic and pulse oximetry equipment have mitigated the potential for thermal injury and for long cables to get in the way of the MRI machine. Magnetic resonance imaging—compatible oxygen cylinders are color coded to allow easy identification. The use of MRI-compatible equipment makes the ioMRI-OR a self-contained environment. Thus, it is important to avoid transferring regular OR equipment to the ioMRI-OR and vice versa. This may be a problem for centers with the ioMRI-OR suite close to regular operating rooms.

**Staff Training**

Before any staff can access the ioMRI-OR for a procedure, he or she must undergo safety training including lectures as well as online training sessions regarding the dangers and issues involving personnel working in a high-magnetic-field zone. These training modalities introduce team members to the required knowledge of MRI basics, safety guidelines, procedures in case of emergencies, and guidelines to screen both patients and employees. Ongoing education in this area is essential, as the turnover of staff members and visitors who must learn and observe this technology remains high. In case of an emergency, the anesthesia team is mainly concerned with safe coordination and evacuation, which makes it necessary for all anesthesiology team members to undergo safety training with a safety mock test as well as a mock emergency code drill.

**Safety Challenges**

Developing a culture of safety requires a system of teamwork to provide caregivers increased control over the constantly changing environment. The team must be small, mission focused, and skilled, with the most experienced member from nursing, anesthesia, or surgery becoming their team leader. The checklist forms are an integral component before starting these procedural steps. This checklist begins in the outpatient setting as the surgeon evaluates the patient and the nurse practitioner screens for implants, such as aneurysm clips and pacemakers, that would prevent the procedure from being performed in the ioMRI-OR. Prescreening is performed by the nursing staff on the day of surgery as well, with a checklist to rule out any implanted devices that cannot be in the OR (Figs. 3 and 4).

**Cleveland Clinic Checklist Protocol for the ioMRI-OR**

At our center, a protocol was developed based on the guidelines put forward by the WHO,25 and it is used for all procedures performed in the OR, ambulatory surgical cen-
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ter, and procedure rooms. A detailed version of the components of the checklist is shown in Fig. 1. For use in the ioMRI-OR, the protocol has been modified to account for operating in a high-risk magnetic field area. The following sequence of events describes how we proceed through our checklists: 1) presurgical briefing (huddle; Video 1, Segment 1), a process that enhances communication among the OR team members (circulatory nurse, surgeon, and anesthesiologist) and the patient and family, enabling them to voice any concerns prior to surgery as well as ensuring that the surgical and anesthesia plan is clear and that the preoperative equipment checklist is ready.

**Video 1. Segment 1:** Presurgical briefing (huddle).

**Segment 2:** Metal screening prior to ioMRI-OR entry. **Segment 3:** Time-out (surgical OR briefing). **Segment 4:** Nursing checklist. **Segment 5:** Sign-out (postsurgical briefing). Click here to view with Media Player. Click here to view with Quicktime.

This briefing also reconfirms patient identity, site and side of surgery (marked by surgeon), special medications (including antibiotics and steroids needed), presence of a valid history and physical, and informed consent.

The surgeon first discusses the planned procedure, positioning, intraoperative neurological monitoring, and possible problems that may be encountered, such as bleeding or seizures, and reviews laboratory results and the availability of imaging and key equipment. The anesthesiologist discusses relevant issues including comorbidities, anesthesia plan, special monitoring, and postoperative destination. The need for and availability of blood products will be reviewed, and the patient reconfirms consent for transfusion. In addition, the nursing staff discusses any concerns, including the presence of informed consent, instrument availability, special surgical instrument requirements, application of compression stockings, need for catheters, and medication issues. The surgeon closes by asking if any of the team members or the patient has any concerns.

Specific to the ioMRI-OR is 2) metal screening prior to ioMRI-OR entry (Video 1, Segment 2). After the huddle, anesthesia is induced in the patient in the induction room, and once the patient is ready, he or she is transferred to the ioMRI-OR for surgery. Prior to entry into the surgical suite, the patient is screened for ferromagnetic material. All staff entering the unit is screened as well to avoid inadvertent errors. A specific team member designated to check entry into this high-risk zone manually checks for ferromagnetic metal. In addition, there are metal detectors located on the walls prior to entering the surgical area and detectors at entry zones to the control room.

After metal screening, a 3) time-out (surgical OR briefing; Video 1, Segment 3) is performed. Once the patient is transferred onto the operating table while under anesthesia, positioning and head fixation with a MRI-compatible head holder are performed. Once the patient has been positioned, registration of the fiducial markers into the navigation device is performed, and the surgical site is painted and draped. After the anesthesiologist announces that the patient is ready for the surgeon, an additional time-out is performed, through which interactive communication among the operating surgeon, anesthetist, and nurse reconfirms the surgical plan. The team affirms the correct patient, correct surgical site and side, correct procedure, and correct position. The surgeon also verifies that all elements or issues are resolved and that antibiotics and other medications are given before announcing the time of incision.

After the surgical OR briefing, a 4) nursing checklist (Video 1, Segment 4) is completed. This is usually performed before entry of the magnet for imaging and may be done multiple times through the case. The nursing team does a thorough sponge count while also documenting every needle, drill bit, and instrument used and noting any discrepancies between the start of the case and the end and entry of the magnet. The nursing checklist is also performed during a pause before definitive wound closure.

After the nursing checklist, a 5) sign-out (postsurgical briefing; Video 1, Segment 5) is performed. The sign-out occurs at the end of surgery at the time of skin closure and essentially consists of a verbal confirmation prior to leaving the room. It includes patient name and procedure performed, disposition of the unused blood products, biopsy material, and counts completed and reconciled; equipment issues, if any, are addressed; and the team performs a final review of their key concerns for recovery and management of the patient.

**Results**

The safety checklist protocol for use in the ioMRI-OR has been implemented at the Cleveland Clinic since its opening in February 2010. We performed 120 ioMRI-OR cases with no adverse events. Although major events are tracked, the items caught with the use of the checklist are not formally tracked because of the preemptive nature of the checklist. The importance of the checklist can be demonstrated by the following case, which occurred in the initial days of ioMRI-OR use. A 62-year-old man underwent craniotomy for resection of a tumor in the ioMRI-OR. Administration of anesthesia, patient positioning and draping, and surgery were performed in a standard manner. A metal band, which is normally contained within the craniotomy drapes, was not removed prior to the start of the case. The presence of this metal band could be a patient safety hazard and could result in a significant imaging artifact. Given that the metal band is included in the nursing checklist protocol count prior to MRI, the band was noted as missing, and a search led to its identification on the drape and its removal, and thus avoiding possible complications for the patient, anesthesiologist, radiologist, and surgeon.

**Discussion**

A commitment to safety has been demonstrated by a number of industries such as aviation, nuclear power, aerospace, and Formula One racing. These fields have been able to map out and assess risk by profiling processes and informing every employee about risk reduction strategies that have been developed to create systems for facilitating rapid and effective mitigation in emergency situations. They have been able to maintain their commitment to a culture of safety by mentoring leaders in risk
reduction and safety. Lessons learned from the aviation industry revealed that nontechnical skills, namely communication and situational awareness, must be an integral part of every team to respond to any adverse event and create a safe environment. The aviation industry has used CRM to standardize team working and communication, thus improving open communication and disrupting any barriers of hierarchy. The CRM model has evolved over the past 20 years and has trained teams to change their attitudes and behaviors in aviation, providing the health care community with a mature working model. These attitudinal changes are essential in health care where the risks to human life can be catastrophic. The US Army completed its first field evaluation of their CRM-based training program, the MedTeams program for hospital emergency departments, which has been commercially available to other hospitals since 1999. The MedTeams training curriculum began as a review of closed risk management cases in a major medical center. It analyses and describes methods in training and early recognition and avoids or mitigates the impact of clinical errors. The main components of the MedTeams curriculum appear in the Team Strategies and Tools to Enhance Performance and Patient Safety (TeamSTEPPS) program that has been available since 2006.

The health care industry relies on safety, with little room for errors that could cause patient death or morbidity. The US Department of Health and Human Services launched “Partnership for Patients: Better Care, Lower Costs” by committing $1 billion toward safety improvement. In the US, the Joint Commission has played an important role in identifying and maintaining high-priority topics in improving the quality of health care, issuing its National Patient Safety Goals program based on these topics. The use of checklists to standardize health care has been proposed as a solution to avoid mistakes, but their success is more complex than simply creating them. Additional barriers to using checklists may be the resistance among physicians to change and a changing culture to empower team members that have traditionally been lower in the care hierarchy to voice their concerns. These barriers limit the universal use of checklists and impede processes of collecting meaningful data and outcomes analysis.

Certain elements are required to successfully implement the checklist, which are further detailed in the Appendix. If the checklist is used in a correct manner, risk mitigation and avoidance of errors are natural consequences. If used inappropriately—as a checkbox tool without team awareness—it may not provide the intended results. Makary et al. evaluated the relationship between surgical room briefings and wrong site surgery, recruiting each participating surgeon as the “physician champion,” and measured attitudes using a Safety Attitude Questionnaire. The study revealed a sustained change in the culture of those who participated in the pilot, and more than half of the participating surgeons adopted the briefing practice into their daily routines. The educational model is used wherein knowledge gained creates a change in attitude, in turn causing a behavioral change and ultimately preventing errors and reducing harm. A simplified algorithm summarizing the steps in the education model that need to be taken by an institution to implement change is shown in Fig. 5. Although appropriate introduction and use of the components described earlier may bring about the successful implementation of the checklist, a number of hurdles may continue to hinder the successful execution of these checklists, and these are described in the Appendix.

Conclusions

Health care errors can lead to patient harm or death. Although hospitals and health care personnel are often perceived as infallible, errors do occur. The ioMRI-OR brings in new challenges and provides many areas of vulnerability that can increase the chance of devastating errors. It is safe to say that with all great technology comes great responsibility, and the onus lies with the treating team to get the patient safely in and out of this high-risk environment. In this report we cover the most important safety measures implemented for ioMRI-OR cases at the Cleveland Clinic. We are still in our learning curve, but we believe that our experience can help in designing a guideline for such cases.

Appendix

The acronym R.E.S.P.E.C.T. has been used at the Cleveland Clinic among caregiver teams to develop open communication and mutual respect for everyone taking care of the patient.

- Retaining patient focus.
- Establishing who each individual is.
- Supporting the role of others.
- Please and thank you.
- Embracing and engaging others (ideas and knowledge).
- Coaching and educating all team members.
- Talk! Talk and more talk (inform each other before, during, and after the case).

Appropriate implementation requires tools to enhance learning and create a common mission or goal focusing on patients first,
which is important in creating a sense of long-lasting achievement. The components include the following:

Organizational leadership in the implementation and maintenance of the surgical checklist. The tone and pace of adopting change are then set for the organization, with clinicians subsequently recommending improvements using their powers of persuasion and authority.

Organizational support in prioritizing patient safety.

Establishment of local champions or team leaders. These individuals are positive about the approach and engage others who may initially be reluctant to start. The leader understands that this is not a series of tasks but an attitude that forms behavior. Ideally, the team creates a culture of safety that is open and fair and avoids blaming individuals while promoting reflective and evidence-based learning. Assembling an appropriate team in which members are accountable for their actions.

Communicating essential team information.

Acknowledging the contribution of each team member.

Demonstrating mutual respect in communication with team members.

Addressing concerns with appropriate follow-up discussions to achieve an acceptable resolution.

Training individuals and providing a knowledge base on which to work, as well as results and feedback from local processes.

Demonstrating evidence of success in the culture of safety improvements.

Hurdles to the successful implementation of checklists:

Unfamiliarity with procedural steps and anxiety about performing new methods.

Hierarchy of staff preventing a free and open discussion about relevant issues.

Time availability and logistics.

Duplicative nature of many of these processes, making the team believe that they are unnecessary.

Inappropriately used checklists that are incomplete, sign-ins lacking in detail, and sign-outs not being performed. Team members in a hurry to finish a case, dismissive replies, or the absence of key personnel.

Disclosure

Dr. Avisitsin holds a patent with Parker Hannifin.

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