Intraoperative Magnetic Resonance Imaging

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Pui-San Loh and Ramani Vijayan

22.1 Introduction

The advent of intraoperative magnetic resonance imaging (iMRI) since the 1990s has revolutionized modern neurosurgery to what it is today [1]. By combining the non-invasive imaging capability of MRI with an operative space, surgeons can now locate and excise lesions precisely, gaining instant quality control over every step in their workflow [2].

Neuronavigation no longer needs to depend on archived images but appropriately timed scans uploaded for real-time guidance. This improves precision in the surgical field that is affected by intraoperative brain shift and distortion from multiple factors such as position changes, anaesthetic effects, cerebral spinal fluid (CSF) loss, tissue type, resected mass and of course, surgical duration [3]. Patients benefit from not only improved overall gross tumour resection rates but also preserved vital neurovascular structures and eloquent areas; an advantage most prominently seen in glioma craniotomy and pituitary tumour resection. With this technology, more than a third of gliomas and a fifth of pituitary adenomas were reportedly requiring further resection. Furthermore, biopsies and implantations can be performed with minimal surgical damage [4]. In the younger age group, the need for additional resection in the immediate post-operative period of 2 weeks is also reduced [5].

However, intraoperative imaging comes with its own set of challenges with regard to both costs and logistics. This chapter focuses on the challenges faced with providing anaesthesia for iMRI in neurosurgery.

22.2 Types of iMRI

The set-up of iMRI has followed two general concepts: operating within the magnet with continuously refreshed images and a dual-room suite offering both surgical and diagnostic facilities. Either magnet or patient can be stationary in the dual-room concept.

22.2.1 Open

The original 'open' system started with a stationary magnet (0.5 T) and a stationary patient [6]. The main advantage is its ability to obtain frequent 'real-time' images but despite this, there are several setbacks. First of all, working space is limited for both surgeons and anaesthetists. Second, all equipment including surgical instruments must be MRI safe. These tools are not only costly but their quality is also often inferior to

P.-S. Loh (✉) • R. Vijayan
Department of Anaesthesiology, University Malaya Medical Centre, 50603 Kuala Lumpur, Malaysia
e-mail: lohps@ummc.edu.my; lpuisan@yahoo.com.sg

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conventional instruments [7]. Newer systems then progressively looked into improving the resolution with a stronger magnetic field compared to the prototype.

22.2.2 Dual-Room

Later development has seen the growth in the concept of having two independent rooms, one with a MRI machine of 1.5–3.0 T, separated by an air lock chamber that could be linked when iMRI is needed in the adjacent operating suite. The initial cost for such a system can be prohibitive but may have a better cost: benefit ratio eventually because ongoing diagnostic scans can be carried out until imaging is needed for the surgical case. In this way, either magnet or patient can be placed stationary with the other moving towards it.

The additional advantages of utilizing a dual-room iMRI will be a less impaired surgical access and allowance for normal surgical instruments such as regular microscopes, drills, retractors and conventional navigation reference frame [7]. However, intraoperative imaging for craniotomy lengthens the procedure as image acquisition can only occur after the patient has been placed within the magnet [8]. With an open cranium, it is imperative to maintain sterility throughout the process of transfer and allowance made for head positioning within the isocentre of the scanner.

Apart from common advantages in the dual-room system, when the magnet is mobile, meticulous care is taken to ensure all ferromagnetic items such as the operating microscope, high-speed drill and bipolar cautery are secured beyond the 5 Gauss (5-G) line. All electric circuits entering the radiofrequency cabin will be filtered with the data and video lines transferred to the control room via a fibre-optic cable [9].

The major setback of having the patient mobile instead of the magnet lies in the need to transfer an anaesthetized patient in a process involving docking onto a MRI compatible trolley and ensuring adequate monitoring plus ventilator support throughout the scanning process in the MRI suite [7]. As an added advantage, such a system provides an opportunity to include several different modalities such as positron emission tomography and biplanar fluoroscopy.

22.3 Providing Anaesthesia for iMRI

The anaesthesia provided for a surgery with iMRI planned is different compared to those with no such requirements. The planning starts much earlier for the neurosurgical case and additional steps have to be taken to ensure MRI safety and efficient workflow which will not interrupt the duration of the surgery nor compromise patient safety. As a comparison, the flow chart below in Fig. 22.1 demonstrates the workflow of providing anaesthesia for a normal neurosurgical case and another with iMRI planned in a dual-room system where either the magnet or patient is mobile.

The practice of iMRI should follow recommended inernational guidelines in anaesthetic care for MRI. In the most recent Practice Advisory on Anaesthetic Care for MRI by the American Society of Anaesthesiologists Special Task Force, several items have been highlighted

Fig. 22.1 The iMRI dual-room suite with the docking trolley in front and an MRI-compatible ventilator by the side of the stationary magnet (Picture courtesy of *C*entre of *I*mage *G*uided and *M*inimally *I*nvasive *T*herapy – *CIGMIT*, University Malaya Medical Centre)

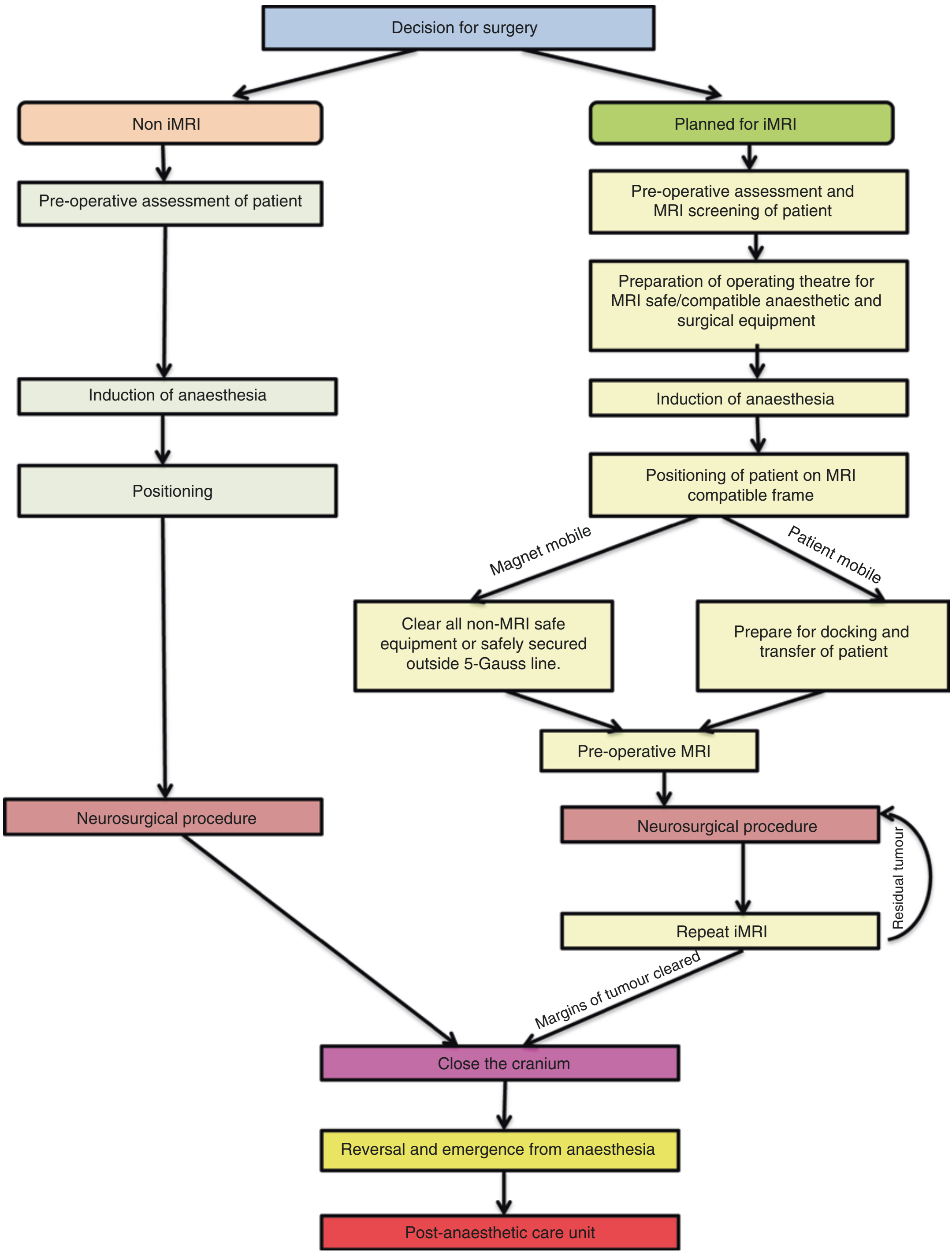

Fig. 22.2 Workflow to compare a non-iMRI case on the left and iMRI on the right

which can be adopted in iMRI [10]. The Practice Advisory differs from documents published previously by focusing specifically on anaesthetic care of patients in the MRI environment compared to broader safety issues by other organizations' guidelines (Figs. 22.2 and 22.3).

Fig. 22.3 A summary of the highlights from the ASA task force in 2015 [10]

1. Education
2. Screening of anaesthetic care providers and ancillary support personnel
3. Patient screening
4. Preparation –
   - Plan for providing optimal anaesthetic care
5. Management during MRI –
   - Monitoring
   - Anaesthetic care
   - Airway management
   - Emergencies
6. Post-procedure care

22.4 Anaesthetic Concerns

22.4.1 Training

Specific training modules must be developed to orientate the whole team working together in the MRI suite [7]. Basic information on work safety in an MRI environment and special considerations for iMRI such as steps in docking and transferring a patient or mobile magnet must be included. The team members who need to undergo this training include surgeons, anaesthesiologists, nurses and the radiographers. An MRI safety officer as the Chief in Training should be selected to document the training records and the list of trained personnel so that only dedicated staff is allowed to manage iMRI cases. Access ought to be restricted to those who are untrained or who are not involved in the surgery.

22.4.2 Planning and Communication

Although the neurosurgeons take the lead to decide for iMRI in their cases, planning and timing must be communicated to the anaesthetic team and other care providers to facilitate preparations for MRI safe equipment, longer lines and placement of monitoring items. Vigilant care must be applied for clear reasons to ensure MRI safety and the sterility of an open cranium. Hence, good communication is vital and with time, the process becomes smoother and faster to accomplish.

22.4.3 Equipment Safety

Preparation of an MRI-safe environment includes labelling and identifying items and devices that are safe to be used and positioned within the magnetic field or otherwise. Specific terminology has been established to describe the relative safety of items in an MRI environment. MRI safe describes an item that poses no risk and likewise MRI unsafe means the item is a hazard in such an environment. MRI conditional refers to items that have no known hazards under specific conditions of use in a specified MRI environment. Such an example would be an MRI conditional anaesthetic machine specified for use under condition for 100 Gauss in a 1.5-T magnet which means it would be unsafe beyond that field strength [11]. Similarly, certain infusion pumps, warming blankets, temperature probes and even pacemakers are available as MRI conditional now. Another terminology is MRI compatibility, a requirement that the magnetic field does not affect a device and vice versa, the device should not interfere with the imaging process (Table 22.1).

22.4.4 Checklist

An important concept to remember is that the magnet is always on [13]. A checklist is used to ensure all appropriate steps are followed for a safe transfer of the patient to the MRI suite or

Table 22.1 Common equipment and devices used in the operating theatre (OT) that need to be located outside the 5-G line before iMRI

Anaesthetic equipment
Anaesthesia machine (unless MRI compatible)
Anaesthesia cart
Resuscitation trolley
Monitoring – Pulse oximetry, ECG, blood pressure (unless MRI compatible)
Desflurane vaporizer [12]
Invasive monitoring transducers
Needles and guidewires
Armoured tracheal tubes
Stethoscopes
Warming blanket device
Intravenous fluid warmer
Nerve stimulators
Temperature probe
Poles for intravenous fluids
Oxygen tanks, regulators and holder (unless MRI safe)
Surgical items
Diathermy – foot pedals, cautery pads and cords
Unsafe instruments – clamps, retractors
Microscope
Headlights, loops
Neuronavigation equipment
General use
Garbage bins
Buckets
Stools and steps
Patient folders
Pens
Handphones, pagers

the transfer of the magnet into the operating suite which must be done with extra caution. When iMRI is undertaken, only designated anaesthetic care providers and MRI staff should be involved. An assigned officer, who may be the nurse manager, takes the lead to call for time out and reads the checklist aloud to tick off all necessary items in the presence and attention of the whole team. When the scanner is not in use for the surgical case, the connecting door should remain closed at all times for the two rooms to function separately (Table 22.2).

Table 22.2 Example of an iMRI anaesthetic checklist for a stationary magnet and mobile patient system

Pre-induction	(✓)
Patient particulars and consent checked	
Surgical position confirmed	
Both ventilators and circuits in OT and MRI checked	
MRI compatible ECG dots/ lead and SpO_2 probe/ cable available	
MRI compatible oxygen tank with resuscitator bag/ T-piece available	
Anaesthetic personnel cleared of electrical/ ferromagnetic items	
Induction	
MRI compatible ECG dots placed	
Plain PVC tracheal tube	
Intubate patient on trolley	
NO ferromagnetic items on patient canvas and OT table before transfer	
Before sterile draping	
Monitoring lines, catheters and circuit that need to be removed before the transfer to MRI are assessable	
Perfusor tubings and intravenous lines secured and adequate in length	
Docking	
Arterial, CVP monitoring lines, hotline and forced air warmer disconnected, temperature probe removed	
Catheter bladder drain, lines and any other tubes removed from sides of OT table	
Manual ventilation taken over	
Oxygenation maintained before removing non-MRI compatible SpO_2	
Transfer from OT to MRI	
Confirm patient's haemodynamic stability for transfer	
MRI ventilator, circuit and monitor checked and complete	
NO electrical/ ferromagnetic items on patient, trolley and anaesthetists/ assistants	
Pathway of transfer cleared	
MRI suite	
IPPV ventilation instituted	
MRI-compatible SpO_2, ECG and NIBP monitoring on	
Intravenous line and drug perfusion running well	
Back in OT	
IPPV ventilation re-instituted	
Arterial, CVP monitoring lines, hotline and forced air warmer reconnected	
Non-MRI compatible SpO_2, ECG and NIBP monitoring on	

OT operating theatre, *IPPV* intermittent positive ventilation, *SpO_2* pulse oximetry, *ECG* electrocardiograph, *NIBP* non-invasive blood pressure, *CVP* central venous pressure

Conclusion

The iMRI suite is considered a hybrid, combining elements of an MRI interventional radiology unit with an operating room. In an increasingly technology driven field of medicine and science, the human factor remains the most critical. Therefore, communication remains the most important element to stress upon with all respective roles in iMRI clearly outlined for such a practice to be useful and safe in neurosurgery.

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