29 Anaesthesia and Sedation for Radiological Imaging

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29.1 Introduction

Cancer has emerged as one of the leading causes of mortality all over the world and its incidence continues to rise. Researchers across the globe are putting in diligent efforts to develop new weapons to combat it. Imaging modalities form the backbone of the management of cancer patients as a means to diagnose tumor and metastasis, decide treatment plans, prognosticate, and do image-guided procedures. Historically, computed tomography (CT) has dominated the scene of oncology imaging because of its easy availability, was less time consuming, and radiologists were more accustomed to it. However, magnetic resonance imaging (MRI) has become the cornerstone of contemporary onco-imaging because of advancements in its technology and concerns about radiation with CT. MRI has several advantages over CT scan with regards to scanning patients with cancer: superior contrast resolution, tissue characterization (e.g., cystic versus solid), ability to perform dynamic post-contrast imaging, and lack of ionizing radiation [1]. MRI has improved sensitivity for many lesions (e.g., metastatic lymph nodes, bone lesions, liver lesions) and allows better assessment of vasculature, e.g., vascular invasion. Furthermore, emerging techniques will keep MRI at the forefront of onco-imaging—whole-body MRI, qualitative diffusion, Positron emission technology (PET) MRI, MRI guided biopsy.

Since CT/MRI is a painless procedure, most imaging studies in adults can be performed without the use of anesthesia or sedation. However, young children are unable to lie still during the study and form the vast majority of those needing anesthesia services for imaging procedures. Anesthesia may be indicated for patients with young age, claustrophobia, severe anxiety, inability to lie still (e.g., parkinsonism), prolonged procedures in the prone position, mental retardation, psychiatric illness, and a history of the need for sedation in past. However, anesthesia in such remote locations has many risks inherent to the location, facilities, monitoring, and patient population (Table 29.1) [2, 3].

The high risk of anesthesia at these locations is reflected in a study by Vander Griend, et al. where out of 101,885 anesthetics for imaging procedures in children, ten anesthesia-related deaths were reported [4]. This incidence is much higher than that reported for operating room anesthesia (1:100,000). In all these cases, pre-existing medical conditions were the major contributory factor to the deaths. The utilization rate

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Table 29.1 Anesthetic challenges in CT/MRI suite

Challenges of anesthesia in CT/MRI suite [2, 3]
(I) Pediatric population with its own set of concerns
(II) It is usually difficult and time consuming to acquire personnel support, extra drugs, or equipment in case a need arises due to the unfamiliar and remote location
(III) Need to maintain physical distance from the patients during the scan
(IV) Restrictions in entry to the suite and access to the patient during the procedure making any assistance for difficult intravenous lines/ airways, or in case of anesthetic emergencies unavailable or delayed

of off-site anesthesia serves has shown tremendous growth in a short span of 28.3% in 2010 to 35.9% in 2014 and it is expected to steadily grow in the future [5]. Hence, anesthesiologists need to be abreast of the challenges and safety concerns of non operating room anaesthesia (NORA).

29.2 General Considerations

29.2.1 Computed Tomography (CT)

CT is a commonly used modality for diagnostic and interventional procedures. The scan quality can be improved by using contrast agents. Personal protective equipment, e.g., lead apron, thyroid shields, and dosimeters should be worn by all staff involved in patient care at the CT scan suite. Movable leaded glass screens separate the patient from the caregivers during the scan. Video monitoring provides remote mirroring of monitor data. The minimum sizing recommendation for a CT scan room is an area of 250 ft^2 with a clear dimension of 3 ft on three sides of the procedure table. The maximal permissible dose of occupational radiation exposure is a cumulative annual dose of 50 millisieverts (mSv) and a lifetime total dose of 10 mSv times the age of the worker [6, 7].

Anaesthesiologists—Anesthesia care providers are also exposed to ionizing radiation during a CT procedure. Radiation dose is determined by:

- Time—Anaesthesiologists may be exposed to longer durations and higher doses of radiation than radiologists during CT scans because the CT team can perform their duties within the shielded control room, while the anesthesiologist may need to remain by the patient's side, particularly for sedated patients with a potentially difficult airway and those undergoing general anesthesia [3].
- Distance—The amount of radiation to the anaesthesiologist decreases in proportion to the square of his distance from the scanning tube.
- Shielding—Lead aprons and thyroid collars should always be worn while maintaining a reasonable distance from the patient [7]. Portable shields and eye protection mitigate risk. Dosimeter badges should be worn by anesthesiologists and staff routinely exposed to ionizing radiation so that cumulative radiation exposure can be monitored regularly over some time [3, 8].

29.2.2 Magnetic Resonance Imaging (MRI)

The property of paramagnetic elements to act as magnetic dipoles and their ample presence in bodily tissues with high water content is the basis of MRI. The magnetic field strength is measured in tesla units and one tesla (T) equals 10,000 gauss. Clinical MRI examinations use field strengths between 0.05 and 3.0 T.MRI suite should be spacious (at least 150 ft^2 control room and cryogen storage of 50 ft^2) [9].

MRI is a time-consuming procedure. The extremely powerful static and gradient magnetic field and radiofrequency electromagnetic waves pose potential hazards to patients and workers [9]. Limitations and hazards for patients and anesthesia providers during MRI [3, 9–11]:

1. Switching the radiofrequency generators on and off produces loud noises (>90 dB).
2. Even physiologic motion (e.g., breathing) can produce image artifacts.
3. Restricted access and patient visibility during the examination for caregivers and during an emergency for emergency personnel.

4. Magnetic field interferes with equipment for patient monitoring and stray radiofrequency currents from the monitoring equipment can in turn potentially degrade the MRI images.
5. The anesthetic equipment cannot be moved when the scan has started as their rapid movement can impair magnetic field homogeneity.
6. Ferromagnetic materials (scissors, pens, keys, mobiles, cylinders, etc.) may turn into dangerous projectiles and must be eradicated from the MRI suite.
7. Implanted biological devices (vascular clips and shunts, wire-reinforced endotracheal tubes, pacemakers, mechanical heart valves) or intraocular ferromagnetic foreign body may get dislodged/ migrate or malfunction.
8. Transdermal patches may consist of aluminum or other metals (e.g., fentanyl, buprenorphine, scopolamine being received by many cancer patients) or tattoo ink (contains iron oxide) that carry the risk of causing skin burns.

MRI suite is functionally divided into four different zones [10]:

- Zone I: freely accessible to everyone.
- Zone II: buffer area between free access of zone one and restrictive access of zone three.
- Zone III: only approved MR personnel and patients that have undergone a thorough screening are allowed inside zone Three. The MR control room is located in this zone.
- Zone IV: actual scanner room, also called the magnet room. People can enter only through zone three.

29.2.2.1 Anesthetic Concerns Specific to MRI Suite

According to the American Society of Anaesthesiologists (ASA) task force advisory on anesthetic care for MRI [10], all the anesthetic care, monitoring and resuscitation equipment, and drug supplies at this off-site facility should be parallel to the recommendation followed for standard operative settings. This includes (but is not limited to) basic amenities, e.g., adequate electrical outlets and lighting, storage areas for equipment and drugs, suction, and standard anesthesia equipment, e.g., an anesthesia machine with integrated medical gases and gas scavenging. MRI safe/conditional anesthesia machines are safer for use in an MRI suite than anesthesia delivered via an elongated circuit through a waveguide using a traditional anesthesia machine kept inside zone III [9, 10]. Age appropriate airway and resuscitation is a must. Alternatively, total intravenous anesthesia (TIVA) can be used by either of the following methods: (1) MRI safe/conditional pumps in zone IV, (2) traditional (i.e., MRI unsafe) pumps in zone III with intravenous tubing passed through a waveguide, or (3) periodic bolus injections in either zone III or IV [3, 9, 10]. At all times, equipment for the administration of positive pressure ventilation with oxygen should be immediately available [9, 11].

29.3 Anesthetic Management of Cancer Patients for CT/ MRI

Anesthetic management of patients undergoing CT/MRI examination presents unique challenges to anaesthesiologists although the scans are usually very short and do not entail any fluid shifts/ blood loss. Anesthetic concern for these procedures is linked mainly to the remote anesthesia location, patient population (cancer patient, pediatric age group), and the procedure (CT: radiation, MRI: ferromagnetic field) [2, 3, 11].

29.3.1 Preoperative Assessment and Investigations

Before anesthetizing the patients, it is mandatory to carry out a thorough pre-anesthetic evaluation of the patient and obtain relevant consent for the procedure. PAC visits should be considered as an opportunity to evaluate the patient based on physical as well as psychosocial aspects. Also, modality-specific concerns should be kept in mind [3]. Any congenital anomalies, previous personal or family history of complications during anesthesia and surgery, history of allergies to

any drug, medical illnesses, recent respiratory illness, current or past intake of any general or chemotherapeutic medications, and history of systemic toxicity due to chemo/radiotherapy should be specifically elicited [2, 3, 12]. Chemotherapy and radiotherapy can lead to various systemic manifestations. (Table 29.2) [13–18] and (Table 29.3) [19, 20].

The presence of an anaesthesiologist is mandatory for sedation in case of a neonate, history of obstructive sleep apnoea, respiratory failure, hemodynamic instability, cardiac disease, anomaly involving head and neck, e.g., Apert's or Crouzon's syndrome, severe gastroesophageal reflux disease, or in a child with myopathies, mitochondrial, or metabolic disease [3, 9, 21, 22]. Oncologic patients requiring high dose medications for their baseline pain control need careful evaluation of treatment regimen to achieve safe and adequate sedation and analgesia [18].

Table 29.2 Effect of chemotherapy drugs on various organ systems [13–18]

Organ system	Drugs	Implication
Pulmonary	Cytotoxic antibiotics Nitrosoureas Alkylating agents Anti-metabolite Plant alkaloids Biological response modifiers Others: taxol	Interstitial pneumonitis; acute non-cardiogenic pulmonary edema; Bronchospasm; Pleural effusion
Cardiac	Anthracyclines Cytotoxic antibiotics Alkylating agents Others, e.g., 5-fluorouracil	Myocardial ischemia and depression, hypo/hypertension, myocarditis, endomyocardial fibrosis, and conduction defects
Hepatotoxicity	Nitrosoureas Cytotoxic antibiotics Anti-metabolites Others: vincristine,5-FU, cisplatin	
Nephrotoxicity	Nitrosoureas Others, e.g., bleomycin, cisplatin, cyclophosphamide, vincristine, methotrexate, mitomycin C	Renal tubular; and glomerular impairment, haematuria, urate nephropathy, hemorrhagic cystitis
Hematological toxicity	Alkylating agents Natural alkaloids Antibiotics	Anemia, neutropaenia, thrombocytopaenia and thrombosis
Neurotoxicity	Cisplatin Carboplatin Methotrexate Vincristine Cyclosporine	Peripheral neuropathy, encephalopathy, autonomic neuropathy cerebellar ataxia
Gastrointestinal toxicity	Almost all chemotherapeutic agents	nausea and vomiting, diarrhea, mucositis, enterocolitis, stomatitis delayed gastric emptying, and aspiration

Table 29.3 Systemic effects of radiotherapy [19, 20]

System	Effects	Remarks
Airway	Fibrosis of soft tissue of mouth, neck, and airway mucosa, Subglottic edema or stenosis, Hypoplasia of the jaw, xerostomia, Mucositis	Limited mouth opening and neck extension, poor submandibular compliance, difficult mask ventilation, and intubation
Respiratory system	Radiation-induced pneumonitis, Restrictive lung disease	Higher risk of intra and postoperative pulmonary complications
Cardiovascular system	Pericarditis and pericardial effusion, Endocardial and valvular fibrosis, Conduction system defects, ischemic heart disease	Risk is increased with simultaneous chemotherapy with vincristine or doxorubicin

Some pediatric malignancies have a higher association with other medical conditions (e.g., Down's syndrome with lymphoma) which increase the likelihood of cardiac anomalies, such as endocardial cushion defects [18, 19]. Standard ASA fasting guidelines are followed for the child(solid food up to 6 h, breast milk up to 4 h, and clear liquids are permitted up to 2 h before the procedure [23]. If the tumor or medical condition is impairing gastric emptying, stricter guidelines may need to be enforced.

A suggested scheme for the pre-anesthetic evaluation of a child with malignancy has been summarized in Table 29.4 [19, 24].

Table 29.4 Pre-anesthetic evaluation concerns for a pediatric oncology patient [19, 24]

Toxicity	Risk factors	Evaluation	Anesthetic consideration
Cardiac	Anthracycline Radiation	Obtain echocardiogram if: • Cumulative drug dose>240 mg/m^2 • Any dose in infants • Chest radiation>40 gy	New-onset hypotension and arrhythmia during anesthesia
Airway, Circulatory	Anterior mediastinal mass/ SVC syndrome	CXR, CT, ECHO, and Flow-Volume loop	The plan will depend on symptoms and status of the tumor, may be done under local anesthesia alone, postponing procedure after local irradiation, or general anesthesia with all precautions
Pulmonary	Pneumonia, BOOP, pulmonary fibrosis from chemotherapy, RT, and HSCT.	CXR, ABG, and pulmonary function tests depending on the severity	The obstructive and restrictive disease may interfere with ventilation. Keeping FiO_2 lowest possible after CT with bleomycin.
Renal and Hepatic	Chemotherapy, radiotherapy, and HSCT	RFT and LFT	Modify drugs and their doses
Hematopoietic	Anemia, leukopenia, hyperleukocytosis, thrombocytopenia	CBC, coagulation profile.	Preoperative transfusion of blood products may be considered in case of severe pathology and anticipated prolonged procedure or image-guided interventions. Consider the use of irradiated and leuco-depleted products.
Neurological	Central and peripheral nerve dysfunction	Establish baseline values	Document
Radiation airway changes	Mucositis, airway fibrosis, and edema	Airway assessment: mandibular mobility, neck movements, MMP class, etc.	Anticipate airway to be difficult even with/ without the use of muscle relaxants
Oncological emergencies	Elevated ICP, SC compression, tumor lysis syndrome, hypercalcemia	Assessment as per particular abnormality	Treatment is based on a particular abnormality present.
Gastrointestinal	Diarrhea, vomiting, ulceration, obstruction, perforation, malnutrition, etc.	Assess aspiration risk, electrolytes, metabolic derangements, and glucose levels as appropriate	Consider hydration and nutrition supplementation. Consider a higher risk of aspiration
Endocrine	Thyroid and growth hormone dysfunction, adrenal suppression	Assessment as appropriate, any exogenous supplementation required.	Consider corticosteroid stress dose as appropriate
Congenital anomalies	Apert's/Crouzon's/Pierre Robin syndrome, etc.	Airway assessment	Anaesthesiologist presence mandatory for off-site anesthesia, DA cart ready

BOOP, bronchiolitis obliterans organizing pneumonia; CXR, chest X-ray; MMP, modified mallampatti class; ICP, intracranial pressure; SC, spinal cord; RFT, renal function test; LFT, liver function test; CBC, complete blood count

29.3.2 Staffing Requirements

Imaging procedures have routinely been conducted using several sedation models and sedation has been administered by the radiology staff or pediatricians at the point of care apart from anaesthesiologists [12, 25–29]. Midazolam is frequently administered by non-anaesthesiologists [26]. For propofol sedation by non-anaesthesiologists (e.g., pediatricians in the pediatrician-delivered model), propofol credentialing is a prerequisite. This encompasses a 3-h didactic session followed by 10 days of OR training under an anaesthesiologist inclusive of 25 supervised propofol sedation administered by the trainee [30]. Even after initial credentialing, to maintain certification to deliver propofol, a minimum administration of 50 propofol sedations per year (with the backup provision of an anesthesiologist) is mandatory by the pediatrician [30].

However, in the recent past, there is increasing awareness about the risks of such practice and now it is commonly recommended that a dedicated trained anesthesia team should provide the service in all pediatric cases [9, 10, 12, 21, 31]. The most dreaded and frequent complication of inducing sedation or general anesthesia at these locations is cardio-respiratory depression, which includes upper airway obstruction, hypoxia, hypotension, and in rare cases even cardiac arrest [9, 10, 12, 24]. Other rarer adverse effects purportedly are nausea, vomiting, disorientation, sleep disturbance, and nightmares.

AAP guidelines for off-site sedation provision recommend the constant presence of at least one dedicated individual trained and competent in providing airway management skills and pediatric advanced life support [12]. Anesthesia technicians (assistants who transport and restock all equipment and supplies) should be available during the preparation of equipment as well as during the scanning procedure. All assistants working in the MRI suite should receive specialized training in patient and personal safety in this environment, as well as the types of special equipment and supplies that may be needed [10, 12].

29.3.3 Safety Requirements for Imaging Facilities with the Provision of Off-Site Anesthesia

A facility for NORA should be fully equipped with a reliable oxygen source, resuscitation equipment, emergency drugs, defibrillator, and provision for recovery care along with staff trained in BLS skills. Safety requirements for NORA services are provided as described by ASA have been mentioned in Table 29.5 [32]. All anesthesiologists providing such care should be familiar with the setup and its limitations to plan accordingly.

29.3.4 Goals of Anesthesia

The goals of providing sedation/anesthesia in imaging suites are mainly to ensure safety and comfort while providing anxiolysis, analgesia, and immobility pain control and control of excessive movement. The AAP has defined the goals of sedation as mentioned in Table 29.6 [33].

29.3.5 Indications of Anesthesia/Sedation

Parental reassurance (along with some reward as an incentive), swaddling, feeding, warmth, quiet atmosphere, and giving sucrose can be sufficient

Table 29.5 Safety requirements for the imaging facilities [32]

ASA guidelines for non-operating room anesthesia
• Full compliance with safety and building codes • Sufficient space for the anesthesia care team • A means of reliable two-way communication to request assistance Constant supply of oxygen with a reliable backup source and gas scavenging • Safe electrical outlets and suction • Adequate monitoring equipment and self-inflating resuscitator bag • Adequate illumination with battery-powered backup • Emergency cart (with a defibrillator, Emergency drugs, and other emergency equipment)

Table 29.6 Goals of sedation as defined by AAP for children undergoing diagnostic/ therapeutic procedures [33]

Goals of sedation:
• To minimize any physical discomfort and psychological trauma
• Anxiolysis, amnesia, and analgesia
• Maximize patient safety
• To restrain abnormal behavior and/or any motion and allow safe procedural completion
• To ensure complete recovery of the patient and allow safe discharge is possible

to allow short, painless procedures to be performed in young infants and children without any sedation [34]. Moderate sedation would suffice for CT scanning with the latest multi-slice scanners which allow rapid image acquisition. However, MRI is very noisy and involves lying still in an enclosed space for a prolonged time, and can be frightening for children. Hence, the majority of infants and toddlers and some older anxious children undergoing complex or prolonged examinations would require to be anesthetized [12, 33]. General anesthesia (GA) is increasingly gaining favor among radiologists because it ensures optimal conditions and reduces failure rates for imaging in children. A large prospective study on compared children undergoing MRI or CT scan receiving either sedation or general anesthesia, found sedation to be incomplete in as high as 16% of cases and it failed in 7% patients whereas while all scans under GA could be completed [3]. It has been observed that the failure rates are drastically low when experienced anaesthesiologists provide sedation, clear protocols are in place and a team dedicated to the facility provides sedation [25]. Lighter plane of anesthesia generally needed for these procedures may have higher airway complications (e.g., laryngospasm, coughing, etc.) that may require urgent treatment and alteration of anesthetic depth [10, 12, 26].

29.3.6 Monitoring

Standardized ASA monitoring guidelines apply when providing anesthesia for NORA (pulse oximetry, capnography, electrocardiogram, non-invasive blood pressure, and the constant presence of a trained person) [33, 34]. All deeply sedated patients and those moderately sedated patients whose visibility or access is hampered, e.g., during an MRI should be monitored using exhaled carbon dioxide ($EtCO_2$) [10]. Body temperature alterations may be seen in young children during prolonged MRI examination and monitoring is indicated in them [35]. Recent advances in NORA monitoring have made closed-circuit monitoring of the patient possible and improved safety to a large extent as compared to the previously done remote monitoring of the patient from the control room through a transparent window [36]. This consists of two cameras (controlled by switches next to the television screens which allow individual control of zoom and focus)to provide visual monitoring. In this setting, one of the cameras is focused on the patient for monitoring respiratory efforts and the absence of unwanted movements. Another camera is directed upon the monitors which are relayed to a screen outside the scan room. In a patient who is receiving GA, the patient camera can be zoomed out to include the anesthesia machine and ventilator in the field of vision. Remote audio monitoring of an oesophageal stethoscope has been reported but not widely practiced [37]. Documentation of the consent and monitoring data and post-anesthesia care instructions are as important for sedation procures as for GA.

29.3.7 Monitoring and Equipment Concern Specific to MRI

Any electromagnetic equipment producing radio frequencies will interfere with image acquisition by MRI and similarly, RF produced by MRI scanners can interfere and make it difficult to monitor the patient [2, 3, 9, 10]. All monitoring and other anesthetic equipment including the anesthesia machine should therefore be MRI [10, 29, 37]. All oxygen or IV tubing, monitoring wires, and equipment cables should be padded and direct contact with the patient's skin is carefully avoided [38]. recently, several manufactur-

ers are making MRI-compatible anesthesia machines as denoted by the equipment label of MRI safe/conditional(e.g., BleaseGenius MRI anesthesia workstation which is safe with MRI strength up to the 1000-Gauss) [10, 37]. The MRI suite setup configuration should allow the anesthesiologist to maintain an unobstructed view of the patient, anesthesia machine, and monitors from a control room, either by direct observation or a video monitor [10, 21, 31]. Radiofrequency currents induced by blood flow through the arch of the aorta may produce ECG artifacts mimicking hyperkalemia [39]. Hence, MR-compatible electrodes should be applied to the patient's chest in a narrow triangle, leads should be braided and short [21, 31, 40]. Newer MRI safe ECG and pulse oximeter use either wireless transmitters or fiberoptic cables to eliminate the use of long conductors that are transmitted to a remote display unit [10, 21, 29, 37, 39]. Capnography signal may be delayed up to 20s due to the longer length of the sampling tubing [10, 29]. Monitoring cables can be passed through the waveguide ports to facilitate remote patient monitoring with MR incompatible equipmenmt [10]. Noise made by the MR scanner may obstruct audio alarms and therefore, all alarms should be visual. Hearing impairment can occur to the staff chronically exposed to loud noise from the MR machine and should use earplugs.

29.3.8 Anesthetic Management of the Patient During CT/MRI

The greatest source of concern is the considerable distance between the anesthesiologist and the patients. When possible, the anesthesiologist should remain at least 0.5–1 m from the bore of the scanner and should move slowly when it is necessary to be near the bore [2, 9, 39]. Neonates can develop increased episodes of hemodynamic instability and decrease in oxygen saturation levels during MRI [41]. Rapid motion in the strong magnetic field near the MRI scanner produces an electrical current within the body, which may cause symptoms such as nausea, vertigo, headache, light flashes, loss of proprioception, or a metallic taste in both patients as well as the anesthesiologist [9, 10]. Open communication is essential between care teams in these procedures. CT suite poses a radiation hazard to the caregivers while in the MRI suite staff needs to be careful about excluding any ferromagnetic objects before entering zone IV of the suite as mentioned earlier [42]. The imaging study may need to be terminated at any time to allow safe entry of caregivers in case of emergency and initiation of resuscitative efforts by the staff in the vicinity [2, 3, 43]. The patient should be immediately shifted to an MR safe location for subsequent treatment.

29.3.9 Equipment Check

One can follow the "SOAPME" acronym [33] -S (suction): suction catheters of apposite size and a functional suction machine, O(Oxygen): dependable oxygen source along with backup emergency oxygen supply, A(Airway): appropriate size airway equipment, P(Pharmacy): emergency anesthesia drugs, M(monitors) and E(Equipment). Apart from these, MRI compatibility of all anesthesia delivery and monitoring equipment should be carefully checked for MRI scans [10, 38].

29.3.10 Airway Management Concerns for CT/MRI Anesthesia

Airway management during an imaging study under anesthesia is unique due to the restricted approachability of the patient's airway and difficulty in visual and auditory assessment (due to the darkroom, physical distance) [2, 3, 10, 29]. The anaesthesiologist should have a backup plan to manage the airway related issues (e.g., apnoea, obstruction, hypoventilation, secretions, laryngospasm) during the MRI [10, 33]. One should avoid deeper levels of sedation in patients with an anticipated difficult airway (Table 29.7) [2, 3, 29, 33, 42].

ASA task force cautions that in patients with risk of airway compromise, a more definitive airway should be established (e.g., intubation or

Table 29.7 Causes of difficult airway management during sedation in imaging suite [2, 3, 29, 33, 42]

Condition	Examples
1. Airway abnormality	Enlarged tonsils, anomalies of the upper or lower airway, history suggestive of obstructive sleep apnoea (OSA), nasal obstruction, etc.
2. High risk of respiratory failure	Neuromuscular disease, Drowsy patient, severe respiratory illness, heart failure, severe pulmonary hypertension, etc.
3. Risk of pulmonary aspiration	Cases with increased intracranial pressure, comatose patient, obstructed bowel, pneumoperitoneum, ascites

supraglottic airway insertion) before the patient's airway becomes less accessible during the scan [10]. If the patient's airway is to be managed near the scanner, it is also necessary to use MRI safe laryngoscope(lithium batteries and plastic laryngoscopes), stylets, and stethoscopes. Airway management using complex equipment like a fiberoptic bronchoscope should preferably be done in a controlled setting outside zone IV.

29.3.11 Anesthesia Techniques and Drugs

Regardless of the type of anesthesia selected, the patient must remain immobile for the procedure since even very small movements cause image artifacts. Maintenance of anesthetic depth sufficient to prevent movement may be challenging. The majority of patients who require anesthetic intervention for CT scans can tolerate the procedure with only monitored anesthesia care (MAC) due to the brief duration and lack of any painful stimulus. A patient's inability to cooperate due to young age, delirium, agitation, or extreme claustrophobia may necessitate relatively deep sedation. Deep sedation is not advisable and may result in hypoxemia, hypercarbia, or airway compromise, especially in obese patients or those with OSA [10, 33, 44]. ASA has defined various levels of sedation ranging from minimal sedation (anxiolysis) to deep sedation depending on the maintenance of the patient's responsiveness, airway patency, respiratory, and cardiovascular functions [26]. The quality of sedation may be differentiated into anxiolysis, hypnosis (from sleepy to unconscious), and amnesia. To each of these components, analgesia may be added during painful procedures.

29.3.12 Medications for Sedation and General Anesthesia

When oral drugs are used (e.g., benzodiazepines, chloral hydrate), one should wait adequate time for its action before considering supplementation. Midazolam is effective orally in doses of 0.25–0.5 mg/kg [45, 46]. Its combination with ketamine (2–3 mg/kg) and atropine (and 0.2 mg/kg) is an effective regimen for oral sedation and may be sufficient for very short non-stimulating procedures like CT scan in some children. However, in most cases, intravenous sedatives are required to provide reliable hypnosis and immobility. Anaesthesiologist may prefer the various combination of midazolam, propofol, ketamine, fentanyl [25, 30, 47–49]. Prophylactic antiemetic therapy with ondansetron (0.1 mg/kg) should be given because of the increased risk of emesis due to concomitant chemotherapy and stress [20]. The various routes and doses of commonly used sedatives/anesthetic drugs have been mentioned in Table 29.8.

Doses should be carefully titrated. Antagonists (naloxone and flumazenil) should be available [53]. Intravenous access secured and maintained throughout. IM route for the administration of drugs is not desirable due to the trauma and associated pain. A large majority of these patients would be receiving chemotherapy and have a chemo port in place which can be accessed using a Huber needle [19, 36]. Strict aseptic technique is critical while handling the chemo port or placing an IV line because the children may be immunosuppressed due to RT/CT or their primary disease [19]. EMLA cream can be applied to the site one hour before the procedure to reduce the pain [24, 36]. Various commonly used sedative agents have been described below:

Midazolam: IV midazolam has been the foundation for pediatric sedation since its introduc-

Table 29.8 Pharmacologic agents for sedation and anesthesia outside the operating room

Drug	Dose (various routes)	Mechanism of action	Anesthetic effect
Midazolam [29, 45, 46, 50–52]	PO: 0.5–1.0 mg/kg IV: 0.05–0.15 mg/kg IM: 0.1–0.2 mg/kg IN: 0.1–0.2 mg/kg	GABA receptor agonist	Anxiolysis, Sedation
Chloral hydrate [36, 46]	PO: 25–50 mg/kg	Unknown	Sedation
Fentanyl [29, 36, 46, 51, 52]	IV: 0.5–2.0 μg/kg IN: 0.5–2.0 μg/kg IM: 50–100 μg/kg	Opioid receptor agonist	Sedation and analgesia
Ketamine [46, 53]	PO: 3–6 mg/kg IV: 0.5–2 mg/kg IM: 2–6 mg/kg Rectal: 5–10 mg/kg	NMDA receptor blocker	Analgesia, sedation, dissociative amnesia & anesthesia
Dexmedetomidine [50, 54, 55]	Bolus: 0.5–1.0 μg/kg over 10 min; Maintenance: 0.3–0.7 μg/kg/h	Central α-2 receptor agonist	Sedation, analgesia, anxiolysis, sympatholytic effect
Remifentanyl [53]	Bolus: 0.5–2 μg/kg Infusion: 0.025–0.1 μg/kg/min	Opioids receptor agonist	Sedation/ analgesia
Etomidate [46, 56]	IV: 0.2–0.4 mg/kg	GABA-A receptor agonist	Sedation/general anesthesia
Propofol [46, 53, 57]	IV: 1.5–2.5 mg/kg Infusion: 6–12 mg/kg/h	GABA-A receptor facilitator	Sedation/general anesthesia
Fospropofol [50, 58]	IV: 6.5 mg/kg Repeat dose: 1.5–2 mg/kg	Propofol prodrug	Sedation

GABA, gamma-aminobutyric acid; PO, oral; IN, intranasal; IM, intramuscular; IV, intravenous; NMDA, *N*-methyl-D-aspartate

tion due to its excellent safety profile along with good anxiolytic and amnesia properties. Therefore, in controlled settings with adequate monitoring, even non-anaesthesiologists can use it to provide sedation. Midazolam is a very useful anxiolytic premedication before the procedure and allows easier parenteral separation from the parents in the case of children [50, 51]. A small initial dose of 0.05 mg/kg IV may calm the child to allow the placement of monitors. Later, more potent sedatives, e.g., ketamine/propofol may be added to allow completion of the procedure, or midazolam can be re-administered (total dose of 0.2 mg/kg) [59]. It also decreases the incidence of post-procedure delirium due to ketamine [47]. Benzodiazepine antidote flumazenil should be available to promptly reverse its overdose [45].

Propofol: Propofol is the mainstay of pediatric procedural sedation [50, 53, 57]. Propofol either alone or combined with other agents like midazolam/fentanyl provides excellent scanning conditions. After a midazolam premedication to calm the child, a small propofol bolus (0.5–1 mg/kg) provides adequate sedation for safe positioning and application of restraining devices to the child while maintaining airway patency. Continuous infusion of propofol (6–10 mg/kg/h) is then begun for the rest of the procedure [50–53]. Subsequently, anesthesia depth can be regulated by stepping up or down by increments or decrements of 0.5–1 mg/kg/h [59]. Rapid recovery is the norm with spontaneous eye opening usually seen within 4 min of stoppage of the infusion [53, 57]. Onco-patients on chemotherapy usually have a chemo port in place and pain on injection with this central access port is not a concern.

Ketamine: Ketamine is another popular drug in pediatric sedation practice. It is usually administered after midazolam premedication. It is usually given in the dose of 0.5–0.75 mg/kg initially followed by further small increments of 0.25 mg/kg as required. It is rarely administered as an infusion in the dose of 25 mg/kg/h [50, 51, 53].

29.3.12.1 Newer Anesthetic/ Sedative Agents

Dexmedetomidine: It is the newer more specific α-2 receptor agonist which is now increasingly being preferred for use in the MRI suite due to its beneficial properties of anxiolysis, analgesia, sedation while avoiding respiratory depression thus improving safety [50, 51, 54, 55]. The main disadvantage of its use is that its administration to pediatric patients is still considered an off-label usage and that the initial bolus administration requires 10–15 min [53].

Fospropofol: It is a progenitor of propofol that has recently been FDA approved for procedural sedation by trained practitioners [50, 58]. Fospropofol is broken down to propofol, formaldehyde, and phosphate in vivo. The recommended dose is an initial bolus 6.5 mg/kg, followed by repeat doses of 1.5–2 mg/kg as needed every four minutes. It is very safe with only minor side effects in clinical studies [50, 58]. Only consistent side effect is a tingling or burning sensation in the genital and perianal area while pain on injection is not a concern, unlike propofol. However, its use in children is also considered off-label currently [58].

29.3.13 Target-Controlled Infusion (TCI)

This system for drug administration uses weight-based simple mathematical calculations to automatically administer a bolus dose and infusion rates using a computerized infusion pump [60].

Propofol TCI A computerized pump can be programmed to administer propofol automatically to achieve a target (plasma) concentration (or plasma concentration) and effect site (brain) concentration of 2.5–3 μg/mL (corresponding to infusion rates of 6 mg/kg/h) [60, 61]. If a greater anesthetic depth is desired, the target level can be increased in small increments (e.g., to 3 μg/mL) [60]. If a shallower depth of anesthesia is desired and the target concentration is reduced (e.g., to 2 μg/mL), the computer automatically stops the infusion briefly and then starts it again at a lower target concentration. A major limitation with TCI is that there is a delay in equilibrium between plasma and brain concentrations [61]. Because the anesthetic drug effect is in the central nervous system, TCI with effect site models is better. With these models, an overshoot in plasma concentration occurs initially (to account for the quicker equilibration to effect site in the brain) and with every increase in target concentration, to create a stronger drug gradient from plasma to brain, and thereby a more rapid effect can be achieved. Multiple models are in use for propofol, of these Paedfusor and Kataria are most commonly used [61]. TCI models are not yet available for infants [61, 62]. The Paedfusor model has been prospectively tested in TCI mode [63].

Remifentanil TCI In the case of remifentanil, only the Minto model of TCI that considers patients' weight, height, and age for plasma concentration modelling are used. For maintenance of analgesia during surgery, a remifentanil infusion of 0.1 μg/kg/min will correspond to a target concentration of about 2.5 ng/mL [64]. When remifentanil is used as an infusion in doses of less than 0.1 μg/kg/min, spontaneous respiration often can be retained, as during endoscopic procedures. However, during surgery, usually, a dose of 0.2–0.5 μg/kg/min (equivalent to ES concentration of 5–12 ng/mL) is needed [64]. To tolerate a laryngeal mask insertion, a rule of thumb is to ensure a dose of 2 μg/kg (≈ effect concentration of 6–8 ng/mL) is administered over 2–3 min, whereas for intubation without muscle relaxant, a dose of 3–4 μg/kg (equivalent toES concentration of 10–12 ng/mL) is needed. When using these doses, however, the ventilation needs to be controlled, because hypopnea and apnea are common. Propofol and remifentanil can be mixed in the same syringe (concentrations of 2.5–10 μg of remifentanil per milliliter of propofol) for ease of delivery depending on the clinical situation [61]. The combination of agents is not recommended for patients under 10 kg or when individual agent titration is required [61].

29.3.14 Patient-Controlled Sedation

Patient-Controlled Sedation (PCS) has a concept similar to that of patient-controlled analgesia. An infusion pump attached to a reservoir delivers an infusion of a sedative drug to the patient. A predetermined bolus is injected when the patient presses a button. This is followed by a lockout period. The endpoint is when the patient is comfortable enough to tolerate the procedure. Most PCS systems involve the delivery of a mixture of propofol and other short-acting drugs, e.g., remifentanil//fentanyl/midazolam. The natural advantage and in-built safety in the system are that over-sedation is avoided and thereby the risk for respiratory obstruction has been prevented [65]. This method of sedation delivery has not been popular in the pediatric population probably due to lack of cooperation in young children and supporting literature.

29.3.15 General Anesthesia (GA)

Indications: Patients requiring deeper levels of anesthesia should receive GA with airway control especially if the patients are not fasting are neurologically impaired, have anticipated difficult airway, developmental delay, behavioral disturbances, cardiac or respiratory instability, or certain procedures where immobility is desired, e.g., eye scan or lung scan [59, 66].

When GA is required, the induction agent should be selected depending on the duration of the procedure. A neuromuscular blocking agent (NMBA) may be unnecessary. A supraglottic device such as the LMA is favored for these procedures [66, 67]. MRI-compatible ETT/ LMA is mandatory for MRI scans [10]. If a general anesthetic is necessary, induction may be accomplished inside the CT suite. For MRI procedures, induction of general anesthesia and establishment of airway access is typically completed in a holding area near the MRI suite, with subsequent transportation of the unconscious patient into the MRI suite [10, 22]. The patient must remain immobile throughout the scan since even small movements cause artifacts in the image [3]. Typically, a relatively light anesthetic depth may be maintained since there are no painful stimuli. If necessary, the scan can be interrupted to allow the anesthesiologist to enter the scan area to assure airway patency and/or administer an NMBA to maintain immobility.

Either an inhalation anesthetic technique, total intravenous anesthesia (TIVA), or a combination of the two may be employed to maintain general anesthesia [22, 59, 68].

Inhalational Technique If an inhalation anesthetic technique is employed during MRI scanning, the use of an MRI safe/conditional anesthesia machine with sevoflurane vaporizer is ideal [10, 59]. Sevoflurane is the usual choice since there are no MRI safe/conditional desflurane vaporizers [22, 68, 69]. In neonates up to 4% Sevoflurane in oxygen whereas in older children up to 8% increased gradually is used [46]. In absence of an MRI-compatible anesthesia machine, a normal machine placed in Zone III with an elongated breathing circuit through a "wave guide" (copper-lined conduit that maintains radiofrequency isolation) may be used [2, 10, 22, 59].

TIVA Technique A TIVA technique propofol using oxygen with nasal cannula is a reasonable alternative to an inhalational anesthetic and preferred choice for many anesthesiologists [59]. This technique is reliable, titratable, and preserves spontaneous ventilation. During MRI scanning, MRI safe/conditional infusion pumps are used to administer the anesthesia and an MRI safe/conditional ventilator or other equipment to provide positive pressure ventilation should be available [10]. If these are not available, multiple lengths of IV tubing are used to connect the patient in the MRI suite to MRI unsafe infusion pumps that are located in the control room. However, awakening and movement are a possibility, if occlusion of the IV tubing or catheter occurs as the pressure occlusion alarm may be delayed due to the length of the tubing.

29.3.16 Management of Emergencies in Radiation Suite

The initial response to any medical (contrast reaction, cardiac arrest) or environmental (fire, quench) emergency is often delayed due to the remote location of the facility and restricted availability of additional personnel or equipment during an emergency.

29.3.16.1 Management of Cardiopulmonary Collapse/ Arrest in MRI Suite

In case of a serious medical emergency, the anesthesiologist should immediately call for help, relocate the patient from zone IV while simultaneously initiating CPR as per standard AHA algorithms [10, 42]. A delay in the institution of life-saving measures may occur due to the need for removal of the patient from the scanner and relocation to a nearby environment. The resuscitation zone should be close to zone IV and have fully stocked with resuscitation equipment defibrillator, monitors, and a crash cart that includes resuscitation drugs, airway equipment, oxygen, and suction [2, 10, 21, 31]. For pediatric cases, responding personnel subspecialized in pediatric resuscitation should be immediately available [21, 59].

29.3.16.2 Adverse Reactions to Iodinated Contrast Media

Up to 3% of patients who receive non-ionic, low osmolarity contrast medium develop some form of reaction to it, though life-threatening reaction occurs only in 0.04% [70, 71]. Reaction to ionized contrast media can range from mild to immediately life-threatening. It is more common in patients at extremes of age, previous history of bronchospasm, allergy, cardiac disease, and those on treatment with beta-blockers and nonsteroidal anti-inflammatory agents [72]. Symptomatic patients need to be treated with corticosteroids and antihistamines. Patients with a previous history of contrast reactions may be administered prophylactic corticosteroid (prednisolone 50 mg or equivalent steroid 12 and 2 h before the contrast procedure along with diphenhydramine 50 mg just before the procedure.

29.3.16.3 Fire Emergency

Radiofrequency energy from the magnet can cause tissue or device heating and can also induce currents in conductors such as (ECG) leads, equipment cables, or fluid-filled tubing [21, 31, 39]. This may lead to skin or other tissue burns, and in rare cases, even fire may result. Therefore, MRI-compatible ECG leads should be used, and equipment cables and IV tubing are not positioned directly on the patient's skin [39]. MRI staff should have-designated fire management roles that have been assigned and practiced beforehand and in case of any such fire emergency, everyone should perform as a team as described in the ASA practice advisory for the prevention and management of OR fires [73]. Every such off-site facility should have a preformulated and documented plan to deal with such a mishap.

29.3.16.4 Projectile Emergencies

All MRI suites should have a preformulated plan to tackle projectile emergencies which should be followed at this occurrence [2, 31, 74]. The scan should be discontinued, and the patient should be immediately removed from the magnet room. A controlled quench is performed to remove the patient from the bore [10]. All precautions for entering the zone IV still apply even after quench as strong static magnetic fields may persist after a quench [31]. Any medical emergency should be managed as indicated in the individual patient [74].

29.3.16.5 Unintentional Quench

A quench is defined as loss of magnet superconductivity with sudden boil-off of cryogenic [–269 °C] liquid helium. Quench is generally intentionally performed in case of any indicated as The most common reason for quench is an intentional magnet shutdown in case of any life-threatening emergency [10, 21, 31]. In an event of the quench, all of the stored energy of the mag-

net is released as heat, which boils off its stored cryogens which are released as gas. In such an event, the magnet's quench duct should vent above the MRI facility into the atmosphere [2, 31]. If improperly vented, the released gas can result in hypoxia to the patient and staff [10, 31]. Although the patient and all staff are evacuated from the scanner room as quickly as possible during a quench, entrance or exit from the suite may not be possible for several seconds due to high pressure against the doors generated by escaping gases. The patient should be immediately administered oxygen after prompt removal from the magnet tube [10].

29.3.17 Recovery Care

The standards of post-anesthesia recovery care after an imaging procedure under sedation/GA should match those in the OR [10, 21, 31]. Provision of oxygen delivery, monitoring, and resuscitation equipment should be there in the recovery area and while on the transport cart. Parental presence should be ensured to calm the child. In the post-procedural phase, all the vital parameters should be continually assessed and properly documented. Immediate availability of personnel trained in basic and advanced life support skills is mandatory [2, 21, 31]. Suitability of discharge should be assessed using modified Aldrete's recovery criteria and post-anesthesia discharge score (stable vital signs, return to a baseline level of consciousness, age-appropriate ambulation, and minimal nausea/vomiting/pain) [75] have been adequately managed. Children should be escorted by a responsible adult and avoid motor activities. Written discharge instructions and contact details in case of any emergency should be provided.

29.4 Summary

Imaging procedures requiring anesthetist-led NORA continue to grow in magnitude and complexity. Safe provision of anesthetic care in radiation suites can be extremely challenging especially in the setting of pediatric malignancy. Awareness of the systemic implications of the malignancy and its therapeutic regimens is mandatory for the safe provision of anesthesia to these patients. One should follow appropriate guidelines for the maintenance of a safe environment for the patient and staff, keeping modality-specific concerns in mind, providing intra and post-procedural monitoring and quality recovery care. All clinicians providing sedation/GA to children should be competent in airway management and resuscitation skills.

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