ANAESTHESIA FOR INTERVENTIONAL RADIOLOGICAL PROCEDURES: A REVIEW ARTICLE

ABSTRACT: Interventional Radiology (IR) is a rapidly advancing subspecialty of medicine that utilizes real-time imaging techniques such as fluoroscopy, ultrasound, computed tomography and magnetic resonance imaging to perform minimally invasive diagnostic and therapeutic procedures. These procedures span a wide range of medical disciplines including vascular, neuro, hepatobiliary, musculoskeletal, genitourinary, and oncologic interventions. Anaesthesia plays a vital role in ensuring procedural success, patient safety and comfort. Anaesthetic management in IR is challenging due to diverse procedures, patient comorbidities, and the remote location of IR suites. Approaches must be carefully tailored, ranging from local anaesthesia with sedation to general anaesthesia, based on procedure complexity and patient factors. Monitored anaesthesia care is common for minor procedures, while general anaesthesia for more complex or high-risk interventions likeTrans-arterial chemoembolization, Radiofrequency ablation, and neuro-interventions. Special considerations must be needed for paediatric, geriatric, and critically ill patients, Effective collaboration between the anaesthesiology and radiology teams is essential to overcome challenges such as limited access, radiation exposure, and the constraints of working in a non-operating room environment. Ensuring effective communication and planning enhances both procedural success and patient safety.This review aims to provide an in-depth overview of anaesthetic considerations for interventional radiology procedures, including indications, anaesthetic techniques, patient-specific challenges, and future developments in this continually evolving field.

ANAESTHESIA MANAGEMENT IN INTERVENTIONAL RADIOLOGY: CURRENT PERSPECTIVES

Keywords: anaesthesia, Interventional radiology, Image-guided interventions, IR suite challenges, non-operating room anaesthesia, patient safety, Sedation,

Introduction:

The field of Interventional radiology (IR) was introduced in the 1960s by Dr. Charles Dotter, known as the "father of interventional radiology," who introduced percutaneous transluminal angioplasty. Since then, IR has rapidly evolved into a vital component of modern medicine.IR is a rapidly expanding field that utilizes image guidance to perform minimally invasive diagnostic and therapeutic procedures across multiple medical specialties. Since its inception in the 1960s, IR has become essential in managing vascular, oncological, hepatobiliary, neurological, and musculoskeletal conditions. The spectrum of procedures ranges from simple image-guided biopsies to complex interventions such as trans-arterial chemoembolization (TACE), radiofrequency ablation (RFA), endovascular aneurysm repair (EVAR), and cerebral thrombectomy. [1,2]The increasing complexity, length, and invasiveness of IR procedures necessitate the development and implementation of robust anaesthetic strategies tailored to individual patient needs. Anaesthesiologists play a critical role in ensuring patient safety, comfort, immobility, and optimal physiological conditions throughout these procedures. Moreover, many IR procedures are performed in remote locations, outside the conventionaloperating room (OR), often posing challenges in termsof equipment, monitoring, staffing, and emergency preparedness. [3,4] Traditionally, IR procedures were performed under local anaesthesia or moderate sedation. However, with the advent of more invasive and prolonged techniques, there is a growing demand for monitored anaesthesia care (MAC), regional anaesthesia, and general anaesthesia (GA), especially in paediatric, geriatric, and critically ill populations.[5] The choice of anaesthetic technique depends on several factors including the type and duration of the procedure, patient comorbidities, cooperation level, pain expected, and the need for absolute immobility.[6]Effective anaesthesia management in IR requires thorough pre-procedural evaluation, risk stratification, and multidisciplinary collaboration between the anaesthesia, radiology, and nursing teams. In addition, the anaesthesiologist must be proficient in managing sedation-related complications, airway emergencies, and haemodynamic instability, especially in patients with limited physiological reserve.[7]

Materials and Methods

The data for this review were compiled from a wide range of articles published between 1982 and 2025, sourced from multiple academic journals. These papers were carefully selected and reviewed to extract relevant information applicable to the focus of this study.

Key Principles:

- **Minimally Invasive Techniques:** IR procedures are done through small incisions,resulting in reduced pain, quicker recovery, and shorter hospital stays.[8]
- **Image Guidance:** Real-time imaging ensures high precision and safety throughout the procedure.[9]
- **Therapeutic and Diagnostic:** IR offers both diagnostic interventions (e.g., biopsies) and therapeutic interventions (e.g., tumour ablation, embolization).[10]
    - **Patient-Focused Anaesthesia Planning:**local, sedation, MAC, or GA is selected based on the procedure's complexity, duration, and patient-specific needs.[11]
    - **Pre-Procedure Risk Assessment:** A comprehensive evaluation should include review of comorbidities (cardiac, hepatic, renal), coagulation profile, allergies (especially to contrast media), and airway evaluation.[12]
    - **Monitoring and Safety in Remote Environments:** Standard ASA monitoring (ECG, NIBP, SpO_2, $EtCO_2$) must be ensured even in off-site IR settings, with readiness for emergencies despite spatial limitations.[13]
    - **Effective Airway Management:** prepared for difficult airway scenarios due to limited patient access during procedures.[14]
    - **Radiation Safety:** Minimize radiation exposure to staff and patients; use protective equipment (lead aprons, thyroid shields) and comply with ALARA principles (As Low AsReasonably Achievable).[15]
    - **Communication and Teamwork:** Maintain continuous communication with the radiology team for timing, contrast use, patient positioning, and any procedural complications.[16]
    - **Contrast Allergy Management:** Identify contrast sensitivities early, premedicate at-risk individuals, and have emergency drugs and airway equipment readily available.[17]

- **Post-Procedure Monitoring:** Provide proper recovery and post-anaesthesia care, monitoring for issues such as prolonged sedation, bleeding, or contrast-induced nephropathy.[18]
- **Use of Sedation Protocols:** Administer sedatives like propofol, fentanyl, or midazolam in titrated doses, with the ability to escalate to GA if required.[19]
- **Multidisciplinary Collaboration:** Optimal outcomes require collaboration between anaesthesiologists, interventional radiologists, nurses, and technologists.[20]
- **Role in Modern Medicine:** IR is now a first-line treatment option for many conditions and is integrated into multidisciplinary care pathways. It continues to expand with innovations in catheter technology, imaging resolution, and targeted therapies.[21]

Common Procedures:

Vascular

1. **Angiography and Angioplasty**
   Diagnostic imaging of blood vessels using iodinated contrast to identify stenosis, occlusion, or vascular anomalies.
   Commonly performed in cerebral, coronary, renal, and peripheral arteries.[22]
2. **Angiography:** catheter-based visualization of blood vessels using contrast dye.
   To assess vascular pathology and guide interventions.[23]
3. **Percutaneous transluminal angioplasty (PTA):** minimally invasive procedureusing a balloon catheter to dilate narrowed vessels, commonly for peripheral arterialdisease(PAD).[24]
4. **Balloon Angioplasty:**Treats vessel stenosis in PAD, renal artery stenosis, and coronary artery disease (CAD).[25]
5. **Stent Placement:** Stents are deployed in blood vessels to maintain patency post-angioplasty, commonly used in renal arteries, iliac arteries, and carotid arteries.
6. **Embolization:** Embolization is the intentional occlusion of blood vessels to treat aneurysms, arteriovenous malformations, gastrointestinal bleeding, or to reduce tumour vascularity (pre-operative embolization).

- Uterine Artery Embolization (UAE) for fibroids.
- Bronchial Artery Embolization (BAE) for haemoptysis.
- Trauma-related embolization for internal bleeding.
- Gastrointestinal Bleeding Control: Embolization of mesenteric arteries.
- Agents include coils, polyvinyl alcohol (PVA) particles, glue, or gelfoam.[26]

7. **Inferior Vena Cava (IVC) Filter Placement:** Used to prevent pulmonary embolism in patients with contraindications to anticoagulation therapy.[27]

Oncologic:

1. **Radiofrequency Ablation (RFA) / Microwave Ablation (MWA)**
   - Local thermal destruction of solid tumors (commonly liver, lung, kidney, bone).
   - Image-guided (usually CT or ultrasound), minimally invasive procedure using either high-frequency alternating current (RFA) or electromagnetic waves (MWA) to induce coagulative necrosis. [28,29]

2. Cryoablation: Induces cell death via repeated freeze-thaw cycles, causing intracellular ice crystal formation and vascular stasis.

- Renal cell carcinoma (especially in high-risk surgical patients), bone metastases, and soft tissue tumors.[30,31]

3. **Trans-arterialChemoembolization:**A palliative procedure for hepatocellular carcinoma where chemotherapy drugs and embolic agents are injected directly into the tumour's blood supply.[32,33]
4. **Selective Internal Radiation Therapy:** Involves injection of radioactive microspheres into liver tumours via hepatic artery for localized radiation therapy.[34,35]

Hepatobiliary and pancreatic

1. **Percutaneous Transhepatic Biliary Drainage:** Relief of malignant or benign biliary obstruction causing obstructive jaundice (e.g., cholangiocarcinoma, pancreatic cancer).

Insertion of a catheter into dilated intrahepatic ducts under ultrasound and fluoroscopy guidance. [36,37]

2. Biliary Stenting

To maintain bile flow and relieve obstruction

Malignant biliary obstruction (e.g., pancreatic cancer, cholangiocarcinoma), benign strictures, or post-surgical leaks. [38,39]

3. Trans-jugular Intrahepatic Portosystemic Shunt

Refractory ascites, variceal bleeding, Budd-Chiari syndrome.

A stent is placed between the portal and hepatic veins via the internal jugular vein to reduce portal hypertension.[40,41]

4. **Cholecystostomy**: Temporary decompression of the gallbladder in critically ill or surgical high-risk patients with acute cholecystitis.

Percutaneous catheter placement into gallbladder under ultrasound or CT guidance.[42,43]

Genitourinary

1) **Percutaneous Nephrostomy:** Drainage of obstructed urinary system.
2) **Ureteral Stenting:** Relieves ureteric obstruction (e.g., stones, malignancy).
3) **Varicocele Embolization:** Minimally invasive treatment for varicocele related infertility.
4) **Renal biopsy:**Image-guided diagnostic procedure for glomerular and parenchymal disease.[44,45,46,47]

Neurointerventional radiology

1) **Cerebral Angiography:** for diagnosis of aneurysms, AVMs, and stroke.
2) **Intracranial Aneurysm Coiling:** Endovascular technique using platinum coils to prevent rupture.
3) **Mechanical Thrombectomy**: in acute ischemic stroke has become standard care for large vessel occlusions.
4) **Carotid Artery Stenting:** Used for significant carotid stenosis as an alternative to endarterectomy.

5) **Balloon-assisted coiling and flow diverters**: are employed for aneurysm treatment.[48,49,50,51,52]

Musculoskeletal

1) **Vertebroplasty and Kyphoplasty:** for osteoporotic vertebral fractures.
2) **Joint Aspiration and Injection:** for diagnosis or corticosteroid delivery.
3) **Bone and Soft Tissue Biopsies:** Image-guided core biopsies of bone or soft tissue lesions.[53,54,55]

Gastrointestinal

1) **Percutaneous Gastrostomy/Jejunostomy:**Feeding tube placement under fluoroscopic or CT guidance**.**
2) Percutaneous drainageof abscesses, hematomas, and pseudocysts using image guidance is standard practice.
3) It reduces the need for surgical drainage and supports antibiotic therapy.[56,57]

Pulmonary

1) **Pulmonary Angiography:** Diagnoses pulmonary embolism (PE).
2) **Pulmonary AVM Embolization**: Embolization of arteriovenous malformations to prevent paradoxical emboli.[58,59]

Central venous access:

1) Peripherally Inserted Central Catheter (PICC)
2) Tunneled Dialysis Catheters
3) Implantable Ports (Port-a-Cath): Used for long-term IV access in oncology, dialysis, or chronic diseases.[60,61]

Imaging Modalities Used in IR

1. **Ultrasound:** Provides real-time, radiation-free imaging. Commonly used for vascular access, biopsies, and regional anaesthesia. Its portability and safety make it ideal for bedside procedures.

2. **Computed Tomography:** Offers **high-resolution anatomic detail**, especially useful for accessing **deep organs** like the **lungs**, **liver**, and **adrenal glands**. Enables precise planning and targeting in complex procedures.
3. **Fluoroscopy:** Provides **dynamic, real-time X-ray imaging**. Widely used in **vascular**, **biliary**, and **gastrointestinal interventions** (e.g., angioplasty, stent placement, cholangiography).
4. **Magnetic Resonance Imaging:** Offers superior **soft tissue contrast** without ionizing radiation. Used selectively due to equipment limitations and patient constraints. Primarily applied in **neuro-interventions** and **musculoskeletal procedures**.[62]

Applications and Benefits of Interventional Radiology (IR)

- Lower risk of infection
- Less postoperative pain and discomfort
- Reduced overall healthcare costs
- High procedural accuracy through real-time imaging guidance (e.g., fluoroscopy, ultrasound, CT)
- Suitable for patients unfit for conventional surgery due to comorbid conditions
- Lower complication and morbidity rates compared to open surgery
- Cost-effective management of complex medical conditions
- Improved patient safety in high-risk groups
- Valuable in treating high-risk surgical patients
- Broad applications in:Oncology, Vascular surgery, Neurology, Nephrology, Gastroenterology
- Faster patient recovery and shorter hospital stays
- Enhanced patient comfort and cooperation due to minimally invasive approach

- Ideal for cases requiring **prolonged patient immobility** (e.g., embolization procedures)
- Essential in managing:
    - Paediatric or uncooperative patients
    - Lengthy or technically complex procedures
    - Airway risk or high aspiration risk
    - Patients with significant coexisting medical diseases
    - Interventions with high bleeding or embolism risk
    - Claustrophobic or highly anxious individuals
    - Patients needing controlled ventilation or deep sedation.[63,64,65]

Anaesthetic considerations:

Pre-Procedural Assessment: A detailed assessment includes ASA classification, airway evaluation, fasting status, comorbidities (renal, hepatic, cardiovascular), and risk of contrast-induced nephropathy. Attention must be given to anticoagulation, allergies (especially to iodinated contrast), and patient cooperation.[66,67]

Local Anaesthesia: Suitable for minor procedures such as superficial biopsies and vascular access.[68]

Moderate Sedation: Involves benzodiazepines and opioids, with monitoring of oxygenation and ventilation; appropriate for cooperative patients.[69]

Monitored Anaesthesia Care: Enables deeper sedation under anaesthesiologist supervision using agents like propofol or dexmedetomidine.[70,71]

General Anaesthesia: Indicated for complex, long, or painful procedures and for uncooperative or high-risk patients; includes airway control and advanced monitoring.[72]

Regional Anaesthesia: Ultrasound- or fluoroscopy-guided nerve blocks provide site-specific analgesia, reduce opioid use, and enhance recovery.[73,74]

Patient-Specific Considerations

- **Paediatric Patients:** Typically require GA due to poor cooperation; regional anaesthesia may reduce opioid use.[75,76]
- **Elderly Patients:** More sensitive to sedatives; prefer lighter sedation or regional techniques to avoid delirium and cardiovascular instability.[77]
- **Critically Ill Patients:** Require advanced haemodynamic monitoring and careful selection of anaesthetic technique to maintain organ perfusion.[78]

Monitoring and Safety: Standard ASA monitoring includes ECG, pulse oximetry, non-invasive blood pressure, and capnography. For high-risk patients, arterial lines, central venous pressure, and urine output monitoring are necessary. Equipment for airway management and resuscitation must be readily available.[79,80]

Challenges in IR Anaesthesia:

- Remote location from main operating theatres
- Radiation exposure risks
- Limited space and staff availability
- Sudden conversion from sedation to GA in emergencies
- Complex comorbidities in patients undergoing IR.

Communication and Team Dynamics

- Need for **close coordination** with radiologists and nurses.
- Often poor **pre-procedure planning** or incomplete patient information.
- **Communication barriers** due to noise or lead shields.

Patient Factors

- **High-risk** (ASA III/IV) with multiple comorbidities.
- **Haemodynamically unstable**, septic, or coagulopathic.
- **Non-fasting**, increasing aspiration risk.
- **Paediatric, geriatric, or pregnant**, requiring special considerations.

Procedure-Related Challenges

- **Lengthy and complex procedures**
- **Use of contrast media** risk of allergic reactions or nephropathy.
- **Painful or anxiety-provoking** (e.g., ablations, biopsies).
- **Risk of sudden complications**: bleeding, embolism, pneumothorax.[81,82]

Discussion and Future Directions:

1. Integration of artificial intelligence (AI) for image interpretation, procedural planning, and real-time guidance, improving accuracy and efficiency
2. Adoption of predictive analytics from AI to aid patient selection, outcome prediction, and complication prevention.[83,84]
3. Fusion imaging (e.g., CT/MRI with ultrasound) and intraoperative 3D/AR visualization for enhanced anatomical guidance
4. Advancements in intraoperative imaging such as cone-beam CT to allow dynamic assessment during procedures.[85]
5. Focus on radiation dose reduction through AI-optimized fluoroscopy and dose monitoring.[86]
6. Deployment of robotic-assisted IR systems to enhance precision, reduce radiation, and enable tele-robotic interventions.
7. Development of minimally invasive devices — smaller catheters, bioabsorbable materials, and drug-eluting technologies.[87]
8. Implementation of radio-genomics to tailor treatments using imaging and biomarker data.[88]
9. Real-time monitoring systems and automated documentation to enhance patient safety and infection control.[89]

10. Use of high-fidelity simulators, VR, and AR for structured training to address IR workforce gaps
11. Transition to outpatient/day-care IR with ambulatory procedures and enhanced recovery protocols.
12. Increased use of federated learning to share AI model training across institutions while preserving data privacy
13. Development of explainable AI (XAI) frameworks to improve clinician trust and meet regulatory standards
14. Stronger multidisciplinary collaboration among IR, anaesthesia, surgery, oncology, and critical care in tumour boards and complex cases
15. Expansion of therapeutic applications across oncology, vascular, neuro, GI, and pain management with novel targeted delivery systems.
16. Growth of multimodal data integration using foundation models to support autonomy in pre-, peri-, and post-procedural settings.
17. Establishment of standardized regulatory guidelines and frameworks for AI/robotics integration, including safety, liability, and ethics.
18. Movement towards partially or fully autonomous robotic navigation in endovascular procedures, leveraging reinforcement and imitation learning.[90]

Conclusion: IR stands at the forefront of minimally invasive medicine, offering high-precision diagnostic and therapeutic options across diverse specialties. As IR procedures become increasingly complex, prolonged, and patient-specific, anaesthesia assumes a critical role not only in ensuring procedural success but also in enhancing patient safety, comfort, and recovery. Anaesthesiologists are now indispensable members of the IR team, tasked with managing a wide spectrum of clinical scenarios from stable outpatients to critically ill individuals in non-operating room environments. This demands a tailored approach to anaesthetic planning, incorporating meticulous pre-procedural assessment, vigilant intra-procedural monitoring, and well-coordinated postoperative care.The evolution of technology such as advanced imaging, robotic assistance, and AI-driven procedural planning has further redefined the expectations from anaesthetic services in IR. These innovations call for adaptability, continual upskilling, and interdisciplinary collaboration. As IR continues to expand its therapeutic reach into oncology, neurology, hepatobiliary, and musculoskeletal domains, the role of anaesthesia will also broaden to match the growing demands in precision, safety, and efficiency. Looking ahead, the integration of data-driven decision-making, personalized sedation protocols, and real-time analytics will be pivotal in enhancing outcomes. Thus, anaesthesia in IR is not merely a supportive element but a cornerstone of patient-centered, technology-enabled, and outcome-driven interventional care.

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