Interventional radiology: current applications, clinical impact, and future directions

Eurasian Clinical and Analytical Medicine Review

Interventional radiology

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Abstract

Interventional radiology (IR) is a rapidly evolving medical specialty that utilizes image-guided, minimally invasive techniques for diagnostic and therapeutic purposes. By offering practical alternatives to conventional surgical procedures, IR significantly reduces patient morbidity, shortens hospital stay, and improves recovery times. Advances in imaging technology, materials science, and procedural techniques have expanded the scope of interventional radiology across vascular, non-vascular, and oncologic applications. This review provides a comprehensive overview of the historical development, fundamental principles, major clinical applications, safety considerations, and future perspectives of interventional radiology.

Keywords

interventional radiology, minimally invasive therapy, embolization, ablation, image-guided interventions

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Introduction

Interventional radiology is a subspecialty of radiology that focuses on performing minimally invasive procedures under imaging guidance. Since its inception in the 1960s, interventional radiology has transformed patient management by providing effective diagnostic and therapeutic alternatives to open surgery. The pioneering work of Charles T. Dotter, who introduced percutaneous transluminal angioplasty, is widely regarded as the foundation of modern interventional radiology [1].

The integration of imaging modalities such as fluoroscopy, ultrasound (US), computed tomography (CT), and magnetic resonance imaging (MRI) has enabled precise targeting of pathological lesions. As a result, interventional radiology has become an essential component of multidisciplinary clinical practice, particularly in vascular disease, oncology, trauma, and palliative care [2].

Fundamental Principles of Interventional Radiology

Interventional radiology is based on three core principles:

- Image guidance: Procedures are performed using real-time imaging to ensure accuracy and safety.
- Minimally invasive access: Most interventions are carried out through small skin incisions or percutaneous needle punctures.
- Targeted therapy: Treatments are directed specifically at the pathological site, minimizing damage to surrounding tissues.

These principles contribute to reduced complication rates, lower healthcare costs, and improved patient satisfaction compared to conventional surgical approaches [3].

Vascular Interventional Radiology

Diagnostic angiography

Diagnostic angiography remains a cornerstone of vascular assessment. It provides high-resolution visualization of arterial and venous anatomy and is essential for evaluating peripheral arterial disease, aneurysms, vascular malformations, and tumor vascularity [4].

Angioplasty and stent placement

Percutaneous transluminal angioplasty (PTA), with or without stent placement, is widely used to treat vascular stenoses and occlusions. Common indications include lower extremity arterial disease, carotid artery stenosis, renal artery stenosis, and central venous obstruction. These techniques have demonstrated outcomes comparable to surgical revascularization, with lower procedural risk and faster recovery [5].

Embolization techniques

Embolization involves the intentional occlusion of blood vessels to control bleeding or devascularize pathological tissue. Indications include gastrointestinal hemorrhage, postpartum hemorrhage, traumatic bleeding, and tumor management. A variety of embolic agents—such as coils, particles, liquid embolics, and plugs—are selected based on clinical requirements [6].

Non-Vascular Interventional Radiology

Image-guided biopsy

Image-guided percutaneous biopsy is a highly accurate and safe method for tissue diagnosis. Ultrasound- and CT-guided biopsies are routinely used for lesions in the lung, liver, kidney, bone, and soft tissues. Compared to surgical biopsy, these techniques offer lower complication rates and reduced procedural costs [7].

Percutaneous drainage procedures

Percutaneous drainage of abscesses, fluid collections, and biliary obstructions is a fundamental non-vascular application of interventional radiology. These procedures often serve as definitive treatment or as a bridge to surgery, particularly in critically ill or high-risk patients [8].

Gastrointestinal and genitourinary interventions

Procedures such as percutaneous gastrostomy, nephrostomy, and biliary drainage play a critical role in managing obstruction, infection, and nutritional compromise. These interventions significantly improve patient quality of life and reduce morbidity [9].

Interventional Oncology

Interventional oncology represents one of the fastest-growing domains within interventional radiology.

Tumor ablation techniques

Thermal ablation techniques—including radiofrequency ablation (RFA), microwave ablation (MWA), and cryoablation—are increasingly used for the treatment of primary and metastatic tumors of the liver, kidney, lung, and bone. These techniques are particularly valuable for patients who are poor surgical candidates [10].

Transarterial therapies

Transarterial chemoembolization (TACE) and transarterial radioembolization (TARE) are established treatments for hepatocellular carcinoma and selected metastatic liver tumors. These methods combine targeted drug or radiation delivery with embolization to achieve tumor control while preserving healthy liver parenchyma [11].

Complications and Safety Considerations

Although interventional radiology procedures are generally safe, potential complications include bleeding, infection, vascular injury, and contrast-related adverse reactions. Proper patient selection, meticulous technique, and post-procedural monitoring are essential to minimize risks [12].

Radiation safety is a critical concern in interventional practice. Adherence to the "as low as reasonably achievable" (ALARA) principle is essential to protect both patients and healthcare personnel from unnecessary radiation exposure [13].

Training and Multidisciplinary Collaboration

Interventional radiologists undergo extensive training that includes diagnostic radiology, procedural skills, and clinical patient management. Multidisciplinary collaboration with surgeons, oncologists, and other specialists enhances treatment planning and optimizes patient outcomes [14].

Future Directions

Technological advancements such as artificial intelligence–assisted image guidance, robotic interventions, and advanced navigation systems are expected to further expand the capabilities of interventional radiology. These innovations promise increased precision, reduced complications, and more personalized treatment strategies [15].

Conclusion

Interventional radiology has become an indispensable component of modern healthcare. Its minimally invasive, image-guided techniques offer safe and effective alternatives to traditional surgical approaches across a wide range of clinical scenarios. Ongoing technological and educational advancements will continue to enhance the role of interventional radiology in patient-centered care.

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Scientific Responsibility Statement
The authors declare that they are responsible for the article's scientific content including study design, data collection, analysis and interpretation, writing, some of the main line, or all of the preparation and scientific review of the contents and approval of the final version of the article.

Animal and Human Rights Statement
All procedures performed in this study were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or compareable ethical standards.

Data Availability Statement
The datasets used and/or analyzed during the current study are not publicly available due to patient privacy reasons but are available from the corresponding author on reasonable request.

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Conflict of Interest
The authors declare that there is no conflict of interest.