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Precision interventional radiology

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ABSTRACT

The recent interest in precision medicine among interventionists has led to the establishment of the concept of precision interventional radiology (PIR). This concept focuses not only on the accuracy of interventional operations using traditional image-guided techniques, but also on the comprehensive evaluation of diseases. The invisible features extracted from CT, MRI, or US improve the accuracy and specificity of diagnosis. The integration of multi-omics and molecule imaging provides more information for interventional operations. The development and application of drugs, embolic materials, and devices broaden the concept of PIR. Integrating medicine and engineering brings new image-guided techniques that increase the efficacy of interventional operations while reducing the complications of interventional treatment. In all, PIR, an important part of precision medicine, emphasizing the whole disease management process, including precision diagnosis, comprehensive evaluation, and interventional therapy, maximizes the benefits of patients with limited damage.

1. Introduction

Interventional radiology, a rapidly developing medical discipline, is becoming the third clinical branch, and equaling internal medicine and surgery. Since its advent in the 1960s, interventional radiology has expanded to encompass various diseases across multiple body systems.[1,2] Interventional radiology consists of various subspecialties such as neurological, digestive, hepatobiliary, vascular, and oncological interventions. It has become an indispensable discipline in clinical medicine.

With the development of precision medicine, the concept of precision interventional radiology (PIR) is proposed. Compared with the narrow concept of PIR, which focuses on the anatomical location by ultrasound (US), computed tomography (CT), magnetic resonance imaging (MRI), and digital subtraction angiography (DSA), the broad concept of PIR pays more attention to the heterogeneity of diseases. It aims to improve the accuracy and specificity of diagnosis and focuses on the efficiency of interventional therapies. In addition, one of the main aims of PIR is to avoid excessive medical treatment and waste of clinical resources.[3] Herein, we outline the concept of PIR in detail and provide prospective views for interventional radiology in the future.

2. The concept of PIR

Owing to the concept of precision medicine advocated in 2015, PIR has been proposed. Before that time, interventional radiology was defined as a minimally invasive procedure using image-guided techniques including US, CT, MRI, and DSA. Interventional radiology offers lower-risk alternatives to various traditional medical and surgical therapies using interventional devices, including puncture needles, catheters, and wires.[2,3] This is the narrow concept of PIR, which emphasizes the accurate anatomical location for percutaneous puncture, intravascular, or non-intravascular therapy. Currently, the concept of PIR does not only focus on the accuracy of the anatomical location, but also on the comprehensive evaluation of interventional procedures with regard to preoperative evaluation and prognosis prediction.[2,4,5]

Precision diagnosis is considered the precondition for interventional therapy. Multiple factors at the gene, protein, metabolism, pathology, laboratory, and radiology levels help to determine the biological behaviors of diseases. These also offer a basis for individualized and systematic treatments of various diseases.[4–6] A comprehensive evaluation of patient selection and the efficacy and safety of interventional techniques, as well as their prognosis, is embodied in the concept of PIR. In particular, the combination of interventional therapies and medical or surgical treatment has expanded its scope. Topics about whom the combination therapy should be applied to as well as when and how it should be applied make PIR sophisticated. Thus, PIR emphasizes the management of the disease rather than interventional therapy alone.[7]

For interventional techniques, more attention has been paid to their precise application and development. For instance, the selection of drugs and embolic materials for intravascular embolization has a great influence on its outcome. Interventionists have suffered from the dilemma of identifying the optimum rate, range, or degree of embolization for decades. In addition, the implantation and release of stents, filters, and coils, as well as the optimum combination of these interventional techniques, are considered in PIR. The development of new materials, drugs, equipment, and techniques has made the PIR a big step. Thus, PIR is an important part of precision medicine, and is a medical activity centered

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on interventional technology. The ultimate aim of PIR is to maximize the benefits of patients and minimize their damage.

3. From anatomical location to comprehensive evaluation based on precision medicine

Under the guidance of US, CT, MR, and DSA, a puncture needle or catheter can be accurately positioned into lesions. By performing biopsy or angiography, these techniques provide diagnostic information for various diseases.[8] US imaging shows lesions clearly on the surface but not on the interbody. CT can show two-dimensional images of lesions. In particular, CT images show the size, shape, and location of the lesions. The adjacent relationship between lesions and their surrounding areas, both on the surface or in the body, can be well displayed. For instance, the vessels of lesions are well identified using enhanced CT. MRI, a non-radiation technique, has a high spatial resolution for soft tissues. MRI can track heat temperature and can be used to guide radiofrequency ablation or microwave ablation. With the emergence of new MRI-compatible materials, MRI is becoming an important direction of imaging technology in the future. DSA is superior to both CT and MR angiography images. Super selection of lesion vessels shows its advantages, which fully embodies the essence of precise location. The imaging technologies mentioned above more or less provide the physical characteristics of lesions visible to the naked eye. However, the complexity of diseases and the defects of image-guided technologies make it difficult to achieve the goal of PIR. In addition, refined classification and management are required to establish precisely guided imaging in clinical practice.[5] Thus, precise imaging evaluation of both anatomical location and sophisticated biological characteristics is needed.

Recently, the integration of radiomics and genomics, proteomics, and metabolomics has provided more details on the biological behaviors of diseases. Some biomarkers guiding patient selection were extracted by multi-omics analysis.[9] By combining multi-omics analysis with the outcome of interventional treatment, the efficacy and prognosis can be predicted.[10] In addition, improved techniques regarding navigation, location confirmation, range and edge of the interventional procedure, route of drug delivery, and dosage make the interventional procedure more accurate.[11] The precise evaluation of the optimum therapeutic scheme, drug or material selection, and imaging techniques is an important part of PIR. Furthermore, the prediction of the efficacy and complications of interventional treatment using multi-data analysis and artificial intelligence should be considered before interventional treatment. In all, details of diagnosis, interventional treatment, and prognosis should be taken into account in PIR, rather than anatomical location only.

4. Precise selection and application of drugs, materials, and devices

The strategy of drug delivery through a hollow needle and catheter is an important part of interventional radiology. It is used to increase the drug concentration in local lesions and reduce systemic toxicity. The concept of precise drug selection is derived from personalized and evidence-based medicine. The issue of drug delivery concerning the route and rate, dosage, and release from carriers is a topic of PIR. The combination of locoregional and systemic treatment conforms to the concept of PIR. Clinical research has demonstrated that chemotherapeutics, molecular targeted, and immune-therapeutic drugs improve the outcome of locoregional treatment.[12] Evaluation based on pathological, molecular, and genetic examinations also provides a reliable basis for combination treatment.[13]

Embolization has been widely used in the treatment of hemorrhagic diseases and tumors by blocking the blood supply to the lesion. Superselective supplied vessel embolization meets the narrow concept of PIR at the anatomical level. Accuracy in embolic rate, range and degree of embolization, and selection of embolic materials or devices broaden the concept of precise embolization. Factors including types of embolic materials, drug carriers, and drug-load volume of carriers significantly influence the outcome of embolization.[14,15] Recently, various multi-functional embolic materials have been developed and applied clinically to replace the simple filling materials, providing more options for endovascular embolization.[16] Standardized strategies for selecting optimum embolic materials and their precise use for specific diseases are topics of PIR.[16] Efforts to develop and apply new types of embolic materials would result in a great process of interventional radiology.

Devices including balloons, stents, filters, and coils are commonly used in interventional radiology, which can diagnose and treat diseases by opening or closing congenital and acquired lumens (blood vessels, digestive tract, airway, etc.). After decades of evolution, the indications and applications of devices have changed. Balloon dilation is mostly used in the treatment of cardiovascular and cerebrovascular diseases, and it often temporarily dilates the biliary tract, portal vein, and cerebral vessels before stent implantation.[17]

Owing to the appearance of many new types of stents, such as bare metal stents and drug-eluting stents, biocompatibility has improved and the rate of restenosis has decreased significantly.[17] Biodegradable stent, 3D printing biodegradable polymer stents, coated stents, and MRI-compatible stents have amplified the application of stent implantation. However, problems of stent deformation, thrombosis, tissue growth inhibition, and damage around the stent remain unsolved.[18]

A filter is used to prevent vascular embolic diseases by shedding a thrombus from peripheral blood vessels. The selection of filter type (permanent or temporary), time of implantation and removal, long-term complications of permanent filter implantation, blockage by thrombus, and injury to the vascular wall and surrounding tissue induced by the continuous compression of the filter legs have confused interventional physicians for years. Degradable filters and drug-coated filters are expected to solve the problems of blockage and relieve compression after long-term filter implantation. The retrievable filter greatly reduces the complication of long-term filter implantation, even though two operations under DSA guidance are needed.[19,20]

A coil is a permanent implant material that makes the distal vessels and organs functionally useless. For PIR, the texture of the coil and the release speed have a significant impact on the embolization effect and should be carefully assessed. The controllable catheter helps control the release speed and shape of the coil. In addition, coils combined with other embolic materials are a new strategy for embolization.[21]

Above all, interventional radiology techniques have improved significantly, and more options are currently offered to the patients and interventional physicians. In addition, the precise selection and application of drugs, embolic materials, and devices really impact the outcome of interventional treatment. Therefore, the development, selection, and application of drugs, embolic materials, and devices are the main areas of PIR.

5. Pre-therapeutic and prognostic imaging evaluation and intraoperative guidance

Imaging evaluation is the foundation of the entire process of PIR. Image evaluation methods have evolved in recent years. Traditional radiology techniques, including US, CT, and MRI, reflect the morphological features of lesions. Molecular imaging techniques, such as pet-CT, pet-MR, and ECT, visualize the biological characteristics of lesions at anatomical positions. Multimodal medical image fusion is used to overcome the shortcomings of a single image. It has been demonstrated that multimodal medical image fusion significantly improves the early diagnosis rate and decreases the misdiagnosis rate. Multimodal medical image fusion is also used to screen optimum drugs and to evaluate therapeutic effects in real time.[22] The auxiliary equipment based on artificial intelligence analysis can also improve the accuracy of traditional radiology.[23] Thus, various imaging methods provide alternatives to traditional imaging evaluations.

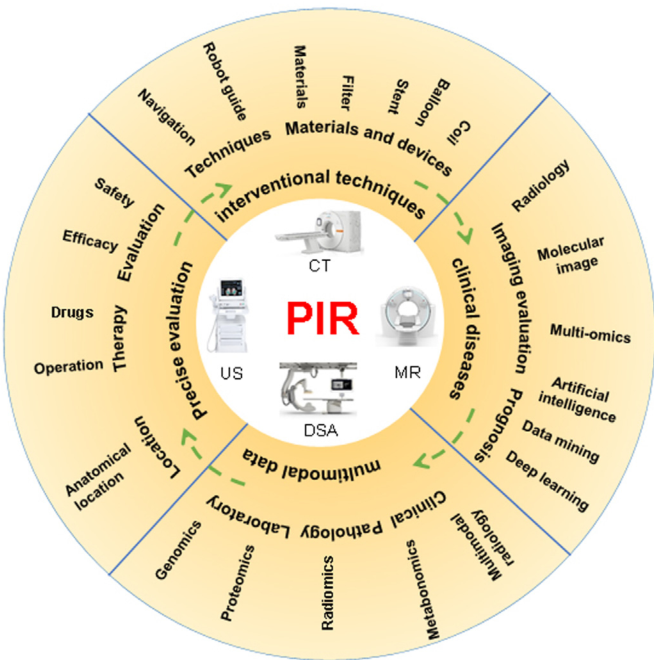

Fig. 1. The concept of precise interventional radiology(PIR). PIR focus on accuracy in anatomical location, comprehensive evaluation, accurately interventional operation and prognosis prediction.

New types of imaging evaluation do not totally depend on the naked eye, but on information beyond the visible images. Radiomics extracts non-visible information from US, CT, and MRI. Radiomics combined with genomics, pathomics, proteomics, and metabolomics provides a multi-omics evaluation of biological behaviors.[24] On the one hand, it reflects the complicated heterogeneity of diseases and provides personalized guidance for diagnosis and treatment. Moreover, it also screens the commonalities and identifies potential biomarkers and therapeutic targets that help to classify disease and ultimately improve the accuracy of diagnosis and efficacy of treatment.

The integration of medicine and engineering causes the spring of multimodal image fusion guide technology, robot-assisted puncture technology, imaging segmentation technology, optical or electromagnetic navigation technology, and other new navigation technologies. These technologies have been used to guide interventional operations and provide more information and clearer images during interventional operations.[22,25–27] Under the guidance of these new image-guided techniques, the intraoperative location is more accurate, and the operation is more stable and repeatable. Concurrently, it also reduces the dependence on the doctor's surgical experience, shortens the training time, and reduces the operation risk or complications.

6. Precise diagnosis is the premise of interventional therapy

Over the past few decades, interventionists have focused on precise puncture and the super selection of supplied vessels. Significant progress has been made in establishing a clinical path for interventional radiology. First, using radiology images as well as genes, molecules, and pathology, the interventionists could obtain a precise diagnosis. A precise diagnosis should provide comprehensive information about the biological behaviors of diseases. Interventional operations guided by image techniques are then applied. Finally, a prognostic model for interventional therapy or examination was established. Precision diagnosis plays a basic role in PIR, which helps in patient selection, indication evaluation, treatment scheme determination, and prognosis prediction. Owing to the application of deep analysis, data mining, and artificial intelligence analysis as well as molecular imaging, multimodal imaging, and multi-omics, the concept of precision diagnosis consists of both morphological and pathophysiological diagnoses.[19,21] Precision diagnosis also reflects the occurrence, development, and prognosis of diseases. With interventional therapies based on precision diagnosis, the goal of maximizing patients' benefit and minimizing damage can be realized.

7. Conclusion

Currently, PIR is a new and refined discipline, not limited to the improvement of diagnosis and treatment at the anatomical level, but the integration of interventional radiology with surgery, internal medicine, molecular diagnostics, pathology, pharmacology, and other disciplines (Fig. 1). It will significantly promote clinical diagnosis and treatment by both covering the whole disease process and dividing it into different modules for precise evaluation and treatment. Future studies should focus on maximizing the benefits of patients with limited damage, which is also an important direction of medicine in the future.

Declarations of competing interest

None.

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Jiansong Ji[1], Shiji Fang[1], Minjiang chen, Liyun zheng, Weiqian Chen, Zhongwei Zhao

Key Laboratory of Imaging Diagnosis and Minimally Invasive Intervention Research, Lishui Hospital of Zhejiang University, Fifth Affiliated Hospital of Wenzhou Medical University, Lishui, 323000, China

Yongde Cheng[*]

Magazine of the Journal of Interventional Medicine, Shanghai, 200052, China

[*] Corresponding author. Magazine of the journal of interventional medicine, Shanghai, 200052, China.

E-mail address: yongdech@163.com (Y. Cheng).

[1] Contributed equally to the manuscript.