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Application Progress of MRI-IVIM, T1mapping and T2mapping in Diagnosis and Treatment of Breast Diseases

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Abstract: This article summarizes the application progress of MRI-IVIM, T1mapping, and T2mapping techniques in the diagnosis and treatment of breast diseases. These techniques, leveraging their advantages of being non-radiative, high soft tissue resolution, and multi-functional imaging, provide significant support for the diagnosis of breast diseases. IVIM technology measures the microscopic motion of water molecules to reflect the microcirculatory perfusion of lesions; T1mapping technology measures T1 relaxation time to reveal the physical properties of tissues, aiding in distinguishing different types of breast tissue; T2mapping technology measures T2 relaxation time to reflect changes in the microscopic structure of tissues, providing sensitive indicators for early detection of breast diseases. These techniques can distinguish between benign and malignant lesions, assess the tumor microenvironment, predict breast cancer subtypes, and evaluate treatment efficacy, thus providing a basis for the selection and adjustment of treatment plans. However, these techniques also face challenges such as high costs and limited accessibility, lack of standardized data interpretation, and prolonged examination times that affect patient comfort. Future development directions will focus on the integration of technologies and multi-modal imaging, artificial intelligence and automation, and technological optimization and cost reduction, aiming to achieve personalized diagnosis and precise treatment of breast diseases, thereby improving treatment outcomes and patient quality of life.

Keywords: Breast Diseases; MRI-IVIM; T1mapping; T2mapping.

1. Introduction

Breast diseases, as a major threat to women's health, have shown a continuous upward trend in the global scope in recent years. Breast cancer, in particular, not only has a high incidence rate, but also its complex biological behavior and diverse clinical manifestations bring great challenges to diagnosis and treatment. According to statistics, breast cancer has become one of the main causes of cancer death among women in the world, which seriously threatens the quality of life and life expectancy of patients [1]. Therefore, it is particularly urgent to explore more accurate and efficient methods for diagnosis and treatment of breast diseases.

In the rapid development of medical imaging technology, Magnetic Resonance Imaging (MRI) has established a prominent position in the diagnosis of breast diseases due to its advantages of being non-radiative, having high soft tissue resolution, and offering multi-functional imaging. In recent years, with continuous innovation and upgrades in MRI technology, advanced imaging techniques such as Intravoxel Incoherent Motion (IVIM), T1 mapping, and T2 mapping have emerged, providing new perspectives and tools for the early detection, accurate diagnosis, and evaluation of treatment efficacy in breast diseases [2-3].

IVIM technology can reflect the microcirculation perfusion of lesions by measuring the microscopic movement of water molecules in tissues, which provides important information for the blood supply characteristics of breast lesions. T1mapping technology reveals the physical characteristics of tissues under a specific magnetic field by accurately measuring the T1 relaxation time of tissues, which is helpful to distinguish different types of breast tissues. The T2mapping technique reflects the changes of tissue microstructure by measuring T2 relaxation time, which provides a sensitive index for early detection of breast diseases.

This study summarizes the application progress of MRI-IVIM, T1mapping and T2mapping in the diagnosis and treatment of breast diseases, and discusses the potential and value of these technologies in improving the diagnostic accuracy, guiding the selection of treatment schemes, and evaluating the curative effect and prognosis. Through in-depth analysis of the principles, application status and future development trend of these technologies, new ideas and references are provided for clinical diagnosis and treatment of breast diseases, and then the level of diagnosis and treatment of breast diseases is promoted in an all-round way.

2. Basic Principles of MRI Technology

MRI is a medical imaging technology based on the principle of nuclear magnetic resonance (NMR). It uses powerful magnetic fields, radio frequency pulses and advanced computer image processing technology to non-invasively obtain high-resolution images of human internal structure and function. The basic principle of MRI technology is shown in Figure 1.

NMR is the core principle of MRI technology, which is based on the behavior of hydrogen nuclei in human body under the action of external strengthening magnetic field. In a strong magnetic field environment, hydrogen nuclei will be arranged in the direction of the magnetic field to form a magnetic moment; After the RF pulse with a specific frequency is applied, the hydrogen nucleus absorbs energy and produces resonance, which deviates from the original arrangement direction. After the RF pulse, the energy released by the hydrogen nucleus returns to the initial state, and the energy released in this process can be captured by MRI equipment and converted into image signals.

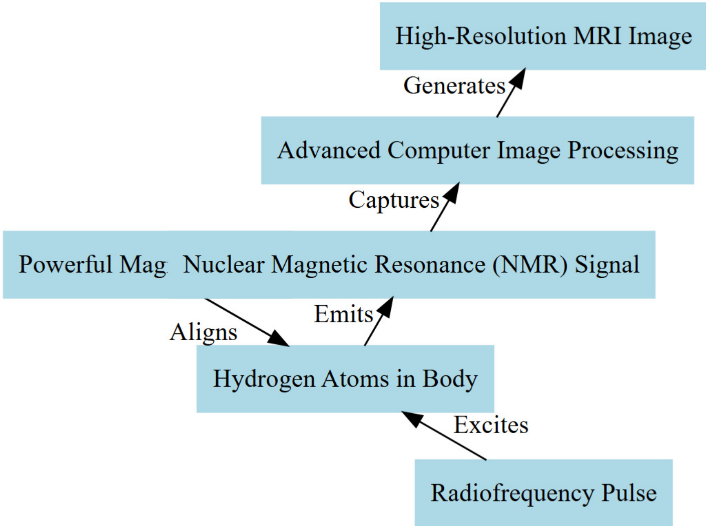

Figure 1. Basic principles of MRI technology

In order to accurately locate the internal structure, MRI equipment uses the combination of main magnetic field and gradient magnetic field. The main magnetic field ensures the initial magnetization of the hydrogen nucleus, while the gradient magnetic field makes the hydrogen nucleus have different resonance frequencies by changing the magnetic field intensity at different positions, thus realizing the spatial positioning. Combining RF pulse excitation with signal reception, as well as the subsequent image reconstruction process, including signal processing and calculation, a detailed image of human internal structure, especially a high-contrast image of soft tissue, is finally generated, which greatly facilitates medical diagnosis.

3. Application Progress of MRI-IVIM, T1mapping and T2mapping Technology

3.1. Application of Diagnosis of Breast Diseases

IVIM technology can evaluate the information of tissue diffusion and perfusion at the same time, which is of great significance for the diagnosis of breast diseases. In the diagnosis of breast benign diseases such as breast cyst and fibroadenoma, IVIM technology can distinguish different types of benign diseases by measuring pure diffusion coefficient (D value) and perfusion-related diffusion coefficient (D* value). For example, breast cysts usually show low D value and low D* value, while fibroadenomas may show high D value and D* value [4]. In the diagnosis of breast cancer, IVIM technology also shows its advantages. Breast cancer tissue usually has high angiogenesis and cell density, so it shows high D* value and low D value on IVIM images [5]. IVIM technology can also be used to evaluate the therapeutic response of tumor. By comparing the changes of D value and D* value before and after treatment, the therapeutic effect can be judged more accurately.

T1 mapping technology can quantify the longitudinal relaxation time (T1 value) of tissues and reflect the microstructure and water molecule environment of tissues. In the diagnosis of breast diseases, T1 mapping technology can help distinguish benign and malignant lesions. Generally speaking, because of its rapid growth and high metabolic activity, malignant tumor will lead to the decrease of T1 value. Therefore, by measuring T1 value, breast cancer can be diagnosed and differentiated from other benign lesions [6-7]. In addition, T1 mapping technology can also be used to evaluate the therapeutic response of tumors. Tumors with effective treatment usually show an increase in T1 value, because tumor cell death and inflammatory reaction will lead to changes in the water molecule environment of tissues after treatment.

T2 mapping technology quantifies the transverse relaxation time (T2 value) of tissues, reflecting the water content of tissues and the size of extracellular space. In the diagnosis of breast diseases, T2 mapping technology can help identify the pathological changes such as edema and inflammation. Benign lesions such as breast cysts usually show a high T2 value, while malignant tumors may show a low T2 value. T2 mapping technique can also be used to evaluate the therapeutic response of tumors [8]. After treatment, with the death of tumor cells and the reduction of inflammatory reaction, T2 value may increase. Therefore, by measuring the change of T2 value, the therapeutic effect can be judged.

3.2. Application in the Selection of Treatment Scheme

MRI-IVIM technology is a noninvasive method to evaluate tumor microenvironment, which separates diffusion and perfusion effects by fitting the double exponential model of signal attenuation. This technique can provide quantitative information reflecting cell distribution and vascular perfusion, and it has potential and value in differentiating benign and malignant breast lesions, predicting breast cancer subtypes and evaluating curative effect. For example, IVIM combined with dynamic contrast-enhanced MRI (DCE-MRI) can improve the diagnostic efficiency in the differential diagnosis of non-mass enhanced adenopathy and breast cancer, in which TIC type and D* value are independent risk factors for predicting NME breast cancer [9].

T1mapping technology can be used to distinguish normal glands from benign tumors and normal glands from breast cancer by quantitatively measuring T1 value. Among all the indexes related to T1 value, △T1% has the best differential diagnosis efficiency in both groups. This means that

T1mapping technology can help doctors distinguish the nature of breast lesions more accurately, so as to make a more suitable treatment plan [10-11]. T2mapping technology can be used to distinguish normal glands from breast cancer by quantitatively measuring T2 value, in which T2 value is correlated with tumor size and ADC value, and may be used as a quantifiable imaging index to reflect the prognosis of breast cancer [12]. The difference of T2 value between normal gland and breast cancer is statistically significant, which indicates that T2mapping technology has potential application value in the diagnosis and treatment scheme selection of breast cancer [13].

Based on a self-developed multi-gene model, the research team adopted a precision therapy regimen that sequentially combines "anthracycline-taxane" with "gemcitabine" and "carboplatin," significantly increasing the survival rate of high-risk triple-negative breast cancer patients by over 10% [14]. This achievement highlights the importance of integrating precision medicine models with imaging techniques (such as MRI-IVIM, T1mapping, and T2mapping) in breast cancer treatment, making treatment plans more personalized and improving therapeutic outcomes. The MRI-IVIM, T1mapping, and T2mapping techniques play a crucial role in the selection of treatment regimens for breast diseases by providing more accurate differentiation of lesion characteristics, helping doctors develop more precise treatment plans.

3.3. Application of Curative Effect Evaluation and Prognosis Judgment

MRI-IVIM technology can reflect the changes of microstructure of breast lesions through quantitative analysis of water molecule diffusion. During the treatment, the necrosis and apoptosis of tumor cells and the remodeling of surrounding tissues will cause changes in the diffusion characteristics of water molecules. For example, with the progress of effective treatment, the cell density in the tumor decreases and the extracellular space increases, and the diffusion parameters in IVIM will change accordingly [15]. This change can prompt the improvement or progress of the disease earlier than the traditional imaging methods, and provide a basis for clinical timely adjustment of treatment plans.

T1mapping technique is used to evaluate breast diseases according to the difference of longitudinal relaxation time (T1 value) of tissues. After treatment, the T1 value of the diseased tissue may change due to the change of composition (such as the regression of inflammation and the formation of fibrosis, etc.). By continuously monitoring the dynamic changes of T1 value, we can accurately understand the physiological and pathological changes of tissues during the treatment of breast diseases, and accurately judge whether the disease is developing towards improvement or deterioration. T2mapping technique uses transverse relaxation time (T2 value) to evaluate breast diseases. During the treatment of breast diseases, for example, the edema of tumor tissue after chemotherapy and the damage degree of surrounding normal tissues after radiotherapy can be reflected by the change of T2 value [16]. T2mapping also has a unique advantage in evaluating the therapeutic effect of mastitis, which can show the change of water content in inflammatory tissue, thus reflecting the degree of remission of the disease.

MRI-IVIM technology can identify the heterogeneity in breast tumors. It has been found that some regions in tumor tissues have special diffusion patterns of water molecules, which may be related to the invasion and recurrence potential of tumors [17]. After operation or comprehensive treatment, IVIM examination of breast tissue can remind clinicians to pay close attention to it if it is found that there is still a local diffusion area with high recurrence risk characteristics, so as to find signs of recurrence early. At the same time, IVIM parameters have certain potential in predicting local recurrence and distant metastasis, and its multi-parameter model can comprehensively evaluate the biological behavior of tumors.

T1mapping and T2mapping techniques are also of great value in predicting the recurrence of breast diseases. In the follow-up of breast tumor after treatment, if the T1 and T2 values in the lesion area change abnormally, such as the stable T1 value suddenly decreases and the T2 value increases, it may indicate tumor recurrence or new lesions [18]. This is because the composition and structure of recurrent tumor tissues are different from those after normal treatment, and this difference will be reflected by the change of relaxation time. Moreover, combining the two techniques can analyze the microscopic changes of tissues more comprehensively, improve the accuracy of predicting recurrence, and help to formulate more reasonable follow-up strategies and intervention measures.

4. Challenges and Future Development Direction

Although MRI-IVIM, T1mapping and T2mapping technologies have shown great potential in the diagnosis and treatment of breast diseases, they still face some problems, such as technology popularization and high cost, lack of standardization in data interpretation, long examination time affecting patients' comfort and technical limitations, such as high misdiagnosis rate or missed diagnosis rate in specific types of breast lesions and insufficient sensitivity to tiny lesions or special types of breast cancer. These problems not only limit the wide application of these technologies, but also point out the direction for future research and development.

In the future, the development directions of MRI-IVIM, T1mapping and T2mapping technologies will focus on technology fusion and multimodal imaging, artificial intelligence and automation, technology optimization and cost reduction. By combining these MRI techniques with ultrasound, molybdenum target X-ray, PET-CT and other imaging techniques, more comprehensive and accurate diagnostic information can be provided. At the same time, with the help of artificial intelligence and machine learning, developing an automatic data analysis and diagnosis assistant system can not only improve the accuracy and efficiency of data interpretation, but also reduce the dependence on professionals. In addition, through technological innovation and process improvement, it will also be an important development direction to reduce the cost, improve the cost performance and penetration rate of equipment, optimize the inspection process, shorten the inspection time and improve the comfort of patients.

Furthermore, combining the genetic information, clinical manifestations and imaging features of patients, personalized diagnosis and precise treatment of breast diseases can help to formulate more appropriate treatment plans and improve the treatment effect and quality of life of patients. Using the Internet and cloud technology to realize the remote transmission and sharing of MRI images, promote the balanced distribution of medical resources, and develop a cloud-based MRI data analysis and diagnosis platform, which can provide telemedicine services for more patients. To sum up, with the continuous progress of technology, MRI-IVIM, T1mapping and T2mapping technology will play a greater role in the diagnosis and treatment of breast diseases.

5. Conclusion

IVIM technology can reflect the microcirculation perfusion of breast lesions by measuring the microscopic movement of water molecules in tissues, which provides important information for the blood supply characteristics of breast lesions. T1mapping technology helps to distinguish different types of breast tissues by accurately measuring T1 relaxation time of tissues. T2mapping technology reflects the changes of tissue microstructure by measuring T2 relaxation time, which provides a sensitive index for early detection of breast diseases. The development of these technologies not only improves the diagnostic accuracy of breast diseases, but also helps to guide the selection of treatment schemes and evaluate the curative effect and prognosis. However, these technologies still face challenges such as technology popularization and high cost, and lack of standardization in data interpretation. The future development direction will focus on technology integration and multimodal imaging, artificial intelligence and automation, technology optimization and cost reduction, so as to realize personalized diagnosis and precise treatment of breast diseases.

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