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REVIEW

Multimodal Magnetic Resonance Imaging and Radiomics in Brucella Spondylitis: Diagnostic Applications and Differential Diagnosis

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Abstract: Brucella spondylitis (BS) is one of the most common and serious complications of brucellosis, with insidious clinical manifestations and lack of specificity, which often delay the disease and cause a series of adverse consequences such as multi-organ involvement and dysfunction in severe cases. Due to the lag of laboratory-related laboratory tests and pathological examinations and the many factors that interfere with the confirmed results, the diagnosis and treatment of BS are affected. Magnetic resonance imaging (MRI) is particularly important in the diagnosis of BS and in the assessment of disease progression, treatment efficacy, and prognosis through a refined response to the structure and function of diseased tissues due to its multiparametric imaging and good tissue resolution. Radiomics, as an emerging means to quantitatively analyze image information and provide disease diagnosis and treatment assistance, is gradually showing its important value, by screening the omics features of the imaging affected vertebral bodies, constructing a diagnostic model based on machine learning, and conducting research on the diagnosis and differential diagnosis of BS.

Keywords: brucella spondylitis, conventional magnetic resonance, functional magnetic resonance, radiomics, machine learning, disease staging

Introduction

Brucellosis is the world's most common zoonotic infectious disease caused by Brucella (Brucella.spp) infection. There are about 500,000 new cases in the world every year,[1] and the susceptibility of humans to brucellosis is obviously related to occupational exposure, with farmers and herders accounting for 85.5% of the total number of patients,[2] brucellosis is defined as a class B infectious disease in China, with an incidence rate of about 8/1 million, and the epidemic time of brucellosis is 3~8 months every year, and the patients are mainly concentrated in the areas with more developed animal husbandry in the north,[3] and there is an epidemic trend of spreading to the east.[4] The pathogenesis of brucellosis involves a complex interaction between bacteria and the host immune system, and after Brucella invades the host through the digestive tract, respiratory tract, and broken skin and mucous membranes, it has evolved strategies to evade immune recognition and change the immune response mechanism, including affecting innate immunity, antigen presentation, manipulation of host immune metabolism, pyroptosis, etc., and finally establishing chronic infections with multiple manifestations in the host.[5,6] The main manifestations are bone damage caused by Brucella by affecting the release of pro-inflammatory factor TNF-α by macrophages and monocytes, and the osteoarticular system is most susceptible to involvement, such as arthritis, spondylitis, and sacroiliitis are the most common complications, with a prevalence of about 2~60%, of which brucelli spondylitis is the main one. Lesions first occur in the anterior part of the endplate,[7] with L4 and L5 predominantly.[8] Brucella infection may affect the vertebral bodies, intervertebral discs, epidural, paraspinal, and intermuscular spaces.[9] Focal inflammation caused by brucella infection destroys bone structure and surrounding soft tissues, forming an abscess that compresses and infects the neuraxial blood vessels and nerves, and the clinical symptoms are pain and movement disorders. The non-specific clinical manifestations of BS increase the complexity of disease diagnosis, resulting in prolonged disease, involvement of multiple organ systems, and even severe sequelae such as limb

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disability and paraplegia.[5,10] Although the mortality rate of BS is low, pain and mobility impairment can seriously affect the quality of life of patients, and there is also a risk of disability, so early diagnosis is of great significance. In the early stages of the disease, fever, fatigue, diaphoresis, and musculoskeletal pain are predominantly presenting.[11] Current diagnosis is based on specific brucellosis serology, which mainly includes standard test-tube agglutination tests, tiger red plate agglutination tests, and brucellosis IgG and IgM antibody tests. The low positive rate of pathogen culture makes serology play an important role in diagnosis, and it is also concerned that serology is prone to false positive and false negative results due to the high background titer in endemic areas, cross-reactivity with other negative staining species, and the influence of disease course. At present, the treatment of brucella spondylitis at home and abroad is mostly based on the specific condition of the patient, including acute and chronic phases and whether it is complicated by complications in other parts, and the antimicrobial therapy with doxycycline, rifampicin, quinolones, and third-generation cephalosporins is the main antimicrobial therapy.[12] Although the systematic treatment plan is gradually improving, there is still a lack of effective evaluation criteria for the evaluation of the treatment effect and monitoring of recurrence of brucella spondylitis, which needs to be further studied and explored.

According to the latest expert consensus on the diagnosis of BS imaging, DR combined with MRI is recommended for the diagnosis and follow-up of patients with BS.[13] Magnetic resonance imaging (MRI) has become the mainstream examination method due to its excellent imaging ability of bone marrow, intervertebral disc, paravertebral soft tissue and spinal canal, but for patients with obvious spinal pain and fever symptoms, the visual qualitative of traditional conventional MRI based on signal changes is far from enough, and intramedullary infection needs to be quantitatively evaluated. Whether the internal microenvironment has undergone pathological changes, causing some patients to miss the best treatment point or insufficient antibiotic use and delay the disease and make the disease chronic. In recent years, magnetic resonance imaging has been used as the most commonly used imaging method in the field of BS research because of its excellent non-invasive soft tissue characteristics, and new magnetic resonance technologies such as intravoxel incoherent motion, dynamic contrast-enhanced magnetic resonance imaging, DTI, T2mapping and other functional magnetic resonance technologies for quantitative analysis, and even radiomics have gradually begun to be applied to the diagnosis, disease staging and disease prognosis evaluation of BS, which is of great significance for understanding the structural and pathophysiological changes of lesions and adjacent surrounding tissues.

Conventional Magnetic Resonance

Plain X-rays and CT scans have limited diagnostic capabilities for brucella spondylitis, and conventional MRI has become an important imaging tool for early clinical detection and differential diagnosis. Bai et al[14] selected 20 patients with brucellella spondylitis from 2009 to 2014 for routine magnetic resonance imaging scans, and found that in most cases, routine MRI results combined with epidemiological history and serology were more accurate in diagnosis, and paravertebral and epidural masses, nerve invasion, and compression were more likely to occur in the cervical and thoracic spine than in the lumbar spine. Conventional magnetic resonance imaging can provide differential diagnostic value for BS and other diseases with similar signal manifestations (spinal tuberculosis, etc) through a series of morphological features of tissue lesions, such as prone sites, vertebral body destruction, kyphotic deformity, dead bone, osteophyte formation, intervertebral space changes, and abscess sites.[15,16] However, MRI findings of common spinal diseases, such as BS, Tuberculous spondylitis (TS), single spinal metastases, and vertebral degeneration, may overlap and interfere with diagnosis. At the same time, in the evaluation of the clinical treatment effect of BS patients, it is difficult to reflect the short-term efficacy from the perspective of conventional magnetic resonance imaging alone, and the response sensitivity of different populations to treatment is also different. Brucella spondylitis has mild bone destruction, less dead bone, and a small paravertebral abscess, but bone hyperplasia is more pronounced, and sclerotic edges are often seen around the bone destruction, mainly involving the lumbar spine. Liu et al[17] showed that the affected vertebral bodies of brucelli spondylitis exhibited a diffuse and uniform long T1 long T2 signal, while the vertebral body height remained unchanged. In addition to imaging to show morphology, MRI is also capable of quantitative analysis. Diffusion weighted imaging (DWI) is a method that uses Brownian motion to detect the diffusion of water molecules in living tissues, and the quantitative parameter apparent diffusion coefficient (ADC) can reflect the diffusion ability and microstructure of biological tissues. It is possible to non-invasively evaluate the diffusion movement of water molecules

in human tissues, and the apparent diffusion coefficient (ADC) is a quantification of the diffusion movement. Peng et al[18] calculated the ADC values of a total of 330 diseased vertebrae in 50 patients with BS and found that the ADC values of the former were higher than those of normal vertebrae, which could be used to evaluate the treatment effect.

Functional Magnetic Resonance

Functional magnetic resonance imaging can non-invasively quantitatively analyze a series of characteristics such as water molecule diffusion, tissue microcirculation and blood perfusion at the lesion site, providing multiple options for the display of disease tissue structure changes and pathophysiological characteristics, and providing important research and clinical application value for the diagnosis and treatment of BS, especially treatment evaluation and prognosis.

Incoherent Movement within Voxels

Intravoxel incoherent motion (IVIM) is a double-exponential, multi-b-value model based on a derivative technique based on DWI first proposed by Bihan et al[19] in 1986. A multi-b scanning protocol provides information on tissue microcirculation and perfusion without the use of contrast.[20] With the improvement of the performance of MRI scanning equipment and the development of sequences, it meets the requirements of IVIM for high signal-to-noise ratio, making its clinical exploration more rapid, and widely used in glioma, prostate cancer and breast cancer research.

Diffusion-Weighted Imaging of a Double Exponential Model

The IVIM parameters can be separated from diffusion by biexponential model analysis, enabling the measurement of diffusion-related parameters D (reflecting tissue diffusion) and perfusion-related parameters, including D* (reflecting pseudo-diffusion coefficients), f (reflecting perfusion fractions). The D value (ADC slow) is the simple diffusion coefficient, which represents the pure diffusion motion of water molecules, the D* value (ADC fast) is the pseudo-diffusion coefficient, which reflects the diffusion motion or rapid diffusion motion of simple water molecules related to the perfusion of blood flow in the tissue, and the f-value is the perfusion fraction, which reflects the volume ratio of the perfusion-related effect in the local microcirculation to the overall diffusion effect of the blood volume in the region of interest, between 0 and 1. Wu et al[21] measured the D*f, and D values of the affected vertebral lesions in 30 patients with TBS and BS, and found that there was no significant difference between D* and f, while the D value of TBS was higher than that of BS, and the area under the receiver's operating characteristic curve could reach 0.825 when the two were used to distinguish between the two. Wang et al[22] found that the D and f values of the BS group were significantly higher than those in the early BS group. The pathophysiological characteristics of BS can explain the alterations in D and f values. The f-value is not only positively correlated with bone marrow microvascular density, but also indicates capillary wall endothelial cell permeability, and is used to reflect differences in vascular distribution between benign and malignant bone marrow diseases.[23] Brucella infection stimulates neovascularization, increases microvascular density, and increases F-score. When an acute attack of BS occurs due to weakened immunity or overload of bacteria, the resulting inflammatory response results in disruption of bone marrow microcirculation, increased vascular permeability, and the formation of characteristic granulomas, ie, large aggregates of macrocore cells, epithelioid macrophages, and the outermost layer of inflammatory lymphocytes and granulocytes stained by Brucella immunostaining.[24] Tissue edema, inflammatory cell infiltration, and destruction of microvessels and trabeculae resulting from the inflammatory response mainly affect the quantitative parameter D, which increases it significantly.[25] Guo et al[26] indirectly detected the infiltration of inflammatory cells and the accumulation of water molecules in sacroiliitis in patients with axial spondyloarthritis (axSpA) by detecting the transport of water molecules from the capillaries to the bone marrow cavity by D value. The difference between the BS group and the early BS group was not only morphological, but also the microenvironmental changes of the infected bone marrow at the cellular level, suggesting the advantage of D-values for monitoring cell diversity in the inflammatory state of the bone marrow. D* is proportional to mean capillary segment length and mean blood flow velocity, and inversely proportional to mean transit time (MTT), indicating the speed of bone marrow microcirculation.[23] Wu et al[27] showed that the D* and f of brucella spondylitis were higher than those of spinal tuberculosis, and the D* was statistically significant, and f was non-significant. D* and f reflect tissue microcirculatory perfusion, with obvious proliferation and repair of brucella spondylitis, a large number of neovascularization in the

diseased vertebral body, and incomplete neovascular endothelium, while the pathological changes of spinal tuberculosis are caseous necrosis without neovascularization.[28,29] This results in a higher D* value for brucella spondylitis than for tuberculosis. The non-statistically significant f-value may be susceptible to some physiological activities,[30] but it still reflects a tendency for borgle perfusion to be higher than that of tuberculosis. The f-value and D* value are very unstable, and the validity of their values depends largely on the correct selection of the b-value. The diffusion of simple water molecules is represented by the D value, and the higher the D value, the faster the diffusion of water molecules and the lower the cell density. Granulomas are not only rich in neovascularization, but also have high cell density, small EES space, parenchymal cell degeneration, necrosis, limited diffusion of water molecules, and low D value. Hyperplastic granulomas can be treated aggressively to restore normal tissue structure, and the diffusion movement of water molecules gradually improves, resulting in a gradual increase in D-values after treatment. The larger the D-value, the richer the microcirculation, which is not only manifested in the number of local blood vessels in the lesion, but also related to the local blood perfusion, the difference between D* and f values is not statistically significant, and may not have substantial changes in the microcirculation at the lesion during the treatment process, but rather in the changes in vascular permeability and cell density.[31]

The parameters of the IVIM biexponential model can reflect the true spread within the lesion without being affected by perfusion-related diffusion, but the application of high b value in the IVIM model will significantly prolong the scanning time and increase the motion and sensitivity artifacts, so the search for standard and stable scanning parameters is an urgent need to be solved in future research.

Diffusion-Weighted Imaging of the Stretch Index Model

The biexponical model sometimes does not fully reflect the diffuse motion of the human body, and Bennett et al[32] proposed a multi-exponential model, the Stretched-exponential Model (SEM), in 2003. SEM assumes that the diffusion coefficient within voxels is continuously distributed, and uses the Distributed Diffusion Coefficient (DDC) and the Diffusion Heterogeneity Index (α) to reflect the diffusion rate and the complexity of the tissue structure within the voxels. α characterize the deviation of signal attenuation from single exponential behavior, ranging from 0 to 1, with a low α index indicating high water diffusion heterogeneity in voxels and a non-exponential diffusion signal attenuation, while a high α index (close to 1) indicating low water diffusion heterogeneity in voxels, indicating a single exponential diffusion signal attenuation. The DDC value refers to the amount obtained by fitting the tensile index function to the data, which is a part of the composite parameters of the continuous distribution of each ADC weighted by the volume ratio of water molecules, and has a high correlation with the ADC value. a is associated with the heterogeneity of water molecule diffusion within voxels, varying between 0 and 1. When it is close to 1, it indicates that the diffusion of voxels is homogeneous, showing a single exponential attenuation. On the contrary, the heterogeneity of intra-voxel diffusion increases near 0, showing a complex multi-exponential attenuation, which reflects a positive correlation between microstructural diffusion heterogeneity and cell pleomorphism, the number of neovascularization, and the degree of micronecrosis.[33,34] Wu et al[27] showed that the a-value of brucella spondylitis was slightly higher than that of tuberculosis, which may be due to the microvascular proliferation and new bone of brucellosis, while tuberculosis has necrosis, dead bones, multinucleated giant cells, and epithelioid cells, and tuberculosis spread more unevenly than brucellosis, but the difference between the two is not large.

Quantitative Dynamic Contrast-Enhanced Magnetic Resonance Imaging

Quantitative Dynamic Contrast-Enhanced Magnetic Resonance Imaging (DCE-MRI) is an imaging method that can semi-quantitatively or quantitatively assess tissue perfusion and microenvironment changes. Due to the introduction of pharmacokinetic models, quantitative analysis not only reflects the contrast agent transport in the form of perfusion maps, but also analyzes the contrast agent exchange between blood vessels and tissues mainly in the form of osmotic maps, which is more sensitive to changes in the microstructure and microcirculation of tissues.[35] Contrast medium-related microcirculation parameters were calculated by pharmacokinetic modeling, where Vp represents the volume of plasma per unit volume of tissue; VE represents the volume of the extravascular intercellular space, which is positively correlated with tissue inflammation; The larger the KEP, the higher the amount of contrast media entering the vessel

from the interstitial space per unit time; Ktrans indicates vascular permeability. Niu et al[36] performed conventional MRI and DCE-MRI on 56 patients with BS with diseased vertebral bodies and normal vertebrae, and only 32 obvious lesions were found by conventional noncontrast scanning, and no clear lesions were found in 24 cases, and no obvious enhancement was found on contrast scanning, which may be difficult to detect by conventional MRI due to the damage of microstructure and vascular endothelial cells in the early pathological changes of BS. However, the quantitative parameters of DCE-MRI can reflect the subtle inflammatory changes such as inflammatory cell infiltration, microcell destruction and microvascular changes in the early stage of BS patients. At the same time, it was found that the volume transport constant (Ktrans), rate constant (Kep), and extracellular volume fraction (Ve) values in the extravascular space (Ve) per unit tissue volume increased between the lesion vertebral body and the normal vertebral body of the lesion group, and the plasma volume fraction (Vp) value decreased, indicating that the quantitative parameters of DCE-MRI can reflect the inflammatory damage and tissue repair in the lesion vertebrae, which has high value for the diagnosis and early diagnosis of BS. Zhao et al[37] found that the quantitative parameters of DCE-MRI have certain diagnostic and differential diagnostic value for BS by comparing the differences of DCE-MRI parameters in BS, TS and spinal metastases and correlating them with pathological results, among which the Ktrans, Kep, and Vp values gradually decreased in spinal metastases, BS, and TS, which may be explained from a pathological point of view due to abnormal neovascularization unique to tumors. Imperfection in neovascular structure and function leads to more active tissue microcirculation and intravascular and extravascular contrast agent transport, as well as increased cell density due to abnormal cell division. In contrast, the main causative factor of BS is the imbalance between the immune system and the virulence of Brucella, which causes less tissue inflammation and damage than the tissue destruction and caseous necrosis of TS, resulting in a statistically significant difference in the pathophysiological characteristics of tissue microcirculation in the lesion area, so that the quantitative parameters can characterize different diseases. DCE-MRI can not only provide a reference in the diagnosis of BS, but also has potential clinical application value in the assessment of disease stage and activity. Changes in the local microenvironment will lead to changes in the quantitative parameters of magnetic resonance, which can be visually and quantitatively explained by the changes in the local lesion microenvironment, which can effectively evaluate the treatment effect of brucella spondylitis. In the study of Qiao et al,[38] the values of K trans, K ep, Ve, and Vp of the affected vertebral bodies in TBS patients were lower than those in BS patients. In other words, there is a likely causal relationship between the worse blood supply to the diseased vertebral body in TBS patients and the more severe bone destruction of the affected vertebral body in TBS patients. From the perspective of microenvironment changes, Ktrans and Kep reflect the degree of vascular permeability and vascular endothelial cell damage, and the higher the value, the more severe the vascular endothelial injury and the greater the vascular permeability.[39,40] The pathological manifestations of brucelli spondylitis are mostly granulomas,[41] which contain a large number of new blood vessels, and the basic pathological changes in the acute phase of the inflammatory response are exudation, so the vascular permeability is high, and the contrast medium of macromolecules is more active in intravascular and EES exchange, so in the untreated brucella spondylitis lesions, no matter the number of new blood vessels or the high permeability of blood vessels, the vertebral edema of conventional MRI lesions is more obvious, the enhancement of enhanced scanning is more significant, and the Ktrans and Kep values are higher; After active and strict treatment, although the number of new blood vessels in the lesion vertebral body was still at a high level, and the original lesion showed no obvious change or expansion of the scope and increase in the number of lesions in conventional MRI, the vascular endothelial cell space was significantly narrowed, the permeability was significantly improved, the exchange ability of macromolecular contrast medium in the blood vessels was weakened, and the microenvironment at the lesion site was improved to a certain extent, so the quantitative parameters Ktrans and Kep values of DCE-MRI decreased after treatment. The Ve value, which represents the volume fraction of EES, was not statistically significant before and after treatment, and may be related to the fact that the diseased bone tissue is slower than the vascular repair during treatment, and EES recovery may take longer.[42] The above studies have shown that DCE-MRI has important value in the diagnosis, monitoring and evaluation of BS, and the best quantitative parameters can be screened out in combination with relevant recovery and prognostic indicators, so as to more comprehensively evaluate the treatment and prognosis and guide the clinical diagnosis and treatment of BS.

Magnetic Resonance Diffusion Tensor Imaging (DTI)

Due to the differences in the microstructure of tissues in vivo, the direction and rate of free dispersion of water molecules in three-dimensional space are different, and this difference is the basis of DTI imaging. The non-invasive and quantitative analysis of the diffusion characteristics of water molecules in tissues can not only show the structural integrity of nerve and muscle tissues, but also have certain advantages in showing articular surface cartilage and spinal cord injuries, and find pathological changes that cannot be shown by conventional MRI, providing important information for the treatment and prognosis of clinical diseases.[43] The main diffusion coefficients of DTI include fractional anisotropy (FA), mean diffusivity (MD), axial/radial diffusivity (AD/RD), and apparent diffusion coefficient (ADC). Wu et al[44] investigated the value of DWI and DTI in the diagnosis and prognosis of BS by performing CT, conventional MRI, DWI and DTI scans in 50 patients with confirmed BS, and found that DTI and DWI were more sensitive than conventional MRI in diagnosing BS. The overall average ADC values of the cervical, thoracic and lumbar spine were higher than those in the control group, and the reaction blood supply was abundant endplate and subendplate bone, the bone marrow microenvironment was invaded by the virulence of Brucella, local inflammatory response stimulation, tissue edema, bone marrow ischemia and necrosis, granulation tissue growth and other changes, which enhanced the free diffusion of water molecules. The FA value was lower than that of the control group, indicating that the complete arrangement structure of chondrocytes was disrupted, and the diffuse movement direction of water molecules was reduced. At 6 to 12 months after BS treatment, ADC values decreased and FA values increased in the acute and subacute phases, indicating chondrocyte proliferation repair and collagen fiber bundle reshaping. DTI can sensitively detect changes in BS chondrocytes and collagen fiber bundles at an early stage, providing quantitative information on pathophysiological changes and predicting recovery. Zhang et al[45] also correlated DTI parameters with serum agglutination experimental titers, and found that ADC values were positively correlated with serological titers, but FA values were not significantly correlated. These studies suggest that DTI, in combination with relevant laboratory measures, can have some suggestive effect on the assessment of the efficacy of BS.

T2 Mapping

T2 mapping is a T2 quantitative measurement imaging method developed based on T2-weighted sequences. It is particularly sensitive to intracartilage water molecules, collagen fibers, and tissue anisotropy, and can detect abnormal signal changes before morphological changes are detected by the lateral magnetization attenuation of tissues.[46] Pathological processes in skeletal muscle, such as inflammation, edema, atrophy, and fat infiltration, can affect the changes in T2 value, which not only reflect the pathological changes in the internal structure of skeletal muscle, but also provide information on the metabolism and activation of muscle tissue, and is a sensitive indicator for monitoring and detecting skeletal muscle lesions.[47–49] Images are typically acquired using a multi-echo SE or TSE sequence, and then the images are fitted to obtain a T2Map to measure the T2 value. At present, this technology is mainly used in the osteoarticular system, especially osteoarthritis, myocarditis and myocardial fibrosis, to evaluate the severity and recovery of tissue damage non-invasively and quantitatively. A prospective study using conventional MRI versus T2mapping to distinguish BS from TS[50] found that conventional MRI can distinguish between the two by a number of distinguishing features. For example, abscess formation can be distinguished by the location of the abscess and its spread. BS is more common with paravertebral abscesses, which are small and localized; TS, on the other hand, is more common as a psoas abscess, which is enlarged and spread widely. Further studies found that the T2 value in the BS vertebral injury lesion group was significantly higher than that in the TS vertebral injury lesion group and the BS adjacent to the normal vertebral group, which may be due to the bacteria entering the vertebral body from the blood circulation, triggering inflammatory pathological reactions such as exudation, hyperplasia, necrosis, etc., with the progression of the injury, the extracellular water molecules increased, different degrees of congestion occurred at the lesion, and the edema change prolonged the T2 relaxation time, which has a certain value in distinguishing BS and TS. However, the experimental sample is small and the staging of the disease is lacking, so the results need to be further studied and verified. K et al[51] found that on the endplate and vertebral bodies measured by T2mapping, the LBP group had a change in biodynamic properties compared with the control group, and the higher T2 value in the

LBP group was associated with changes in the biochemical composition caused by inflammation, such as water and matrix composition, suggesting inflammatory damage and nutrient transport disorders at the early lesions. Ma et al[52] used this technique to quantitatively analyze the T2 values of the anterior fibrous annulus, nucleus pulposus, and posterior fibrous annulus, and found that the T2 values of each part of the intervertebral disc were negatively correlated with the degeneration grade of the lumbar intervertebral disc and facet joints. At the same time, the injury is more severe than in other locations, resulting in a more pronounced decrease in T2 values in that location than in other disc locations.

Radiomics

Radiomics is an emerging quantitative analysis method for extracting a large number of imaging features from image images at high throughput, and can be used as a non-invasive image research strategy.[53] By describing the spatial distribution of voxel gray in the image, multiple histogram parameters reflecting lesions were obtained, which could provide more quantitative information for the identification of similar lesions. Initially, Lambin et al[54] proposed a radiomics method based on CT imaging for the first time, considering that the heterogeneity of tumors in the temporal and spatial domains greatly limited biopsy techniques. This was followed by the analysis of MRI, positron emission tomography and ultrasound images. At present, radiomics based on images such as CT, MRI, and ultrasound has made significant progress in the diagnosis, staging, efficacy analysis, and prognosis of tumors of the gastrointestinal, respiratory, neurological, and reproductive systems.[55–57] However, MRI radiomics has been studied in the differential diagnosis of brucellillus spondylitis and purulent spondylitis.

The application of radiomics in spinal diseases has developed rapidly, including the identification and segmentation of spinal anatomy, the differential diagnosis of spinal infectious diseases, the differential diagnosis of spinal tumors, and the prediction of benign and malignant compression fractures of the vertebral body.[58] The study by Zhichang Fan[59] based on T2-weighted image fat suppression (T2WI-FS) images to construct clinical, independent radiomics and clinical-radiomics fusion models to distinguish BS and TS showed that independent radiomics random forests (RF) model and clinical-imaging fusion support vector machines, The SVM) model showed good discrimination performance, with AUC of 0.998 and 0.984 (Supplementary Table 1), respectively, and Pahati Tuxunjiang et al[60] constructed six models based on different images, including LR, SVM, RF, decision tree (DT), extreme gradient boosting (XG boost), and k-nearest neighbor (KNN). For the differentiation of BS and TS, the results showed that the T1WI-based LR model had the best differential diagnostic performance, with an AUC of 0.913. He et al[61] retrospectively delineated the conventional T1WI images of 77 confirmed spinal tuberculosis patients and 34 BS patients, extracted features, and put them into five conventional machine learning models for training and validation, and found that the logistic regression model in the validation set showed high diagnostic performance, and the results showed that machine learning, especially the machine learning algorithm constructed by LR, had a high diagnostic advantage in the discrimination between BS and TS. It can provide a reliable diagnostic basis for the diagnosis and prognosis of BS and TS. Another study also showed that radiomics can help distinguish between TS and BS, and in addition, radiomics label-based RF models and co-label-based RF LR models showed stronger discrimination compared to MRI-label-based LR models. Zhou et al[62] demonstrated high classification performance in the ability to distinguish between BS and TS by the independent omics model constructed by Zhou et al,[62] and the AUC values of the training set and the validation set reached 0.811 and 0.644, respectively. These results provide a useful reference for the development of medical image processing technology, and have certain practical application value for clinical diagnosis and treatment. Supplementary Figure 1 provide data on Zhou et al. Compared with the macroscopic lesion information revealed by traditional imaging, radiomics features have the ability to reveal the heterogeneity of lesions at the microscopic level, thus effectively assisting in differential diagnosis. This provides new ideas and methods for the early screening and diagnosis of diseases, and has important clinical application and promotion value. Radiomics has high application prospects and experimental value in infectious spinal lesions. In the future, more abundant and effective imaging feature information will be excavated to provide patients with more accurate and personalized diagnosis and treatment services, and at the same time promote the development of imaging medicine in a more intelligent and diversified direction.

Summary and Outlook

Conventional MRI provides clear visualization of anatomical structures and signal characteristics in the vertebral body, intervertebral discs, muscles, ligaments, and spinal cord. However, its reliance on morphological features often lags behind underlying pathophysiological changes, limiting its utility in early lesion detection and disease evaluation. In contrast, functional MRI techniques such as DCE-MRI enable quantitative monitoring of tissue perfusion and microcirculation, offering advantages in longitudinal assessment of treatment efficacy, though current evidence lacks validation against long-term clinical outcomes. IVIM complements DCE-MRI by quantitatively analyzing water molecule diffusion and microvascular perfusion in living tissues without contrast agents. Meanwhile, DTI and T2 mapping provide multi-angular quantitative insights into water molecule diffusion, reflecting inflammatory damage and repair processes in BS. Radiomics based on magnetic resonance imaging extracts high-dimensional features to deliver detailed, personalized information for managing infectious diseases like BS, with reported models demonstrating high performance (eg, AUC up to 0.998); nevertheless, these results are susceptible to overfitting due to small cohort sizes and require robust validation to ensure generalizability.

Overall, conventional and functional MRI, alongside radiomics, enhance the understanding of spinal injury and repair mechanisms in BS, facilitating improved efficacy and prognostic assessments. Key findings from the reviewed literature underscore the diagnostic superiority of multimodal MRI over conventional imaging alone, particularly in differentiating BS from tuberculous spondylitis (TS) and pyogenic spondylitis (PS), where radiomics models achieve high accuracy in identifying subtle microstructural differences. For instance, interpretable radiomics nomograms based on MRI features have shown promise in clinical settings by providing non-invasive, quantitative biomarkers for early detection and staging. However, the reviewed findings logically align with existing evidence but tend to overstate clinical readiness, as most studies are retrospective, limited by methodological heterogeneity (eg, variable b-values in IVIM or scanner field strengths), and reliant on small, predominantly Chinese cohorts, which may introduce regional biases. Furthermore, BS-specific challenges, such as resource limitations in endemic regions (eg, pastoral areas in northern China or the Middle East with restricted access to advanced MRI scanners), have not been adequately contextualized. Cost-feasibility trade-offs among techniques must also be considered: for instance, DTI's prolonged scan times and susceptibility to motion artifacts may hinder routine use in resource-constrained settings, whereas IVIM's non-invasive, contrast-free nature offers greater practicality, albeit with lower reproducibility in perfusion metrics. Radiomics, while promising, faces interpretive challenges due to its "black-box" algorithms and preprocessing demands, potentially exacerbating adoption barriers in low-resource environments.

In clinical practice, we recommend integrating multimodal MRI into the management of BS to optimize diagnostic accuracy and treatment monitoring. For patients presenting with non-specific symptoms in endemic areas, initial evaluation should combine conventional MRI with functional sequences (eg, IVIM or DCE-MRI) to assess microstructural and perfusion changes, followed by radiomics analysis for differential diagnosis against TS or PS. This approach can guide antibiotic therapy selection and surgical interventions, such as in cases of cervical BS where real-time PCR and biopsy confirmation are complemented by MRI-based classification. Additionally, in resource-limited settings, prioritizing cost-effective protocols—like abbreviated MRI scans with radiomics triage—could enhance accessibility while maintaining diagnostic efficacy.

Although this narrative review synthesizes timely advancements, its contributions are incremental, building upon prior knowledge rather than introducing transformative innovations. Looking ahead, future research should prioritize expanding sample sizes through multi-center, international collaborations to mitigate overfitting and enhance reproducibility, as evidenced by recent two-center studies on interpretable radiomics for differentiating BS from tuberculous spondylitis. Integrating deep learning with multimodal MRI—such as developing nomogram models for early versus advanced BS staging, as explored in 2025 investigations—could enable horizontal multi-parameter diagnostics and differential diagnoses. Longitudinal studies combining functional MRI parameters with prognostic indicators (eg, serological titers, pain scores, and neurological outcomes) are essential for establishing correlations, predicting disease progression, and identifying independent predictive biomarkers. Additionally, incorporating hybrid imaging (eg, MRI with PET-CT) and cost-effectiveness analyses will address feasibility in endemic areas, proposing pragmatic strategies

like portable MRI protocols or AI-driven triage tools.[63,64] Ultimately, these efforts will refine clinical guidelines, fostering personalized, equitable management of BS worldwide.

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Disclosure

The authors report no conflicts of interest in this work.

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