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Research Progress on the Application of Artificial Intelligence in the Diagnosis and Treatment of Inflammatory Bowel Disease Using Both Traditional Chinese Medicine and Western Medicine

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Abstract: ***Inflammatory bowel disease (IBD) is a group of chronic, relapsing inflammatory bowel disorders, primarily comprising Crohn's disease (CD) and ulcerative colitis (UC). As global prevalence continues to rise and understanding of IBD deepens, research on the diagnosis and treatment of IBD has become a priority for scholars, with early diagnosis and precision treatment being two key areas of focus. However, because current diagnostic methods for IBD lack a gold standard and are subject to the subjective judgment of physicians, they have inherent limitations. In recent years, the rapid development of artificial intelligence (AI) technology has provided new approaches and methods for the diagnosis and treatment of IBD. Leveraging its strengths in image analysis and processing, big data analysis, and predictive modeling, AI technology has been successfully applied and validated in certain clinical settings. Furthermore, it can integrate the Four Diagnostic Methods of Traditional Chinese Medicine (TCM) and tongue diagnosis data to enable intelligent pattern differentiation, thereby assisting in the development of integrated TCM-Western medicine treatment plans. This article aims to review the current status of AI technology applications in the integrated diagnosis and treatment of IBD, elucidate its applications and advantages in early diagnosis, pathological analysis, imaging examinations, disease prediction, personalized Western medical treatment, TCM pattern identification and treatment, and integrated TCM-Western medical interventions, and discuss the challenges it faces and future directions for development.***

Keywords: Artificial intelligence, Inflammatory bowel disease, Crohn disease, Ulcerative colitis, Traditional Chinese medicine.

1. Introduction

Inflammatory bowel disease (IBD), which primarily includes ulcerative colitis and Crohn's disease, is a group of chronic, recurrent inflammatory gastrointestinal disorders whose global incidence has been steadily rising in recent years. The disease has an insidious onset and complex clinical manifestations, and there is no universally accepted gold standard for diagnosis. Currently, clinical diagnosis requires a comprehensive evaluation combining endoscopy, pathology, laboratory tests, and medical history. The diagnostic and treatment process is complex, and diagnostic outcomes are easily influenced by the physician's subjective experience, leading to missed diagnoses, misdiagnoses, and treatment delays. At the same time, traditional, one-size-fits-all treatment models struggle to account for individual patient differences and fail to meet the demands of precision medicine.

With the rapid development of big data and artificial intelligence (AI) technologies, intelligent algorithms such as machine learning and deep learning can efficiently mine multidimensional medical data, overcoming the limitations of traditional diagnosis and treatment. These technologies have demonstrated significant advantages in image recognition, pathological analysis, disease prognosis, and personalized treatment. Furthermore, AI offers new approaches for pattern differentiation and treatment in traditional Chinese medicine (TCM) as well as for integrated traditional Chinese and Western medicine (TCM-WM) diagnosis and treatment. This article systematically summarizes the progress in applying artificial intelligence technologies to the diagnosis, treatment, and integrated Chinese and Western medicine approaches for inflammatory bowel disease (IBD). It identifies current challenges in technological application and outlines future development prospects, aiming to provide a reference for the clinical implementation and scientific innovation of intelligent, precision diagnosis and treatment of IBD.

2. The Concept of Artificial Intelligence

AI refers to the ability of computer programs to understand and solve problems—in other words, incorporating human intelligence into machines. As one of the most transformative technologies in today's tech landscape, artificial intelligence is not merely a simulation of individual intelligent behaviors, but rather the construction of a comprehensive system capable of autonomously perceiving, learning, reasoning, and optimizing decisions. AI encompasses multiple subsets, with machine learning (ML) being one of its core components. Simply put, ML enables computers to automatically learn patterns or regularities from large amounts of data, thereby eliminating the need for programmers to manually write specific instructions and rules. This shift from "passive execution" to "active learning" has fundamentally transformed traditional data processing models and is particularly well-suited to the multidimensional and highly complex data analysis requirements of the medical field. By incorporating vast amounts of data and analyzing patients' genomes, transcriptomes, proteomes, epigenomes, immunomes, and microbiomes, ML can classify patients based on specific differences [1]. ML-guided IBD research holds immense potential to accelerate the application of precision medicine [2]. Deep learning (DL) [3], a subset of ML, utilizes multilayer neural networks (also known as deep neural networks) to mimic the structure and functioning of the human brain, thereby enabling computers to process more complex data. Compared to traditional machine learning, deep learning does not require manual feature extraction and can autonomously uncover deep correlations within raw data; its advantages are particularly pronounced when processing unstructured data such as endoscopic images and histological sections. Inspired by human neural networks, deep learning has led to the development of artificial neural networks (ANNs), which are currently primarily applied to classification, regression, and disease prediction. Based on the number of layers, ANNs can be classified into shallow neural networks (SNNs) and deep neural networks (DNNs). DNNs consist of multiple hidden layers, enabling them to efficiently capture complex features. Convolutional neural networks (CNNs) are a special type of DNN; they are currently primarily used in the field of image processing and analysis and have demonstrated outstanding performance [4]. AI, DL, and ANN already play a critical role in clinical image analysis, diagnostic assistance, and predictive and prognostic support [5]. In the field of IBD, the application of AI primarily encompasses disease diagnosis and treatment, genomic data analysis, and risk prediction models [6].

3. Application of AI Technology in IBD Diagnosis

3.1 Current Status of IBD Diagnosis

In recent years, the number of patients seeking medical care for IBD has been on the rise [7]. This trend is not only related to an increase in the disease's incidence but is also attributable to heightened public health awareness and expanded clinical screening efforts; however, the insidious nature and complexity of the disease continue to pose significant challenges to diagnosis and treatment. Currently, there is no universally accepted gold standard for diagnosis. A comprehensive, multidisciplinary approach is required for the differential diagnosis of ulcerative colitis (UC), Crohn's disease (CD), and non-IBD conditions. In clinical practice, a comprehensive assessment often requires combining endoscopic findings, pathological results, laboratory parameters, and the patient's medical history. The diagnostic process is lengthy and cumbersome, placing a significant burden on both patients and healthcare providers. The European Crohn's and Colitis Organization (ECCO) has noted [8] that the lack of consensus on the definition of each "minimal lesion" and its respective thresholds, coupled with the influence of human subjective judgment, ultimately leads to diagnostic discrepancies. There are significant differences in lesion recognition and severity assessment among physicians of varying experience levels, and misdiagnoses and missed diagnoses are more likely to occur in primary care settings, leading to delays in patient treatment. Therefore, AI, as an auxiliary tool, can help physicians improve diagnostic accuracy and reduce biases in subjective judgment by interpreting endoscopic images and histopathological slides, performing big data analysis, building predictive models, and analyzing the gut microbiome, thereby providing valuable guidance for personalized treatment.

3.2 Applications of AI in Imaging Diagnosis

3.2.1 Application Areas in Imaging Diagnosis

In the field of gastrointestinal endoscopy, AI is primarily applied in two areas [9]: First, computer-aided detection (CADe), which identifies abnormal areas in images, particularly mucosal lesions. Second is computer-aided diagnosis (CADx), which analyzes detected lesions to make precise diagnoses. These two major functions form a closed-loop process of "lesion detection—lesion analysis—precise diagnosis," effectively addressing the limitations of manual endoscopy. AI models can automatically analyze endoscopic images, helping physicians quickly identify abnormal lesions in the gastrointestinal tract and accurately distinguish between ulcerative colitis (UC) and Crohn's disease (CD) [10]. This not only reduces the burden on physicians but also improves the accuracy of early diagnosis. Especially for inexperienced young physicians, AI serves as a reliable tool, enhancing the overall level of diagnosis and treatment. When AI models analyze endoscopic images, the role of datasets is crucial, as they significantly impact the model's accuracy, reliability, and generalization ability. High-quality, properly annotated datasets form the foundation of model training and directly determine its clinical applicability. HyperKvasir is a widely used dataset for endoscopic image analysis of gastrointestinal diseases and serves as a vital resource for training AI models. Based on this dataset, AI can effectively assess the severity of gastrointestinal diseases and assist in determining Mayo scores [11]. A study using the HyperKvasir dataset compared the performance of different CNN models and found that all four CNN models achieved very high predictive accuracy. Among them, the DenseNet121 architecture performed best, with an accuracy of 87.50% and an AUC of 0.90, significantly outperforming the baseline model. This study demonstrated the accuracy and effectiveness of AI in the diagnosis of gastrointestinal diseases [12].

3.2.2 Applications in UC

AI systems can help diagnose ulcerative colitis (UC) and grade lesions by analyzing endoscopic images. Since UC lesions are mostly confined to the mucosal layer and present with diverse endoscopic findings, manual grading is prone to subjective factors; AI enables objective and standardized grading. The computer-aided diagnosis system developed by Maeda Y et al. [13] is capable of diagnosing and accurately grading UC endoscopically. The system achieved a diagnostic sensitivity of 74%, a specificity of 97%, and an accuracy of 91%. A study constructed a 159-layer CNN as a deep learning (DL) model, incorporating 16,514 endoscopic images from 3,082 UC patients. It found that the CNN performed exceptionally well in distinguishing moderate-to-severe UC, with an AUROC of 0.966 and a positive predictive value (PPV) of 0.87, sensitivity of 83.0%, specificity of 96.0%, and demonstrated high agreement with experienced physicians, with a weighted κ value of 0.84 [14]. The Gutierrez team developed and trained an ANN model to assess the Endoscopic Mayo Score (EMS) using colonoscopy images. The results showed that the model's AUROC values for different Mayo score intervals (≥1, ≥2, ≥3) were 0.84, 0.85, and 0.85, respectively, indicating that this method has significant potential for assessing endoscopic findings in UC [15].

3.2.3 Applications in CD

The main complications of CD include intestinal fibrosis and strictures. Studies have shown that AI can not only accurately identify intestinal fibrosis and strictures but also predict their progression; in some cases, AI outperforms traditional physicians in diagnostic accuracy [16]. Crohn's disease lesions are segmental and transmural, with early lesions often being subtle; AI can detect these subtle lesions at an early stage, providing a basis for early intervention. Wang et al. [17] developed an algorithm based on a random forest model to predict early postoperative complications in patients with CD. The study demonstrated that the algorithm possesses excellent predictive capability (AUC in the training set = 0.965; AUC in the validation set = 0.924). With the assistance of AI, physicians can not only detect lesions in the early stages of CD but also predict their progression and postoperative complications, thereby enabling the timely formulation of treatment plans and reducing the risk of missed diagnoses and potential complications.

3.3 Clinical Data Analysis and Prediction Using AI

Through data analysis, AI offers new approaches to the diagnosis and prediction of IBD. The pathogenesis of IBD is complex, involving multiple factors such as genetics, immunity, and the environment; AI can integrate multidimensional data, overcoming the limitations of traditional analysis. AI has achieved notable results in areas such as using genomic data, big data analysis and predictive modeling, early prediction of postoperative complications, prediction of histological remission, and diagnosis of IBD based on the gut microbiome. Park et al. [18] developed a deep learning model that combined RNA sequencing data from patients who underwent endoscopy and had biopsy tissue samples collected, successfully distinguishing between UC and CD. By using unsupervised learning algorithms, the model was able to extract key information from RNA sequence data and accurately classify UC and CD. Ashton J et al. [19] developed a model using ML and genomic data capable of classifying patients with CD and UC to aid clinical diagnosis. One study effectively distinguished UC patients from healthy individuals based on gene expression data from 32 genes by combining the DRPT feature selection algorithm with an SVM classifier, demonstrating high diagnostic accuracy during active UC [20].

ML-based models can integrate patients' clinical characteristics and biomarkers to predict the onset, recurrence, or remission of IBD. Jiang et al. used a CNN model to analyze disease activity in endoscopic examinations and predict remission in UC; the model provided objective assessment data. In disease activity assessment, the accuracy rate was 90.15%. In predicting histological remission, the CNN model achieved an accuracy rate of 91.28% and a Kappa value of 0.826, surpassing the 87.69% accuracy rate achieved by endoscopists [21]. Iacucci M et al. developed a CNN-based model to classify biopsies from UC patients according to the PHRI, Robarts, and Nancy histological indices and to predict the 12-month risk of recurrence after histological remission. Validation comparisons showed that the CNN model was highly consistent with human pathologists in terms of endoscopic assessment and prediction of recurrence risk [22]. A study analyzing multidimensional data—including patients' laboratory test results, demographic characteristics, and disease locations—found that AI demonstrated strong practical utility in predicting CD [23]. Furthermore, with advances in molecular biology, the analysis of gut microbiota has emerged as a new approach to IBD diagnosis. Imbalances in the gut microbiota are closely associated with the onset and progression of IBD, and AI can rapidly analyze the characteristics of microbiome data to enable non-invasive auxiliary diagnosis. Research has shown that using ML models to analyze gut microbiome data for the diagnosis of UC and CD has achieved extremely high accuracy, with predictive accuracy reaching 90% [24].

3.4 Applications of AI in Pathological Analysis

In the diagnosis of IBD, histopathological examination plays a crucial role in determining disease subtypes and assessing disease activity. The analysis of histopathological sections relies on the professional expertise of pathologists and involves a heavy workload and considerable time; AI can effectively improve the efficiency and consistency of this analysis. AI-assisted histopathological analysis enhances work efficiency while ensuring high accuracy. Currently, several AI-based histopathological diagnostic models have been successfully applied in clinical IBD practice, yielding favorable results [25]. Other studies have also shown that using ML models to classify disease phenotypes based on currently underutilized mucosal histopathological indices may improve the chances of disease remission [26].

4. Applications of AI in Personalized Treatment

Current treatments for IBD typically involve a combination of medication, surgery, and lifestyle adjustments. Specific treatment strategies vary depending on the type of disease, disease course, severity of symptoms, and individual patient characteristics. Traditional treatments often follow a "one-size-fits-all" approach, which struggles to accommodate the unique characteristics of each patient's condition. To provide optimal care for every patient, precision medicine [27] strategies and personalized treatment plans represent an important direction for the future of IBD treatment.

AI technology can analyze and integrate clinical and other data to build predictive models, thereby forecasting drug responses to reduce unnecessary medication and side effects for patients, and assist physicians in developing personalized treatment plans. Gardiner et al. [28] used machine learning (ML) software—RandomForest (RF) and xgboost 2.0.3 as building blocks—to integrate multiple datasets (genomic and transcriptomic), demographic, pharmacological, and pharmacodynamic data to predict drug efficacy and individual patient responses. This approach not only evaluates the effectiveness of therapeutic drugs for IBD patients but also serves as a novel method for the early stages of drug development under precision medicine strategies. This demonstrates the potential of combining patient drug response prediction with state-of-the-art omics, bioinformatics, and ML/AI methods. Furthermore, AI can play a significant predictive role in biologic therapy. Currently, four anti-TNF-α drugs are available for treating IBD: infliximab and adalimumab (for UC and CD), secukinumab (for CD only), and golimumab (for UC only) [29]. AI can help adjust clinical treatment strategies by predicting patients' responses to drugs such as infliximab [30]. A study by Popa et al. [31], which utilized a machine learning (ML) model, successfully predicted disease activity within one year of anti-TNF-α drug use. Validated through an independent external cohort, this model enables clinical decisions regarding dose adjustments or transition to alternative biologics, demonstrating AI's valuable potential in assisting clinicians with decision-making and fully showcasing its ability to facilitate personalized treatment. Anti-integrin drugs, also classified as biologics, offer efficacy and targeted action while minimizing the impact on the systemic immune system and resulting in relatively fewer side effects. One study demonstrated that AI can help identify UC patients who will fail to achieve steroid-free clinical remission by week 22 during treatment with vedolizumab. This can help us predict treatment outcomes at specific stages, improve treatment strategies, and avoid blind adjustments and unnecessary drug use. At the same time, AI-based predictions of drug efficacy not only aid clinical treatment but also provide valuable support for future drug development, shortening the drug development cycle and reducing R&D costs.

5. AI-Empowered Differential Diagnosis and Treatment in Traditional Chinese Medicine and Integrated Traditional Chinese and Western Medicine

In the context of Traditional Chinese Medicine, inflammatory bowel disease is classified as "diarrhea" or "dysentery." The core pathogenesis often involves damp-heat accumulating in the intestines, spleen deficiency leading to impaired transport and transformation, qi stagnation and blood stasis, and spleen-kidney deficiency. Clinically, treatment emphasizes syndrome differentiation and tailored therapy; different syndromes correspond to distinct therapies such as Chinese herbal formulas, acupuncture, and enemas. However, TCM syndrome differentiation relies heavily on the practitioner's individual experience, and the determination of syndromes and the formulation of herbal prescriptions involve a high degree of subjectivity, making it difficult to establish a standardized system. Artificial intelligence offers a novel approach to addressing the challenges of standardizing and objectifying TCM diagnosis and treatment [32]. Existing machine learning models can batch-process TCM "Four Diagnostic Methods" data from IBD patients—including facial complexion, tongue appearance, pulse characteristics, features of abdominal pain and diarrhea, and accompanying systemic symptoms—to extract multidimensional data. Through feature selection algorithms, these models uncover intrinsic correlations between tongue and pulse findings, symptoms, and TCM syndrome patterns, automatically constructing syndrome differentiation models that reduce diagnostic errors among young TCM practitioners. At the same time, convolutional neural networks can perform pixel-level feature extraction on standardized tongue images to identify key indicators such as tongue color, thickness of the tongue coating, ecchymoses, and tooth marks, thereby achieving objective quantification of tongue diagnosis and aiding in the differentiation of common TCM syndrome patterns in IBD, such as internal damp-heat, spleen-stomach deficiency, and mixed cold-heat [33]. In the context of integrated Chinese and Western medicine treatment, AI can integrate Western medical endoscopic scores, laboratory inflammatory markers, and microbiome data with TCM syndrome patterns and records of Chinese herbal medicine use to construct treatment efficacy prediction models. These models can predict the long-term remission rates and recurrence risks for patients with different syndrome patterns when treated with Western medicine alone, oral Chinese herbal medicine, Chinese herbal retention enemas, or combined Chinese and Western medicine regimens, thereby assisting physicians in devising optimal integrated treatment plans for patients. In addition, AI can mine databases of classical and modern TCM formulas for treating IBD. By using association rule algorithms to identify high-frequency drug combinations and core therapeutic methods, it provides data support for the development of new TCM drugs for IBD and the optimization of compound formulations, thereby promoting the deep integration of traditional TCM experience with modern precision medicine [34].

6. Conclusion

In summary, AI technology has demonstrated tremendous potential in the early diagnosis of IBD, imaging examinations, pathological analysis, personalized Western medical treatment, drug response prediction, drug development, as well as TCM syndrome differentiation and treatment, and the screening of integrated Chinese and Western medical treatment regimens. The combination of AI and big data is vigorously driving the development of precision medicine through the integration of Chinese and Western medicine. Nevertheless, the practical application of AI still faces many challenges, such as data quality and standardization. The effectiveness of AI is highly dependent on data quality; in the future, we will need to establish higher-quality, standardized clinical datasets that include Western medical laboratory and imaging data as well as information from the four diagnostic methods of TCM to ensure that AI algorithms can be applied effectively and accurately to patients in different hospitals and regions; Algorithm interpretability: AI algorithms — especially deep learning (DL) models — are often referred to as "black boxes" because their decision-making processes are difficult to explain. To build greater trust in AI among doctors and patients in the future, it is necessary to develop AI algorithm models that are more transparent and clearly explainable; Clinical validation and large-scale implementation: The large-scale implementation of AI requires more clinical trials related to the integration of Western and TCM to verify its feasibility and effectiveness; Regulatory and Ethical Considerations: Regulatory bodies must establish strict standards and regulations that balance the privacy of both Western and traditional Chinese medical diagnostic and treatment data to ensure that the use of AI technology complies with medical ethical requirements. In summary, once these issues are resolved, AI is expected to become a vital tool for integrating Western medicine's precise diagnostics with traditional Chinese medicine's syndrome differentiation and treatment, playing an increasingly important role in the collaborative diagnosis and treatment of IBD and bringing tangible benefits to both physicians and patients.

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