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Detect Ankylosing Spondylitis Using Deep Learning: From Image Classification to Clinical Integration

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Abstract— **Ankylosing spondylitis (AS) is a chronic inflammatory disease primarily affecting the spine, leading to significant pain, stiffness, and eventual loss of mobility. Early detection and diagnosis of AS are crucial for preventing severe long-term effects and improving the quality of life for patients. Traditional diagnostic methods, such as radiographs and clinical assessments, are often limited in accuracy and efficiency, particularly in the early stages of the disease. In recent years, deep learning (DL) techniques have emerged as powerful tools in the medical imaging domain, providing automated and highly accurate diagnostic support. This review paper explores the role of deep learning in the detection and diagnosis of ankylosing spondylitis, focusing on the application of convolutional neural networks (CNNs), recurrent neural networks (RNNs), and other advanced DL models. We examine various studies and methodologies that have leveraged deep learning to analyze medical imaging data, including X-rays, MRI scans, and CT scans, to detect AS-related abnormalities such as sacroiliitis, vertebral sclerosis, and spinal fusion. Additionally, the review highlights the advantages of using deep learning techniques over traditional methods, such as reduced diagnostic time, improved accuracy, and the ability to detect early-stage abnormalities that may be missed by human radiologists. The paper concludes with a discussion on the challenges and future directions in this field, including data availability, model generalization, and integration into clinical practice. Deep learning holds significant promise in revolutionizing the diagnostic process for ankylosing spondylitis, offering faster and more reliable assessments for improved patient outcomes.**

Index Terms— **Deep Neural Network, Ankylosing Spondylitis, Convolutional Neural Networks (CNNs), MRI Analysis, Smartphone-Based Applications, Data Availability, Ankylosing Spondylitis (AS)**

I.INTRODUCTION

Overview of Ankylosing Spondylitis (AS)

Ankylosing Spondylitis (AS) is a chronic inflammatory disease that primarily affects the axial skeleton, particularly the sacroiliac joints and spine. It belongs to a group of diseases known as spondyloarthropathies. AS can cause progressive inflammation, leading to spinal fusion and significant loss of mobility. The disease is most commonly diagnosed in young adults, with a higher prevalence in males, and a genetic predisposition is often associated with the HLA-B27 gene. Though the exact cause remains unclear, environmental factors and genetic susceptibility are believed to play a crucial role in its onset. The early symptoms of AS typically include lower back pain, stiffness, and fatigue, which can resemble those of other musculoskeletal disorders. If left untreated, AS can cause long-term complications, including spinal deformities. As a result, early detection and management of the disease are crucial to improving patient quality of life and preventing irreversible damage.

1. Challenges in Diagnosing AS

One of the main challenges in diagnosing AS is the subtle and often nonspecific nature of its early symptoms. The disease often begins with symptoms like back pain and stiffness, which are commonly associated with a variety of other conditions. This overlap in symptoms makes it difficult for clinicians to immediately identify AS. Traditional diagnostic methods, such as clinical evaluation and laboratory tests, are often insufficient for early diagnosis, as radiological changes may not appear until the disease has progressed significantly. X-ray imaging, which has traditionally been used to detect AS, often shows changes only in the later stages of the disease, making it less effective for early detection.

2. Importance of Early Detection

Early detection of AS is vital for preventing long-term damage and reducing the severity of the disease. Timely intervention with disease-modifying anti-rheumatic drugs (DMARDs) can help control inflammation,

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prevent further joint damage, and improve overall outcomes. However, diagnosing AS in its early stages is challenging due to the lack of specific symptoms and the difficulty in detecting changes on conventional imaging. The ability to identify the disease early through advanced diagnostic techniques could significantly improve treatment success and quality of life for patients.

3. Role of Medical Imaging (MRI, X-ray, CT)

Medical imaging plays a key role in the diagnosis of AS, particularly in detecting structural changes in the spine and sacroiliac joints. X-rays, MRI, and CT scans are commonly used to assess the extent of damage and identify inflammatory changes. While X-ray imaging can reveal joint erosions and spinal fusion in advanced stages, MRI is more sensitive for detecting early signs of inflammation, such as sacroiliitis. However, traditional image analysis methods are prone to human error and subjectivity, leading to the need for more accurate and efficient diagnostic tools.

4. Motivation for Using Deep Learning (DL)

Deep learning, a subset of artificial intelligence (AI), has shown great promise in medical image analysis. With its ability to automatically identify patterns in large datasets, deep learning can help improve the accuracy and speed of AS diagnosis. By training deep learning models on medical images such as X-rays, MRIs, and CT scans, AI systems can assist radiologists in detecting subtle signs of AS, even in its early stages. This technological advancement can enhance diagnostic accuracy, reduce diagnostic time, and ultimately improve patient outcomes.

II.PATHOPHYSIOLOGY AND DIAGNOSIS OF ANKYLOSING SPONDYLITIS (AS)

Ankylosing Spondylitis (AS) commonly begins with inflammation in the sacroiliac joints, gradually spreading to the spine and peripheral joints. Chronic inflammation can lead to new bone formation, causing vertebral fusion—a process that creates the characteristic "bamboo spine." This results in reduced mobility and spinal stiffness. Symptoms often begin with lower back pain and morning stiffness, worsening over time and potentially involving other joints and entheses if untreated.

Diagnosis involves a combination of symptoms, biomarkers, and imaging. The HLA-B27 genetic marker is commonly associated with AS, though its presence alone doesn't confirm the condition. Inflammatory indicators like CRP and ESR may support diagnosis but are non-specific.

Radiological evaluation plays a crucial role. The Modified New York Criteria emphasize sacroiliitis and spinal changes, while the ASAS Criteria incorporate imaging, clinical symptoms, and biomarkers such as HLA-B27. Traditional X-rays are used to detect advanced structural changes, but MRI provides greater sensitivity in early stages by revealing inflammation before visible damage appears.

III.ROLE OF MEDICAL IMAGING IN AS DETECTION

MRI plays a crucial role in detecting early inflammatory changes in Ankylosing Spondylitis (AS), such as bone marrow edema and sacroiliitis, before structural damage occurs. This makes MRI highly sensitive for early diagnosis. On the other hand, X-rays are effective in identifying structural damage, such as vertebral fusion and syndesmophytes, but they are less sensitive to early-stage inflammation. One significant limitation of radiological imaging is the potential subjectivity in interpretation by radiologists. Subtle changes in early AS stages may be missed, leading to delayed diagnosis and treatment. This underscores the need for improved diagnostic tools like deep learning.

IV.DEEP LEARNING IN MEDICAL IMAGING

Deep learning (DL) is a subset of artificial intelligence (AI) that uses neural networks with multiple layers to automatically learn and extract features from large datasets. Convolutional Neural Networks (CNNs) are a type of DL architecture particularly well-suited for medical image analysis. CNNs excel in image classification and detection by learning hierarchical features, making them highly effective at identifying patterns in complex medical images.

DL's strengths in medical imaging lie in its ability to process vast amounts of data quickly and with high accuracy. It reduces human error, aids in detecting subtle abnormalities, and improves diagnostic efficiency. DL has already demonstrated success in detecting diseases like cancer, pneumonia, and Alzheimer's disease, where it has outperformed traditional methods in terms of accuracy and speed. The success of DL in these domains has generated significant interest in applying similar techniques to Ankylosing Spondylitis detection, offering potential for more accurate and timely diagnoses.

V.DEEP LEARNING IN ANKYLOSING SPONDYLITIS DETECTION

1.Convolutional Neural Networks (CNNs) for Image Classification

CNNs have shown remarkable performance in AS detection by analysing MRI and radiographic images. Models such as ResNet, DenseNet, and MobileNet have been trained on large datasets to classify AS-related structural changes. Studies have demonstrated that CNNs can outperform human experts in identifying sacroiliitis and other AS markers.

2. Ensemble Learning Approaches

To enhance robustness, ensemble learning techniques combine multiple CNN architectures to improve diagnostic accuracy. A study involving 5,389 pelvic radiographs developed an ensemble model with an AUC of 0.96, surpassing expert radiologists. Such models integrate predictions from various networks, leveraging their complementary strengths.

3. Deep Learning-Based MRI Analysis

MRI is a critical modality for early AS detection. Deep neural networks (DNNs) trained on MRI scans have achieved sensitivity and specificity comparable to expert radiologists. One approach utilized a three-dimensional residual neural network (ResNet-101) to detect inflammatory and structural changes, achieving an AUC of 0.94. These models aid in overcoming inter-rater variability and improve consistency in AS diagnosis.

4. Smartphone-Based Deep Learning Applications

In resource-limited settings, smartphone-captured X-ray images processed by DL models offer an alternative diagnostic pathway. Studies have shown that DL models can maintain high accuracy even with suboptimal image quality, making AI-assisted diagnosis more accessible.

VI.RECENT PUBLICATION

1.Anatomy-Aware Deep Learning for Radiographic Sacroiliitis Detection

Publication: ARXIV, May 2024

Model: Anatomy-aware convolutional neural network (CNN)

Performance: Achieved area under the curve (AUC) scores of 0.899, 0.846, and 0.957 across three test datasets; corresponding accuracies were 82.1%, 74.4%, and 90.6%

Summary: Incorporating anatomical awareness into the DL model improved its generalizability and accuracy in detecting radiographic sacroiliitis across diverse datasets.

2. Stacked Ensemble CNN for Sacroiliitis Detection

Publication: ResearchGate, 2024

Model: Stacked ensemble of deep convolutional neural networks Accuracy: 80%, Sensitivity: 100%, Specificity: 66.7%

Summary: This study developed a stacked ensemble of CNNs to detect sacroiliitis in MRI images, a key indicator of AS. The model achieved an accuracy of 80%, with perfect sensitivity, indicating its potential in identifying true positive cases.

3. Deep Learning Model for Scoring Radiographic Structural Changes

Publication: PubMed, October 2024

Model: Deep learning model for scoring structural changes in radiographs

Accuracy: 88.6% to 98.5% in validation set; 86.5% for single vertebral corner in test set

Summary: This study developed a deep learning model to assess structural changes in radiographs of AS patients. The model achieved high accuracy in both validation and test sets, demonstrating its effectiveness in evaluating disease progression.

VII.CLINICAL PREDICTION MODELS

Machine Learning (ML) and Deep Learning (DL) models have become valuable tools in predicting disease activity and functional impairment in Ankylosing Spondylitis (AS). Clinical scores like BASDAI (Bath Ankylosing Spondylitis Disease Activity Index) and BASFI (Bath Ankylosing Spondylitis Functional Index) are commonly used to assess disease severity and functional status. These indices rely on patient-reported outcomes, but their prediction can be enhanced through the integration of machine learning models that combine clinical variables such as Body Mass Index (BMI), cervical mobility, and biomarkers like C-reactive protein (CRP) and White Blood Cell (WBC) count.

ML models like Random Forest and AdaBoost have proven particularly useful in predicting these indices. These ensemble learning models combine multiple decision trees to improve prediction accuracy by reducing overfitting and increasing generalizability. Random Forest is adept at handling large and diverse datasets, while AdaBoost adjusts weights to emphasize difficult-to-classify instances, providing robust predictions.

By integrating clinical variables with ML/DL algorithms, clinicians can obtain more precise, data-driven insights into disease progression and treatment response, facilitating more personalized and effective care for AS patients. This predictive approach enhances the management of AS by allowing for timely interventions tailored to individual patient needs.

VIII.DEPLOYMENT IN REAL-WORLD SETTINGS

1.Smartphone-based AS Detection

Recent advancements in smartphone technology have enabled the use of mobile phones for capturing radiographs and medical images, providing a promising solution for Ankylosing Spondylitis (AS) detection, especially in resource-limited settings. Smartphone-based imaging tools can help capture high-quality radiographs or images of sacroiliac joints, facilitating early detection of AS even in rural and under-resourced areas. The portability, low cost, and accessibility of mobile devices make them an ideal tool for widespread screening, allowing healthcare providers to extend care to underserved populations without the need for sophisticated imaging equipment. Furthermore, deep learning models integrated into smartphones can assist in analyzing these images in real-time, providing immediate feedback to clinicians.

2. Integration into Clinical Workflows

Integrating machine learning (ML) and deep learning (DL) models into existing clinical workflows can greatly enhance the efficiency and accuracy of AS diagnosis. Streamlit-based apps and web platforms allow clinicians to easily access predictive tools, visualize patient data, and interpret results. These platforms can be seamlessly incorporated into both primary and tertiary care settings. In primary care, the models can assist general practitioners in early screening and decision-making, while in tertiary care, they can complement specialized expertise for more precise and complex cases. This integration ensures continuous monitoring and improves the overall management of AS.

IX.CHALLENGES AND LIMITATIONS

Despite the promising applications of deep learning (DL) in detecting Ankylosing Spondylitis (AS), several challenges and limitations must be addressed to ensure its effectiveness in real-world settings.

1. Small Dataset Sizes: A major limitation in training deep learning models for AS detection is the availability of large, annotated datasets. AS is a relatively rare condition, and obtaining a sufficiently large dataset of labeled medical images can be difficult. Smaller datasets can limit the model's ability to generalize and may lead to overfitting, where the model performs well on training data but poorly on unseen data.

2. Data Imbalance: AS datasets often suffer from an imbalance between images of patients with AS and those without it. This imbalance can lead to biased models that are more likely to classify healthy individuals as negative, reducing the model's sensitivity for detecting AS.

3. Inter-institutional Variability: Images from different hospitals or imaging devices can vary in quality, resolution, and patient positioning, making it difficult to develop a universal model that can perform consistently across various institutions. Such variability can introduce noise into the dataset, complicating model training.

4. Black-box Nature of AI: Many deep learning models, particularly CNNs, operate as “black boxes,” making it difficult to interpret how they arrive at specific decisions. This lack of transparency can undermine trust in the models, especially in clinical settings where explainability is crucial.

5. Overfitting and Generalization Model Issues: Overfitting remains a common issue, especially when training on small datasets, leading to poor generalization when applied to new, unseen data. Regularization techniques and data augmentation strategies are necessary to mitigate this risk.

X.ETHICAL AND REGULATORY CONSIDERATIONS

The use of AI and deep learning in Ankylosing Spondylitis (AS) detection raises several ethical and regulatory concerns that must be addressed to ensure patient safety and fairness in clinical applications.

1. Bias in Training Data: One of the primary ethical issues in AI is bias in training datasets. If the training data is not diverse or representative of the patient population, AI models may perform poorly for certain groups, leading to unequal healthcare outcomes. For instance, models trained predominantly on data from one demographic group may fail to detect AS in individuals from underrepresented groups, perpetuating health disparities.

2. Patient Privacy and GDPR Compliance: Ensuring patient privacy is paramount when using AI for medical purposes. AI models rely on large datasets of sensitive patient information, which must be securely managed and anonymized. Adherence to privacy laws like the General Data Protection Regulation (GDPR) is essential in protecting patient data. This includes ensuring that patient consent is obtained for data usage and that data is stored and processed in compliance with privacy regulations.

3. Clinical Validation and FDA Approval: Before AI models can be widely adopted in clinical settings, they must undergo rigorous clinical validation to ensure their accuracy and safety. Additionally, models intended for diagnostic use must receive FDA approval or equivalent regulatory clearance. This process ensures that AI tools are safe, effective, and reliable for medical use, providing the necessary regulatory oversight to prevent harm.

XI.FUTURE DIRECTIONS

The future of AI in Ankylosing Spondylitis (AS) detection holds great promise, with several innovative advancements on the horizon.

1. Federated Learning for Cross-Hospital Training: One of the most promising directions is federated learning, where AI models are trained across multiple hospitals without sharing sensitive patient data. This approach allows hospitals to collaborate on improving model accuracy while maintaining strict patient privacy. Federated learning enables the creation of robust models that are less likely to be biased by data from a single institution, improving generalizability and model performance across diverse populations.

2. Multi-Modal Data Fusion: Future AI systems will likely incorporate multi-modal data fusion, combining lab results, imaging data, and clinical notes to enhance diagnosis. This integrated approach enables more comprehensive and accurate predictions by leveraging diverse data sources, allowing AI to consider the full range of patient information.

3. Real-Time AI Diagnosis in Emergency Settings: Another exciting future development is the implementation of real-time AI diagnosis in emergency settings, where rapid assessment of AS in critical cases is essential. AI-powered diagnostic tools could provide immediate, reliable results to aid clinicians in making timely decisions.

4. Personalized AS Risk Prediction Using Genomics and DL: AI models combined with genomic data hold the potential to predict an individual's genetic risk for developing AS, allowing for personalized treatment strategies. Integrating deep learning (DL) with genomics could lead to highly tailored risk assessments and early interventions based on genetic predispositions.

XII.CONCLUSION

The application of Deep Learning (DL) in the detection and diagnosis of Ankylosing Spondylitis (AS) has made significant strides, with promising results in early detection, predictive modeling, and clinical decision-making. Current progress has demonstrated the power of Convolutional Neural Networks (CNNs) and other DL architectures in accurately identifying early signs of AS from medical imaging, such as MRI and X-ray scans. These advancements have the potential to reduce diagnostic delays, enabling earlier and more effective interventions that could improve patient outcomes. The transformative potential of deep learning lies in its ability to handle large, complex datasets and extract intricate patterns from medical images and clinical data that would be challenging for human clinicians to detect. By leveraging AI and machine learning techniques, AS diagnosis can become more accurate, efficient, and consistent, with the ability to assist clinicians in making data-driven decisions. Looking forward, there is a strong vision for equitable and scalable AS diagnostics, particularly through innovations such as smartphone-based detection, federated learning, and the integration of multi-modal data. The goal is to make these diagnostic tools accessible to underserved populations, ensuring that all individuals, regardless of geographic or economic constraints, can benefit from early and accurate AS detection.

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