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A Review on Recent Advancements in Scoliosis Detection System

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Abstract

Scoliosis, particularly Adolescent Idiopathic Scoliosis (AIS), represents a prevalent orthopedic condition characterized by a lateral curvature and axial rotation of the spine. Early detection and intervention are critical to prevent curve progression and associated complications. This review critically examines ten significant research studies spanning clinical diagnostics [1][2], genetic predisposition analysis [5][7], artificial intelligence (AI)-based detection methods [3][4][8][9], and large-scale epidemiological investigations [10]. The integration of deep learning algorithms into scoliosis screening has demonstrated substantial potential in enhancing diagnostic accuracy while minimizing reliance on radiographic imaging [3][4]. Genetic studies have elucidated loci such as LBX1 [5], suggesting hereditary susceptibility, although clinical translation remains limited [7]. Epidemiological data underline the need for structured screening initiatives [10], particularly during adolescence. Despite these advancements, challenges persist, including the external validation of AI models, standardization of clinical protocols, and integration of multimodal data for personalized care. This review synthesizes current knowledge, identifies key research gaps, and highlights future directions toward developing comprehensive, non-invasive, and predictive scoliosis management frameworks.

Introduction

Scoliosis is a three-dimensional deformity of the spine, characterized by lateral curvature and vertebral rotation exceeding 10 degrees. As illustrated in Figure 1, scoliosis leads to a visible lateral curvature of the spinal column compared to a normal spine.

Among various types, Adolescent Idiopathic Scoliosis (AIS) accounts for nearly 80% of cases, typically affecting adolescents during their growth spurts [2]. Its etiology remains multifactorial and poorly understood, with genetic predisposition, biomechanical imbalances and environmental influences playing contributory roles [5][7].

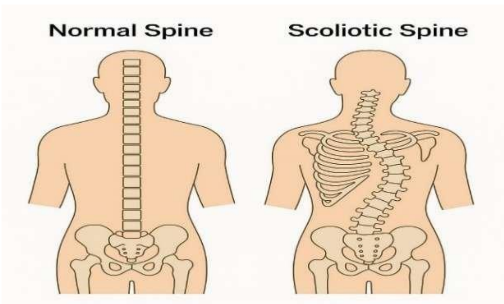

Figure 1. Comparison between a normal spine and a scoliotic spine.

Early detection of scoliosis is crucial, as untreated progression can lead to physical deformities, psychological stress, and cardiopulmonary complications [2]. Traditional diagnostic methods

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such as the Adams Forward Bend Test and Cobb angle measurement via radiographs, although widely used, have limitations including subjective variability and radiation exposure risks [6].
Recent technological advancements, particularly in Artificial Intelligence (AI) and Deep Learning (DL), have enabled non-invasive scoliosis detection through imaging techniques like back surface analysis and 3D depth sensors [3][4][8][9]. These innovations aim to supplement or replace traditional screening, offering scalable and radiation-free alternatives.
Moreover, epidemiological studies [10] have emphasized the importance of mass school screenings to detect AIS at early stages. Genetic research has identified loci such as LBX1 [5], offering insights into familial susceptibility, although translation to clinical practice remains limited.
Given the evolving landscape of scoliosis detection and management, this review synthesizes recent literature across clinical, technological, and genetic domains to highlight progress, challenges, and opportunities for future research and clinical application.

Methodologies
This review adopts a structured and systematic approach based on the analysis of ten peer-reviewed research articles published between 1996 and 2022. The inclusion criteria for paper selection were:

- Relevance to scoliosis detection [3][4][8][9], prediction, genetic analysis [5][7], or clinical management [1][2].
- Utilization of imaging modalities, artificial intelligence techniques, or genetic investigations.
- Studies involving human participants or real clinical datasets.
- Publication in reputed, high-impact journals such as JBJS [1][6], Communications Biology [3], Spine Journal [4][7], PLOS ONE [9], and IJERPH [10].

Databases including **PubMed, Google Scholar, IEEE Xplore,** and **SpringerLink** were searched using keywords such as "AIS detection," "Deep learning scoliosis screening," "MRI scoliosis diagnosis," and "Genetic factors in scoliosis."
Each study was critically appraised based on research objectives, methodologies, experimental designs, findings, limitations, and contributions to the field.
Based on the outlined selection strategy and appraisal process, the following section presents a comprehensive review and synthesis of significant research contributions toward scoliosis detection and management.

Literature Review
Over the years, scoliosis research has evolved significantly, incorporating advances in clinical diagnostics, artificial intelligence, genetic investigations, and epidemiological surveillance. As shown in Figure 2, scoliosis detection methods have progressed from basic clinical examinations to advanced AI-based screening technologies.

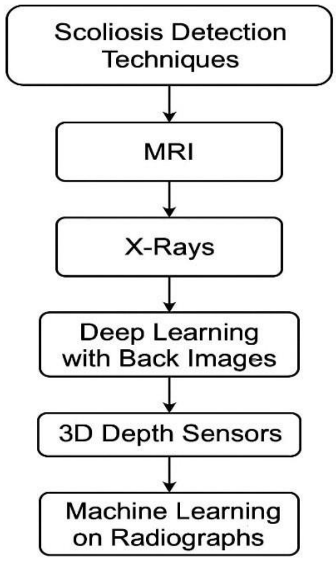

Figure 2:Evolution of scoliosis detection techniques from clinical examination to AI-based screening.

Early studies, such as the prospective MRI investigation conducted by **Evans et al. [1]**, emphasized the importance of magnetic resonance imaging (MRI) in identifying neuroanatomical abnormalities in juvenile idiopathic scoliosis patients. Their findings revealed that approximately 26% of cases had underlying neurological pathologies, advocating routine MRI screening to prevent delayed diagnosis.
Expanding on clinical management, **Mo and Cunningham [2]** provided a comprehensive overview of pediatric scoliosis treatment strategies, emphasizing the effectiveness of bracing and establishing surgical intervention thresholds for progressive curves exceeding 50 degrees. Their work reinforced the critical role of early intervention in minimizing curve progression during growth spurts.
With technological advancements, artificial intelligence (AI) and deep learning models have become pivotal in scoliosis screening. **Yang et al. [3]** developed and validated deep learning algorithms using simple back images to detect scoliosis, achieving a high area under the curve (AUC > 0.94) and demonstrating the feasibility of noninvasive, radiation-free mass screening.

Similarly, **Kokabu et al. [4]** applied convolutional neural networks (CNNs) on three-dimensional depth sensor imaging, achieving strong correlation (r = 0.91) with Cobb angle measurements, thereby offering a rapid, portable solution suitable for clinical and community settings.

Genetic research has also contributed to understanding scoliosis etiology. Lee et al. [5] reviewed multiple genetic factors implicated in scoliosis, notably the **LBX1** gene, while also evaluating the effectiveness of various bracing strategies. Additionally, **Justice et al. [7]** provided evidence of a possible X-linked genetic locus associated with familial idiopathic scoliosis, suggesting a hereditary pattern in a subset of cases.

Investigations into the symptomatic burden of scoliosis revealed additional clinical insights. **Ramirez et al. [6]** conducted a large cohort study to assess the prevalence of back pain among children with idiopathic scoliosis. Their findings indicated that while back pain was relatively common (32%), underlying pathological causes were rare, emphasizing the importance of cautious clinical evaluation before extensive diagnostic imaging.

Emerging machine learning architectures have further improved predictive capabilities. **Wang et al. [8]** introduced a Capsule Neural Network (CapsNet) model that predicted AIS curve progression from initial spinal radiographs with approximately 77% accuracy, outperforming traditional convolutional approaches. Similarly, **Fraiwan et al. [9]** employed deep transfer learning on X-ray images for multi-class disease classification, achieving a remarkable 96% classification accuracy using DenseNet201.

Finally, epidemiological trends have been illuminated through large-scale database analyses. **Sung et al. [10]** conducted a nationwide study in South Korea, revealing a scoliosis incidence rate of 760 per 100,000 adolescents and a low surgical intervention rate (0.7%), underscoring the effectiveness of conservative management approaches when early detection is achieved. The prevalence statistics for AIS are illustrated in Figure 3, highlighting the importance of early community-level screening."
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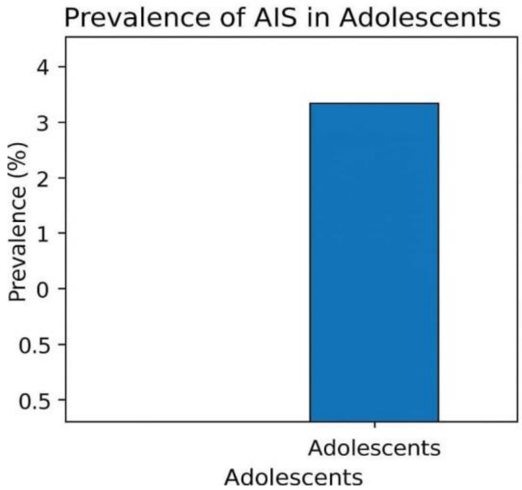

Figure 3: Prevalence of Adolescent Idiopathic Scoliosis (AIS) among adolescents.

Collectively, these studies demonstrate a progressive shift from traditional radiographic reliance towards AI-assisted, non-invasive screening methods, coupled with a growing understanding of genetic contributions to scoliosis. However, the real-world deployment of these technologies, external validation across diverse populations, and integration of multi-modal data sources remain key areas for future research.

Conclusion

The reviewed literature indicates substantial progress in scoliosis detection methods, moving from conventional radiographic techniques [1][2] to AIdriven, non-invasive screening models [3][4][8][9]. Early diagnosis through MRI [1] and machine learning models [3][4][8][9] has the potential to significantly reduce the disease burden. Genetic insights [5][7] have improved understanding of AIS, although their clinical application remains underexplored. Large-scale epidemiological studies [10] highlight the importance of communitylevel interventions. However, issues such as model generalization, validation across diverse populations, and long-term clinical integration need to be addressed to maximize the benefits of these advancements.

Future Enhancement

Future research should prioritize:

- **Integrated multi-modal diagnostics:** combining imaging, clinical, and genetic data [5][7].
- **Cross-population AI validation:** ensuring models like CNN [4] and CapsNet [8] are generalizable.
- **Radiation-free alternatives:** based on 3D sensors [4] and non-radiographic approaches.

- **Real-time mobile applications:** leveraging lightweight models for scoliosis detection [9].
- **Translation of genetic discoveries:** into clinical risk stratification tools [5].
- **Prospective longitudinal studies:** to track AI-driven early interventions [8][9].

By pursuing these enhancements, scoliosis management can evolve towards a predictive, preventive, and personalized model of care.

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