REVIEW ARTICLE

CONTENTS

The science of posture: how the spine shapes health and mobility

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ABSTRACT

The spine is a key component of the skeletal system, with a complex anatomical structure that varies along its length. Its specific structure allows it to fulfill multiple functions, including maintaining proper upright posture. Human posture reflects the coordinated interaction between the kinesthetic sense, muscular system, and nervous system. Various factors influence posture formation, including environmental conditions, lifestyle, physical activity, nutrition, and genetics. Data from Poland indicate that postural defects affect 30% to 60% of children and adolescents, with variations due to assessment methods. According to the Center for Health Information Systems, incorrect posture was diagnosed in 17.14% of children and adolescents aged 0–18 years, with 9.7% of spinal deformities identified in children aged 2–9 years. This study explores the etiological factors of spinal deformities, particularly scoliosis, including genetic predisposition, environmental influences, and hormonal factors such as vitamin D. This study is based on a literature review and analysis of research on postural defects, particularly scoliosis, focusing on prevalence, etiology, and risk factors. The methodology involves a systematic search of peer-reviewed articles, clinical studies, and epidemiological reports from databases such as PubMed, Google Scholar, Scopus, and Web of Science. Research suggests a possible correlation between scoliosis severity and vitamin D levels. Vitamin D is essential for bone mineralization and neuromuscular function, and deficiencies may contribute to reduced postural stability and increased spinal curvature. Some studies indicate a negative correlation between vitamin D levels and Cobb angle severity, though further research is needed.

KEY WORDS: posture, scoliosis, spinal curvatures, vitamin D

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INTRODUCTION

The spine is a key component of the skeletal system, with a complex anatomical structure that varies along its length and differs between its sections. Physiologically, the spine is not merely a straight column connecting the skull to the pelvis; rather, it possesses characteristic curvatures. These spinal curvatures function like a spring, absorbing shocks and counteracting the forces acting on different spinal segments [1].Thanks to its specific structure, the spine fulfills numerous functions. Among its primary roles are providing support, protecting the spinal cord, and maintaining the physiological positioning of internal organs within the thoracic and abdominal cavities. The spine is also responsible for maintaining proper upright posture [2].

HUMAN POSTURE AND ITS DETERMINANTS

Human posture is a motor habit shaped by both morphological and functional changes in an individual. It is influenced not only by physical health but also by mental well-being. Posture reflects the coordinated interaction between the kinesthetic sense, the muscular system, and the nervous system. It is also subject to continuous changes with age, particularly evident during periods of growth and development. Various factors affect the formation of posture, including environmental conditions, lifestyle, physical activity, nutrition and genetic predisposition. However, despite the body's adaptability, modern lifestyle changes exceed its ability to adjust, leading to postural defects [3-5].

POSTURAL DEFECTS AND THEIR PREVALENCE

Postural defects in children are commonly diagnosed through preventive screenings. These defects can be congenital or acquired musculoskeletal conditions. Various factors affect the formation of posture, including environmental conditions, lifestyle, physical activity, nutrition and genetic predisposition [3]. Data from Poland indicate that postural defects affect 30%

to 60% of children and adolescents, with variations due to different assessment methods and evaluation criteria [6]. According to the Center for Health Information Systems (CSIOZ), as reported by Wawrzyniak et al. (2017), incorrect posture was diagnosed in 17.14% of children and adolescents aged 0 to 18 years, with 9.7% of spinal deformities identified in children aged 2 to 9 years.

The risk of postural defects is highest during periods of rapid growth, particularly between the ages of 5 and 7 and during puberty [7].

COMMON POSTURAL DEFECTS IN CHILDREN

In Poland, the most frequently diagnosed postural defects in children include Scheuermann's kyphosis (juvenile kyphosis), scoliosis, and static lower limb deformities [6]. Scoliosis, also referred to as adolescent idiopathic scoliosis (AIS), is a three-dimensional spinal deformity characterized by lateral curvature in the frontal plane, anterior or posterior deviation in the sagittal plane, and segmental axial rotation [8]. AIS is most commonly manifests between ages 10 and 20 [9]. This significant health issue, with a prevalence ranging from 0.47% to 11.1%, has significant influence on the patient's quality of life [10]. Scheuermann's disease (juvenile kyphosis) is a condition characterized by damage of the growth cartilage plates covering the vertebral bodies, leading to sagittal spinal curvature abnormalities. It results in permanent thoracic hyperkyphosis. Its prevalence ranges from 0.4% to 10% among adolescents aged 13–17 years [11].

Both scoliosis and Scheuermann's kyphosis cause structural changes not only in the spine but also in the chest, pelvis, head positioning, and lower limbs. These conditions affect not only the skeletal system but also the muscular, fascial, ligamentous, and nervous systems. Spinal curvature abnormalities impact ribcage structure, leading to pulmonary and cardiac complications. Advanced spinal deformities can also impair abdominal and pelvic organ function [12].

ETIOLOGY AND ROLE OF VITAMIN D

Both of these diseases have well-established diagnostic criteria, based on imaging and clinical assessments, and treatment approaches, including monitoring progression, rehabilitation, bracing, and, in severe cases, surgery their common feature is largely unknown etiology (scoliosis in 85–90% of cases is idiopathic) [13]. Current treatment focuses on disease progression rather than its cause. This has driven research efforts to uncover the underlying causes of spinal deformities, which could aid in both prevention and treatment [14].

One emerging hypothesis is the role of vitamin D in spinal deformities [10]. Vitamin D is crucial for numerous physiological processes. It plays a key role in bone mineralization, calcium-phosphorus homeostasis, and bone formation [11]. Some studies suggest that vitamin D contributes to postural balance [12] and is positively correlated with bone mineral density and negatively correlated with Cobb angle severity [14]. However, its precise role in scoliosis and juvenile kyphosis pathogenesis remains unclear.

Given current knowledge and existing etiological theories, the prevention of scoliosis and Scheuermann's disease is not yet possible. However, early detection and proper treatment can prevent severe deformities [14]. Identifying a significant correlation between vitamin D levels and these spinal conditions could enhance our understanding of their pathogenesis and inform preventive or therapeutic strategies.

AIM

The primary aim of this article is to analyze and discuss the most common postural defects in children, with a particular focus on scoliosis. The study seeks to explore the underlying etiological factors contributing to these spinal deformities, including genetic predisposition, environmental influences, and hormonal factors, particularly the potential role of vitamin D in skeletal development and postural stability. Additionally, this article aims to evaluate the prevalence and risk factors associated with postural defects, highlighting the importance of early detection, preventive strategies, and appropriate therapeutic interventions. By synthesizing existing research and epidemiological data, this work intends to provide a comprehensive understanding of how postural defects develop, their impact on overall health, and the possible interventions that can mitigate their progression. Furthermore, given the increasing prevalence of spinal deformities in children and adolescents, the study aims to underscore the need for further research to establish potential causal relationships between vitamin D levels and spinal health. Ultimately, the findings may contribute to improved prevention strategies and inform clinical approaches for the early management of postural defects, helping to reduce the long-term health consequences associated with spinal abnormalities.

MATERIALS AND METHODS

This study is based on a comprehensive literature review and analysis of existing research on postural defects, particularly scoliosis, with a focus on its prevalence,

etiology, and potential risk factors. The methodology involves a systematic search and evaluation of peer-reviewed scientific articles, clinical studies, and epidemiological reports from databases such as PubMed, Google Scholar, Scopus, and Web of Science.

SELECTION CRITERIA

The inclusion criteria for the reviewed studies were:

- Publications in peer-reviewed journals from the last two decades (2000–2024), with exceptions for historically significant studies.
- Studies focused on postural defects in children and adolescents, including scoliosis and Scheuermann's disease.
- Research investigating potential risk factors, including genetic, environmental, and hormonal influences.
- Studies assessing the role of vitamin D in bone health and postural stability.

Exclusion criteria included:

- Studies focusing on adults with acquired spinal deformities due to trauma, degenerative diseases, or occupational factors.
- Non-English language articles without an available translation.
- Case reports and small-scale studies with limited statistical significance.

DATA COLLECTION AND ANALYSIS

The study involved an in-depth review of research findings, including:

1. **Epidemiological Data** – Reports and statistical analyses on the prevalence of postural defects among children and adolescents
2. **Etiological Studies** – Research examining genetic, environmental, and physiological factors influencing spinal deformities
3. **Clinical Studies** – Evaluations of diagnostic techniques, including radiographic measurements such as the Cobb angle for scoliosis assessment
4. **Interventional Studies** – Analysis of treatment methods, including physiotherapy, bracing, and surgical interventions
5. **Biochemical Studies** – Investigations into the role of vitamin D in bone health and its potential association with scoliosis progression.

A qualitative synthesis of data was performed to identify trends, correlations, and gaps in existing research. Relevant studies were grouped based on their focus areas, and key findings were compared and contrasted to draw meaningful conclusions. Additionally, where applicable, statistical data from large-scale epidemiological studies were referenced to support claims regarding prevalence and risk factors.

This methodological approach ensures a structured and evidence-based assessment of postural defects, providing insights into their causes, consequences, and potential preventive measures.

REVIEW

STRUCTURAL CHANGES

Scoliosis is generally defined as a complex three-dimensional deformity of the spinal axis. The primary diagnostic criterion for this condition is radiographic examination, which determines the Cobb angle. In scoliosis, the Cobb angle exceeds 10° [15, 16]. This condition not only involves an increased Cobb angle but also vertebral rotation. It is also associated with a reduction in normal spinal kyphosis, leading to a condition known as hypokyphosis [16]. The literature differentiates between "true" and "false" scoliosis. In false scoliosis, also known as paramorphism, vertebral rotation is absent, and spinal curvature changes result from leg length discrepancies, postural disorders, or inflammatory conditions [17].This condition leads to structural changes in the spinal column, affecting vertebrae, joint capsules, muscles, ligaments, and ribs [14]. Scoliosis results from anatomical changes in vertebral structure, particularly in the growth plates located at the upper and lower parts of each vertebra, responsible for vertical growth. The further development of scoliosis causes compression in these regions, leading to structural changes in immature, growing vertebrae. Compressed areas experience slowed growth, resulting in vertebral wedging, while non-compressed areas undergo normal or accelerated growth, causing vertebral protrusion [18]. This wedging leads to progressive movement in the direction of least resistance, toward the convex side of the spine. As compression forces act on the vertebrae, they shift laterally, forming an apical vertebra. Simultaneously, rotational movement occurs along the vertical axis. During this process, the vertebral body rotates toward the convex side, while spinous processes shift toward the concave side [14].

These movements lead to changes in vertebral bodies, laminae, growth plates, and spinous processes. Intervertebral discs also undergo deformation, with compression occurring on the concave side and thickening on the convex side [14]. The spinal curvature results in shortening of joint capsules, which leads to intervertebral joint compression and contributes to degenerative changes in these joints.

Scoliosis also affects surrounding muscles. On the

concave side, the intervertebral muscles, quadratus lumborum, spinal extensors, psoas major and minor, and oblique abdominal muscles shorten. Ligaments are also affected. The posterior and anterior longitudinal ligaments, interspinous ligaments, and flat ligaments shorten, restricting spinal movement toward the convex side [19].

Changes in bony and connective tissue structures result in rib displacement following spinal rotation. On the concave side, ribs are pushed forward and downward, leading to compression in the posterior thoracic area and the formation of an anterior chest bulge. This bulge appears on the same side as the spinal concavity. On the convex side, ribs separate and shift backward, forming a posterior rib hump. The backward movement of ribs narrows the chest cavity on the convex side, pressing against the scapula and causing it to protrude [14,19]. The lateral movement of the spine disrupts spinal column balance, altering head positioning relative to the pelvis. The head is no longer centered above the pelvis, leading to biomechanical changes that contribute to spinal joint degeneration [14].

PATHOGENESIS AND ETIOLOGY

The etiology of scoliosis remains largely unknown. However, it is recognized as a multifactorial disorder [20]. The condition is associated with congenital or acquired spinal abnormalities. Patients diagnosed with scoliosis often exhibit other systemic disorders, such as brainstem malformations, balance and sensory impairments, and connective tissue anomalies due to collagen arrangement abnormalities [21, 22]. The development and progression of scoliosis have been attributed to genetic, environmental, and hormonal factors [59], which will be briefly discussed in this section.

GENETIC FACTORS

Many studies emphasize the role of genetic factors in the development of scoliosis [21]. Genetic predisposition is one of the most extensively studied factors in adolescent idiopathic scoliosis (AIS) [25, 26]. Research indicates that first-degree relatives of individuals with scoliosis (parents or siblings) have an 11% risk of developing AIS, whereas second- and third-degree relatives have a 2.4% and 1.4% risk, respectively [25, 26]. This suggests that scoliosis inheritance is influenced by multiple factors. Studies on over 1,000 patients from 200 families, where at least two family members were diagnosed with AIS, identified a locus on the X chromosome in 15% of examined individuals. This locus may be associated with a familial predisposition to AIS and could explain why scoliosis is more common in females than males [27]. Other research by Miller (2007) found that changes in specific autosomal chromosome regions might also contribute to scoliosis development [28]. Twin studies show a scoliosis concordance rate of 73% in identical twins and 36% in fraternal twins [29].

Genetic research on AIS patients reveals that nearly all individuals (97%) have a positive family history, indicating that at least one gene is responsible for the condition [30]. Further studies have identified several genes linked to AIS development, including MTNR1B, SNTGI, and CHD7 [20, 31, 32,]. However, their expression varies, and inheritance patterns remain unclear, suggesting that multiple genes contribute to scoliosis development [25, 30, 20].

Additionally, environmental factors influence scoliosis risk. Studies show that diet, toxins, and other external influences significantly impact AIS development [23, 24].

This literature review continues with further discussion on environmental and hormonal factors, epidemiology, progression, classification, treatment, and prognosis of scoliosis.

DISCUSSION

Scoliosis is largely idiopathic, with genetic predisposition playing a crucial role in its development. Family history studies indicate a significantly higher risk among first-degree relatives, with twin studies further supporting genetic influence. Specific chromosomal loci and genes associated with skeletal growth and neuromuscular regulation have been linked to scoliosis, suggesting a hereditary component. However, environmental factors, including posture, nutritional deficiencies, and mechanical loading, also contribute to its progression.

Emerging research suggests a possible correlation between scoliosis severity and vitamin D levels. Vitamin D is essential for bone mineralization and neuromuscular function, and deficiencies have been associated with reduced postural stability and increased spinal curvature. Some studies indicate a negative correlation between vitamin D levels and Cobb angle severity, though further research is needed to confirm this relationship.

Early detection remains critical for effective management. Screening programs facilitate early diagnosis, allowing for timely intervention through physiotherapy and bracing. For severe cases exceeding a Cobb angle of 40°, surgical correction is often required. While current treatment strategies focus on halting progression, ongoing research into genetic predisposition, hormonal regulation, and nutritional factors may provide new insights into scoliosis prevention and management.

CONCLUSIONS

Scoliosis is a complex and multifactorial spinal deformity that significantly impacts musculoskeletal health and overall well-being. This study highlights the anatomical, genetic, and environmental factors contributing to its development and progression. The condition is primarily diagnosed based on radiographic findings, with a Cobb angle exceeding 10° as the defining criterion. Structural changes, including vertebral wedging, ligament shortening, and rib displacement, not only affect spinal alignment but may also compromise pulmonary and cardiovascular function in severe cases.

The etiology of scoliosis remains largely idiopathic, though strong genetic associations have been identified, with familial predisposition and specific chromosomal loci playing a role. Environmental and hormonal influences, particularly vitamin D deficiency, may further contribute to disease progression, though more research is needed to establish a definitive causal relationship. The potential link between vitamin D levels and scoliosis severity suggests that nutritional factors could be considered in prevention and management strategies.

Early detection is essential for effective intervention, as timely screening and conservative treatments such as bracing and physiotherapy can help prevent curve progression. In advanced cases, surgical correction remains the primary approach to restoring spinal alignment and function. Given the increasing prevalence of scoliosis, further research is needed to explore novel therapeutic approaches, including genetic screening, neuromuscular training, and targeted nutritional interventions. Expanding our understanding of the underlying mechanisms of scoliosis will allow for more effective prevention, early diagnosis, and individualized treatment strategies, ultimately improving patient outcomes.

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CONFLICT OF INTEREST

The Authors declare no conflict of interest.

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