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# Scoliosis In Young Athletes: Influence of Gymnastic Training and Screening Strategies

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**Abstract**

**Objective.** This review aims to evaluate the prevalence of scoliosis among young athletes, specifically focusing on the biomechanical influence of gymnastic training and the efficacy of various screening strategies for early detection.

**Methods.** A comprehensive analysis of recent literature and clinical studies (including rhythmic, artistic, and acrobatic gymnastics) was conducted. The review synthesizes data on epidemiological trends, training-related risk factors, and diagnostic accuracy of non-invasive screening tools.

**Results.** Research indicates that young gymnasts exhibit a significantly higher prevalence of scoliosis compared to the general population, with "scoliosis suspected status" reaching approximately 28.8% in competitive cohorts. The etiology is multifaceted, often described through the "dangerous triad" of generalized joint hyperlaxity, delayed skeletal maturity, and asymmetric mechanical loading. High training volumes—exceeding 22–26 hours per week—and the repetitive execution of spinal hyperextension elements ("the arch") are identified as primary contributors to sagittal curvature alterations and overuse injuries. However, active sports participation, when properly monitored, can also play a protective role in reducing curve progression. Effective screening remains the cornerstone of management; the Adam's Forward Bend Test (AFBT) combined with scoliometer measurements (ATR) and modern 3D surface

topography (ST) provides a reliable, radiation-free framework for monitoring athletes during the critical growth period of 10–15 years.

**Conclusion.** Young gymnasts represent a high-risk group for the development of spinal deformities. Integrating standardized, non-invasive screening protocols into routine pre-participation physical evaluations (PPE) is essential for early diagnosis and the success of conservative treatment strategies, ensuring the long-term musculoskeletal health of adolescent athletes.

**Keywords:** Adolescent Idiopathic Scoliosis, Gymnastics, Biomechanics, Screening, Surface Topography, Scoliometer, Sports Medicine

## 1. Introduction

Adolescent idiopathic scoliosis (AIS) is a complex, three-dimensional spinal deformity that represents a significant health concern for the pediatric athletic population. While the prevalence of AIS in the general population is relatively low, young gymnasts have been identified as a high-risk group, with some studies reporting a 10-fold higher incidence compared to non-athletic peers. This elevated risk is frequently attributed to the "dangerous triad"—a combination of generalized joint hyperlaxity, delayed skeletal maturity, and the persistent asymmetric mechanical loading inherent to gymnastic training. As these athletes undergo intensive training during critical growth periods, the repetitive execution of extreme ranges of motion and hyperextension elements can significantly influence spinal morphology. Given the potential for rapid curve progression during puberty, the implementation of effective, non-invasive screening strategies, such as the Adam’s Forward Bend Test and 3D surface topography, is essential for early diagnosis and the success of conservative treatment. This paper examines the interplay between gymnastic training and spinal health, highlighting the necessity of standardized screening protocols to safeguard the long-term well-being of young athletes.

## 2.Methods

The research was conducted as a narrative review to synthesize current evidence on scoliosis prevalence in gymnasts, the biomechanical impact of their training, and the efficacy of modern screening protocols. A systematic literature search was performed primarily in the PubMed database, supplemented by ScienceDirect, MDPI, and SpringerLink, targeting peer-reviewed original research and clinical trials published between 2000 and 2025. Keywords used in the search included combinations of "Adolescent Idiopathic Scoliosis," "gymnastics," "biomechanics," and "surface topography." The inclusion criteria focused on adolescent athletes aged 10–18 within rhythmic, artistic, and acrobatic disciplines, specifically examining joint hyperlaxity, training volume, and non-invasive diagnostic tools. Articles were restricted to those published in English or Polish, while studies on adult professionals or surgical techniques were excluded to maintain a focus on conservative screening in pediatric populations. Ultimately, 20 key publications were selected and organized into thematic chapters covering epidemiology, biomechanical influences, and diagnostic strategies to provide a comprehensive framework for sports medicine practitioners.

### 3.1. Scoliosis in Young Gymnasts

Scoliosis is defined as a complex, three-dimensional spinal deformity characterized by a lateral deviation of the spinal column of at least 10 degrees, which is typically accompanied by vertebral rotation [1, 2, 5]. In approximately 80% of cases, the condition is classified as idiopathic, meaning it develops during the pubertal growth period without a clearly identifiable cause [1, 2, 5]. Adolescent idiopathic scoliosis (AIS) is the most prevalent form of the deformity, primarily affecting individuals between the ages of 10 and 18 years [1, 2]. Global prevalence rates for AIS in the general population are estimated to range between 0.47% and 5.2%, with research consistently indicating that both the incidence and the clinical severity of the curves are significantly higher in females than in males [1, 2]. Recent epidemiological data from specific regions, such as China, identifies spinal abnormalities as a major health threat to adolescents, ranking alongside conditions like myopia and obesity [2].

The prevalence of scoliosis among young athletes is notably higher than in the general population, with broad estimates for the athletic community reaching approximately 27% [1, 2]. Gymnastics is frequently identified as a high-risk sport for spinal deformities due to its intensive physical demands and the specialized nature of its training elements [1, 2, 5]. A seminal study by Tanchev et al. reported a 10-fold higher incidence of scoliosis in rhythmic gymnastic trainees (12%) compared to non-athletic peers (1.1%) [5]. More recent large-scale

clinical screenings of young competitive gymnasts aged 10–16 years have identified a "scoliosis suspected status"—determined through the Adam's forward bend test and scoliometer measurements—in 28.8% of the participants [1]. Within specific gymnastic disciplines, suspected scoliosis was observed in 33% of rhythmic gymnasts, 28% of acrobatic gymnasts, and 18.3% of artistic gymnasts [1]. Furthermore, objective imaging assessments of female collegiate gymnasts have identified a scoliosis prevalence of 20% [3].

The elevated risk in this population is often attributed to a multifactorial etiology referred to as the "dangerous triad," which comprises generalized joint laxity, delayed maturity, and asymmetric spinal loading [3, 5]. Generalized joint hyperlaxity, frequently assessed using the Beighton scale, is a significant predictor of scoliotic status; the lack of stability from overstretched soft tissues can fail to effectively support the immature spine [1, 5]. Elite gymnasts also frequently experience delayed pubertal development and a later onset of menarche due to the combination of intense physical training and strict dieting [1, 5]. This delay effectively prolongs the "vulnerable growing years," exposing the growth plates to mechanical stressors for a longer duration [5]. Asymmetric loading is another primary concern, particularly in rhythmic gymnastics where athletes spend roughly 75% of training time using a dominant hand for implement control, which imposes uneven axial and torsional pressure on the developing spine [5].

Anthropometric characteristics, skeletal maturity, and training volume further influence the risk of developing spinal deformities [1, 2]. Gymnasts with suspected scoliosis are typically older and demonstrate lower bone strength compared to their non-scoliotic counterparts [1]. Training intensity is a critical factor, as research indicates that gymnasts with scoliosis train for an average of nearly 26 hours per week, compared to approximately 22 hours for those without the condition [1]. The requirement for an extreme range of motion (ROM) and the repetitive execution of spinal hyperextension elements place significant mechanical pressure on the adolescent spine [4, 5]. This stress is particularly acute during peak growth velocity, when rapid skeletal growth may outpace the development of supporting musculature [1]. Additionally, the nearly universal presence of a "flat back" posture (thoracic hypokyphosis and lumbar hypolordosis) in rhythmic gymnasts is considered a significant predisposing factor in the pathogenesis of structural scoliosis [5].

### 3.2. Influence of Gymnastic Training on the Spine

Gymnastic training imposes unique biomechanical demands on the developing skeleton, requiring a delicate balance between extreme flexibility, high-level strength, and precise motor

control [8, 11]. One of the most critical factors influencing the morphology of the immature spine is the cumulative volume of athletic training [10, 12]. Research involving large cohorts of children has demonstrated a significant association between the total number of training hours and alterations in the sagittal curvature of the spine [10]. Specifically, high-intensity training in young athletes can lead to an increase in the magnitude of thoracic kyphosis and lumbar lordosis, suggesting that the immature spine undergoes structural adaptations in response to repetitive mechanical loading [10]. In disciplines such as acrobatic gymnastics, where training often begins at a very early age, regular monitoring of these curvatures is essential to detect postural abnormalities and ensure the safe progression of the athlete [12].

A hallmark of gymnastics training is the emphasis on spinal hyperextension, often referred to as the "ubiquitous arch" [7]. This is primarily achieved through exercises like the back-bend, which gymnasts may perform thousands of times over a career spanning a decade or more [7]. While there are long-standing concerns regarding the potential harm of these movements, current reviews indicate that, when managed correctly, spine stretching does not appear to be an inherent threat to the health of the gymnast [7]. However, the repetitive nature of these hyperextension and loading cycles can lead to specific "overuse" injuries [11]. These include spondylolysis (stress fractures of the pars interarticularis), Scheuermann's disease, and various intervertebral disc pathologies, including degeneration and acute ring apophysis injuries [11]. The mechanical sources of pain are common in this population and must be addressed through comprehensive rehabilitation focusing on trunk strength and the correction of biomechanical deficits [11].

The relationship between gymnastics and adolescent idiopathic scoliosis (AIS) also involves a significant element of natural selection or "morphesthesia" [9]. Studies suggest that patients with AIS are more likely to participate in gymnastics because their underlying musculoskeletal characteristics—such as generalized joint laxity and increased spinal flexibility—provide a natural competitive advantage in a sport that rewards extreme ranges of motion [9]. Interestingly, while gymnastics is a high-demand sport, general sports participation has been found to have a protective effect against the progression of scoliotic curves [6]. In a large observational study, adolescents with AIS who remained active in sports showed a reduced risk of curve progression and a lower requirement for bracing compared to those who were sedentary [6].

For elite gymnasts experiencing low back pain (LBP), specific postural re-education programs have proven effective [8]. Clinical trials comparing the Mézières method and Isostretching have shown significant improvements in postural stability and a reduction in pain intensity [8]. These

global postural treatments are particularly valuable in rhythmic gymnastics, where extreme flexibility and long training hours place continuous strain on the lumbar spine [8, 13]. Furthermore, factors such as poor hip mobility and a high Body Mass Index (BMI) have been identified as significant contributors to the development of low back pain in adolescents, highlighting the importance of a holistic approach to the athlete's physical preparation [13].

### 3.3. Screening Strategies for Scoliosis in Young Athletes

The early identification of adolescent idiopathic scoliosis (AIS) is widely recognized as a critical factor in the success of conservative management [17, 19]. Detecting spinal deformities at an early stage, particularly before the attainment of skeletal maturity, allows for the timely initiation of bracing and physiotherapeutic scoliosis-specific exercises (PSSE). This early intervention significantly reduces the risk of curve progression to a magnitude that would require invasive surgical correction [17, 19]. In the athletic population, screening strategies are especially vital, as intensive training loads and high levels of muscular development can sometimes mask or, conversely, exacerbate the early signs of trunk asymmetry [14, 15].

Sports medicine physicians play a pivotal role in this screening process. During routine pre-participation physical evaluations (PPE), they have a unique opportunity to evaluate the spinal health of healthy adolescents on a regular basis [15]. National surveys indicate that while a majority of sports medicine specialists (approximately 80%) declare they assess for scoliosis in their daily practice, there remains a significant need for standardized education regarding international diagnostic guidelines, such as those provided by SOSORT. Ensuring that medical personnel are well-versed in these standards is essential for improving diagnostic precision and minimizing unnecessary radiological referrals [15].

The clinical gold standard for scoliosis screening remains the Adam’s Forward Bend Test (AFBT), which allows for the visual detection of rib humps or lumbar prominences resulting from vertebral rotation [14, 17, 19]. To provide an objective measure of these clinical findings, the use of a scoliometer to determine the Angle of Trunk Rotation (ATR) is considered indispensable [14, 17]. The selection of an appropriate ATR threshold for referral—commonly 5° or 7°—is a subject of ongoing clinical debate [17, 19]. While a lower threshold increases the sensitivity of the screening program, ensuring that fewer cases are missed, it also results in a higher rate of "false positive" cases. These cases often represent mild asymmetries that may not progress to structural scoliosis but still require periodic monitoring during the peak growth velocity period [17, 19].

Modern screening strategies are increasingly integrating back surface topography (ST) technologies, such as rasterstereography and 3D markerless scanning [14, 18]. These non-invasive methods allow for the three-dimensional reconstruction of the torso's surface without exposing the young athlete to ionizing radiation, making them an ideal tool for the frequent monitoring required in high-impact sports [18]. Recent studies in athletic cohorts have confirmed the high reliability and diagnostic accuracy of 3D surface topography, which provides detailed asymmetry indices that correlate strongly with radiographic parameters [14]. The integration of these advanced technologies with traditional physical examinations allows for the creation of a comprehensive, radiation-free postural profile for the athlete [14, 18].

The efficacy of a screening program is also highly dependent on its timing and organizational model. Research suggests that screening is most effective when targeted at children aged 10 to 15 years, a period characterized by rapid skeletal growth and high spinal plasticity [16, 19]. Comparative analyses of different screening models indicate that systematic, school-based or sports-club-based programs are more effective at detecting early-stage AIS than relying solely on opportunistic visits to primary care providers [16]. Despite ongoing discussions regarding the cost-effectiveness of mass screening, the consensus among specialists is that the clinical benefit of preventing severe deformity through early detection far outweighs the risks and costs associated with late-stage diagnosis and complex spinal surgery [16, 17].

## 4. Discussion

The findings of this review underscore a significant discrepancy between the prevalence of scoliosis in the general adolescent population and those engaged in high-level gymnastics. While global prevalence for adolescent idiopathic scoliosis (AIS) typically hovers between 0.47% and 5.2% [1, 2], studies on gymnasts consistently report much higher rates, ranging from 12% in rhythmic gymnastic trainees [5] to as high as 28.8% for "scoliosis suspected status" in multi-disciplinary cohorts [1]. This suggests that gymnastics training either predisposes athletes to spinal deformities or, as the "morphesthesia" hypothesis suggests, individuals with subclinical scoliosis and associated joint laxity are naturally selected for the sport due to their superior flexibility [9, 15].

The biomechanical analysis reveals that the "dangerous triad"—comprising hyperlaxity, delayed maturity, and asymmetric loading—is central to the development of these deformities [1.5, 3]. Generalized joint laxity, while a prerequisite for elite performance, appears to undermine the structural stability of the immature spine [1, 5]. Furthermore, the repetitive nature of the "ubiquitous arch" and hyperextension elements required by the Code of Points

places extreme stress on the posterior elements of the vertebrae, often leading to a high incidence of spondylolysis and disc pathology alongside scoliotic changes [7, 11]. Interestingly, the cumulative volume of training plays a pivotal role; gymnasts with suspected scoliosis averaged nearly four additional hours of training per week compared to their healthy peers, reinforcing the "dose-response" relationship between mechanical load and spinal adaptation [1, 10].

Despite these risks, the role of sports participation remains complex. While specific gymnastic loads can be detrimental, general physical activity has been shown to reduce the progression of existing curves and the subsequent need for bracing [6]. This highlights a critical need for a balanced approach where athletic performance does not come at the cost of long-term musculoskeletal health. The integration of non-invasive screening tools, such as the scoliometer and 3D surface topography, offers a promising solution [14, 18]. These technologies allow for the frequent monitoring of "false positive" or borderline cases—individuals who may not yet meet the criteria for structural scoliosis but who are at high risk during peak growth velocity [17, 19].

## 5. Conclusion

Young athletes, particularly those in gymnastic disciplines, represent a high-risk group for the development and progression of adolescent idiopathic scoliosis due to a complex interplay of biomechanical and physiological factors. The combination of inherent musculoskeletal traits, such as generalized joint hyperlaxity and low bone mass, with the extreme mechanical demands of intensive training necessitates rigorous clinical monitoring throughout the pubertal growth period. Standardizing screening protocols within routine pre-participation physical evaluations through the use of clinical tests and non-invasive 3D surface topography allows for the early detection of deformities while significantly reducing cumulative radiation exposure. Ultimately, the implementation of targeted postural interventions and evidence-based screening strategies ensures that the spinal integrity of adolescent gymnasts is protected without compromising their ability to achieve elite athletic performance.

## Disclosure

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Author's contribution:

Conceptualization, Anna Dziegciarczyk, Z. Wiater; methodology, A. Włodarczyk, K. Brankowska; software, K. Swoboda, M. Kuryek; validation, F. Banyś, A. Polakowska and A.

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