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Exercise in Adolescent Idiopathic Scoliosis: A Narrative Review

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ABSTRAK

Latar Belakang: Adolescent Idiopathic Scoliosis (AIS) merupakan deformitas tulang belakang tiga dimensi yang muncul pada masa remaja dan berpotensi mengalami progresivitas selama periode pertumbuhan sehingga dapat memengaruhi fungsi neuromuskuloskeletal, keseimbangan postural, dan kualitas hidup pasien. **Tujuan:** Penelitian ini bertujuan untuk meninjau peran latihan dalam penatalaksanaan konservatif AIS dalam mengendalikan progresivitas kurva, memperbaiki kontrol postur, dan meningkatkan fungsi dan kualitas hidup pasien. **Metode:** Penelitian ini menggunakan desain *narrative literature review* dengan menelaah berbagai literatur ilmiah yang relevan mengenai intervensi latihan pada AIS. Pencarian literatur dilakukan melalui basis data PubMed, Scopus, dan Google Scholar menggunakan kata kunci terkait seperti "adolescent idiopathic scoliosis", "scoliosis exercise", "physiotherapeutic scoliosis-specific exercises", "Schroth method", dan "SEAS". Artikel yang termasuk meliputi penelitian asli, *systematic review*, meta-analysis, dan pedoman klinis yang membahas latihan sebagai bagian dari manajemen konservatif AIS. Literatur yang terpilih kemudian dianalisis secara deskriptif untuk mengidentifikasi pendekatan latihan yang digunakan dan implikasi klinisnya. **Hasil:** Hasil telaah menunjukkan latihan berbasis Physiotherapeutic Scoliosis-Specific Exercises (PSSE) seperti metode Schroth dan Scientific Exercise Approach to Scoliosis (SEAS) berperan dalam memperbaiki koreksi tiga dimensi tulang belakang, meningkatkan kontrol neuromuskular, memperbaiki keseimbangan postural, dan membantu menghambat progresivitas kurva. Latihan seperti penguatan otot inti dan latihan aerobik berkontribusi dalam meningkatkan stabilitas trunk dan kapasitas fungsional pasien. **Kesimpulan**: Latihan merupakan komponen dalam penatalaksanaan konservatif AIS dan berpotensi meningkatkan hasil klinis dan kualitas hidup pasien. Oleh karena itu, program latihan yang berbasis bukti dan disesuaikan secara individual sangat direkomendasikan dalam praktik rehabilitasi untuk memaksimalkan efektivitas terapi konservatif pada AIS.

ABSTRACT

Background*: Adolescent Idiopathic Scoliosis (AIS) is a three-dimensional spinal deformity that emerges during adolescence and has the potential to progress during the growth period, thereby affecting neuromusculoskeletal function, postural balance, and the patient's quality of life.* ***Objective****: This study aims to review the role of exercise in the conservative management of AIS in controlling curve progression, improving postural control, and enhancing patient function and quality of life.* ***Methods****: This study used a narrative literature review design by examining various relevant scientific literatures regarding exercise interventions in AIS. Literature searches were conducted through the PubMed, Scopus, and Google Scholar databases using related keywords such as "adolescent idiopathic scoliosis," "scoliosis exercise," "physiotherapeutic scoliosis-specific exercises," "Schroth method," and "SEAS." Included articles consisted of original research, systematic reviews, meta-analyses, and clinical guidelines discussing exercise as part of the conservative management of AIS. The selected literature was then analyzed descriptively to identify the exercise approaches used and their clinical implications.* ***Results****: The review results show that exercises based on Physiotherapeutic Scoliosis-Specific Exercises (PSSE), such as the Schroth method and the Scientific Exercise Approach to Scoliosis (SEAS), play a role in improving three-dimensional spinal correction, enhancing neuromuscular control, improving postural balance, and helping to inhibit curve progression. Exercises such as core muscle strengthening and aerobic exercise contribute to improving trunk stability and the functional capacity of patients.* ***Conclusion****: Exercise is a component of the conservative management of AIS and has the potential to improve clinical outcomes and patients' quality of life. Therefore, evidence-based and individually tailored exercise programs are highly recommended in rehabilitation practice to maximize the effectiveness of conservative therapy in AIS.*

INTRODUCTION

Adolescent Idiopathic Scoliosis (AIS) is a three-dimensional spinal deformity defined by a lateral curvature with a Cobb angle ≥10° and vertebral rotation in individuals aged 10-18 years, without an identifiable underlying cause. Its prevalence ranges from 2-3%, with a higher incidence in females and increased risk of progression during the pubertal growth period (Aljohani *et al*., 2025; Mohamed *et al*., n.d.). Curve progression in AIS is influenced by skeletal growth, asymmetric spinal loading, and altered neuromuscular control, which may lead to postural imbalance, pain, reduced pulmonary function, and psychosocial disturbance when untreated (Jinnah *et al*., 2025; Ekawana *et al*., 2022). Conservative management is determined by curve magnitude and skeletal maturity: observation is generally recommended for mild curves, bracing for moderate curves, and surgery for severe progressive deformities (Kuang *et al*., 2025; Seleviciene *et al*., 2022).

Among conservative approaches, Physiotherapeutic Scoliosis-Specific Exercises (PSSE) have gained increasing attention because they target three-dimensional correction through auto-elongation, derotation, stabilization, postural training, and breathing control. International guidelines from the Scoliosis Research Society and Society on Scoliosis Orthopaedic and Rehabilitation Treatment recommend exercise as part of non-operative management, particularly in mild to moderate AIS (Berdishevsky *et al*., 2016; Negrini *et al*., 2018).

Recent evidence suggests that PSSE may reduce curve progression and improve postural symmetry and health-related quality of life; however, the strength of

evidence remains heterogeneous due to variation in exercise protocols, intervention duration, adherence monitoring, and comparator groups across studies. Several randomized and prospective studies report favorable outcomes, yet meta-analyses indicate that effect sizes are often modest and highly dependent on patient selection and combination with bracing (Seleviciene *et al*., 2022). In addition, long-term effects on Cobb angle stabilization and functional outcomes remain insufficiently established, which explains why exercise prescription is still inconsistent in routine clinical practice. Therefore, this narrative review aims to critically examine current evidence regarding specific exercise interventions in AIS, focusing on their effectiveness in controlling curve progression, improving postural control, and enhancing functional outcomes and quality of life, as well as discussing their practical integration into rehabilitation strategies.

RESEARCH METHOD

This study was conducted as a narrative literature review to synthesize current evidence regarding exercise-based interventions in the management of Adolescent Idiopathic Scoliosis (AIS), particularly within physical medicine and rehabilitation. Literature published between 2009 and 2025 was considered to capture both foundational guidelines and recent developments in exercise-based scoliosis management. A comprehensive search of electronic databases, including PubMed, Scopus, and Google Scholar, was performed using combinations of keywords such as “adolescent idiopathic scoliosis,” “AIS,” “scoliosis exercise,” “physiotherapeutic scoliosis-specific exercises,” “PSSE,” “Schroth method,” “SEAS,” “core strengthening,” “aerobic exercise,” “yoga,” “pilates,” and “rehabilitation.”

The inclusion criteria were:

(1) articles published in English;

(2) original research, systematic reviews, meta-analyses, clinical guidelines, and consensus statements; and

(3) studies focusing on AIS and exercise-based conservative management.

Exclusion criteria included non-English publications, studies unrelated to AIS, surgical-only interventions, and articles without accessible full text. The initial search identified relevant publications, of which 28 articles were selected after screening titles, abstracts, and full texts for relevance to the review objectives. Study selection was conducted narratively based on thematic relevance, methodological contribution, and representation of major exercise approaches used in AIS management. As a narrative review, no formal PRISMA flow diagram was applied, and no standardized risk of bias tool was used.

However, study quality was considered descriptively by prioritizing higher-level evidence such as systematic reviews, meta-analyses, randomized controlled trials, and international clinical guidelines. The level of evidence therefore ranged from clinical guidelines and systematic reviews (high-level evidence) to individual randomized trials and observational studies (moderate-level evidence). The discussion was organized into two main sections: the first addresses essential aspects of AIS, including clinical characteristics and rehabilitation relevance, while the second focuses on exercise interventions, covering Physiotherapeutic Scoliosis-Specific Exercises (PSSE), Schroth method, SEAS, brace-associated exercise, and other supportive modalities such as core strengthening, aerobic exercise, yoga, and Pilates.

RESULTS AND DISCUSSION

Definition, Prevalence, Classification, and Pathophysiology of Adolescent Idiopathic Scoliosis

Adolescent Idiopathic Scoliosis (AIS) is a three-dimensional spinal deformity characterized by a lateral curvature of the spine accompanied by vertebral rotation with a minimum Cobb angle of 10°. This structural deviation differentiates scoliosis from simple postural asymmetry because it involves both coronal and rotational deformities of the vertebral column (Jinnah *et al*., 2025; Mohamed *et al*., n.d.). Among the different types of scoliosis affecting pediatric populations, AIS is the most common and typically develops in individuals between 10 and 18 years of age without a clearly identifiable underlying cause. The global prevalence of AIS ranges from approximately 0.47% to 5.2%, showing that the condition represents a significant musculoskeletal health concern during adolescence. Epidemiological data from Indonesia estimate the prevalence to reach approximately 2.93%, reflecting a similar trend to global findings (Aljohani *et al*., 2025). AIS occurs more frequently in females than males, with an estimated female-to-male ratio of around 3:1. This sex disparity becomes more pronounced as the curvature severity increases, suggesting potential hormonal and growth-related influences on disease progression (Aljohani *et al*., 2025). Because AIS often develops during the rapid growth phase of adolescence, early detection and classification are essential for preventing curve progression and long-term functional impairment.

From a morphological perspective, scoliosis can be categorized according to the number and configuration of spinal curves. The two most common patterns are single curves forming a C-shaped configuration and double curves forming an S-shaped configuration (Mohamed *et al*., n.d.). The severity of scoliosis is primarily determined using the Cobb angle measured on standing spinal radiographs. Based on this measurement, scoliosis is generally classified into mild (10°- 20°), moderate (20°-40°), and severe deformities exceeding 40° (Jinnah *et al*., 2025; Mohamed *et al*., n.d.). This classification is clinically important because it guides treatment decisions and monitoring strategies. Mild curves are often managed with observation and conservative approaches, whereas moderate curves may require bracing and rehabilitation programs. Severe curves carry a higher risk of structural progression and may require surgical intervention to prevent cardiopulmonary compromise and further deformity.

One of the most widely used systems for describing AIS curve patterns is the Lenke classification. This system divides scoliosis curves into six major types based on the location and structural characteristics of the spinal curvature, including proximal thoracic, main thoracic, and thoracolumbar or lumbar curves. In addition to identifying the main curve type, the Lenke system incorporates a lumbar modifier (A, B, or C) that evaluates the relationship between the lumbar apex and the center sacral vertical line. A sagittal thoracic modifier (-, N, +) is also included to describe the sagittal profile of the thoracic spine (Baghdadi *et al*., 2024; Wei *et al*., 2025). This classification is widely used in clinical practice because it provides a standardized framework for determining surgical strategies, particularly in selecting the appropriate fusion levels. The Lenke classification also assists clinicians in identifying structural versus compensatory curves, which is essential in planning selective thoracic fusion procedures. Furthermore, the reliability and reproducibility of the Lenke system have made it the preferred method for describing AIS curve patterns in both clinical research and surgical planning (Baghdadi *et al*., 2024; Wei *et al*., 2025).

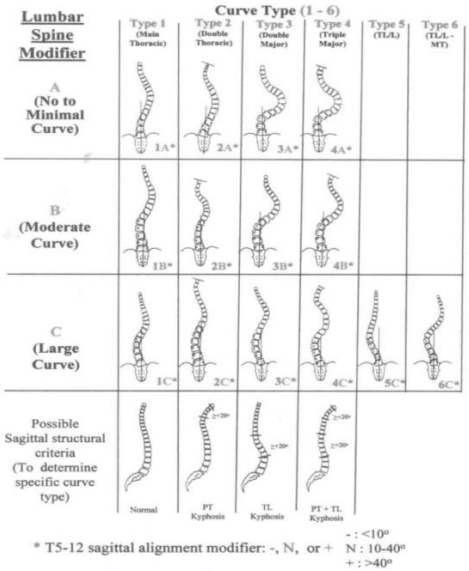


Figure 1. Lenke classification system for Adolescent Idiopathic Scoliosis
(Baghdadi *et al.,* 2024)

In conservative rehabilitation approaches, additional classification systems have been developed to better guide exercise-based interventions. One such system is the Lehnert-Schroth classification, which conceptualizes the body as a series of interconnected postural blocks, including the shoulder block, thoracic block, lumbar block, and pelvic-hip block. Curve types are determined primarily through posterior postural observation and trunk asymmetry patterns (Wei *et al*., 2025). Four main curve patterns are described in this system: the three-curve pattern (3C) characterized by thoracic dominance with balanced pelvic alignment; the three-curve pattern with pelvic shift (3CP); the four-curve pattern (4C) with thoracolumbar or lumbar dominance; and the four-curve pattern with pelvic shift (4CP), in which the pelvis deviates contralaterally relative to the convexity of the main curve. This classification is particularly important in physiotherapeutic scoliosis-specific exercise programs because it guides individualized correction strategies. By identifying the dominant structural blocks, therapists can design exercises aimed at reducing vertebral rotation, rib prominence, and trunk asymmetry. As a result, the Lehnert-Schroth classification plays a significant role in optimizing conservative management and functional rehabilitation outcomes (Wei *et al*., 2025).

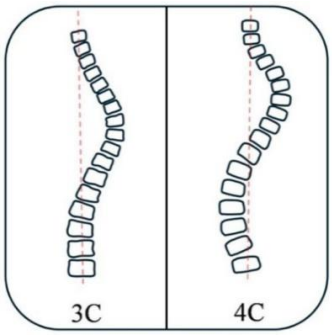


Figure 2. Lehnert-Schroth classification
(Wei *et al.,* 2025)

Further refinement of conservative treatment planning has led to the development of the Augmented Lehnert-Schroth (ALS) classification. This updated system expands the original Schroth classification by introducing more detailed curve subtypes based on body blocks, pelvic shift, and coronal balance. The ALS classification includes variations of three-curve and four-curve patterns with differences in curve length, apex location, and thoracolumbar relationships (Wei *et al*., 2025). These additional subdivisions allow for greater precision when designing individualized rehabilitation programs and orthotic management strategies. The system is particularly useful when combining scoliosis-specific exercises with modern brace designs such as the Chêneau or Gensingen brace. By providing a more comprehensive description of the spinal deformity, the ALS classification improves the ability of clinicians to tailor conservative interventions to each patient's structural pattern. Ultimately, this approach aims to maximize postural correction, reduce curve progression, and enhance functional outcomes without surgical intervention (Wei *et al*., 2025).

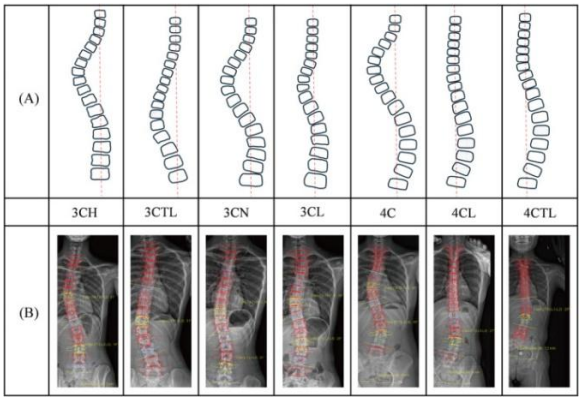


Figure 3. Augmented Lehnert-Schroth classification (Wei *et al.,* 2025)

The pathophysiology of AIS is considered multifactorial, involving a complex interaction of genetic, hormonal, biomechanical, and environmental factors that contribute to the development and progression of spinal deformity (Chatelain *et al*., 2024). Genetic predisposition plays a substantial role, as studies have demonstrated an increased incidence of scoliosis among first-degree relatives of affected individuals. Twin studies also reveal higher concordance rates among monozygotic twins compared with dizygotic twins, further supporting a genetic contribution to disease development (Kuang *et al*., 2025). Molecular investigations have identified several single nucleotide polymorphisms associated with AIS, particularly within chromosomal regions 6p24.1, 10q24.31, and 19p13.3. These genetic variations are believed to influence genes involved in vertebral development, bone metabolism, and neuromuscular regulation (Febyan *et al*., 2023). Hormonal factors also contribute significantly to AIS, particularly during adolescence when rapid skeletal growth occurs. Growth hormone and insulin-like growth factor-1 regulate bone growth and metabolism, and abnormal levels of these hormones may contribute to asymmetric vertebral growth (Jinnah *et al*., 2025; Kuang *et al*., 2025). Sex hormones such as estrogen and testosterone further influence bone remodeling and mechanical strength, potentially explaining the higher prevalence and progression risk in females (Kuang *et al*., 2025).

Biomechanical mechanisms also play a critical role in the progression of AIS. During adolescence, vertebral growth occurs through active growth plates in the vertebral bodies and secondary apophyses. The rapid increase in chondrocyte

proliferation during the pubertal growth spurt makes the spine particularly susceptible to deformity progression. According to the Hueter-Volkmann principle, increased compression on a growth plate inhibits growth, whereas reduced compression allows relatively faster growth. In AIS, the concave side of the curve experiences greater compressive forces than the convex side, resulting in asymmetric vertebral growth and wedge-shaped deformities that progressively increase spinal curvature (Frost *et al*., 2019; Roberts, n.d.). Alterations in intervertebral disc mechanics further contribute to this process by creating uneven pressure distribution between the annulus fibrosus and nucleus pulposus. Excessive compression on the concave side and relative distraction on the convex side lead to changes in disc shape and orientation, promoting vertebral rotation and segmental instability (Frost *et al*., 2019; Roberts, n.d.). Additionally, many AIS patients exhibit thoracic hypokyphosis, which reduces the natural sagittal curvature of the thoracic spine and increases susceptibility to rotational instability (Aljohani *et al*., 2025). Environmental and lifestyle factors such as poor nutrition, vitamin D deficiency, and low physical activity levels may further influence bone health and spinal stability, potentially increasing susceptibility to deformity development and progression (Kuang *et al*., 2025).

Figure 4. Conceptual diagram multifactorial etiology and comprehensive rehabilitation considerations in Adolescent Idiopathic Scoliosis
(Kuang *et al.,* 2025)

Diagnosis, Clinical Impact, and Prognosis of Adolescent Idiopathic Scoliosis

The diagnosis of Adolescent Idiopathic Scoliosis (AIS) begins with a comprehensive clinical evaluation that integrates medical history, physical examination, and supporting diagnostic investigations. A detailed anamnesis represents the first and essential step in identifying early signs of scoliosis and differentiating idiopathic cases from other spinal pathologies. Clinicians should inquire about the initial onset of spinal curvature, who first noticed the deformity, and whether the curvature has progressed over time. The presence of persistent pain or neurological symptoms may indicate underlying pathological conditions such as tumors, neurological disorders, or syndromic abnormalities including Arnold-Chiari malformation and tethered cord syndrome (Jinnah *et al*., 2025; Mohamed *et al*., n.d.). Family history also plays an important role, as AIS frequently shows hereditary tendencies that may increase susceptibility among first-degree relatives. In addition, birth history, motor development, and pubertal milestones should be evaluated because skeletal maturity and growth velocity are strongly associated with curve progression risk. For female patients, the age of menarche is particularly important because it serves as a clinical indicator of remaining growth potential and helps guide decisions regarding treatment timing (Jinnah *et al*., 2025; Mohamed *et al*., n.d.).

Beyond physical symptoms, psychosocial factors must also be considered during the clinical evaluation of AIS. Adolescents often experience visible changes in body posture such as shoulder asymmetry, rib prominence, and pelvic imbalance, which may significantly affect body image and self-esteem. These physical changes can lead to emotional distress, social withdrawal, and even symptoms of anxiety or depression in some patients. Consequently, psychological assessment should be integrated into the multidisciplinary management of scoliosis to ensure a holistic approach to patient care. Early recognition of psychosocial distress allows clinicians to provide appropriate counseling and support, which may improve treatment adherence and quality of life outcomes. Furthermore, adolescents are particularly vulnerable to peer perception and social comparison, making visible deformities more impactful during this developmental stage. Addressing both the physical and psychological aspects of scoliosis is therefore essential in comprehensive patient management (Jinnah *et al*., 2025).

Physical examination plays a central role in confirming the presence of scoliosis and evaluating its severity and potential underlying causes. The examination typically begins with basic anthropometric measurements, including height and weight, followed by an assessment of trunk balance, curve flexibility, and symmetry of the shoulders, scapulae, and pelvis (Mohamed *et al*., n.d.). Observation of the skin, facial features, and lower extremities is necessary to identify potential congenital anomalies or syndromic conditions associated with secondary scoliosis. Examination of the lower limbs is also important for detecting leg length discrepancies, as this condition can produce functional scoliosis that usually resolves when the patient sits down (Polis *et al*., 2025). Postural assessment includes evaluating spinal alignment in both the coronal and sagittal planes, along with head tilt and pelvic balance. A comprehensive neurological examination should also be performed to assess motor strength, sensory function, and reflexes, including abdominal reflexes that may reveal neurological abnormalities such as syringomyelia or tethered cord syndrome. Gait analysis is another useful component of the examination, as abnormalities such as foot drop may indicate underlying neuromuscular pathology (Polis *et al*., 2025).

One of the most widely used clinical screening methods for detecting scoliosis is the Adams Forward Bending Test (AFBT). During this examination, the patient stands with their back facing the examiner and bends forward until the spine becomes parallel to the floor. The examiner observes the back for asymmetry in the ribs, shoulders, or paraspinal muscles, which may indicate vertebral rotation and structural scoliosis (Mohamed *et al*., n.d.). This test is often combined with the use of a scoliometer, a handheld device that provides a quantitative measurement of trunk rotation. The Angle of Trunk Rotation (ATR) obtained from the scoliometer helps determine whether further radiographic evaluation is necessary. An ATR value of 5° or greater is generally considered indicative of a possible Cobb angle of at least 20°, warranting additional investigation (Febyan *et al*., 2023; Mohamed *et al*., n.d.). The combined use of AFBT and scoliometer significantly improves early detection accuracy, with reported sensitivity ranging from 92% to 100% and specificity between 60% and 91%. Early detection is particularly important during adolescence because scoliosis progression often accelerates during rapid growth phases.

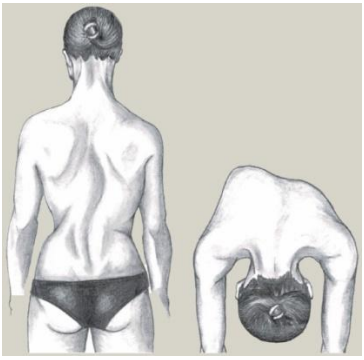


Figure 1. Adams Forward Bending Test
(Mohamed *et al.,* n.d.)

Additional physical assessment techniques can further evaluate spinal alignment and functional impairment in patients with AIS. The plumb line test is commonly used to assess spinal balance when the patient stands upright. In this procedure, a weighted string is positioned at the level of the seventh cervical vertebra (C7) and allowed to hang vertically toward the pelvis. The examiner then observes whether the line deviates from the midline of the spine, which may indicate coronal imbalance or spinal curvature (Fortin *et al*., 2016). Respiratory assessment may also be necessary, particularly in patients with severe spinal curvature that can affect thoracic mechanics. Screening for Forced Vital Capacity (FVC) is recommended because a reduction below 60% of the predicted value may indicate significant respiratory impairment requiring further medical management (Febyan *et al*., 2023). In addition to structural evaluation, aesthetic assessment is increasingly recognized as an important component of clinical evaluation. Instruments such as the Walter Reed Visual Assessment Scale (WRVAS), Spinal Appearance Questionnaire (SAQ), Anterior Trunk Symmetry Index (ATSI), and Posterior Trunk Symmetry Index (POTSI) are commonly used to assess patient perception of deformity and postural appearance (Kuru Çolak *et al*., 2025). These tools provide valuable insight into the psychological and cosmetic impact of spinal deformities.

Radiological assessment is essential for confirming the diagnosis of AIS and determining the severity of spinal curvature. The Cobb angle is the most widely used measurement for quantifying spinal deformity and guiding treatment decisions (Kuru Çolak *et al*., 2025). Conventional standing radiography remains the gold standard for evaluating scoliosis because it allows accurate measurement of spinal curvature and identification of curve patterns. Radiographic images are typically obtained in posterior-anterior and lateral projections while the patient is standing, allowing clinicians to assess spinal alignment in both the coronal and sagittal planes (Polis *et al*., 2025). In certain clinical situations, additional imaging may be required to rule out underlying neurological abnormalities. Magnetic Resonance Imaging (MRI) is particularly recommended in cases presenting with atypical features such as left thoracic curves, neurological deficits, cavus foot deformity, or unexplained headaches (Kumar *et al*., 2024).

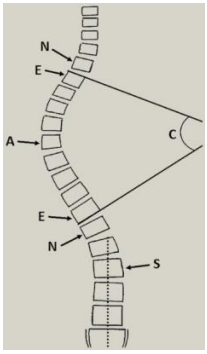


Figure 2. Measurement of the Cobb angle
(Mohamed *et al.,* n.d.)

Because patients with AIS often require repeated imaging to monitor curve progression, minimizing radiation exposure has become an important consideration in modern scoliosis management. Repeated exposure to conventional radiography can lead to cumulative radiation doses, which is particularly concerning in children and adolescents who are more sensitive to radiation effects. To address this issue, low-dose imaging technologies such as the EOS slot-scanning 2D/3D imaging system have been developed (Oakley *et al*., 2019). This advanced system uses two orthogonal X-ray sources simultaneously to produce biplanar images within a short acquisition time. The resulting images allow for accurate three-dimensional reconstruction of spinal deformities while significantly reducing radiation exposure compared with traditional radiography. Studies have reported radiation dose reductions of approximately 50-80% when using EOS imaging systems. In addition to imaging techniques, skeletal maturity assessment is also essential in predicting curve progression. Risser staging evaluates the degree of ossification of the iliac apophysis and is categorized into stages 0 to 5, where stage 0 indicates no visible ossification and stage 5 indicates complete ossification and fusion (Mohamed *et al*., n.d.). Lower Risser stages indicate greater remaining growth potential and therefore a higher risk of curve progression.

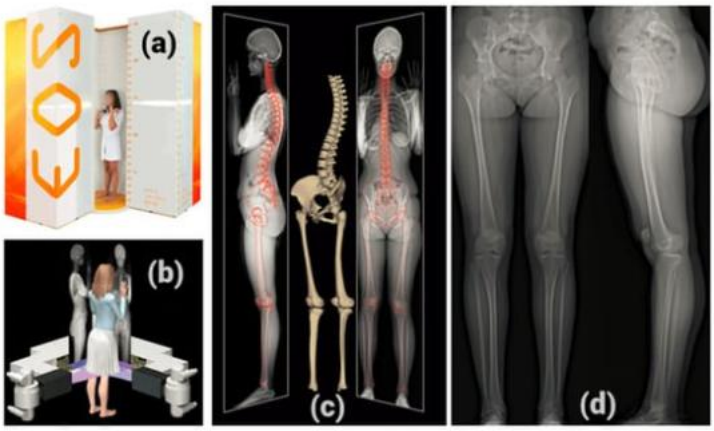


Figure 3. EOS low-dose imaging system used for three-dimensional evaluation of spinal deformities with reduced radiation exposure. (Oakley *et al*., 2019)

Adolescent Idiopathic Scoliosis can produce a wide range of structural, functional, and participation-related impairments that affect the overall well-being of patients. According to the International Classification of Functioning, Disability and Health (ICF) framework, AIS primarily affects body structures related to movement,

particularly the trunk (s7), as well as structures associated with cardiovascular and respiratory systems (s4) (Du *et al*., 2016). Functional impairments in AIS involve multiple physiological domains, including mental functions, sensory perception and pain, cardiovascular and respiratory function, metabolic processes, and neuromusculoskeletal control. Among these, the most frequently reported problems include reduced joint mobility (b710) and difficulties maintaining body weight (b530). Patients may also experience disturbances in body image perception (b1801), which can influence emotional well-being and self-esteem (Du *et al*., 2016). Additional impairments include altered temperament and personality traits (b126), reduced energy levels (b1300), emotional dysfunction (b152), chronic back pain (b28013), respiratory limitations (b440), reduced exercise tolerance (b455), decreased joint stability (b715), diminished muscle strength (b730), impaired muscular endurance (b740), and abnormal gait patterns (b770). These findings highlight the multidimensional impact of AIS and emphasize the importance of multidisciplinary rehabilitation strategies.

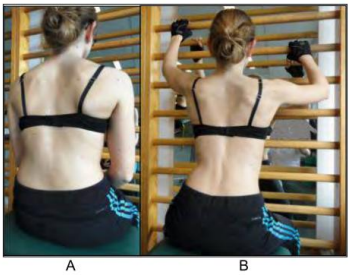
In addition to impairments in body structure and function, AIS also affects activity and participation in daily life. Qualitative analyses have identified six major domains of activity limitation and participation restriction in patients with AIS, including general tasks and demands (d2), mobility (d4), self-care (d5), interpersonal interactions (d7), major life areas such as education (d8), and community and social life (d9) (Du *et al*., 2016). The most frequently reported limitations involve participation in play activities (d880), reported by approximately 61% of patients, and involvement in recreational or leisure activities (d920), reported by about 60%. These limitations reflect how spinal deformity and associated symptoms may restrict engagement in social and physical activities that are important for adolescent development. As a result, rehabilitation programs for AIS should focus not only on correcting spinal alignment but also on improving participation in meaningful daily activities. Prognosis in AIS is influenced by several factors including family history, joint laxity, thoracic hypokyphosis, trunk rotation greater than 10°, and the timing of the adolescent growth spurt. The risk of curve progression increases significantly when the Cobb angle is high and skeletal maturity, indicated by a low Risser stage, is still incomplete (Karachalios *et al*., n.d.).

Exercise-Based Interventions in Adolescent Idiopathic Scoliosis

Exercise-based management plays a central role in the conservative treatment of Adolescent Idiopathic Scoliosis (AIS). According to recommendations from the Society on Scoliosis Orthopaedic and Rehabilitation Treatment (SOSORT), conservative management includes observation, Physiotherapeutic Scoliosis-Specific Exercises (PSSE), and bracing, depending on the severity of the curvature and the patient's skeletal maturity (Berdishevsky *et al*., 2016; Seleviciene *et al*., 2022). Among these interventions, exercise therapy aims not only to limit curve progression but also to improve neuromuscular control, postural alignment, and overall functional capacity. Exercise programs for AIS are typically individualized according to the patient's curve pattern and the three-dimensional deformity of the spine. The multidimensional nature of scoliosis characterized by lateral deviation, vertebral rotation, and sagittal plane alterations requires targeted therapeutic strategies addressing these biomechanical factors. Consequently, exercise interventions are designed to improve postural awareness, spinal stability, and muscular balance. These approaches ultimately contribute to improved quality of life and functional independence in adolescents with scoliosis.

Physiotherapeutic Scoliosis-Specific Exercises (PSSE) represent a cornerstone of conservative treatment in AIS. These exercises are designed to correct spinal

deformities through active postural correction and neuromuscular stabilization tailored to the individual curve pattern (Berdishevsky *et al*., 2016; Seleviciene *et al*., 2022). PSSE is recommended as a primary intervention in mild scoliosis during growth and as an adjunctive therapy in patients undergoing bracing to enhance the effectiveness of mechanical correction (Berdishevsky *et al*., 2016; Seleviciene *et al*., 2022). The objectives of PSSE extend beyond reducing the Cobb angle; they include achieving three-dimensional active postural correction, improving spinal stability, enhancing trunk symmetry, and supporting respiratory function in thoracic curves (Negrini *et al*., 2018). Additionally, PSSE promotes neuromuscular coordination and patient awareness of spinal alignment. The SOSORT guidelines emphasize several core principles underlying these exercises, including three-dimensional auto-correction, integration of corrected posture into daily activities, stabilization of the corrected alignment, and patient education to improve treatment adherence (Negrini *et al*., 2018). These principles ensure that therapeutic gains achieved during supervised exercise sessions can be maintained during everyday movements and activities.



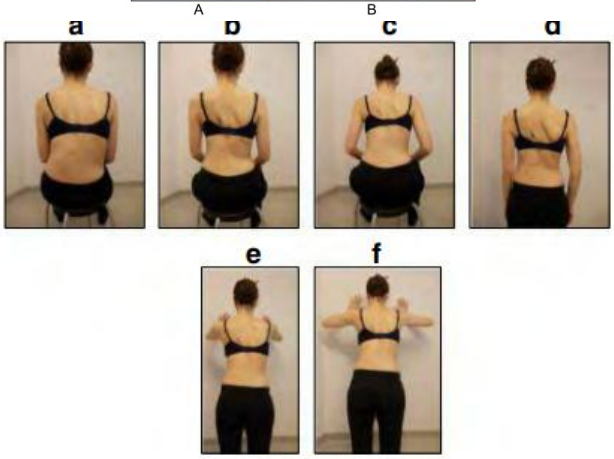


Figure 1. Exercise-based interventions for AIS, including 3D auto-correction principles in PSSE, the Schroth “Pezziball” exercise and SEAS active self-correction exercises integrated into functional movement training.

Among the various PSSE methods, the Schroth method is one of the most widely studied and implemented approaches. This method focuses on three-dimensional spinal correction through specific postural adjustments, muscle activation, and rotational breathing techniques designed to restore muscular symmetry and spinal balance (Berdishevsky *et al*., 2016). The Schroth approach is based on five fundamental principles: auto-elongation, deflection of lateral curvature, derotation of vertebral rotation, rotational breathing, and stabilization of the corrected posture. These principles are applied through targeted exercises such as the 50× Pezziball exercise, prone exercises, and sail exercises (Berdishevsky *et al*., 2016). For example, the Pezziball exercise involves sitting on a Swiss ball in front of a mirror while performing three-dimensional self-correction with support from a wall bar, promoting postural awareness and trunk muscle activation. Other exercises, such as prone and sail positions, aim to correct thoracic and lumbar curvature through traction forces, muscle activation, and directed breathing. These exercises encourage expansion of the concave thoracic regions and activation of muscles along the convex side of the curvature to restore spinal balance.

Evidence suggests that Schroth exercises can produce meaningful clinical improvements in patients with AIS. A randomized controlled trial conducted by Kuru *et al*. demonstrated that supervised Schroth exercises were significantly more effective than home-based programs and observation alone in improving Cobb angle, trunk rotation, hump height, and quality of life (Kuru *et al*., 2016). In that study, adolescents aged 10-18 years with Cobb angles ranging from 10° to 60° were assigned to supervised exercise, home-based exercise, or control groups. Participants in the supervised group performed 1.5-hour sessions three times per week for six weeks, followed by an additional 18 weeks of home exercises. The home-based group received one supervised session and then continued independently for 24 weeks. Results showed that supervised training produced superior outcomes, likely due to higher adherence, better technique retention, and continuous professional guidance (Kuru *et al*., 2016). These findings highlight the importance of therapist supervision and structured training programs in maximizing the effectiveness of scoliosis-specific exercise interventions.

Another widely recognized PSSE approach is the Scientific Exercise Approach to Scoliosis (SEAS). Unlike the Schroth method, which emphasizes structured postural correction exercises, SEAS focuses on active self-correction integrated into functional activities and neuromotor control training (Kuang *et al*., 2025; Kumar *et al*., 2024). The central goal of SEAS is to train the neuromotor system to automatically maintain corrected spinal alignment during everyday movements. The process begins with patient education to enhance understanding of the individual spinal deformity and promote conscious postural adjustments. This awareness enables patients to achieve optimal spinal alignment through voluntary self-correction in three dimensions. Subsequent stages involve stabilization exercises that stimulate neurosensory feedback and promote the development of automatic reflex mechanisms for maintaining correct posture (Berdishevsky *et al*., 2016; Kuang *et al*., 2025). SEAS exercises can be incorporated into routine functional activities such as

standing from a seated position, climbing stairs, maintaining balance on one leg, or reaching overhead.

Clinical evidence also supports the effectiveness of SEAS in managing AIS. Studies by Romano *et al*. reported that patients undergoing SEAS demonstrated improved Cobb angles, reduced angle of trunk rotation (ATR), and a lower need for bracing at follow-up compared with those receiving conventional physiotherapy (Romano *et al*., 2015). Moreover, SEAS can be applied throughout different phases of scoliosis treatment, including before bracing, during brace use, and after brace weaning. Prior to bracing, SEAS exercises enhance spinal mobility, allowing braces to achieve more effective mechanical correction. During bracing, modeling exercises help increase corrective pressure on spinal prominences, while endurance exercises maintain muscular support and spinal alignment (Berdishevsky *et al*., 2016; Kuang *et al*., 2025). Typical SEAS programs involve supervised sessions two to three times per week for approximately 45 minutes, combined with daily home exercises lasting around 20 minutes. This structured approach supports long-term neuromuscular adaptation and postural stability.

Comparative evidence suggests that PSSE methods, including Schroth and SEAS, contribute significantly to clinical outcomes in AIS management. A meta-analysis by Anwer *et al*. reported that PSSE significantly reduced Cobb angle and angle of trunk rotation while improving quality of life among adolescents with scoliosis (Anwer *et al*., 2015). Furthermore, a systematic review by Negrini *et al*. demonstrated that combining PSSE with bracing produced superior outcomes compared with bracing alone, particularly in reducing the need for surgical intervention (Negrini *et al*., 2009). In that analysis, the surgery rate among patients treated with bracing alone was approximately 23%, whereas those receiving combined bracing and PSSE showed rates between 0% and 14%. A more recent review comparing Schroth and SEAS reported significant reductions in Cobb angle exceeding 5° for both methods, although the level of evidence appeared slightly stronger for the Schroth approach (Khaledi *et al*., 2022). However, direct head-to-head comparisons between these two methods remain limited, indicating the need for further research to determine their relative effectiveness.

Although PSSE demonstrates beneficial effects in AIS management, current evidence remains heterogeneous across studies. Variability in intervention duration, exercise frequency, supervision intensity, and curve severity makes direct comparison difficult. Several studies report clinically meaningful Cobb angle reduction, whereas others show modest radiographic changes despite improvements in posture and quality of life. This inconsistency suggests that therapeutic benefit may depend strongly on patient selection, skeletal maturity, and adherence level. Controversy also remains regarding the comparative superiority of PSSE methods. Although Schroth is supported by a relatively larger number of controlled studies, direct head-to-head trials comparing Schroth and SEAS are still limited, preventing definitive conclusions regarding which method offers superior long-term correction. Furthermore, many available studies involve small sample sizes and relatively short follow-up periods, reducing external validity for long-term progression prevention.

Adherence represents a major clinical challenge in exercise-based scoliosis management. Home-based exercise programs frequently demonstrate lower effectiveness than supervised protocols because adolescents often experience reduced motivation, inconsistent technique performance, and limited long-term compliance. This creates an important implementation gap between efficacy observed in controlled studies and effectiveness in routine clinical practice. In

addition, PSSE implementation may be limited by therapist availability, need for specialized training, and access to scoliosis-specific rehabilitation centers, particularly in low-resource settings. Therefore, although exercise-based treatment remains an essential component of conservative AIS management, its effectiveness should be interpreted within the context of methodological limitations and practical barriers in clinical application

In addition to PSSE, other forms of exercise may contribute to the supportive management of AIS. Core muscle strengthening exercises are frequently incorporated into rehabilitation programs because patients with AIS often exhibit trunk muscle asymmetry, neuromuscular imbalance, and reduced postural control (Li *et al*., 2021; Smit, 2020). Strengthening exercises targeting the transversus abdominis, multifidus, oblique muscles, diaphragm, and pelvic floor help improve dynamic spinal stability and reduce micro-instability. Improved trunk endurance also allows patients to maintain upright posture for longer periods without fatigue, which may reduce the risk of progressive deformity (Smit, 2020). Aerobic exercise further complements rehabilitation by improving cardiovascular fitness and respiratory function, particularly in patients with thoracic curves that limit lung expansion (Bas *et al*., 2011). Activities such as cycling, brisk walking, jogging, and swimming can enhance physical conditioning and psychosocial well-being. High-intensity cycling programs have been shown to increase VO_2max and anaerobic threshold in adolescents with scoliosis, reflecting improved cardiopulmonary capacity (Bas *et al*., 2011). Then, mind-body exercise approaches such as yoga and Pilates may support postural awareness, flexibility, and trunk control. Although these modalities are not considered corrective treatments for structural deformity, they can improve balance, muscle coordination, and overall quality of life when incorporated as complementary therapies (Bas *et al*., 2011).

Table 1. Evaluating exercise-based interventions in Adolescent Idiopathic Scoliosis

Study	Design	Sample	Intervention	Outcome
Kuru *et al*., 2016	Randomized controlled trial	Adolescents 10-18 years, AIS Cobb 10°-60°	Supervised Schroth vs home-based Schroth vs control	Supervised Schroth significantly improved Cobb angle, trunk rotation, hump height, and QoL
Romano *et al*., 2015	Controlled clinical study	AIS during growth period	SEAS vs conventional physiotherapy	SEAS improved Cobb angle, ATR, and reduced bracing requirement
Anwer *et al*., 2015	Meta-analysis	Multiple AIS studies	PSSE	Significant reduction in Cobb angle and trunk rotation, improved QoL
Negrini *et al*., 2009	Systematic review	AIS treated conservatively	Bracing + PSSE vs bracing alone	Combined treatment reduced surgery rate more effectively

Khaledi *et al*., 2022	Systematic review	AIS exercise studies	Schroth vs SEAS	Both effective; evidence slightly stronger for Schroth

CONCLUSION AND RECOMMENDATION

Adolescent idiopathic scoliosis (AIS) is a three-dimensional spinal deformity that develops during adolescence and may progress during the growth period, affecting spinal structure, neuromusculoskeletal function, postural balance, and quality of life. Accurate diagnosis relies on clinical evaluation combined with radiological assessment, with Cobb angle measurement remaining the gold standard for determining curve severity and guiding treatment decisions. Exercise plays a central role in the conservative management of AIS, particularly for patients with mild to moderate curves during active growth. Physiotherapeutic Scoliosis-Specific Exercises (PSSE), especially the Schroth and Scientific Exercise Approach to Scoliosis (SEAS) methods, are widely recommended by SOSORT due to their ability to promote three-dimensional spinal correction, improve neuromuscular control, and enhance postural stability. Additional supportive exercises, such as core strengthening and aerobic training, contribute to improved trunk stability, physical fitness, and functional capacity. The success of conservative treatment should not be evaluated solely by changes in the Cobb angle, but also by the ability to control curve progression, maintain postural balance, and improve long-term functional outcomes and quality of life. Therefore, it is recommended that exercise-based management for AIS be implemented through individualized, evidence-based rehabilitation programs under professional supervision, while future research should focus on high-quality comparative studies to further clarify the long-term effectiveness of different exercise approaches in AIS management.

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