AOTH

Review

Adolescent idiopathic scoliosis - therapeutic approaches

Stefania-Christina Arvanitaki, BSc PT

Msc in Rehabilitation Following Spinal Cord Lesions. Spinal Pain Management, Medical School, National and Kapodistrian University of Athens, Athens, Greece

Abstract

Adolescent Idiopathic Scoliosis (AIS) is the most common form of spinal deformity. The selection of an appropriate therapeutic approach remains crucial to prevent curve progression and to ensure patients' functionality and quality of life. This mini review article aims to comparatively evaluate the effectiveness of the main conservative and surgical treatment approaches for AIS, highlighting the advantages, limitations, and indications of each method. A thorough search of recent literature was conducted using PubMed, EBSCO Open Research, and Google Scholar, focusing on high-quality studies published within the last seven years, in order to capture the indications, effectiveness, and limitations of each therapeutic approach. In the field of conservative management, the review highlights the effectiveness of combined treatment regimens incorporating bracing and targeted exercise programs, such as the Schroth and SEAS methods, in stabilizing the spinal curve. The Schroth method emerges as the most well-documented therapeutic approach, followed by the SEAS and BSPTS methods. In contrast, the effectiveness of certain methods, such as FED, FITS, Lyon, DoboMed and Side Shift, has not been sufficiently substantiated. Furthermore, there is a lack of documented evidence supporting the superiority of any particular PSSE method, highlighting the need for further high-quality research. The present review indicates that PSIF is the main surgical option for AIS, while AVBT appears to be a promising alternative. Overall, the review demonstrates the effectiveness of conservative, surgical, and combined approaches in the management of AIS. However, future research involving long-term studies is necessary to adequately evaluate the long-term effectiveness of these interventions.

Keywords

Adolescent idiopathic scoliosis; conservative management; braces; physiotherapy; operative intervention

Corresponding author

Stefania-Christina Arvanitaki
steafania.arvanitaki@gmail.com

Introduction

This review article addresses the topic of Adolescent Idiopathic Scoliosis (AIS), with a particular focus on its therapeutic approaches. To compile the relevant literature, a systematic search was conducted across the electronic databases PubMed, EBSCO Open Research, and Google Scholar. Initially, the following search terms were used with the Boolean operator AND: "Adolescent Idiopathic Scoliosis AND Treatments," "Adolescent Idiopathic Scoliosis AND Bracing," "Adolescent Idiopathic Scoliosis AND Conservative Management," "Adolescent Idiopathic Scoliosis AND Operative Intervention," "Adolescent Idiopathic Scoliosis AND Physiotherapy," "Adolescent Idiopathic Scoliosis AND Criteria for Surgery," and "Adolescent Idiopathic Scoliosis AND Vertebral Body Tethering." The search was limited to studies published in English and yielded 7,787 open-access articles. Articles were excluded if they were irrelevant to the objectives of this review, contained duplicate data, or did not pertain to AIS, such as studies involving patients with other spinal disorders. Eligible studies included patients aged 10 years and older, diagnosed with AIS, with a Cobb angle greater than 10° and investigated any form of treatment. Eligibility for inclusion was assessed by a single reviewer. Relevant full-text articles, systematic reviews, and meta-analyses were retrieved and thoroughly examined. Additionally, the reference lists of the selected studies were screened for further relevant publications. Subsequently, full-text articles were excluded for specific reasons. A publication date restriction was applied, limiting the review to studies published from 2019 onward. Letters to the editor, animal studies, case reports, and case series were excluded.

AIS is a three-dimensional rotational deformity of the spine that primarily affects individuals between the ages of 11 and 18.[1] Its etiology remains unclear, as there is no evidence of congenital abnormalities, neuromuscular conditions, or syndromic disorders that could explain its onset.[2] However, recent studies have suggested potential associations with genetic mechanisms, hormonal fluctuations, such as altered estrogen levels, and various biochemical markers, including calmodulin, melatonin, vitamin D, and low bone mineral density. [1] AIS is commonly identified through the Adam's forward bend test and should be further evaluated using a scoliometer.[3] The severity of the spinal curvature is most reliably assessed by calculating the Cobb angle, which is the gold standard measurement. The Cobb angle is defined as the angle formed between lines drawn parallel to the superior endplate of the most tilted upper vertebra and the inferior endplate of the most tilted lower vertebra.[4] It can also be measured between perpendiculars to these lines and is typically obtained using anteroposterior radiographs of the spine.[4,5] Spinal curvatures ≤10° in the coronal plane are not classified as scoliosis. Curvatures of 11°–25°are categorized as mild, 25°–45° as moderate, and >45° as severe. The Cobb angle is essential in the clinical evaluation of AIS, as it guides individualized treatment planning and facilitates monitoring of curve progression and treatment response.[6] While mild scoliosis is typically asymptomatic, more severe curvatures (Cobb angle > 40°) may result in musculoskeletal pain, visible deformity, psychosocial impact, and, in some cases, impaired pulmonary function, potentially leading to decreased functional capacity or disability.[3] These consequences underscore the importance of a structured and individualized therapeutic approach tailored to each patient's needs.[2] As the development of scoliosis cannot be prevented, early detection is critical for initiating timely and appropriate therapeutic interventions.[7] Management strategies range from conservative approaches, such as bracing, physiotherapy, and targeted therapeutic exercises, to surgical procedures when indicated. Treatment decisions for AIS should be based on a comprehensive clinical assessment that considers both radiological parameters, such as curve type and Cobb angle and individual patient-related factors, including skeletal maturity, remaining growth potential, curve progression, and psychological and socioeconomic aspects.[2]

The primary research question addressed is: What is the most appropriate therapeutic approach for AIS, considering the severity and specific characteristics of each case? This review aims to investigate treatment approaches for AIS by evaluating their efficacy and clinical relevance.Through a comprehensive analysis of the literature and available clinical data, the objective is to identify optimal therapeutic strategies for the management of the condition. Furthermore, it examines the factors influencing treatment selection, highlighting the benefits and limitations of each intervention. Finally, the review aims to identify gaps in the current literature and propose directions for future research.

The structure of this paper is as follows: Chapter One outlines the fundamental characteristics of AIS, including its epidemiology, pathogenesis, risk factors for progression, and the Lenke classification system. Chapter Two focuses on diagnostic methods and the importance of early detection. Chapter Three analyzes various treatment approaches, emphasizing their effectiveness and the key factors influencing treatment decisions. Finally, chapter Four presents the conclusions and discusses perspectives for future research.

The study of AIS is of critical importance, as early diagnosis and appropriate therapeutic intervention can help to preserve functionality, prevent progression, and improve patient's quality of life.

Fundamental Characteristics of Adolescent Idiopathic Scoliosis

AIS is a three-dimensional rotational deformity of the spine that primarily affects adolescents between the ages of 11 and 18.[1] It is the most common type of scoliosis and is distinguished from other forms by the absence of congenital, neuromuscular or syndromic abnormalities.[3] In the context of diagnosis, AIS is characterized by lateral curvature of the spine in the coronal (frontal) plane, hypokyphosis (less than 10° of kyphosis) in the sagittal plane, and axial vertebral rotation in the transverse plane .[8] AIS significantly reduces the range of motion, impairing spinal function and pelvic alignment.[9] Axial rotation of the pelvis disrupts postural equilibrium, leading to uneven mechanical load distribution, which exacerbates the deformity and increases the risk of musculoskeletal complications, such as herniated discs and sciatica.[4,10,11] The location of the curve within the spine, type (C-shaped or S-shaped), and magnitude of the scoliotic curve are key determinants in the progression of deformity and in maintaining static and dynamic postural balance.[11,12] Thoracic curves with higher Cobb angles are more likely to progress compared to single lumbar or thoracolumbar curves, which typically show milder progression but are associated with compromised postural stability.[11,13] An earlier age of diagnosis is strongly correlated with a higher risk of curve progression, making adolescence a critical period for detection and intervention.[11] Without timely treatment, AIS may progress until skeletal maturity, potentially leading to severe deformity.[14] In scoliosis, the vertebrae remain in a fixed state of rotation, increasing torsional stiffness and altering the mechanical behavior of intervertebral discs. Disc elasticity plays a crucial role in their biomechanical response to external forces, thereby influencing disease progression.[15]

The Lenke classification system is the most widely used tool for evaluating and categorizing scoliosis in AIS and serves as a key guide for individualized treatment planning.[8]

The severity of scoliosis is primarily assessed using the Cobb angle, often in conjunction with the Angle of Trunk Inclination (ATI) and the Apical Vertebral Rotation (AVR).[16] The Cobb angle is essential for diagnosis, treatment planning, and follow-up.[7] A Cobb angle of less than 10° is not considered clinically significant and does not meet the criteria for scoliosis, while angles exceeding 30° are associated with increased health risks in adulthood.[5,6] Curvatures from 11° to 25° are classified as mild, from 25° to 45° as moderate, and those exceeding 45° as severe.[6] It has been observed that reducing the ATI has been associated with improved spinal stability and a lower risk of scoliosis progression.[6]

Individuals with AIS may experience postural imbalance, pain, reduced exercise tolerance, psychosocial distress, and discomfort during daily activities.[12,17] While mild scoliosis is often asymptomatic, more severe curves (Cobb angle>40°) are associated with pain, cosmetic deformities, respiratory impairment, and decreased quality of life.[3] In some cases, AIS may also be associated with osteoporosis. When a spinal curvature of 10° or more in the coronal plane is accompanied by an ATI greater than 3°, therapeutic intervention is typically recommended.[18]

Epidemiology and Prevalence

AIS represents the most common form of scoliosis, accounting for approximately 84% to 89% of all cases.[6] Epidemiological data indicate that the global prevalence of AIS among adolescents ranges from 0.47% to 5.2% , while its incidence in the general pediatric population is estimated at approximately 2% .[17,19] AIS primarily affects otherwise healthy adolescents, with a significantly higher prevalence in females. [14] The female-to-male ratio increases with age, reaching up to 8:1.[9] Furthermore, adolescent girls are at considerably higher risk for curve progression. Types of curves also differ by gender, with thoracolumbar and lumbar curves more common in boys and thoracic or double curves more frequently observed in girls.[7]

Mild scoliotic curves occur with a relatively high frequency in the adolescent population, whereas more severe deformities are less prevalent.[20] Curves with a Cobb angle greater than 10° are found in 1–3% of the population, those greater than 30° in 0.15–0.3%, and curves exceeding 40° in approximately 0.4% of adolescents aged 10–16 years.[3,20] AIS exhibits wide phenotypic variability. However, only a small proportion of cases require treatment.[21] Less than 10% of patients need therapeutic intervention and only 0.7–1% undergo surgery within five years of diagnosis.[8,19] In 2023, 75% of surgical procedures are performed exclusively via the posterior surgical approach, confirming its status as the standard method.[19] As a final point, AIS does not affect life expectancy, as mortality rates are comparable to those of the general population.[3]

Pathogenesis

Scoliosis is classified as idiopathic when no identifiable or well-defined underlying cause can be determined, a fact attributed to the complexity of its pathophysiological mechanism.[22] Its etiology remains unclear, as there is no evidence of congenital abnormalities, neuromuscular conditions, or syndromic disorders that could explain its manifestation.[2] However, recent studies has suggest potential associations with biomechanical and genetic mechanisms, hormonal fluctuations, such as altered estrogen levels, and various biochemical markers, including calmodulin, melatonin, vitamin D, and low bone mineral density.[1,9] Numerous single nucleotide polymorphisms (SNPs) have been linked to AIS, supporting a genetic predisposition.[9] Nevertheless, no consistent pattern of inheritance has been established.[3] Limited knowledge of its pathophysiological mechanisms hinders the development of targeted treatments for idiopathic scoliosis.[15]

Risk Factors

The main risk factors for scoliosis progression include female sex, a family history of severe scoliosis, early age of diagnosis (<12 years), and low skeletal maturity. Skeletal maturity is assessed using the Risser sign, with lower values indicating a higher risk of curve progression. The Risser sign is determined via pelvic radiography and is based on the ossification of the iliac apophysis, ranging from 0 to 5.[3]

Lenke Classification

The Lenke classification is the international standard for categorizing AIS, based on curve type, sagittal alignment, and rotational deformities. It aims to standardize classification and minimize the extent of spinal fusion, thereby guiding personalized surgical treatment.[8,23] The system identifies six primary types of scoliotic curves using standing anteroposterior and lateral radiographs, as well as supine side-bending radiographs. Curves are considered structural if they exceed 25° on bending films or if thoracic kyphosis is greater than 20° on the standing lateral radiograph, otherwise, they are classified as non-structural. Correction of the structural curve typically results in spontaneous correction of the non-structural curve.[8] The classification is based on identifying the largest curve using the Cobb angle and determining whether curves are structural or non-structural via bending radiographs. When the main thoracic (MT) curve is the largest, the classification corresponds to Lenke types 1 to 4, whereas if the thoracolumbar or lumbar (TL/L) curve is largest, it is classified as types 5 or 6. Lenke type 1 includes cases where only the MT curve is structural. In type 2, both the proximal thoracic (PT) and MT curves are structural. Type 3 includes structural MT and TL/L curves, while in type 4, all three curves (PT, MT, and TL/L) are structural. In type 5, only the TL/L curve is structural, and in type 6, both TL/L and MT curves are structural. Furthermore, lumbar modifiers (A, B, and C) describe the position of the central sacral vertical line (CSVL) relative to the apex of the lumbar curve, while sagittal modifiers ("–", "N", "+") are used to describe thoracic kyphosis between T5 and T12.[8]

Diagnostic Methods in AIS

AIS can be detected in asymptomatic adolescents through three primary clinical screening methods: the forward bending test (Adam's test), the scoliometer, and Moiré topography. The Adam's test demonstrates high sensitivity (92–100%) for thoracic deformities with Cobb angles greater than 20°, but is less reliable in detecting lumbar scoliosis. During the test, the patient stands upright and then bends forward with arms hanging and the spine parallel to the floor. The examiner observes the patient's back from behind, assessing for asymmetry or rib prominence that may indicate scoliosis (Fig. 1).[3] While Adam's test is considered a reliable diagnostic tool, its predictive accuracy may be affected by factors such as the patient's age, the size and location of the curve, spinal flexibility, and the examiner's experience, thus making early-stage detection more challenging.[16]

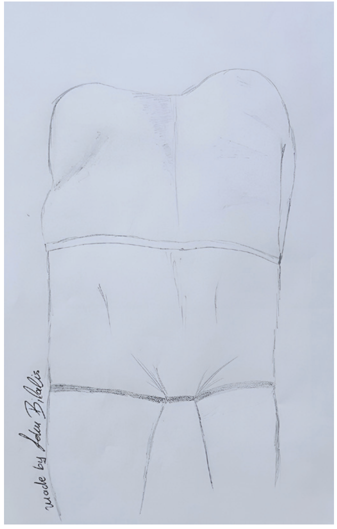

Figure 1.*Adam's Test*

The scoliometer is used to determine whether radiographic confirmation is warranted.[3] It measures the ATI, which correlates with the Cobb angle determined via radiographs. Referral for radiologic evaluation is generally recommended when ATI measures fall between 5° and 7°.[3] A Cobb angle less than 5° is considered within normal limits, whereas values greater than 7° suggest pathological scoliosis.[7] A change in Cobb angle of ≥5° is widely regarded as clinically significant.[4] Patients with the same ATI may exhibit different Cobb angles on radiographs, and vice versa. In children with normal body mass, an ATI of 7° approximately corresponds to a Cobb angle of 20°.[3] Notably, applying a 5° ATI referral threshold in children aged 6–12 years significantly enhances early detection of scoliosis. Although the predictive reliability of ATI is lower in younger children, it improves with age.[16] Additionally, the apical vertebral rotation (AVR), a critical component of the three-dimensional deformity, is also assessed via radiography. AVR is influenced by the sagittal alignment of the spine and the degree of ligamentous flexibility.[16]

Radiography imaging is indicated in adolescents presenting with a visible scoliotic curve, notable thoracic or lumbar asymmetries, a family history of scoliosis, or for monitoring progression in previously diagnosed cases.[3] The decision to initiate radiographic evaluation also depends on factors such as the patient's age, gender, body habitus, and the rate of curve progression.[16]

Moiré topography, though less commonly used, employs a specialized device that projects a topographic pattern onto the patient's back to visually detect asymmetries between the right and left sides, serving as an adjunctive tool in scoliosis screening.[3]

Therapeutic Approaches in Adolescent Idiopathic Scoliosis

The scoliotic curve progresses primarily during the adolescent growth spurt. Early diagnosis and treatment before skeletal maturity can slow or even reverse curve progression, thereby increasing the likelihood of successful non-surgical management.[3] In contrast, delayed intervention significantly reduces treatment effectiveness.[21] Management aims to halt or correct the deformity, while improving the biomechanical stability of the spine.[3,21] The treatment plan may include observation, conservative approaches such as bracing or therapeutic exercises, or surgical intervention.[2]

Patients with scoliotic curves between 10° and 25° are typically monitored with radiographic assessments at intervals of 3, 6, or 12 months, with physical therapy also recommended in these cases.[2,3] For curves between 25° and 45°, bracing is indicated. When the curve exceeds 40°–45° and skeletal maturity has not been reached, operative intervention may be considered, particularly in cases of documented progression or failure of conservative treatment.[2,19] Most surgical procedures are performed between the ages of 12 and 14.[19]

Conservative Management

The primary goal of conservative treatment in AIS is to halt the progression of the spinal curve, while also aiming to improve aesthetics and restore function.[15,21] When appropriately administered, conservative therapy may even lead to correction of the deformity.[15]

Braces

Brace treatment is the most widely used conservative method for halting the progression of spinal deformity in adolescents.[21] Its primary goal is to prevent the scoliotic curve from exceeding 50°, which typically indicates the need for surgical intervention, and from surpassing 40°, a threshold associated with an increased risk of progression in adulthood.[24] Long-term brace use has been linked to a reduced need for surgical treatment.[7] All types of orthoses aim to support and guide spinal growth by applying external mechanical correction, helping to maintain or improve alignment until skeletal maturity is reached.[7,14] Brace treatment requires adjustment during the initial weeks to ensure proper fit on the patient's body and typically begins when curve progression is observed or when the Cobb angle exceeds 30°.[14,25] It may also be effective for curves greater than 40°, although success is highly influenced by the duration of brace use and the patient's compliance.[15] Consistent brace use reduces the risk of curve progression and the likelihood of requiring surgical intervention. Additionally, skeletal maturity, the severity of rotational deformity, and the elastic properties of intervertebral discs are key factors in predicting treatment success.[15,26] Correction is achieved through mechanical forces that redistribute spinal loading, with the aim of stabilizing the spine until skeletal maturity is reached.[15] Treatment is considered complete once skeletal maturity is achieved, as the risk of further curve progression significantly decreases.[24] Treatment failure is defined as a curve progression greater than 6° or the need for surgery.[14]

On the other hand, brace treatment may lead to adverse effects, such as limitations in daily activities, reduced self-esteem, and compromised respiratory function.[4] Prolonged use without an appropriate exercise program may result in muscle weakness, stiffness, psychological distress, and reduced quality of life.[18,27] Since the impact on quality of life is mainly psychological, mental health support is essential. The combination of bracing protocols and structured exercise programs is recommended to enhance physical fitness and improve mental well-being.[26]

Orthotic braces are classified into two main categories. Passive braces, which stabilize the spine without applying corrective forces, and active braces, which exert targeted pressure to gradually correct spinal deformity.[25] Common types include the Progressive Action Short Brace (PASB), Lyon brace, Milwaukee brace, Boston brace (BB), Chêneau brace, SpineCor brace, and the Providence Nighttime Brace (PNB), which is specifically designed for nighttime use.[21] The PASB is a custom-made thoraco-lumbo-sacral brace used mainly for thoraco-lumbar and lumbar curves.[21] The Milwaukee brace extends from the neck to the pelvis.[25] The Boston brace is one of the most widely used and is designed to be worn discreetly under clothing. It applies targeted pressure to specific areas of the torso, promoting gradual correction while maintaining comfort and discretion.[25] The Chêneau brace, a customized and less conspicuous alternative to the Boston brace, applies asymmetrical corrective forces to guide the spine toward a more physiological alignment. It includes strategically placed expansion zones to achieve three-dimensional correction and supports guided growth through remaining skeletal maturity.[25] The SpineCor brace features elastic straps and a soft structure for comfort and discretion, though its clinical effectiveness remains controversial.[26] Full-time thoracic braces are preferred for younger patients with progressive, extensive, or rigid thoracic curves and are typically worn for 18–23 hours daily. However, therapeutic benefits have also been observed with daily use of approximately 12 hours. Nighttime braces are suited for skeletally mature patients, particularly those with lumbar or smaller curves, and are designed to reduce the psychosocial burden of treatment adherence.[14]

The study by Capek V et al. (2023)[14] compared 358 patients with AIS treated with either the PNB or the BB. The BB group demonstrated less curve progression and a lower surgical indication rate, particularly in premenarchal females and in cases involving thoracic curves or curves greater than 30°. Despite good compliance, the effectiveness of the PNB was limited.

In the study by Aulisa AG et al. (2019)[15], 160 patients with AIS greater than 40°, who refused surgical treatment, were treated with either a PASB or Lyon brace (worn 20–22 hours/day), depending on the type of curve. Significant reductions in Cobb angle and vertebral rotation were observed, with the most patients achieving curve correction. Conservative treatment was particularly effective, especially in cases where vertebral rotation was less than 20° and the Risser stage was between 0 and 2.

In a follow-up study by Aulisa AG et al. (2021)[21] on 163 patients with AIS who wore the PASB for 18–22 hours daily, a 15° reduction in curve magnitude was recorded in patients with curves both below and above 30°. At long-term follow-up (>10 years), only a slight 2° increase was observed, confirming the PASB's effectiveness in improving lumbar and thoracolumbar scoliosis and demonstrating positive long-term outcomes even in cases of moderate curvature.

The study by Alsiddiky AM et al. (2024)[25] evaluated 52 patients treated with either the Boston or Chêneau brace. No statistically significant difference in quality of life was found between the two groups, although patients using the BB reported greater treatment satisfaction and lower anxiety levels. No differences were observed in functional capacity, pain, self-image, or mental health. Additionally, prolonged brace use did not adversely affect anxiety or quality of life, supporting adherence to long-term conservative treatment.

Regarding brace weaning, both immediate and gradual discontinuation have been found to be equally effective in preserving treatment outcomes. However, gradual weaning prolongs the overall treatment duration and may be associated with adverse effects, such as reduced spinal mobility, muscle weakness, decreased bone mineral density, and deterioration of body image , all of which may negatively impact quality of life. Immediate discontinuation is recommended as the preferred approach, as it facilitates a faster return to physical activity and daily functioning. [24]

The study by Cheung PWH et al. (2024)[24] compared gradual brace weaning, including six months of nighttime use, with immediate brace discontinuation. No significant differences were found in Cobb angle changes, postural balance, or quality of life. Both protocols were equally effective in maintaining correction, while curve progression was more closely related to initial curve magnitude and skeletal maturity than to the weaning protocol itself.

Physiotherapy Approach: Therapeutic Exercises

Physiotherapy is recommended as the primary treatment for mild cases of AIS with a low risk of progression.[5] Exercise is considered a preferred intervention due to its low cost, minimal side effects, and positive impact on mental health, particularly in mild to moderate curves during the growth period.[27] Additionally, correcting pelvic rotation has been found to enhance therapeutic outcomes.[10]

Fahim et al. (2022)[7] demonstrated that a seven-week therapeutic exercise program can reduce

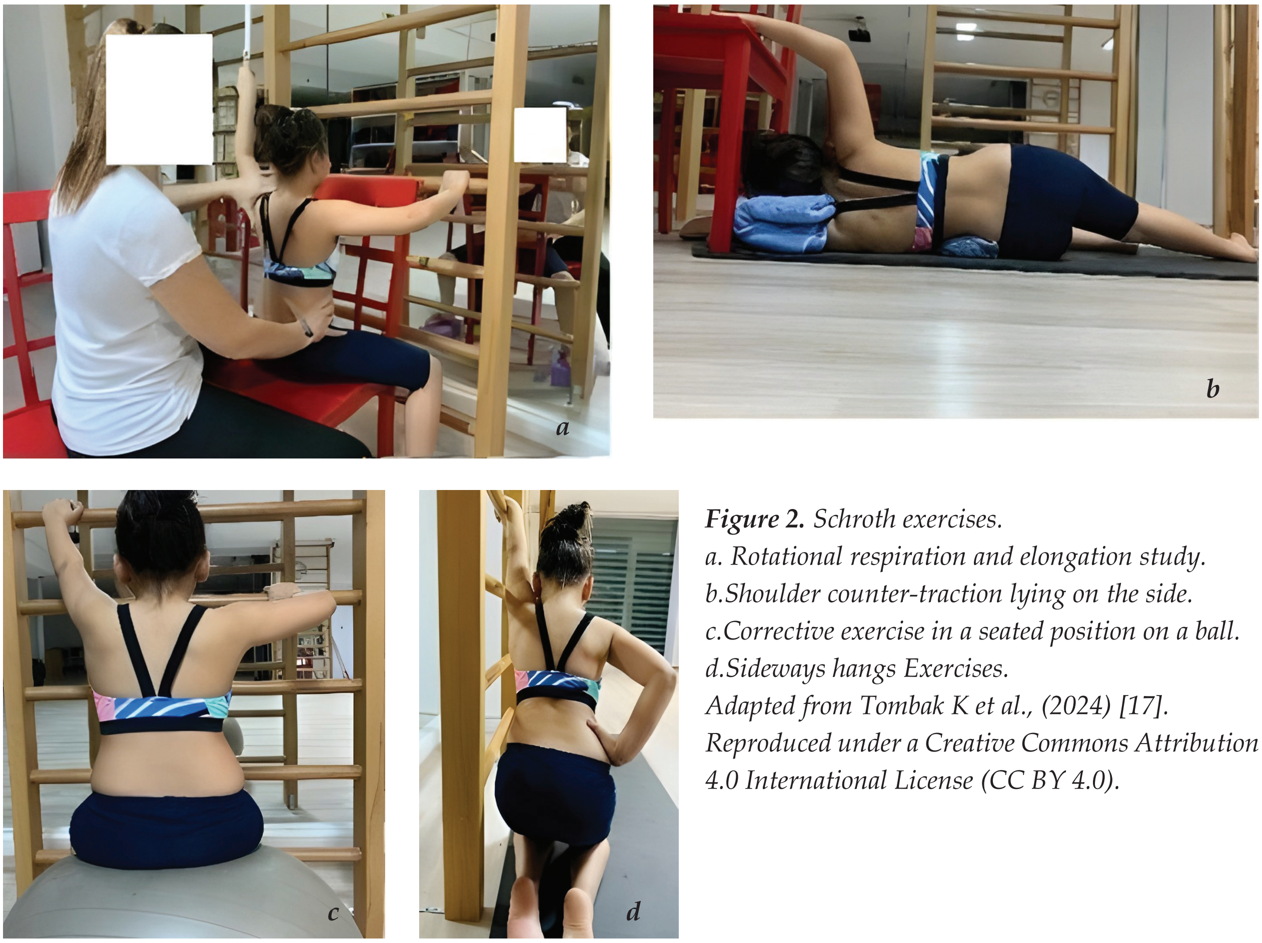

Figure 2. *Schroth exercises.*
a. Rotational respiration and elongation study.
b.Shoulder counter-traction lying on the side.
c.Corrective exercise in a seated position on a ball.
d.Sideways hangs Exercises.
Adapted from Tombak K et al., (2024) [17].
Reproduced under a Creative Commons Attribution 4.0 International License (CC BY 4.0).

the Cobb angle in AIS. The SEAS, Schroth, and CSEs methods are effective, with Schroth showing a slight advantage. The combination of exercise and bracing may be more effective, although prolonged brace use can negatively affect trunk function and muscle endurance.

Physiotherapeutic Scoliosis Specific Exercises (PSSE)

Targeted physiotherapy for AIS, such as the Schroth protocol, is the preferred conservative treatment for curves under 25°.[10] PSSE are individually tailored to assist patients in correcting their posture in three dimensions through stability and strengthening exercises.[6] Three-dimensional active self-correction refers to the patient's active effort to realign the trunk in all planes by utilizing their motor abilities, aiming to achieve correct posture and to apply corrective adjustments during daily activities.[22] Evidence supports the efficacy of PSSE in reducing or preventing further scoliosis progression, with a low risk of adverse effects.[5,10] Additionally, PSSE improves neuromotor control, respiratory function, aesthetic symmetry, and quality of life.[5,13]

The frequency of PSSE application varies according to the chosen method, patient needs, and adherence, ranging from 2 to 7 sessions per week. In Europe, there are eight main recognized PSSE schools, including the Scientific Exercise Approach to Scoliosis (SEAS), Barcelona Scoliosis Physical Therapy School (BSPTS), Side Shift, Lyon, Dobomed, Schroth, Functional Individual Therapy of Scoliosis (FITS), and Fixation-Elongation-Derotation (FED). The FITS method focuses on restoring myofascial restrictions and applying corrected postures during daily movements. The FED method utilizes a specialized mechanotherapeutic device to deliver targeted corrective forces for scoliosis adjustment.[22]

Khaledi A et al. (2021)[8] demonstrated that PSSE are more effective than general exercises (such as respiratory and core strengthening exercises), which not only target the management of AIS but also address other spinal deformities, including kyphosis and lordosis.

Seleviciene V et al. (2022)[22] found that PSSE can stabilize or reduce scoliosis deformity. Among the methods evaluated,only the Schroth method significantly decreased the ATR. The Schroth, SEAS, and BSPTS methods proved effective in reducing the Cobb angle and improving spinal alignment. Moreover, the Schroth and SEAS methods demonstrated significant improvements in quality of life, especially in functional capacity and mental well-being.

The study by Gao et al. (2019)[28] demonstrated that combining of PSSE with bracing results in greater improvements in Cobb angle, muscle strength, and pulmonary function compared to bracing alone, which was associated with reduced muscle endurance and pulmonary capacity.

Schroth Exercises

The Schroth method for patients with AIS improves muscle function and vital capacity and reduces scoliotic deformities by improving both the Cobb angle and trunk rotation.[10,17] As a result, it contributes to body symmetry and posture correction.[17] Correction is achieved through a combination of passive and active interventions.[18] The approach is based on asymmetric isometric exercises combined with specialized breathing techniques and proprioceptive training, aiming to achieve three-dimensional spinal alignment and the restoration of a normal respiratory pattern.[10,11,17] These improvements enhance quality of life and reduce the need for surgical intervation.[17] Schroth therapy targets muscles that have developed asymmetrically due to scoliosis and emphasizes the retraining of breathing patterns through self-observation and feedback techniques.[12,17] It includes specific posture and gait correction exercises, that use aids such as mirrors, rice bags, pull-up bars, rods, and balance balls to promote proper alignment and enhance visual feedback (Fig.2a-d).[17] In the Schroth method, the correction of movement patterns during daily activities is a central goal.[6] The design of individualized exercise programs depends on pelvic orientation, relative to thoracic or lumbar curves, and precise identification of the type and number of scoliotic curves.[6,17]

Schroth programs are typically implemented through one-on-one sessions with a physiotherapist, which enhance self-esteem and body awareness. Alternatively, they can be performed at home for reduced cost and convenience, or used as a complementary approach alongside orthotic bracing. However, supervised implementation is not always feasible due to limited access to qualified therapists, appropriate equipment, or proximity to treatment centers.[12] The effectiveness of home-based exercises is sometimes questioned, since the absence of supervision may impact both proper execution and adherence. Nonetheless, both methods can be effective when properly applied and regularly monitored by a specialist.[17] Clinical settings are considered more suitable for optimal outcomes, as the method requires expert instruction and technical precision.[18] It is emphasized that a personalized approach facilitates the integration of therapeutic strategies into everyday life.[17]

Ceballos-Laita L et al. (2023)[6] found that the Schroth method, when applied as a standalone intervention, significantly improved the Cobb angle, ATI, and quality of life, compared to other treatments or to no intervention.

Abdel-Aziem AA et al. (2021)[11] showed that combining equine therapy with Schroth exercises is more effective than Schroth exercises alone in improving symmetry, posture, kyphotic and rotational spinal deformities, pelvic rotation, and dynamic balance among adolescents with AIS.

Fan Y et al. (2021)[13] demonstrated that applying the Schroth exercise protocol, combining supervised sessions with home exercises for 40 patients, led to a reduction in the Cobb angle and stabilization of scoliosis over a two-year period, regardless of the main curve location.

Tombak K et al. (2024)[17] assessed 37 patients aged 10–16 years with incomplete skeletal maturity, comparing supervised Schroth exercises to a home-based program over a three-month period. Both groups performed daily exercises with progressively increasing repetitions. Following the intervention, both groups demonstrated significant reductions in ATI, as well as improvements in quality of life and body image, confirming therapeutic efficacy of the Schroth method.

Khaledi A et al. (2024)[18], through a systematic review, confirmed a significant reduction in Cobb angle in patients with AIS following the Schroth method.

Seleviciene V et al. (2022)[22] concluded that the Schroth method significantly reduces the ATI and markedly improves quality of life in patients with AIS.

Scientific Exercise Approach to Scoliosis (SEAS)

The SEAS method was initially developed based on the Lyon approach and gradually evolved into a non-invasive treatment focused on active self-correction.[12,22] It aims to enhance muscle endurance, motor control, balance, and posture through functional exercises, primarily performed at home. The program consists of individualized sessions lasting approximately 40 minutes, recommended at a frequency of at least twice per week.[12] SEAS promotes patient autonomy and aims to correct functional deficits such as muscle weakness and coordination disorders.[12,22]

Fahim T et al. (2022)[7] reported that SEAS method is more effective than conventional physiotherapy in improving the Cobb angle and preventing curve progression associated with brace use, which may adversely affect trunk muscle function and endurance.

Seleviciene V et al. (2022)[22] concluded that the SEAS method is effective in stabilizing spinal deformities and, in some cases, in reducing the Cobb angle, while also significantly improving quality of life in patients with AIS.

Dobosiewicz method (Dobomed), Side-shift Program, Lyon Method and BSPTS Method (Barcelona Scoliosis Physical Therapy School)

The DoboMed technique is utilized preoperatively or as part of conservative treatment in combination with bracing, although it may also be implemented as a standalone intervention.[12] Its primary objective is to correct spinal deformities and restore symmetry of the pelvis and shoulders. The approach incorporates external visual feedback to promote thoracic kyphosis and lumbar lordosis, alongside specific breathing techniques designed to facilitate three-dimensional mobilization of the thorax.[12,22]

The Side-shift method serves as a complementary treatment for the management of AIS. It integrates breathing techniques similar to those used in the Schroth and DoboMed methods, along with lateral trunk shifts toward the concave side of the spinal curve. This approach aims to correct scoliosis through weight transfer and active patient engagement.[12]

The Lyon method is a complementary therapeutic approach, typically employed in conjunction with orthopedic bracing, which constitutes the primary component of treatment. It emphasizes core stabilization and the enhancement of proprioception and balance. The method deliberately avoids spinal extension, while promoting thoracic kyphosis and lumbar lordosis. The program includes three-dimensional mobilization of the spine and sacroiliac region, alongside patient education focused on proper posture and the development of proprioceptive awareness.[22]

The BSPTS method is derived from the Schroth approach and focuses on comprehensive three-dimensional postural correction through isometric contractions, controlled breathing, and selective muscle activation. It integrates cognitive, sensory, and kinesthetic strategies to improve posture, respiratory function, and motor control, with a strong emphasis on incorporating these corrections into daily activities.[22]

Core-stabilization exercises (CSEs)

CSEs have emerged as an effective therapeutic approach for managing AIS, as they contribute to improved spinal alignment and stability, while helping to restore the unequal distribution of mechanical loads on the vertebrae. CSEs also facilitate neuromuscular function of paraspinal muscles and enhance spinal mobility. The method consists of four stages of segmental stabilization. It begins with targeted manual contact

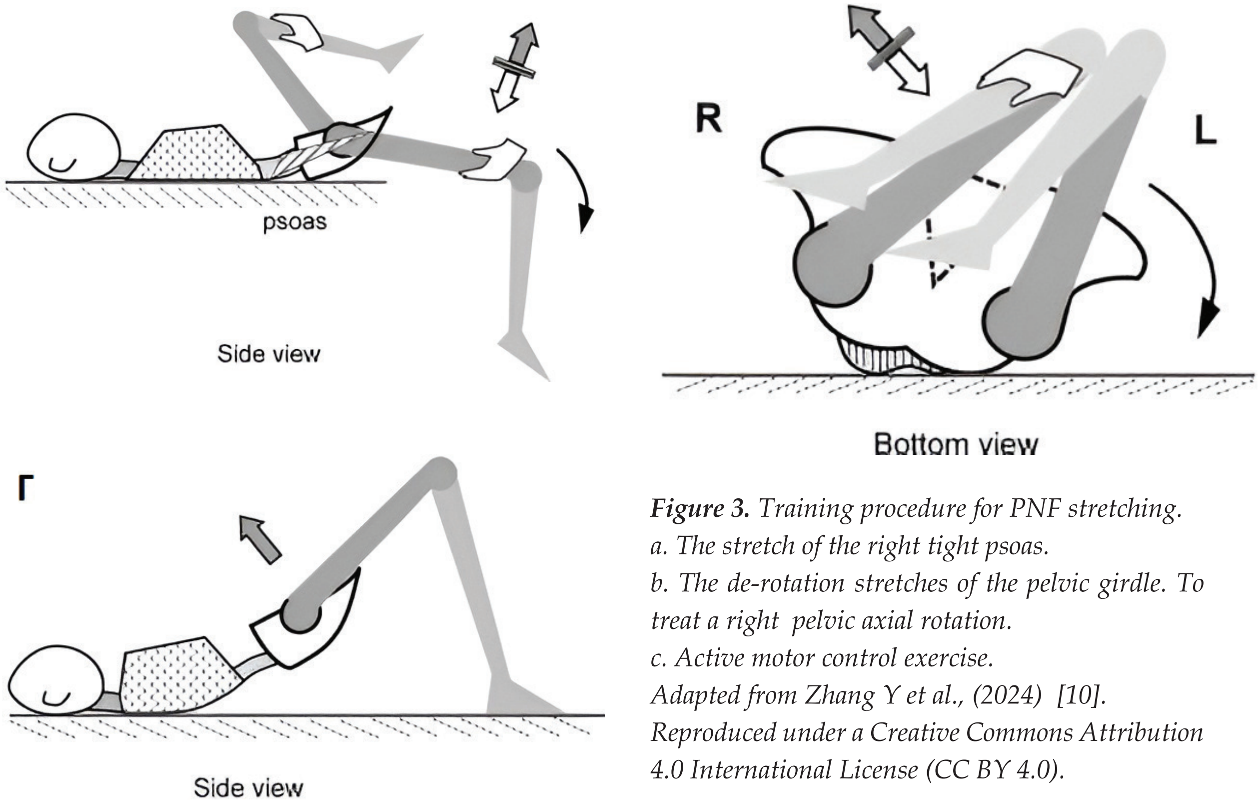

Figure 3. Training procedure for PNF stretching.
a. The stretch of the right tight psoas.
b. The de-rotation stretches of the pelvic girdle. To treat a right pelvic axial rotation.
c. Active motor control exercise.
Adapted from Zhang Y et al., (2024) [10].

applied to the transverse process on the convex side of the spinal curve, followed by joint mobilization to restore neutral alignment of the spinal segments. This is followed by active stabilization, during which the patient's guided participation is encouraged. The final phase involves sensorimotor training, aimed at improving postural control and dynamic balance through controlled external perturbations.[4]

Won SH et al. (2021)[4] investigated the long-term effects of CSEs in adolescents with lumbar scoliosis. Participants were divided into two groups: the experimental group followed a supervised CSEs program three times per week for six months, while the control group performed home-based stabilization and strengthening exercises. Both groups exhibited improvements in Cobb angle. However, the experimental group demonstrated a more significant and sustained reduction at the 12- and 18-month follow-ups, supporting the long-term effectiveness of the intervention.

Proprioceptive Neuromuscular Facilitation (PNF)

The PNF technique, which utilizes diagonal and rotational movement patterns, contributes to improved trunk–pelvis alignment in individuals with AIS. The therapeutic protocol includes stretching of shortened pelvic muscles to restore muscular balance, correction of pelvic axial rotation, and motor control exercises aimed at enhancing dynamic stability and functional alignment (Fig.3a-c). Pelvic axial rotation, which is closely associated with the three-dimensional spinal deformities obesrved in AIS, represents a key target for individualized and goal-oriented therapeutic interventions[10]

Zhang Y et al. (2024)[10] evaluated the efficacy of a combined PNF and Schroth intervention in 42 adolescents with mild idiopathic scoliosis. The group receiving the combined therapy demonstrated greater improvements in Cobb angle, pelvic rotation, trunk rotation, apical vertebral rotation, and self-image compared to the Schroth-only group, although the differences were relatively minor.

Operative Intervention

Patients with scoliosis exceeding 40–45° prior to skeletal maturity are at an increased risk of curve progression and often require surgical intervention.[2] The primary objectives of surgery are to correct spinal deformity, restore spinal and pelvic balance, and achieve stable arthrodesis, while also improving trunk symmetry and minimazing complications.[20,29] Accurate assessment of spinopelvic alignment is essential for optimal surgical planning. However, favorable outcomes are not always guaranteed, particularly in cases of mild scoliosis. [4,10] Additionally, the invasive nature of surgical treatment raises concerns regarding postoperative pain and prolonged recovery periods.[4]

The posterior surgical approach is the most commonly employed technique for treating AIS, whereas the anterior approach is primarily reserved for thoracolumbar and lumbar curves, although its application is limited due to potential respiratory complications. To overcome these limitations,less invasive techniques such as thoracoscopic and video-assisted surgery have been developed to improve surgical access.[29] Regardless of the chosen approach, all surgical procedures carry a risk of intraluminal neurological injury. To mitigate this risk and monitor spinal cord integrity, intraoperative neuromonitoring using transcranial motor evoked potentials (TcMEPs) is employed. A loss of TcMEP signals restricted to the lower limbs indicates a surgical cause, while global signal loss is attributed to anaesthetic factors. Neuromonitoring allows for immediate intraoperative adjustments, and in cases of persistent deficits, staged surgical procedures are recommended.[30]

Chan A et al. (2021)[30] evaluated surgeon-directed intraoperative neuromonitoring in 142 scoliosis correction surgeries. The absence of postoperative neurological deficits confirmed the reliability of the method and validated the loss of TcMEP signals as a precise predictor of intraoperative neurological risk.

Barone G et al. (2023)[19] conducted a long-term follow-up study involving 63 patients with AIS who underwent spinal fusion, with an average follow-up duration of 31.9 years. One group received spinal fusion without implants, while the other underwent fusion with internal osteosynthesis. Although the implant group exhibited a higher rate of reoperations, no significant differences were observed between the groups in terms of long-term quality of life, pain levels, or functional outcomes. Notably, implant-free procedures were more frequently associated with long-term degenerative changes, whereas implant-based surgeries tended to result in early postoperative complications. Despite these distinctions, both groups reported overall satisfaction and a return to physical activity, suggesting that either surgical approach may provide satisfactory long-term functional results.

Chen L et al. (2020)[29] assessed the safety and effectiveness of various surgical techniques in 1,970 patients with AIS. Posterior spinal fusion (PSF) yielded the greatest improvement in pulmonary function and was associated with the lowest complication rate. Video-assisted thoracoscopic anterior spinal fusion (VAT) achieved the most effective correction of the Cobb angle due to its minimally invasive nature. However, its success requires specialized surgical expertise. For severe deformities, a combined anterior and posterior fusion (ASF + PSF) is recommended for its high corrective capacity. In contrast, wedge thoracotomy (WT) is generally discouraged, as it has been linked to postoperative declines in pulmonary function.

In addition, the postoperative period represents a critical phase in the rehabilitation of patients with AIS. Effective perioperative care encompasses pain control, prevention of complications, progressive mobilization, and psychological support. Beyond conventional approaches,, the Enhanced Recovery After Surgery (ERAS) protocol has been developed as an optimized perioperative pathway designed to reduce surgical stress and accelerate recovery. This protocol incorporates evidence-based interventions, including the administration of tranexamic acid, controlled hypotension, and multimodal analgesia.[31]

Ding H et al. (2022)[31] conducted a study involving 90 patients with AIS who underwent PSF. Half of the participants received conventional perioperative care, while the other half followed the ERAS protocol. Although there were no significant differences in baseline characteristics between the groups, the ERAS group demonstrated higher hemoglobin levels, reduced intraoperative blood loss, less postoperative pain, earlier mobilization, shorter hospital stays, and fewer blood transfusions, highlighting the superiority of this optimized approach.

Posterior Spinal Instrumentation and Fusion (PSIF)

PSIF is the standard treatment for severe cases of AIS, offering spinal stability and reducing the risk of pseudoarthrosis.[29,32] However, it is associated with several drawbacks, including increased intraoperative blood loss, postoperative pain, risk of infection, and aesthetic limitations.[20] The extensive surgical exposure and the considerable length of the spinal fusion can significantly limit spinal ROM, potentially impeding a full return to physical activity.[9,19] Over the long term, this reduced mobility may contribute to degenerative changes in adjacent intervertebral discs.[32]

In this surgical approach, there is ongoing debate regarding the optimal selection of the lowest instrumented vertebra (LIV) in spinal fusion.[23] The degree of postoperative mobility loss is closely related to both the chosen LIV and the surgical technique employed.[9] The Lenke classification system guides the extent of fusion, depending on scoliosis type.[8] For Lenke 5C and 6C curves, when the criteria for fixation at L3 are not fully met, fixation at O4 has been shown to be beneficial. This strategy helps preserve partial mobility of the L3/L4 disc, supports deformity correction, and enhances functional recovery.[23]

Yang JH et al. (2021)[23] evaluated 36 patients who underwent PSIF with temporary fixation at L4. Improvements were observed in Cobb angle and coronal balance. Additionally, reductions in L3–S1 lordosis and L3–L4 disc mobility were noted. However, a lower LIV was associated with an increased risk of complications and functional deterioration.

Minimally Invasive Scoliosis Surgery (MISS)

MISS is recommended for mild and flexible scoliosis curves, aiming to reduce complications associated with PSIF. MISS offers advantages such as smaller incisions, less soft tissue disruption, reduced intraoperative blood loss, and faster postoperative recovery. However, it requires advanced surgical expertise and greater reliance on intraoperative imaging, which results in increased radiation exposure.[20]

Alhammoud A et al. (2021)[20] compared MISS and PSIF in 107 patients with AIS. MISS achieved comparable curve correction in Lenke 5C curves but was less effective in Lenke 1-4. No significant differences were found between the groups in postoperative pain, length of hospitalization, complications or reinterventions. However, MISS was associated with significantly lower blood loss but required a longer operative time.

Anterior Vertebral Body Tethering (AVBT)

AVBT is a less invasive alternative that preserves spinal mobility and harnesses the patient's remaining growth to achieve gradual, dynamic correction of the deformity.[32]

O'Donnell et al. (2023)[32] compared AVBT and PSIF in adolescents with severe AIS over a six-week postoperative period. The AVBT group demonstrated significantly reduced pain, faster functional recovery, improved mobility, and more rapid attainment of daily functional milestones, compared to the PSIF group.

Ponte Osteotomies (POs)

Corrective spinal surgeries are frequently accompanied by iatrogenic hypokyphosis, a condition that elevates the risk of degenerative disc disease and cervical kyphosis. This complication is often attributed to overly aggressive correction techniques or the exclusive use of pedicle screws, underscoring the importance of careful treatment planning and selection.[33] Ponte osteotomies are effective in restoring thoracic kyphosis (TK) in hypokyphotic patients, but they are associated with increased risks, including higher complication rates and greater blood loss. Therefore, careful selection of appropriate indications is essential. This technique enhances TK and overall spinal alignment, thereby reducing the likelihood of iatrogenic hypokyphosis.[33]

Faldini C et al. (2024)[33] reported that POs significantly improved TK in hypokyphotic patients (TK <10°). However, in patients with normal TK (10°–

Table 1. Results of a systematic review by Faldini C et al. (2024) [33].					
	Mean Change in TK	Frontal Plane Deformity Correction Rate	Mean Operative Time	Mean Blood Loss	Complication Rate
Group with POS	−5,5° to 18,9°	62,0% to 84,0%	236 to 368,2 min	619,7 to 1141 mL	3,1% to 34,2%
Group without POS	−18,6° to 13,5°	58,7% to 83,0%	187 to 339,8 min	723 to 979,8 mL	0% to 6,1%

40°), no benefit was observed and POs may even aggravate the deformity. No differences were found in coronal plane correction between groups. Notably, the non-POs group experienced reduces blood loss and shorter operative time (Table 1).

In conclusion, POs may significantly improve TK in patients with hypokyphotic scoliotic curves, potentially outweighing associated risks. However, their use is not recommended in mild, flexible curves with normal TK.[33]

Discussion

The aim of this review was to evaluate the effectiveness and suitability of current therapeutic approaches for AIS, as well as to explore the factors influencing treatment selection. Given the multidimensional and complex pathogenesis of AIS, its precise etiology and natural progression remain incompletely elucidated and continue to be subjects of ongoing scientific investigation. The present review highlights the broad spectrum of treatment approaches for AIS, ranging from conservative to surgical interventions, and emphasizes the importance of individualized treatment planning based on the patient's age, curve severity, and skeletal maturity. The findings indicate that early diagnosis and intensive conservative management can slow curve progression, thereby increasing the likelihood of avoiding surgery and improving long-term treatment outcomes. Conversely, while surgery remains indispensable for advanced cases, it carries significant risks, including neurological complications, infections, and blood loss and is associated with a prolonged recovery period.[13,22]

Conservative treatments, such as Schroth or SEAS exercises and bracing, have been shown to effectively stabilize or even reduce scoliotic curves, particularly in mild cases when detected early and patient compliance is high. Bracing is typically indicated for curves measuring between 25° and 40–45°, while surgical intervention is generally recommended for more severe curves (>40°) in skeletally immature patients. However, emerging evidence suggests that certain patients with curves exceeding 45° may still derive benefit from conservative management, although additional research is needed to substantiate this approach. [2,3,15,19]

In the realm of conservative treatment, orthotic bracing is primarily employed to prevent the progression of the scoliotic curve until skeletal maturity is reached.[7] Its effectiveness largely depends on the duration of use and the patient's level of compliance.[21,25] Compliance, in turn, is influenced by quality of life. However, few studies have explored the relationship between brace type and quality of life, highlighting the need for further investigation. A variety of braces are available, including passive, active, and night-time braces, with each type selected based on the specific characteristics of the spinal deformity.[25] The efficacy of the SpineCor brace remains controversial, and additional research is needed to clarify its therapeutic value.In contrast, the PASB has demonstrated strong clinical efficacy, while studies suggest that the BB is more effective than the nighttime PNB, particularly in patients with thoracic curves and Cobb angles exceeding 30°.[14,21] Notably, patients using the BB report lower levels of psychological distress compared to those wearing the Chêneau brace, despite the BB's greater visibility.[25] This underscores the multifactorial nature of treatment success and highlights the importance of brace design, psychological support, and patient education in optimizing treatment efficacy. The study by Cheung PWH et al. (2024)[24] demonstrated that both gradual and immediate discontinuation of bracing are effective, with immediate cessation offering the benefit of a faster return to daily activities. Finally, combined therapy involving bracing and targeted exercise programs such as Schroth or SEAS appears to enhance treatment outcomes. Nevertheless, further high-quality studies are required to substantiate the long-term efficacy of bracing in the management of AIS.[7,28]

Therapeutic exercise is a preferred and cost-effective intervention for managing AIS, with minimal risk of side effects.[7] It has been demonstrated to significantly reduce the Cobb angle, while also improving neuromuscular control, respiratory function, and quality of life.[5,7,13,22] Among PSSE methods, Schroth, SEAS, and BSPTS are supported by substantial scientific evidence, whereas FED, FITS, Lyon, DoboMed, and Side Shift currently lack adequate data to substantiate their effectiveness.[13,22] The combination of hippotherapy with Schroth exercises shows promise. However, further research with long-term follow-up is necessary.[11] Currently, there is insufficient evidence to conclusively establish the superiority of any single method over others and direct comparative studies among the various approaches are lacking. This highlights the need for more rigorous research to guide the development of clinical guidelines for therapy selection. Additionally, CSEs are simple to implement and have demonstrated significant improvements in the Cobb angle, although Schroth exercises yield faster and more efficient results.[4,18] NST may also be beneficial, but its long-term efficacy warrants further investigation.[4] Finally, PNF, particularly when combined with Schroth exercises, appears to enhance trunk balance in patients with AIS.[10]

In the surgical treatment of AIS, intraluminal neurological damage is a potential risk. Surgeon-directed intraoperative neuromonitoring is instrumental in mitigating the risk of such complications by enabling the immediate detection of neurological changes and facilitating prompt intervention. However, improved documentation and evaluation of signal loss incidents and subsequent interventions are warranted.[30] Furthermore, research has demonstrated that surgical techniques without osteosynthesis are primarily associated with long-term degenerative changes, whereas those incorporating implants entail a higher risk of early postoperative complications and a potential need for reoperation.[19] This highlights the importance of individualized selection of the surgical approach. Spinal fusion remains the standard technique for the treatment of AIS, with the choice of the LIV being a critical determinant of long-term outcomes and postoperative function.[29] The optimal selection of the LIV remains a subject of ongoing debate, as it significantly affects long-term spinal alignment and functional results.[23] Studies have identified PSF as the preferred approach owing to its low complication rates and minimal impact on pulmonary function, in contrast to ASF and WT, which have been associated with adverse respiratory effects. In severe cases, a combined ASF and PSF approach is recommended, while VAT procedures require highly specialized surgical expertise.[29] Although the traditional PSIF technique is widely utilized, it has been linked to increased surgical risk, postoperative pain, and reduced spinal mobility, potentially contributing to long-term degenerative changes.[20,32] The optimal selection of the LIV remains a subject of ongoing debate, as it significantly affects long-term spinal alignment and functional results.[23] As demonstrated by a comparative study, AVBT represents a less invasive alternative, offering benefits such as reduced postoperative pain, enhanced spinal mobility, and accelerated recovery, while MISS has emerged as a suitable option for less severe deformities. However, concerns regarding increased radiation exposure and its limited applicability in complex cases require further investigation.[20,32] Finally, the use of POs in hypokyphotic scoliotic curves has been shown to significantly improve thoracic kyphosis, despite potential risks such as increased intraoperative bleeding.[33] The considerable variability in surgical techniques and materials underscores the need for standardization to enhance the reliability of clinical studies and the overall effectiveness of therapeutic interventions.

Limitations of the Study

This review has certain methodological limitations, including temporal and language restrictions in the literature search, heterogeneity in intervention durations, and small sample sizes in several studies. These factors limit the interpretation of the findings and the generalizability of the conclusions.

Conclusions

AIS is a complex musculoskeletal disorder requiring multifactorial assessment and an individualized therapeutic approach. The present study emphasizes the significance of early diagnosis in improving long-term treatment outcomes and highlights the need for extended research, given the prolonged duration of therapeutic interventions. The findings indicate that, in cases of mild to moderate curvature, conservative management, comprising orthotic bracing and therapeutic exercises, offers significant benefits, particularly when implemented consistently and under regular supervision. Nonetheless, the effectiveness of such interventions in curves exceeding 40° remains contentious and warrants further high-quality investigation.

Orthotic braces are classified as passive or active, with selection determined by patient's individual needs. The BB has demonstrated greater effectiveness compared to the PNB, particularly in thoracic curves and Cobb angles greater than 30°, while the therapeutic value of the SpineCor brace remains controversial. Further research is required to elucidate the effects of brace design, psychological support, and patient education on treatment adherence. Additionally, comparative studies evaluating the impact of different braces on quality of life remain insufficient. Immediate discontinuation of bracing may be preferable, as prolonged use can result in trunk muscle weakening. Finally, combining bracing with targeted exercises appears to enhance treatment effectiveness.

Therapeutic exercise is a preferred intervention for managing AIS due to its low cost and minimal side effects, with the Schroth method demonstrating the most robust evidence base. SEAS and BSPTS have also shown efficacy in reducing the Cobb angle, whereas other methods (FED, FITS, Lyon, DoboMed, Side Shift) currently lack sufficient scientific support. High-quality studies employing standardized intervention protocols are necessary to determine their comparative effectiveness. While CSEs are simple to implement, Schroth exercises appear to yield faster outcomes. Also, NST shows promise but requires further investigation. Finally, the combination of PNF and Schroth exercises appears to enhance postural balance restoration.

Surgical intervention is indicated for severe or progressive curves exceeding 40° in skeletally immature patients but entails risks such as complications and reduced postoperative spinal mobility. PSIF emerges as the standard approach. However, it is associated with decreased spinal mobility and the development of degenerative lesions.. Further high-quality research is needed to determine the optimal LIV. AVBT addresses these limitations more effectively, whereas ASF and WT are linked to respiratory complications and therefore are not recommended. Additionally, VAT requires further investigation. The effectiveness of MISS in severe deformities and concerns regarding radiation exposure also warrant further research. POs appear beneficial in hypokyphotic curves. In conclusion, early conservative intervention may reduce the need for surgical treatment, highlighting its importance in the holistic management of AIS. Future research should focus on evaluating therapeutic approaches using larger sample sizes and standardized intervention protocols.

Conflicts of Interest

The authors declare no conflicts of interest.

References

1. Addai D, Zarkos J, Bowey AJ. Current concepts in the diagnosis and management of adolescent idiopathic scoliosis. Childs Nerv Syst. 2020;36(6):1111–1119. doi:10.1007/s00381-020-04608-4. PMID: 32314025; PMCID: PMC7250959.
2. Menger RP, Sin AH. Adolescent Idiopathic Scoliosis. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2024. PMID: 29763083.
3. Kuznia AL, Hernandez AK, Lee LU. Adolescent Idiopathic Scoliosis: Common Questions and Answers. Am Fam Physician. 2020;101(1):19–23. PMID: 31894928.
4. Won SH, Oh DW, Shen M. An 18-month follow-up study on the effect of a neuromuscular stabilization technique on Cobb's angle in adolescent idiopathic scoliosis: A single-blind, age-matched controlled trial. J Back Musculoskelet Rehabil. 2021;34(1):87–93. doi:10.3233/BMR-191559. PMID: 32986652.
5. Liu D, Yang Y, Yu X, Yang J, Xuan X, Yang J, et al. Effects of specific exercise therapy on adolescent patients with idiopathic scoliosis: A prospective controlled cohort study. Spine (Phila Pa 1976). 2020;45(15):1039–1046. doi:10.1097/BRS.0000000000003451. PMID: 32675606; PMCID: PMC7373466.
6. Ceballos-Laita L, Carrasco-Uribarren A, Cabanillas-Barea S, Pérez-Guillén S, Pardos-Aguilella P, Jiménez Del Barrio S. The effectiveness of Schroth method in Cobb angle, quality of life and trunk rotation angle in adolescent idiopathic scoliosis: A systematic review and meta-analysis. Eur J Phys Rehabil Med. 2023;59(2):228–236. doi:10.23736/S1973-9087.23.07654-2. PMID: 36692412; PMCID: PMC10170402.
7. Fahim T, Virsanikar S, Mangharamani D, Khan SN, Mhase S, Umate L. Physiotherapy interventions for preventing spinal curve progression in adolescent idiopathic scoliosis: A systematic review. Cureus. 2022;14(10):e30314. doi:10.7759/cureus.30314. PMID: 36381707; PMCID: PMC9650952.
8. van Royen BJB. Understanding the Lenke Classification for Adolescent Idiopathic Scoliosis (AIS). Curr Probl Diagn Radiol. 2023;52(4):233–236. doi:10.1067/j.cpradiol.2023.01.003. PMID: 36774215.
9. Mehkri Y, Hernandez J, McQuerry JL, Carmona J, Ihnow S. Global spine range of motion in patients with adolescent idiopathic scoliosis before and after corrective surgery. Cureus. 2021;13(11):e19362. doi:10.7759/cureus.19362. PMID: 34909319; PMCID: PMC8653949.
10. Zhang Y, Chai T, Weng H, Liu Y. Pelvic rotation correction combined with Schroth exercises for pelvic and spinal deformities in mild adolescent idiopathic scoliosis: A randomized controlled trial. PLoS One. 2024;19(7):e0307955. doi:10.1371/journal.pone.0307955. PMID: 39078854; PMCID: PMC11288462.
11. Abdel-Aziem AA, Abdelraouf OR, Ghally SA, Dahlawi HA, Radwan RE. A 10-week program of combined hippotherapy and Schroth's exercises improves balance and postural asymmetries in adolescence idiopathic scoliosis: A randomized controlled study. Children (Basel). 2021;9(1):23. doi:10.3390/children9010023. PMID: 35053648; PMCID: PMC8774272.
12. Day JM, Fletcher J, Coghlan M, Ravine T. Review of scoliosis-specific exercise methods used to correct adolescent idiopathic scoliosis. Arch Physiother. 2019;9:8. doi:10.1186/s40945-019-0060-9. PMID: 31463082; PMCID: PMC6708126.
13. Fan Y, To MKT, Yeung EHK, Wu J, He R, Xu Z, et al. Does curve pattern impact on the effects of physiotherapeutic scoliosis specific exercises on Cobb angles of participants with adolescent idiopathic scoliosis: A prospective clinical trial with two years follow-up. PLoS One. 2021;16(1):e0245829. doi:10.1371/journal.pone.0245829. PMID: 33493172; PMCID: PMC7833215.
14. Capek V, Baranto A, Brisby H, Westin O. Nighttime versus fulltime brace treatment for adolescent idiopathic scoliosis: Which brace to choose? A retrospective study on 358 patients. J Clin Med. 2023;12(24):7684. doi:10.3390/jcm12247684. PMID: 38137753; PMCID: PMC10743948.
15. Aulisa AG, Guzzanti V, Falciglia F, Giordano M, Galli M, Aulisa L. Brace treatment of idiopathic

scoliosis is effective for a curve over 40 degrees, but is the evaluation of Cobb angle the only parameter for the indication of treatment? Eur J Phys Rehabil Med. 2019;55(2):231–240. doi:10.23736/S1973-9087.18.04782-2. PMID: 29517186.
16. Kluszczyński M, Mosler D, Wąsik J. Morphological differences in scoliosis curvatures as a cause of difficulties in its early detection based on angle of trunk inclination. BMC Musculoskelet Disord. 2022;23(1):948. doi:10.1186/s12891-022-05878-6. PMID: 36324093; PMCID: PMC9628035.
17. Tombak K, Yüksel İ, Ozsoy U, Yıldırım Y, Karaşin S. A comparison of the effects of supervised versus home Schroth exercise programs with adolescent idiopathic scoliosis. Children (Basel). 2024;11(3):354. doi:10.3390/children11030354. PMID: 38539389; PMCID: PMC10969552.
18. Khaledi A, Minoonejad H, Akoochakian M, Gheitasi M. Core stabilization exercises vs. Schroth's three-dimensional exercises to treat adolescent idiopathic scoliosis: A systematic review. Iran J Public Health. 2024;53(1):81–92. doi:10.18502/ijph.v53i1.14685. PMID: 38694867; PMCID: PMC11058387.
19. Barone G, Giudici F, Manzini F, Pironti P, Viganò M, Minoia L, et al. Adolescent idiopathic scoliosis surgery: Postoperative functional outcomes at 32 years mean follow-up. Children (Basel). 2023;11(1):52. doi:10.3390/children11010052. PMID: 38255365; PMCID: PMC10814093.
20. Alhammoud A, Alborno Y, Baco AM, Othman YA, Ogura Y, Steinhaus M, et al. Minimally invasive scoliosis surgery is a feasible option for management of idiopathic scoliosis and has equivalent outcomes to open surgery: A meta-analysis. Global Spine J. 2022;12(3):483–492. doi:10.1177/2192568220988267. PMID: 33557618; PMCID: PMC9121169.
21. Aulisa AG, Toniolo RM, Falciglia F, Giordano M, Aulisa L. Long-term results after brace treatment with progressive action short brace in adolescent idiopathic scoliosis. Eur J Phys Rehabil Med. 2021;57(3):406–413. doi:10.23736/S1973-9087.20.06129-8. PMID: 32990686.
22. Seleviciene V, Cesnaviciute A, Strukcinskiene B, Marcinowicz L, Strazdiene N, Genowska A. Physiotherapeutic scoliosis-specific exercise methodologies used for conservative treatment of adolescent idiopathic scoliosis, and their effectiveness: An extended literature review of current research and practice. Int J Environ Res Public Health. 2022;19(15):9240. doi:10.3390/ijerph19159240. PMID: 35954620; PMCID: PMC9368145.
23. Yang JH, Shin JW, Park SR, Kim SK, Park SJ, Min JH, et al. Transient fixation of L4 vertebra preserves lumbar motion and function in Lenke Type 5C and 6C scoliosis. Sci Rep. 2021;11(1):10192. doi:10.1038/s41598-021-89674-7. PMID: 33986432; PMCID: PMC8119700.
24. Cheung PWH, Chan OKO, Wu H, Lai MKL, Wong LPK, Tang S, et al. Immediate vs gradual brace weaning protocols in adolescent idiopathic scoliosis: A randomized clinical trial. JAMA Pediatr. 2024;178(7):657–668. doi:10.1001/jamapediatrics.2024.1484. PMID: 38829664; PMCID: PMC11148786.
25. Alsiddiky AM, Alharbi KS, Ababtain OA, Alnuwaybit AF, Zamzami MA, Basalah AA, et al. Brace-related stress and quality of life parameters between Chêneau and Boston braces: A cross-sectional comparative study on adolescent idiopathic scoliosis in Saudi Arabia. Orthop Surg. 2024;16(8):2011–2018. doi:10.1111/os.14121. PMID: 38858814; PMCID: PMC11293924.
26. Wang H, Tetteroo D, Arts JJC, Markopoulos P, Ito K. Quality of life of adolescent idiopathic scoliosis patients under brace treatment: A brief communication of literature review. Qual Life Res. 2021;30(3):703–711. doi:10.1007/s11136-020-02671-7. PMID: 33098493; PMCID: PMC7952337.
27. Zhou Z, Liu F, Li R, Chen X. The effects of exercise therapy on adolescent idiopathic scoliosis: An overview of systematic reviews and meta-analyses. Complement Ther Med. 2021;58:102697. doi:10.1016/j.ctim.2021.102697. PMID: 33636298.
28. Gao C, Zheng Y, Fan C, Yang Y, He C, Wong M. Could the clinical effectiveness be improved under the integration of orthotic intervention and scoliosis-specific exercise in managing adolescent idiopathic scoliosis?: A randomized controlled tri-

al study. Am J Phys Med Rehabil. 2019;98(8):642–648.

29. Chen L, Sun Z, He J, Xu Y, Li Z, Zou Q, et al. Effectiveness and safety of surgical interventions for treating adolescent idiopathic scoliosis: A Bayesian meta-analysis. BMC Musculoskelet Disord. 2020;21(1):427. doi:10.1186/s12891-020-03233-1. PMID: 32615956; PMCID: PMC7333422.
30. Chan A, Banerjee P, Lupu C, Bishop T, Bernard J, Lui D. Surgeon-directed neuromonitoring in adolescent spinal deformity surgery safely assesses neurological function. Cureus. 2021;13(11):e19843. doi:10.7759/cureus.19843. PMID: 34963855; PMCID: PMC8702385.
31. Ding H, Hai Y, Guan L, Liu Y, Pan A, Han B. The outcome of enhanced recovery after surgery vs. a traditional pathway in adolescent idiopathic scoliosis surgery: A retrospective comparative study. Front Surg. 2022;9:989119. doi:10.3389/fsurg.2022.989119. PMID: 36277279; PMCID: PMC9581125.
32. O'Donnell JM, Gornitzky AL, Wu HH, Furie KS, Diab M. Anterior vertebral body tethering for adolescent idiopathic scoliosis associated with less early post-operative pain and shorter recovery compared with fusion. Spine Deform. 2023;11(4):919–925. doi:10.1007/s43390-023-00661-6. PMID: 36809648; PMCID: PMC10261228.
33. Faldini C, Viroli G, Traversari M, Manzetti M, Ialuna M, Sartini F, et al. Ponte osteotomies in the surgical treatment of adolescent idiopathic scoliosis: A systematic review of the literature and meta-analysis of comparative studies. Children (Basel). 2024;11(1):92. doi:10.3390/children11010092. PMID: 38255405; PMCID: PMC10814379.

Cite this paper as

Arvanitaki SC. Adolescent idiopathic scoliosis - therapeutic approaches. AOTH. 2025; 76(3):45-63.