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Invited Topical Review

Physiotherapy management of adolescent idiopathic scoliosis

Arnold YL Wong , Tony SH Chiu

Department of Rehabilitation Sciences, The Hong Kong Polytechnic University, Hong Kong SAR, China

KEY WORDS

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Introduction

Scoliosis is a complex, three-dimensional structural change of the spine, characterised by lateral curvature, vertebral rotation and sagittal plane deviations.[1] Clinically, scoliosis is defined as a lateral spinal deviation exceeding 10 deg, measured by the Cobb angle on posteroanterior radiographs (Figure 1).[2] The curve location is determined by the vertebra most laterally deviated and rotated from the midline. Thoracic curves may cause varying degrees of rib and rib cage deformity, closely related to curve severity.

Scoliosis is classified by aetiology into congenital, neuromuscular, de novo and idiopathic types. Idiopathic scoliosis accounts for 80 to 85% of cases.[3] Idiopathic scoliosis is diagnosed after excluding other causes (eg, neuromuscular disorders or vertebral malformation). It is further categorised by age at diagnosis: infantile (< 3 years), juvenile (3 to 10 years) and adolescent (10 to 18 years). Adolescent idiopathic scoliosis (AIS) represents most idiopathic cases. This review summarises the epidemiology, aetiology, screening, assessments and physiotherapy management of AIS to support physiotherapists in delivering evidence-based care.

Epidemiology

The prevalence of AIS ranges from 0.5 to 5.2% in epidemiological studies,[3,4] but it is generally accepted to affect 2 to 3% of the general population.[5] Females are approximately four times more likely to develop AIS than males,[4] with the female:male ratio increasing with curve severity: 1.4:1 to 2.4:1 for Cobb angles > 10 deg, 5.4:1 for > 20 deg and 10:1 for > 30 deg.[6] Most children with AIS present with mild curves (Cobb angles 10 to 20 deg) and may only be observed, while some develop moderate curves (20 to 30 deg). Approximately 10% progress to severe scoliosis (Cobb angle ≥ 40 deg).[7] Notably, up to two-thirds of AIS cases may experience curve progression during puberty.[8]

Natural history

The natural history of AIS is influenced by several factors, including sex, timing of menarche, growth potential (eg, Risser grade, distal radius and ulna classification score, or Tanner stage), curve apex location and initial curve severity (Box 1).[5] AIS typically manifests during the peak growth period between ages 11 and 14 years, with the most rapid curve progression at puberty onset.[9] Girls are particularly susceptible to progression during periods of accelerated growth.[10] The risk of curve progression is highest in individuals with larger initial Cobb angles and greater remaining growth potential. An initial Cobb angle of 25 deg is a stronger predictor of progression beyond 30 deg at skeletal maturity than age, sex or growth potential alone.[11] Thoracic curves are most likely to progress, with studies reporting 58 to 100% progressing.[5] Curves measuring 30 to 50 deg at bone maturity may progress by an average of 10 to 15 deg over a lifetime.[10,12] Curves > 50 deg at maturity typically progress at 1 deg/year.[13]

Various statistical and machine learning models have been developed to predict curve progression using factors such as Risser sign, Cobb angle, chronological age and paraspinal muscle characteristics.[14–16] However, most lack external validation across multiple cohorts, limiting their generalisability.

The consequences of untreated AIS depend on curve severity and may include back pain, pulmonary compromise (eg, reduced vital capacity) and psychological issues, such as depressive symptoms or low self-esteem.[5,17,18] While some individuals with untreated AIS function comparably to those without scoliosis, others may experience chronic back pain, progressive deformity and cosmetic concerns. Personalised follow-up plans and intervention strategies are essential after skeletal maturity, tailored to Cobb angle, risk of progression and long-term sequelae. Clinicians should educate families about the natural history of AIS to support informed decision-making.

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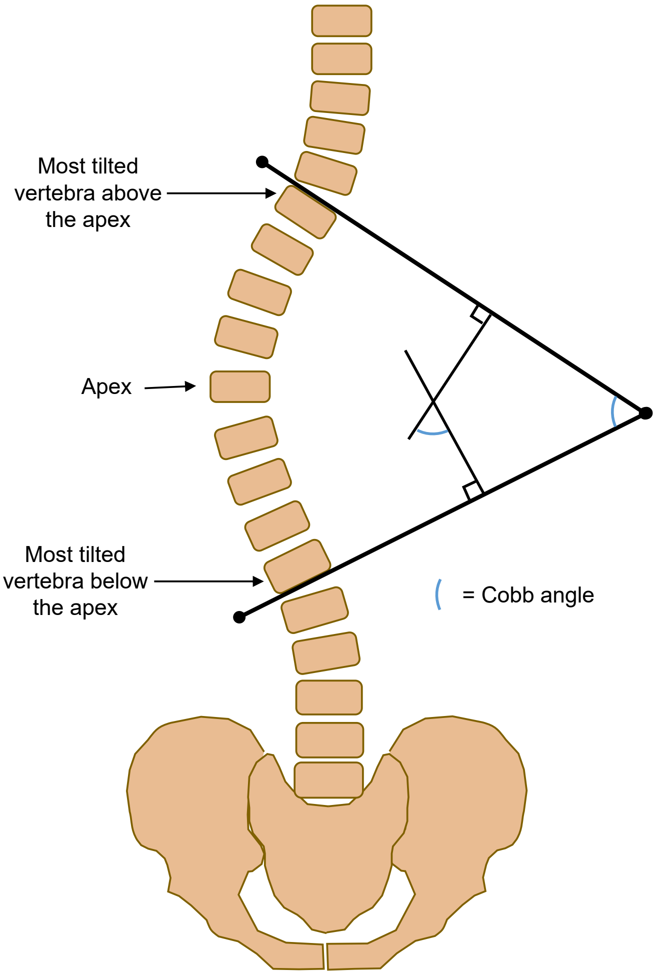

Figure 1. Measurement of the Cobb angle from a radiograph. The Cobb angle is the angle between the superior surface of the most tilted vertebra above the apex and the inferior surface of the most tilted vertebra below the apex. For convenient calculation within the margins of the radiograph, the angle can be calculated between perpendiculars drawn from those two lines.

Aetiopathogenesis

Biomechanical factors

The aetiology of AIS remains uncertain, although several biomechanical hypotheses have been proposed. One hypothesis suggests that scoliosis may result from asymmetrical growth between the anterior and posterior spinal columns.[19,20] Roaf reported disproportionate anterior spinal outgrowth relative to the posterior elements.[21] According to the Heuter-Volkmann's law, asymmetrical loading of the vertebrate can induce three-dimensional asymmetrical growth of certain parts of the vertebrae, thereby contributing to the development or progression of scoliosis.[22] Magnetic resonance imaging studies have demonstrated that adolescents with structural AIS often exhibit longer anterior vertebral elements compared with posterior elements,[23–26] especially in the thoracic spine. However, it remains unclear whether this is a cause or consequence of the condition.[22,27,28] Stokes et al proposed that, regardless of the initial trigger, asymmetric loading in the skeletally immature spine may initiate a vicious cycle of asymmetrical growth and curve progression.[29,30]

Additionally, children with AIS are more likely to exhibit joint hypermobility.[31,32] Sports such as gymnastics and dance, which favour hypermobile individuals, are associated with a higher prevalence of AIS.[33,34] The repetitive, asymmetrical loading and the tendency to maintain the thoracic spine in a lordotic position during these activities may exacerbate pre-existing scoliosis.[35]

Box 1. Summary of tools for grading growth potential.

Risser grade
This system measures the ossification of the iliac crest apophysis on pelvic radiograph, scored from 0 (no ossification) to 5 (full bony fusion). A lower grade indicates more remaining spinal growth; therefore, greater risk of curve progression.
Distal radius and ulna classification score
This method examines how the growth plates in the distal radius and ulna appear and close on radiography. Because these plates mature in a predictable sequence, the score provides a fine-grained estimate of skeletal maturity and growth potential.
Tanner stage
This staging system classifies pubertal development into five stages based on secondary sexual characteristics such as breast/genital development and pubic hair. Earlier Tanner stages reflect higher growth potential, while later stages indicate that most growth has already occurred.

Paraspinal muscle factors

Given the inherited instability of the spine without trunk muscle support, paraspinal muscles are thought to play a critical role in the development and progression of spinal curvature. A recent systematic review reported very low-certainty to low-certainty evidence indicating that, compared with the convex side, paraspinal muscles on the concave side exhibit fewer type I fibres, smaller muscle volume, lower lean muscle mass and decreased muscle activity during standing.[36] Additionally, very low-certainty evidence suggested that greater side-to-side asymmetry in muscle surface electromyography activity at the lower end vertebra of the curve predicts curve progression.[36] Further, very low-certainty evidence suggested lower expression of the genes *PAX3* and *H19* and higher expression of *ADIPOQ* in paraspinal muscles on the concave side in teenagers with AIS.[36] Similarly, children with AIS exhibited reduced *PAX3* gene expression compared with non-AIS controls. As *PAX3*, *H19* and *ADIPOQ* are associated with myogenic progenitor cells, these alterations in muscle-related gene expression may partially explain the observed paraspinal muscle asymmetry in children with AIS.

A recent meta-analysis found moderate-certainty evidence that compared with non-AIS controls, children with AIS had significantly larger head, neck or limb repositioning errors.[37] Low-certainty evidence also indicated that children with AIS exhibit significantly higher motion detection thresholds and more aberrant somatosensory evoked potential than controls. These proprioception deficits, together with asymmetrical paraspinal muscle characteristics, support the use of scoliosis-specific exercises to restore proprioceptive function and paraspinal muscle control in this population. Implementing such exercises may disrupt the 'vicious cycle' proposed by Stokes et al, by introducing new neuromuscular activation patterns to rebalance the spine.[38]

Genetic factors

There is growing evidence from studies of scoliosis among twins to support that genetics contribute to the development of AIS. A meta-analysis found concordance rates (both twins have a scoliotic curve) of 73% in monozygous twins and 36% in dizygous twins. Monozygous twins often exhibit similar curve development and progression.[39] Research has shown that AIS inheritance patterns may involve dominant genes, maternal transmission, multiple genes, X-linked genes or gene-environment interactions.[5] Future research should incorporate genome-wide and epigenome-wide association studies to clarify the causality between gene polymorphisms and AIS pathogenesis or progression.

Numerous studies have investigated genes related to connective tissue in AIS. Certain gene polymorphisms (eg, *LBX1*, *PAX3*, *TBX1*) have been associated with AIS risk or curve progression in at least two ethnic groups.[5,40] However, findings from other candidate gene analyses remain inconsistent.[40] These mixed findings suggest that epigenetic mechanisms may play a significant role in the pathogenesis and progression of AIS.[40]

Other factors

Several additional factors have been proposed in the pathogenesis of AIS, including reduced melatonin levels, northern latitude of residence, asymmetric rib growth, altered calmodulin levels in platelets or paraspinal muscles, osteopenia, vitamin D intake, zinc or copper levels, and variations in growth or sex steroid hormones.[5,35,41] However, further investigation is warranted to clarify their roles. Collectively, the aetiology and progression of AIS are multifactorial.

Classification of adolescent idiopathic scoliosis

Various classification systems have been developed to describe the curve types in AIS. Curves are commonly categorised by the location of the apex: cervical, cervicothoracic, thoracic, thoracolumbar, lumbar and S-shaped.[42] King and Moe introduced the King's classification to categorise AIS into five types based on curve patterns to guide spinal fusion using Harrington rods and bracing.[43] However, with advances in surgical instrumentation, the Lenke classification has largely replaced the King's system, due to its superior intra-rater and inter-rater reliability and its utility in guiding surgical decision-making.[44] The Lenke system considers six curve types, a lumbar modifier and the sagittal profile of the spine, distinguishing between major (the curve with the greatest magnitude and usually structural), minor (a smaller curve that may be structural or non-structural) and non-structural curves (those bending $<$ 25 deg on side-bending radiographs).[45]

While the Lenke classification is primarily used for surgical planning, therapists administering Schroth exercises employ a unique clinical classification system to guide exercise prescription for patients with scoliosis. This system assesses alignment and posture across four body blocks: shoulder (neck and shoulder regions); thoracic (thoracic curve region); lumbar (lumbar curve region); and hip-pelvic (pelvis and lower limbs).[46] Based on the location of the major or minor curve, the presence of a compensatory curve, pelvic balance and the side of major curve convexity, curves are classified into four Schroth curve types for treatments.

Rigo's classification, developed to guide Cheneau rigid brace design, builds on the Schroth classification and identifies five curve types based on the location of external features and pelvic position.[47] It has demonstrated acceptable intra- and inter-rater reliability.[47] Similarly, the Rigo-Weiss classification, designed for Cheneau Light bracing, further refines curve patterns into four basic types with subtypes based on pelvic imbalance.[48] Both the Rigo and Rigo-Weiss classifications rely on both clinical observation and radiological findings for curve assessment.

Screening for adolescent idiopathic scoliosis

School-based screening can facilitate earlier detection of AIS than clinical presentation. However, routine screening is not universally adopted due to concerns about cost-effectiveness. For example, in 2004, the US Prevention Services Task Force recommended against routine screening of asymptomatic adolescents.[49] School screening typically employs single-modality assessments to identify children with AIS for further management. As AIS is characterised by vertebral rotation, which is related to Cobb angles, rib cage deformity and a rib hump during forward trunk bending, examiners look for a rib hump or use a scoliometer to quantify the angle of trunk rotation between the posterior surfaces of the left and right hemithoraces during the Adam's forward bending test.[50,51] The angle of trunk rotation measured by scoliometer correlates with coronal Cobb angles and computed tomography-measured apical vertebral rotation in thoracic and thoracolumbar curves.[52] Professional societies—including the Scoliosis Research Society (SRS), International Society on Scoliosis Orthopaedic and Rehabilitation Treatment (SOSORT) and International Research Society of Spinal Deformities—recommend angle of trunk rotation $\geq$ 7 deg as the threshold for further evaluation to minimise overdiagnosis and unnecessary radiographic exposure.[53–55]

Moiré topography was one of the first technologies used for the clinical diagnosis of scoliosis.[56] It is a non-invasive, radiation-free technique that projects a striped pattern onto the naked back of teenagers in standing during school-based screening (Figure 2). A camera captures the resulting Moiré fringes, which form contour lines resembling a topographic map to analyse the shape and asymmetry of the back. This method has demonstrated high test-retest reliability, high intra- and inter-rater correlation, and moderate to high correlation with radiographic Cobb angles.[57] However, its accuracy may be reduced in children with obesity or severe scoliosis.

A 2018 systematic review found that compared with single-modality screening, combining two screening modalities (Adam's test, scoliometer and Moiré topography) achieved the highest sensitivity (91.8 to 93.8%), specificity (99.2%) and positive predictive value (81.0%), with the lowest false-positive (0.8%) and false-negative rates.[3,58] Conversely, using Adam's test with a scoliometer alone resulted in lower sensitivity (71.1 to 84.4%), specificity (97.1%) and positive predictive value (29.3 to 54.1%), with higher false-positive (2.9%) and false-negative (28.9%) rates.[59,60] The false-negative rate of Adam's bending test alone, with or without scoliometer, ranged from 15.6 to 28.9%,[59,60] while Moiré topography alone demonstrated 100% sensitivity and a 0% false-negative rate.[60]

Other scoliosis screening technologies (eg, infrared thermography,[61] smartphone-based surface topography application,[62] rasterstereography[63,64] and ultrasound imaging[65]) with or without machine learning algorithms have been developed for detecting trunk asymmetry or measuring spinal curvature. Although these methods have demonstrated good reliability and good to excellent association with radiographic Cobb angles, further research is warranted to evaluate their sensitivity and feasibility for large-scale screening in diverse adolescent populations, considering factors such as cost, accuracy and required training.

Radiographic imaging

Traditional radiographs are commonly used to evaluate Cobb angles, truncal shift and axial vertebral rotation. EOS imaging[a]—a

Figure 2. Moiré topographical shadows on the back of an adolescent showing asymmetry of the spine and thorax. Modified from scoliosis.hku.hk.

low-dose, weight-bearing X-ray technology—has gained popularity due to its ability to capture full-body sagittal and frontal images in standing or sitting positions. EOS delivers 16 to 34 times less radiation than standard digital radiography, while maintaining comparable image quality.[66] Additionally, EOS enables three-dimensional reconstruction of the spine, providing accurate measurements for curve severity assessment and surgical planning. Deep learning models have also been applied to radiograph analysis, reducing the need for manual interpretation.[67]

Management of Cobb angles

Scoliosis is typically assessed using the Cobb method on standing posteroanterior radiographs, which measures the angle between the superior endplate of the uppermost vertebra and the inferior endplate of the lowest vertebra involved in the curve (Figure 1). These borders can be identified manually or automatically using specialised software.[68] The widely accepted margin of error of manual Cobb angle measurement is 5 deg,[10] with inter-rater variability up to 7.2 deg. Computer-assisted measurement methods can achieve accuracy comparable with orthopaedic surgeons (< 5 deg)[69] and reduce the intra- and inter-rater errors to within 3 deg.[70] A systematic review reported that such methods maintain measurement errors between 1.2 and 3.6 deg.[71]

Interventions for adolescent idiopathic scoliosis

The SOSORT guidelines recommend management strategies for AIS based on Cobb angle, rate of progression and remaining skeletal growth potential. For Cobb angles < 20 deg, observation is advised; for 20 to 25 deg, observation or bracing may be considered; for 26 to 45 deg, bracing is recommended; for 46 to 50 deg, either bracing or surgery may be appropriate; and for > 50 deg, surgery is recommended.[10]

Therapeutic exercises

Since the publication of the 2016 SOSORT guidelines, increasing evidence supports the use of therapeutic exercises for AIS to reduce spinal curvature, delay progression or potentially avoid more invasive treatments (eg, bracing, surgery or both). Therapeutic exercises aim to modify the spinal neuromuscular control, actively stabilise the spine in corrected postures and/or induce mechanical change in soft tissues. While generic therapeutic exercises (GTE) address at least one of these components, physiotherapy scoliosis-specific exercises (PSSE)—such as the Scientific Exercise Approach to Scoliosis (SEAS) and Schroth exercises—target all components:[72] personalised self-correction; education to attain desirable neurological changes and muscle control; and training in activities of daily living.[10]

Therapeutic exercises (including GTE or PSSE) can serve as primary treatment for mild curves (up to 20 or 25 deg) or as an adjunct to bracing for more severe curves.[73] When combined with bracing, exercises may enhance brace effectiveness and mitigate side effects such as muscle weakness, flat back and rigidity.[74] Although therapeutic exercises have been routinely used in some Mediterranean and continental European countries for decades, their adoption is now increasing globally.[75]

Numerous non-Cochrane reviews,[3,76–78] meta-analyses[78] and network meta-analyses have evaluated the effectiveness of therapeutic exercises for AIS; they have often included heterogeneous study designs, pooled the effects of diverse types of therapeutic exercises and not adhered to Cochrane methodology. An updated Cochrane review recently provided a rigorous summary of the effectiveness of various therapeutic exercises compared with no treatment and other conservative interventions (eg, bracing, electrical stimulation, manual therapy).[73] This review included 13 randomised controlled trials (RCTs) with 583 participants from nine countries (Brazil, Canada, China, Egypt, Italy, Saudi Arabia, South Korea, Turkey and the USA) published between 2012 and 2022. These therapeutic exercises involved different exercise types, treatment durations from 12 to 42 months and follow-up times (3, 4, 6, 12 months, and 1 year after skeletal maturity). The average age of participants among the included RCTs ranged from 12 to 15 years. Blinding of participants was not feasible in any study. Eight trials had low risk of bias for randomisation, and six for allocation concealment. Subjective outcomes (eg, quality of life, perception of self-image) were at high risk of detection or performance bias. Twelve trials reported objective outcomes (eg, Cobb angles, surface measurements, trunk rotation, bracing and surgery). Six of them had high risk of detection bias, while the remaining six had low risk. No included studies reported on adverse effects. Table 1 summarises the certainty of evidence about therapeutic exercises on various clinical outcomes based on the Cochrane review.[73]

The reported GTEs included Pilates (core stabilisation, spinal correction and balance), general spinal exercises (mobilisation, strengthening, stretching, balance training and walking) and unilateral muscle contraction.[73] One included study also reported preoperative physiotherapist-supervised aerobic exercises using a treadmill or stationary bike.[79] The classical SEAS protocol consists of 15 minutes of daily exercises and a 1.5-hour physiotherapy session monthly, incorporating a cognitive-behavioural approach.[72,80] Some RCTs modified this by including weekly physiotherapist supervised group sessions.[81,82] The Schroth method focuses on identifying one or two exercises—sometimes with external aids (eg, cushions)—that achieve optimal self-correction, which are then repeated in daily sessions. Isometric exercises are performed in the desirable self-correction posture to promote stabilisation and posture maintenance. The exercises involve elongating the spine, de-rotating the trunk, lengthening overactive muscles and strengthening weaker muscles; they also emphasise achieving more symmetrical chest expansion through specific breathing techniques. Traditionally, Schroth exercises were delivered intensively in inpatient settings over 3 to 4 weeks, but are now commonly taught individually or in groups for 5 to 18 outpatient sessions, supplemented by 30 to 45 minutes of home exercises daily or thrice weekly.[73]

Therapeutic exercises versus no treatment

Cobb angle or angle of trunk rotation

One included RCT (16 participants) provided very low-certainty evidence that PSSE had an unclear effect on the Cobb angle compared with no treatment (MD –2.8 deg, 95% CI –12.7 to 7.1).[73] However, low-certainty evidence from an RCT (45 participants) indicated that the PSSE group yielded an average Cobb angle reduction of 2.5 deg, while the no treatment control group showed an average 3 deg increase in the Cobb angle; the original authors considered this clinically meaningful, but data precluded calculation of a confidence interval and therefore meta-analysis.[83]

Low-certainty evidence from one RCT (45 participants) indicated little or no difference in angle of trunk rotation improvement (MD –0.8 deg, 95% CI –3.8 to 2.1).[83] PSSE reduced waist asymmetry compared with no treatment (MD –0.5 cm, 95% CI –0.8 to –0.3, 45 participants, one RCT, low-certainty evidence).[83]

Self-image and quality of life

Low-certainty evidence from one RCT (16 participants) showed a negligible difference between PSSE and no treatment in improving self-image, as measured by the SRS-22 self-image score (MD 0.3, 95% CI –0.3 to 0.9) and SAQ score (MD 0.7, 95% CI –0.1 to 1.4). Two RCTs (61 participants) provided low-certainty evidence that PSSE was slightly better than no treatment in improving quality of life measured by SRS-22 total score (MD 0.2 points, 95% CI 0.1 to 0.4), although the difference was clinically trivial.[83,84]

Back pain and mental health

There was low-certainty evidence that therapeutic exercises led to clinically meaningful improvement in back pain compared with no treatment (SMD 1.7, 95% CI 1.0 to 2.3, 56 participants from two RCTs).[73,79,84] However, there was an unclear difference in mental

Table 1
Certainty of evidence regarding the effectiveness of various therapeutic exercises for adolescent idiopathic scoliosis.

Exercise comparison	Reduced curve progression	Reduced waist asymmetry	Reduced Cobb angle	Reduced angle of trunk rotation	Improved self-image	Improved quality of life	Back pain	Mental health
Therapeutic exercise (PSSE or GTE) versus no treatment		PSSE reduced waist asymmetry	PSSE reduced Cobb angle PSSE had an unclear effect on Cobb angle	PSSE had a negligible effect on angle of trunk rotation	PSSE had a negligible effect on SAQ score or SRS-22 self-image domain score	PSSE slightly improved SRS-22 total score	Therapeutic exercises improved SRS-22 pain and SF-36 pain scores to a worthwhile extent	Therapeutic exercises had an unclear effect on SRS-22 mental health or SF-36 mental health scores
PSSE + bracing versus bracing alone			Adding PSSE to bracing improved Cobb angle		Adding PSSE to bracing had a negligible effect on SAQ score or SRS-22 self-image domain score	Adding PSSE to bracing had a negligible effect on SRS-22 total score	Adding PSSE to bracing had a negligible effect on SRS-22 pain score	Adding PSSE to bracing had a negligible effect on SRS-22 total score
PSSE versus GTE	PSSE reduced the risk of curve progression > 5 deg compared with GTE		The relative effect of PSSE versus GTE on Cobb angle was unclear	PSSE improved angle of trunk rotation compared with GTE to a worthwhile extent	The relative effect of PSSE versus GTE on SRS-22 self-image domain score or WRVA was unclear	PSSE and GTE had similar effects on SRS-22 total score	PSSE had similar effect on SES-22 pain score as GTE	PSSE improved SRS-22 mental health score compared with GTE
GTE + electrostimulation + traction versus electrostimulation + traction			Adding GTE to electrostimulation + traction improved Cobb angle to a worthwhile extent					
PSSE + manual therapy versus manual therapy			Adding PSSE to manual therapy improved Cobb angle to a worthwhile extent	Adding PSSE to manual therapy improved angle of trunk rotation to a worthwhile extent			Adding PSSE to manual therapy improved pain VAS score to a worthwhile extent	
PSSE versus bracing alone			Bracing alone improved Cobb angle more than PSSE alone		PSSE had a similar effect on SRS-22 self-image domain score as bracing alone	PSSE improved SRS-22 total score more than bracing alone	PSSE had a similar effect on SRS-22 pain score as bracing alone	PSSE improved SRS-22 mental health score more than bracing alone

GTE = generic therapeutic exercises, PSSE = physiotherapy scoliosis-specific exercises, SAQ = spinal appearance questionnaire, SRS-22 = Scoliosis Research Society-22 questionnaire, VAS = visual analogue scale, WRVA = Walter Reed Visual Assessment scale.

	Benefit from exercise	Little or uncertain effect	Benefit from comparator
Moderate certainty evidence: the reported effect is likely to be similar to the true effect			
Low certainty evidence: the reported effect may differ substantially from the true effect			
Very low certainty evidence: the reported effect likely differs substantially from the true effect			

health outcomes, as measured by the SRS-22 or SF-36 mental health scores (SMD 3.2, 95% CI –2.2 to 8.6, 56 participants from two RCTs, low-certainty evidence).

Physiotherapy scoliosis-specific exercises with bracing versus bracing alone

Cobb angle

There was low-certainty evidence from two included RCTs (84 participants) that PSSE combined with bracing improved Cobb angle more than bracing alone (MD – 2.2 deg, 95% CI –3.8 to –0.7),[73,81,85] although this difference was not clinically meaningful.

Subjective self-image or quality of life scores

Low-certainty evidence from one RCT (34 participants) showed a negligible difference between PSSE plus bracing and bracing alone in improving the subjective SRS-22 self-image score (MD 0.1 points, 95% CI –0.3 to 0.5), SAQ general scores (MD –0.2 points, 95% CI –0.9 to 0.5 points) or SRS-22 total score (MD 0.2 points, 95% CI –0.1 to 0.5 points).[73]

Back pain and mental health

Low-certainty evidence from one RCT (34 participants) showed a negligible difference between groups in the SRS-22 pain score (MD 0.2, 95% CI –0.2 to 0.6) or quality of life, as measured by the SRS-22 total score (MD 0.02, 95% CI –0.4 to 0.4).[73,84]

Physiotherapy scoliosis-specific exercises versus general therapeutic exercises

Curve progression

Low-certainty evidence from one RCT (110 participants) suggested that curve progression > 5 deg was more common in the GTE group (38%) compared with the PSSE group (7%). The main estimate was clinically worthwhile (RR 0.19), but this was associated with uncertainty (95% CI 0.07 to 0.52).[82]

Cobb angle and angle of trunk rotation

Very low-certainty evidence from four RCTs (192 participants) indicated an unclear difference in effects between PSSE and GTE in reducing Cobb angle (MD –3.0 deg, 95% CI –8.2 to 2.1).[82,86–88] However, moderate-certainty evidence from two RCTs (138 participants) indicated that PSSE resulted in a greater reduction in angle of trunk rotation (MD –3.0 deg, 95% CI –3.4 to –2.5), which was clinically meaningful.[82,88]

Self-image and quality of life

Very low-certainty evidence from three RCTs (168 participants) indicated an unclear difference in effects between PSSE and GTE in improving self-image, as measured by the SRS-22 self-image score and Walter Reed Visual Assessment Scale score (SMD 0.77, 95% CI –0.61 and 2.14 points).[73,82,86,88] Regarding quality of life, there was a negligible difference between PSSE and GTE in improving the SRS-22 total score (MD 0.26 points, 95% CI –0.11 to 0.62).[82,86,88]

Back pain and mental health

Very low-certainty evidence from two RCTs (170 participants) indicated a negligible difference between PSSE and GTE in the SRS-22 pain score (MD 0.04, 95% CI –0.46 to 0.56).[85,86] Very low-certainty evidence from one RCT (110 participants) revealed that PSSE improved the SRS-22 mental health score compared with GTE (MD 0.6, 95% CI 0.4 to 0.7).[82]

Adding therapeutic exercises to other conservative treatments

Cobb angle and angle of trunk rotation

There was low-certainty evidence that adding GTE to electrostimulation and traction resulted in a clinically meaningful reduction in Cobb angle (MD –8.0 deg, 95% CI –11.5 to –4.5, 80 participants from one RCT).[89] Very low certainty-evidence from one RCT (18 participants) showed that PSSE plus manual therapy was superior to manual therapy alone in causing a clinically meaningful improvement in Cobb angle (MD –7.8 deg, 95% CI –12.5 to –3.2) and angle of trunk rotation (MD –8.0 deg, 95% CI –12.7 to –3.3).[90]

Back pain

Very low-certainty evidence from one RCT (18 participants) supported that PSSE plus manual therapy led to a clinically meaningful improvement in back pain compared with manual therapy alone on a 0 to 10 visual analogue scale (MD –2.0, 95% CI –3.1 to –0.9).[90]

Therapeutic exercise versus bracing

Cobb angle

Very low-certainty evidence from one RCT (60 participants) indicated that bracing resulted in better Cobb angles than PSSE alone (MD 2.7 deg, 95% CI 0.3 to 5.0), although this difference was not clinically meaningful.[72]

Self-image and quality of life

Very low-certainty evidence from one RCT (60 participants) showed a negligible difference between PSSE and bracing in changing the SRS-22 self-image score (MD 0.1 points, 95% CI –1.0 to 1.1).[72] Regarding quality of life, PSSE yielded a higher SRS-22 total score (MD 3.2 points, 95% CI 2.1 to 4.2), but this was not clinically meaningful.[72]

Back pain and mental health

Very low-certainty evidence from one RCT (60 participants) showed a negligible difference between PSSE and bracing in the SRS-22 pain score (MD 0.0, 95% CI –0.1 to 0.1). Very low-certainty evidence from the same RCT favoured PSSE over bracing in the SRS-22 mental health score (MD 0.3, 95% CI 0.2 to 0.4), although this difference was not clinically meaningful.

Summary of the effectiveness of therapeutic exercises

Therapeutic exercises for AIS have gained popularity over the past decade. However, the certainty of evidence regarding the effectiveness of GTE or PSSE remains low to very low, primarily due to small sample sizes, heterogeneous interventions, very short-term follow-up before the end of growth, unclear therapists' qualifications and difficulty in blinding patients or examiners. Although the certainty of evidence was very low, therapeutic exercises appear superior to no treatment in improving Cobb angle or waist asymmetry, potentially delaying the need for bracing. Additionally, low- to moderate-certainty evidence supports that PSSE is more effective than GTE in preventing > 5 deg curve progression at the end of growth, or achieving clinically meaningful reductions in angle of trunk rotation.[82] While PSSE cannot substitute for bracing for moderate-degree curves, combining therapeutic exercises with bracing or other conservative treatments may offer additional benefits in preventing curve progression (low-certainty evidence, Table 1). Treatment effectiveness may be influenced by factors such as curve severity, treatment frequency/duration, bracing regimen and follow-up period.[78] Given the potential long-term health consequences of severe scoliosis, including back pain, disability and pulmonary problems, effective containment and reduction of spinal curvature in adolescents or adulthood remain priorities.[91] Large-scale RCTs with middle- or long-term follow-up (at maturity or adulthood) are warranted to further evaluate the effectiveness of therapeutic exercises on clinically relevant outcomes.

Other conservative treatments

Compared with therapeutic exercises, other conservative treatments such as spinal manipulative therapy, myofascial release, electrical stimulation have not been rigorously evaluated in RCTs, and their effectiveness remains uncertain.[92,93]

Effectiveness of bracing

Bracing has been the mainstay conservative treatment for mild to moderate AIS (Cobb angles between 20 and 45 deg) for > 60 years.[5,94,95] Braces may be worn full-time (18 to 23 hours daily), part-time (≤ 16 hours daily) or at night. Night-time bracing targets spinal correction in the supine position without axial loading.[96] Rigid braces provide external support to align the pelvis, trunk and shoulders in a certain position to restore normal body alignment, while soft braces exert a constant force.

A large-scale RCT demonstrated that full-time rigid bracing (72%) was superior to observation alone (42%) in preventing children with curves of 20 to 40 deg from developing a Cobb angle > 50 deg or requiring spinal surgery before skeletal maturity.[97] A recent systematic review and meta-analysis of 31 cohort studies and three RCTs evaluated various bracing concepts and wear times in children with curves between 15 and 45 deg.[98] The review considered seven full-time, rigid braces (eg, progressive action short brace, Boston, Cheneau, Lyon, Genisingen, Osaka Medical College, Rigo-Cheneau and pressure-adjustable orthosis), two part-time rigid braces (Boston and Cheneau), two night-time rigid braces (Charleston and Providence) and one full-time soft brace (eg, SpineCor) involving children with thoracic, thoracolumbar and/or lumbar curves. Most included studies defined success as ≤ 5 deg of coronal curve angle progression during follow-up, ranging from 1 year post-bracing to 10 years after bracing termination. Qualitative analysis found that the success rate of full-time rigid braces ranged from 51 to 100%, depending on brace type and definition of success. Likewise, the success rates of night-time braces ranged from 52 to 89%, while full-time soft braces ranged from 59 to 73%. Two included studies compared full-time and part-time rigid bracing.[99,100] One study found no clear differences,[100] while the other found full-time bracing (82%) to be superior to part-time bracing (31%).[99] Compared with rigid thoraco-lumbo-sacral orthoses, which have success rates between 80 and 94%, soft braces had lower success rates (8 to 65%).[101,102] As 17 included studies had a high risk of bias, meta-analyses were only performed on studies with low or moderate risk of bias that investigated the effectiveness of different brace concepts (eg, full-time or night-time rigid braces, and soft braces) based on ≤ 5 deg of coronal curve progression at follow-up. The pooled data showed that the success rates after at least 1 year of follow-up were: 73% (95% CI 61 to 86) for full-time rigid braces (Figure 1);[102–109] 79% (95% CI 72 to 85) for night-time rigid braces (at least 1 to 2 years of follow-up) (Figure 2);[96,108,110–114] and 62% (95% CI 55 to 70) for full-time soft braces (Figure 3).[102,115,116] However, these results were highly heterogeneous, with I^2 values between 76 and 90%. Because there were insufficient studies on the effectiveness of part-time braces, no meta-analysis was performed. Overall, bracing was most effective for AIS patients with Risser signs of 0 to 2 and 0 to 3 stages of skeletal maturity.[98] While full-time or night rigid braces have good success rates, poor compliance and discomfort can compromise their effectiveness.[117,118] The effectiveness of different brace concepts on various curve types should be investigated in

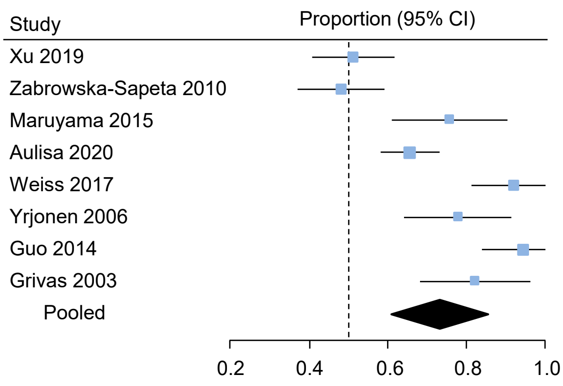

Figure 3. Forest plot success rates for full-time rigid bracing in adolescent idiopathic scoliosis patients. The dashed line marks the success rate observed in the untreated control groups.[98]

future studies, to avoid reliance on indirect comparisons between cohort studies.[98]

Surgical interventions

Surgical correction with instrumentation (eg, posterior spinal fusion, posterior fusion with anterior release, anterior fusion, pedicle screw construct, discectomy with or without thoracotomy, tethering) is indicated for patients with Cobb angles > 45 deg,[119] who are at risk for various health issues (eg, respiratory dysfunction, back pain and curve deterioration in the adulthood) if untreated. While moderate-certainty evidence suggests that spinal fusion improves quality of life of these patients in the medium and long term, physiotherapists can play a key role in perioperative care to optimise the recovery and shorten hospital stay.[119]

Enhanced recovery after surgery (ERAS) protocols—a multidisciplinary, multimodal approach for improving perioperative outcomes—minimise complications and reduce readmission costs after surgery. This approach includes patient and parental education, preoperative scoliosis support groups, use of preoperative oral haematinics and multivitamins, structural physiotherapy program before surgery, early postoperative mobilisation, sit out of bed, postoperative diets, early removal of drain, patient-controlled analgesia, urinary catheter and the early transition to oral analgesics. A recent systematic review summarised the effectiveness of ERAS protocols versus traditional protocols in AIS cases under posterior scoliosis correction.[120] A total of eight prospective and two retrospective non-randomised studies were included (1,040 ERAS patients and 959 traditional protocol patients). The ERAS and traditional protocol groups showed no significant differences in operative time, number of fused levels, preoperative Cobb angles of the main curve, blood loss, complication rates or readmission rates. However, the ERAS significantly reduced hospital stay (MD 1.44 days, 95% CI –1.76 to –1.11 days). Early mobilisation may also reduce complications and infection.[121] While ERAS protocols appear beneficial, robust multicentre RCTs are warranted to confirm their impact on patients' long-term outcomes and healthcare costs in AIS surgery.

Future directions for research and practice

Given that PSSE are superior to no treatment in delaying Cobb angle progression, PSSE should be considered as the first-line intervention for individuals with mild curves (Cobb angles < 20 deg) to potentially postpone the need for bracing. For patients with Cobb angles between 26 and 45 deg, PSSE may be prescribed adjunctively with bracing to further reduce the risk of curve progression. However, additional research is needed to evaluate the long-term cost-effectiveness of this proposed management pathway in children with AIS. In particular, the effectiveness of different brace concepts on various curve types should be investigated in RCTs, as much of the existing recommendations are based on indirect comparisons between cohort studies.[98]

Evidence indicates that even mild AIS can adversely affect self-perceived body image, self-identity and quality of life in teenagers, due to curve progression, psychological challenges[122] and treatment-related stressors.[123] Over 30% of AIS cases managed with observation or bracing experience clinically relevant psychological distress.[124] Notably, a recent Cochrane review suggests that therapeutic exercises or bracing is unlikely to improve self-image or quality of life. Conversely, appropriate social support and coping-based interventions may enhance psychological wellbeing in those with AIS. Psychosocial interventions, including imagery and cognitive behavioural therapy, have demonstrated benefits in reducing postoperative anxiety and pain, improving bracing compliance and increasing participation in social activities.[125] Given the complexity of adolescent psychology and the influence of parenting, future research should explore the effectiveness of various psychosocial interventions for both teenagers with AIS and their parents.

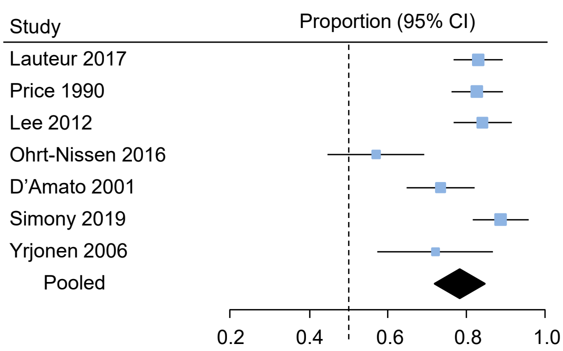

Figure 4. Forest plot success rates for night-time rigid bracing in adolescent idiopathic scoliosis patients. The dashed line marks the success rate observed in the untreated control groups.[98]

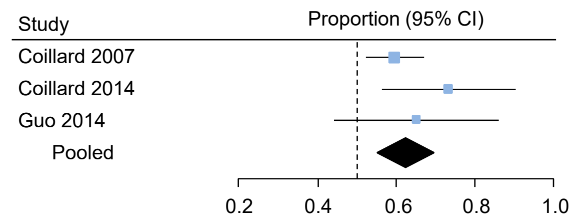

Figure 5. Forest plot success rates for full-time soft bracing in adolescent idiopathic scoliosis patients. The dashed line marks the success rate observed in the untreated control groups.[98]

Since the publication of the SOSORT guidelines in 2018, new evidence regarding various interventions has emerged.[10] It is essential to update these guidelines to better inform clinicians, facilitate personalised care and minimise the long-term societal burden of AIS.[126,127] For instance, novel approaches such as the 'wean-in' strategy may enhance bracing adherence and curve improvement in clinical practice.[12] Additionally, clinicians should recognise the challenges faced by patients and actively engage both patients and parents in shared decision-making to improve patient knowledge, treatment adherence and overall health outcomes.[128]

Footnotes: [a] EOS Imaging, Paris, France

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Correspondence: Arnold YL Wong, Department of Rehabilitation Sciences, The Hong Kong Polytechnic University, Hong Kong SAR, China. Email: arnold.wong@polyu.edu.hk

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