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REVIEW ARTICLE (META-ANALYSIS)

Impact of Therapeutic Exercises Versus General Conservative Modalities and Brace on the Progression of Adolescent Idiopathic Scoliosis: Systematic Review and Meta-analysis

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Abstract

Objective: To compare the effects of therapeutic exercises in preventing Cobb angle progression in adolescent idiopathic scoliosis (AIS) compared with other conservative treatments.

Data Sources: Systematic searches were conducted in MEDLINE via PubMed, Embase, centralized database (CENTRAL), Physiotherapy Evidence Database (PEDro), and cumulative index to nursing and allied health literature up to December 14, 2023, and registered in PROSPERO (CRD42020156639).

Study Selection: Randomized controlled trials involving adolescents aged 10-18 years with AIS and a Cobb angle >10° were included.

Data Extraction: Two reviewers independently extracted study data, assessed the risk of bias using the PEDro scale, and the certainty of evidence—using the Grading of Recommendations, Assessment, Development and Evaluation approach.

Data Synthesis: Nineteen studies involving 832 participants met our selection criteria. The PEDro scale score ranged from 3 to 8 points (0-10). The results on Cobb angle progression showed no significant difference in Cobb angle reduction between therapeutic exercises and minimal intervention in the short term (mean difference [MD]=−1.33; 95% confidence interval [CI], −4.87 to 2.22). The specific therapeutic exercises showed greater Cobb angle reduction compared with general exercises in the short term (MD=−2.57; 95% CI, −4.56 to −0.59) and long term (MD=−6.00; 95% CI, −6.88 to −5.12). No significant difference was observed between therapeutic exercise and brace use in the short term (MD=0.20; 95% CI, −1.74 to 2.14); however, bracing was more effective in the long term (MD=2.66; 95% CI, 0.18-5.14). Therapeutic exercises with bracing significantly reduced Cobb angle in the short term compared with bracing alone (MD=2.25; 95% CI, −3.86 to −0.63).

Conclusions: This systematic review and meta-analysis suggest that therapeutic exercises can be effective in preventing Cobb angle progression in AIS. Specifically, targeted therapeutic exercises led to a greater reduction in Cobb angle compared with general exercises both in the short and long term. Although no significant difference was found between therapeutic exercises and minimal intervention in the short term, combining therapeutic exercises with bracing demonstrated a significant short term advantage over bracing alone. In the long term, bracing was found to be more effective than therapeutic exercises in preventing Cobb angle progression. Given the varied outcomes across different interventions and time frames, further high-quality trials are needed to establish optimal treatment protocols for managing AIS.

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Scoliosis is a complex and progressive condition characterized by a 3-dimensional spine deformity.[1] The etiology of scoliosis can be associated with secondary diseases, such as congenital or neuromuscular conditions. However, in 70%-80% of cases,[1,2] the cause is not well defined and is referred to as idiopathic scoliosis.[1] Idiopathic scoliosis can affect different age groups, but adolescent idiopathic scoliosis (AIS) is the most prevalent.[1,3,4] The AIS affects around 200 million adolescents aged 10-17 years, with a worldwide prevalence ranging from 2% to 3%.[1,3,4] Among those affected, nearly 10% require some form of treatment, and ≤0.1% require surgery.[5,6] The diagnosis of AIS relies on measuring the Cobb angle through x-rays,[1] and is confirmed when the Cobb angle is ≥10° in the frontal plane. The Cobb angle measurement determines the severity of the scoliosis, with curves over 30° posing higher risks of progression in adulthood, as well as the risk of health problems and reduced quality of life.[1]

Since two-thirds of AIS patients experience curve progression during adolescence, treatment aims to slow this progression before skeletal maturity to achieve more effective results and avoid surgery.[7-9] Conservative interventions are the primary treatment options for stabilizing spinal curves, preventing scoliosis progression, and reducing scoliosis complications.[10,11] Conservative interventions for AIS involve therapeutic exercises (TEs), such as physiotherapeutic scoliosis−specific exercises (PSSE) or general conservative modalities (general TEs [GTE]) and the use of orthopedic braces. General conservative modalities refer to a range of general exercises prescribed by physiotherapists aimed at improving overall spine health and function.[1,12,13] PSSE,[14] encompasses principles such as 3-dimensional self-correction, training for daily living activities, stabilization of corrected postures, and patient education.[1] Orthopedic braces are recommended for patients with a Cobb angle >25° and with growth potential.[1,15,16] The combination of TEs with braces can improve muscle flexibility, strength, and back pain in AIS patients, although their effect on curvature progression is uncertain.[11,17,18]

Previous systematic reviews on the effectiveness of conservative treatments for AIS often had present different scopes of TEs, with different treatment modalities, as well as with and without the use of the brace, showing different efficacy in preventing the Cobb angle in AIS. They typically focused on a single modality of conservative intervention, such as GTE,[19-21] or PSSE,[17,22] or specific techniques such as Schroth.[23-25] Additionally, some reviews compared treatments with only 1 control group, such as no-treatment.[5,21] Only 1 recent systematic review has investigated different types of control groups but did not compare different exercise types.[11] Such narrow reviews may overlook beneficial interventions and limit the replication of results in clinical practice. To date, there is no consensus on the benefits of TEs for AIS when stratified by the severity of the scoliotic curve and separated by short- and long-term treatment durations. Therefore, it is still necessary, systematic review, to understand this theme about 3 questions to effectiveness of the TEs (PSSE or specific techniques such as Schroth) general conservative modalities (GTE) and brace (with or without TEs) in the progression of scoliosis, such as: (1) TEs versus minimal intervention/observation; (2) TEs versus bracing; and (3) TEs versus brace plus exercise. The objective of this systematic review is to evaluate the effectiveness of TEs in preventing Cobb angle progression in individuals with AIS, compared with: (1) TEs versus other general conservative modalities (GTE); (2) different types of TEs; and (3) the use of braces alone or in combination with TEs.

List of abbreviations:

AIS	**adolescent idiopathic scoliosis**
GTE	**general therapeutic exercises**
PSSE	**physiotherapeutic scoliosis−specific exercises**
TEs	**therapeutic exercises**

Methods

This systematic review and meta-analysis were conducted following the recommendations of the Cochrane Handbook for Systematic Reviews and reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement.[26] The review protocol was also registered on PROSPERO (CRD42020156639).

Eligibility criteria

We included randomized clinical trials (RCTs) published in peer-reviewed journals with no restrictions on language or date of publication. Nonrandomized studies, case-control studies, and case series were not included.

The following inclusion criteria were considered: (1) participants were adolescents aged 10-18 years with AIS and a Cobb angle above 10°. Exclusions included studies with patients having contraindications to exercise, heterogeneous ages, prior surgery, specific diseases, spinal tumors, or other spine-related conditions; (2) interventions included RCTs using GTE, such as spinal mobilization, Pilates, postural corrective exercises, and core strengthening exercises, as well as PSSE which integrate daily life training activities, 3-dimensional self-correction of posture, stabilization of corrected posture, and patient education. These exercises, prescribed by physiotherapists, aim to prevent AIS progression. There were no restrictions on exercise setting or delivery format, but studies without a therapeutic focus (eg, swimming, weight training, yoga) and those only performing breathing exercises were excluded; (3) studies comparing conservative treatments with TEs were included. These comparisons included TEs versus minimal intervention or clinical observation, TEs versus other TEs modalities, TEs versus brace alone, and TEs in conjunction with brace versus brace alone; (4) studies using the Cobb angle as an outcome measure, focusing on the greatest curvature, whether thoracic or lumbar. Studies lacking pre and posttreatment Cobb angle measurements or presenting only the sum of Cobb angle measurements were excluded.

Data sources and searches

We searched articles from inception to December 14, 2023, in MEDLINE via PubMed, EMBASE, CENTRAL, Physiotherapy Evidence Database (PEDro), and cumulative index to nursing and allied health literature. Keywords and MESH terms such as "scoliosis," "adolescent idiopathic scoliosis," "AIS," and "exercise therapy" were combined. Detailed search strategies for each database are provided in supplemental table S1 (available online only at http://www.archives-pmr.org/). We also analyzed reference lists of eligible studies and checked clinical trial registration websites such as ANZCTR, ClinicalTrials.gov, Brazilian Clinical Trials Registry (ReBEC), and WHO ICTRP.

Study selection and data extraction

The retrieved studies were imported into Rayyan software[a] where all stages of article screening were conducted.[27] Two reviewers (R.M.A. and M.E.C.F.) independently screened titles, abstracts, and full-text versions. Any disagreements were resolved through discussion or arbitration by a third reviewer (H.D.K.).

Data extraction was conducted by 2 reviewers (R.M.A. and M.E.C.F.) who independently extracted study data, with discrepancies resolved through discussion or with a third reviewer (H.D.K.). The data collected included publication details (author, year, and country of publication), study characteristics (design, duration, sample description, and sample size), interventions (type, dose, and frequency), and outcome measures (Cobb angle). We contacted study authors by email, making 3 attempts within a month, to request missing or unclear main outcome data.

Risk of bias assessment

The methodological quality of the RCTs was assessed using the PEDro scale, which evaluates the risk of bias and statistical reporting in RCTs with 11 items.[28-31] The scale yields a score ranging from 0 to 10 points, indicating higher methodological quality with higher scores. Whenever available, the score from the PEDro database website was used. In cases where the score was not available, the 2 review authors (R.M.A. and M.E.C.F.) independently evaluated the risk of bias using the PEDro score.

Assessment of certainty of evidence

Two reviewers (R.M.A. and M.E.C.F.) independently assessed the overall certainty of evidence and strength of recommendations for each outcome using the Grading of Recommendations, Assessment, Development and Evaluation (GRADE) approach.[32] The certainty of evidence was evaluated by the same 2 review authors (R.M.A. and M.E.C.F.), with any disagreements resolved through discussion or arbitration by a third reviewer (H.D.K.). There were 5 downgrading domains, including risk of bias, inconsistency, indirectness, imprecision, and publication bias. The initial certainty of the evidence started as "high," with domains that could be downgraded by one or 2 levels, depending on the level of uncertainty of the evidence.

Statistical analysis

Data synthesis was performed with individual representations of each study. Study and participant characteristics were analyzed with descriptive statistics, including absolute and relative frequencies, mean and SD. If the treatment provided in the study lasted 26 weeks (6 mo) or less, it was categorized as short term treatment. Conversely, if the treatment lasted >26 weeks, it was classified as long-term treatment.

The effectiveness of TEs versus other conservative interventions was assessed by measuring the Cobb angle in degrees, presented as a continuous outcome. Data from the largest Cobb angle and standard deviation were used. If a primary study did not report the largest curve but reported stratified cervical, thoracic, and lumbar curve, only the largest curve, regardless of location, was included for analysis.

When studies did not report the SD for Cobb variability, but provided measures of standard error or confidence interval (CI), the RevMan Calculator tool was used to calculate the SD. This method aligns with Cochrane Handbook guidelines for Systematic Reviews.[33]

The meta-analysis was performed using Review Manager version 5.4 for Mac iOS.[b] The grouped analyses were performed using random effects models, which were selected because of anticipated variability in effects across populations.[34] Heterogeneity among studies was assessed using Cochran's Q test and Higgins' I^2 statistics. I^2 statistical values were used to quantify the degree of heterogeneity, with values <25% indicating low heterogeneity, 25%-50% moderate heterogeneity, and >50% high heterogeneity.[33]

The results of the meta-analysis were expressed as mean difference (MD) and its respective 95% CI. The success of conservative treatment for AIS relies on stabilizing the progression of spinal curvature.[1] TEs interventions aim to maintain the patient's initial scoliosis classification, thus preventing a mild curve from worsening.[1] According to a systematic review, curve stability is maintained when the Cobb angle changes between -5° and 4°. An improvement in the Cobb angle $>4^{\circ}$ indicates significant benefit, exceeding the expected effect of TEs.[35]

Subgroup analysis

Subgroup analyses were performed to adjust scoliosis severity based on the Scoliosis Research Society and the Society on Scoliosis Orthopedic and Rehabilitation Treatment (SOSORT) classification system, which categorizes curvature degrees using the Cobb angle. Classifications include mild ($\leq 24^{\circ}$), moderate (25°-44°), severe (45°-59°), and very severe (60°or more) scoliosis.[1]

Furthermore, a subgroup analysis based on the Risser classification was conducted to provide a more detailed assessment of the differences in risk of progression among treatment subgroups for AIS.

Results

Flow of studies through the review

The initial search across electronic databases identified a total of 3130 records. After duplicates removed and screened by title and abstract, 103 records were eligible for full-text assessment. Subsequently, 84 articles were excluded after full-text evaluation for reasons detailed in supplemental table S1. Finally, 19 randomized controlled trials[12,36-53] met the inclusion criteria and were included in this review. Figure 1 shows the PRISMA flow diagram of the study screening process and results.

Characteristics of the included studies

The studies included were conducted between 2013 and 2023 and involved 832 participants. They focused on comparing the effectiveness of TEs with other conservative treatments for AIS across 9 countries. Seven studies were carried out in high-income countries,[12,36,44,45,47,52,54] whereas most of the studies (n=12) were conducted in low- or middle-income countries.[37-43,46,49-51,53] Supplemental table S1 shows the characteristics of the included studies, reporting geographic distribution, study design, participants, interventions, comparators, and follow-up.

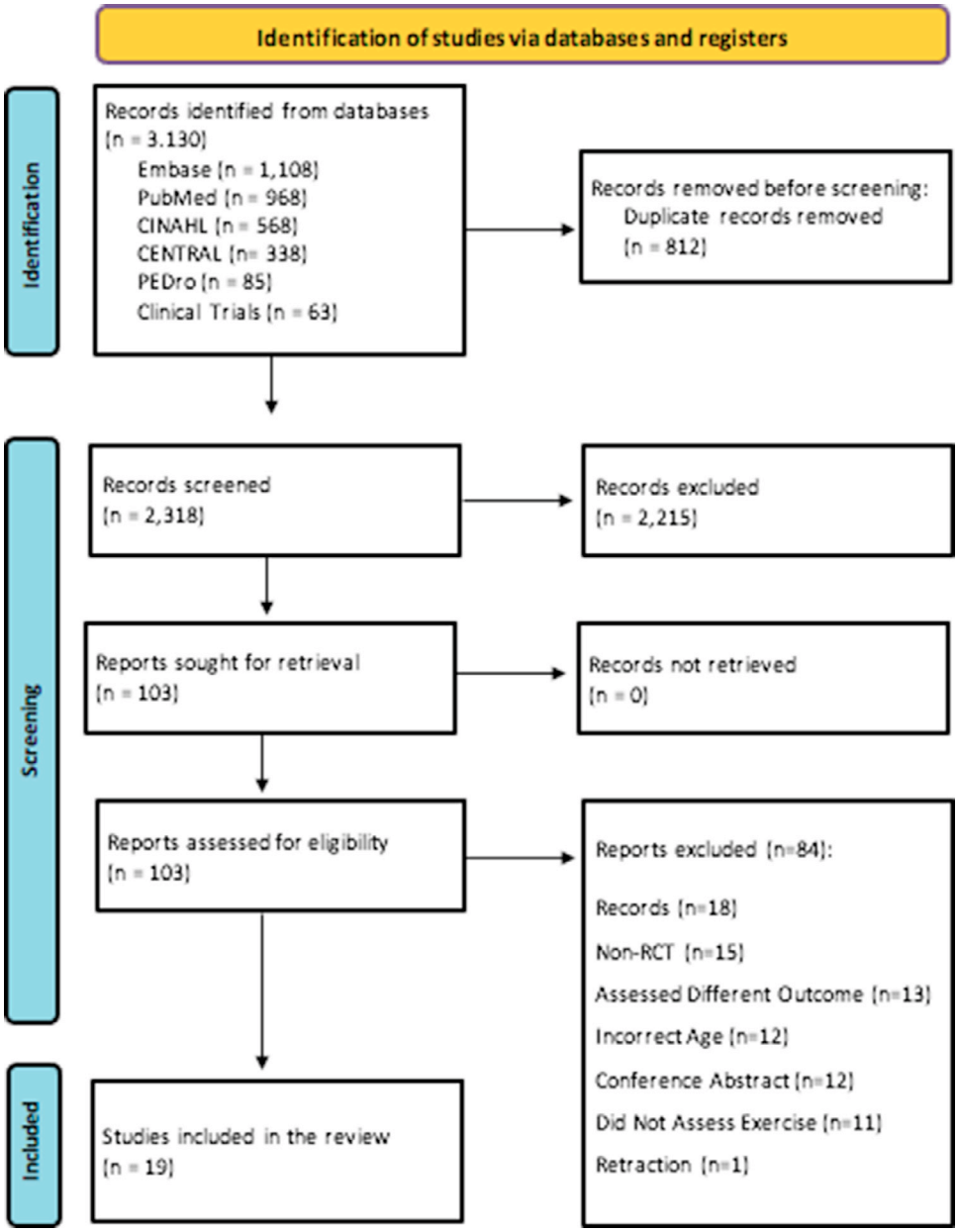

Fig 1 PRISMA flow diagram of the study screening process and results. Abbreviation: PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses.

Participants

The sample sizes of the included studies varied significantly, ranging from 20 participants[51] to 110 participants.[45] Among these participants, 678 were women (83.8%). The mean age of participants was 13.3 years (SD=1.21), mean weight of 47.7 kg (SD=2.87), and mean height of 147.4 m (SD=4.09). The Cobb angle varied from 10° to 60° across the studies, with a mean of 23.8° (interquartile range, 17.11°-29.78°). Risser sign categorization revealed that (5/19) 26.3% of the studies included early skeletal development stages (Risser 0, 0-1, or 0-2).[38,43,45,53,54] About (4 of 19) 21.1% focused on mid to late skeletal maturity stages (Risser 2-5),[39,42,44,50] and another (3/19) 15.7% covered a broad range from early to full maturity (Risser 0-5).[37,49,52] However, (7/19) 36.8% of the studies did not report the Risser sign.[12,36,40,41,46,47,51]

Interventions

Of the 19 studies included in this review, 15 investigated the effects of PSSE, whereas 5 assessed the effects of GTE. All PSSE included 3-dimensional self-correction, stabilization of the corrected posture, and daily living training activities. Among the PSSE interventions, Schroth method was the most prevalent (7 of 15 studies),[12,39,42,44,49,52,54] followed by SEAS method in 2 of the 15 studies.[50,53] GTE predominantly consisted of core stabilization exercises (3of 5 studies), Pilates (1of 5 studies), or corrective exercises (1of 5 studies). Total of the 14 studies compared TEs versus observation. Regardless of the type of exercise, 4 studies assessed the effect of exercise alone while 5 studies evaluated the effect of exercise combined with bracing.[38,49-52]

Comparators

(1) Three studies evaluated the comparison between TEs and versus general conservative modalities (GTE).[37,42,46]

(2) To assess the effectiveness among different exercises, studies were categorized into 3 distinct groups: PSSE versus GTE, evaluated by 7 studies;[12,39,41,44,45,50,51] GTE versus other GTE evaluated by 2 studies;[36,40] and PSSE versus other PSSE evaluated by 1 study.[49]

(3) The comparison between TEs and the use of Brace alone is described by just 1 study.[53]

(4) Finally, 3 studies were included in the comparison between TE combined with the use of bracing versus the use of bracing alone.[38,52,54]

Time

The duration of interventions and patient follow-up varied from 10[39,40,51] to 240 weeks (4.6 y).[45] Although 17 studies assessed the short term effects of TEs (≤26 wk or 6 mo), only 3 studies[45,53,54] treated patients with TEs for >6 months and followed them by a long term.

Risk of bias in studies

The results of the risk of bias assessment are presented in table 1. The PEDro total scores ranged from 3 to 8 points, indicating a methodological heterogeneity among the studies. Notably, 10 of out 19 studies scored 7 or 8 points[38-41,43-45,50-52] meeting most criteria, except for subject and therapist blinding. However, a notable limitation across these studies was the lack of blinding of both subjects and therapists, which is a critical factor in reducing bias. The absence of this blinding increases the likelihood of performance bias and detection bias, particularly in interventions that may influence the participants' or therapists' behavior or expectations. Despite these limitations, the overall risk of bias in these studies was lower than in those with significantly lower scores. In contrast, 6 out of 19 studies had extremely low scores[12,36,37,46,47,54] ranging between 3 and 5 points, reflecting a higher risk of bias and increased uncertainty in their results. These studies likely had several methodological shortcomings, such as inadequate randomization, poor allocation concealment, and lack of control over confounding factors. These weaknesses lead to greater uncertainty in their results, making it more difficult to draw reliable conclusions. The low scores in these studies reflect the higher likelihood of bias, which compromises the internal validity of the studies and increases the risk of drawing misleading or erroneous conclusions.

Effects of interventions

Effect of TEs versus general conservative modalities (GTE)

The short term meta-analysis results summarized in figure 2 included a total of 98 participants from 3 studies compared TEs with GTE with a high risk of bias,[37,42,46] The very low-certainty evidence (downgraded because of risk of bias, inconsistency, and imprecision) suggests no significant difference between participants who received TEs compared with those who received general conservative modalities (GTE) or scoliosis progression monitoring (MD=−1.33 Cobb degrees; 95% CI, −4.87 to 2.22; I^2=66%).

Effect of TEs versus other GTE

The studies were categorized into 3 groups to evaluate the effectiveness of different exercise modalities in the treatment of AIS.

PSSE versus GTE

The short term meta-analysis results, as summarized in figure 3, included data from a total of 202 participants across 7 studies. Among these studies, 6 were assessed as having a low risk of bias,[12,39,41,44,45,50,51] which enhances the reliability of the findings. However, the evidence was considered of low-certainty, primarily because of inconsistency (variability in results across studies) and imprecision (wide CIs), which led to a downgrading of the evidence quality.

The long term meta-analysis with 104 participants from 1 study with low risk of bias,[45] indicate an even greater effect size for PSSE (MD=−6.00 Cobb degrees; 95% CI, −6.88 to −5.12) with low-certainty evidence (downgraded because of inconsistency and imprecision).

Comparisons between general conservative modalities (GTE)

The comparison was not summarized in a meta-analysis because of the heterogeneity of interventions.[36,40,47] Individual study results showed significant differences favoring direction-sensitive exercises over traditional exercise regimes to Alayat et al[36] (MD=−2.57 Cobb degrees; 95% CI, −4.56 to −0.59). Gür et al[40] found no statistically significant difference between core stabilization exercises and traditional breathing and flexibility exercises (MD=−5.43 Cobb degrees; 95% CI, −13.24 to 2.38).[40] Similarly, Sarkisova et al[47] reported no significant difference between lateral planks and front planks (MD=1.00 Cobb degrees; 95% CI, −5.91 to 7.91).

PSSE versus other PSSE

The comparison was reported in only 1 study.[49] Short term results indicate that the addition of the sling to Schroth exercises resulted in a further reduction of Cobb degrees compared with the Schroth-only group (MD=0.93 Cobb degrees; 95% CI, −1.75 to −0.11).

Effect of TEs compared with the use of Brace

The short- and long term results were reported in only 1 study with a high risk of bias and a total of 53 participants.[53] The low-certainty evidence (downgraded 2 levels because of imprecision) suggests no significant difference between the TE group and the brace treatment group at short term (MD=0.20, 95% CI, −1.74 to 2.14). However, the long term results favored the brace treatment group (MD=2.66 Cobb degrees; 95% CI, 0.18-5.14) with low-certainty evidence (downgraded 2 levels because of imprecision).

Effect of TEs combined with brace versus use of brace alone

Figure 4 summarizes the short term meta-analysis results, involving a total of 87 participants from 2 studies with a low bias risk.[38,52] The moderate-certainty of evidence (downgraded because of imprecision) suggests that the inclusion of PSSE in patients already using a brace resulted in a mean reduction in the Cobb angle compared with the use of the brace alone (MD=−2.25 degrees; 95% CI, −3.86 to −0.63; I^2=0%).

In contrast, the long term analysis, based on a single study with a high risk of bias,[54] involving 53 participants, did not find

Table 1 Risk of bias measured by the PEDro scores of included studies.

	Items of the PEDro Scale*											
Author	1†	2	3	4	5	6	7	8	9	10	11	Total
Alayat et al[36]	S	Y	N	Y	N	N	N	N	N	Y	Y	4
Dursun et al[37]	Y	Y	N	N	N	N	Y	Y	N	Y	Y	5
Gao et al[38]	Y	Y	Y	Y	N	N	Y	Y	N	Y	Y	7
Gür et al[40]	Y	Y	N	Y	Y	N	N	Y	Y	Y	Y	7
Kim and Hwangbo[12]	N	Y	N	Y	N	N	N	Y	N	Y	Y	5
Kocaman et al[39]	Y	Y	Y	Y	N	N	Y	Y	Y	Y	Y	8
Kumaret al[41]	Y	Y	Y	Y	N	N	Y	Y	Y	Y	Y	8
Kuru et al[42]	Y	Y	Y	Y	N	N	N	Y	N	Y	Y	6
Mohamed et al[44]	N	Y	Y	Y	N	N	Y	Y	Y	Y	Y	8
Monticone et al[45]	Y	Y	Y	Y	N	N	Y	Y	N	Y	Y	7
Moubarak et al[43]	Y	Y	Y	Y	N	N	Y	Y	N	Y	Y	7
Qi et al[46]	Y	Y	N	Y	N	N	N	N	N	Y	Y	4
Sarkisova et al[47]	Y	Y	N	Y	N	N	N	N	N	Y	N	3
Schreiber et al[52]	Y	Y	Y	Y	N	N	Y	Y	Y	Y	Y	8
Yagci et al[51]	N	Y	N	Y	N	N	Y	Y	Y	Y	Y	7
Yagci et al[50]	Y	Y	N	Y	N	N	Y	Y	Y	Y	Y	7
Zapata et al[54]	N	Y	N	Y	N	N	Y	N	N	Y	Y	5
Zhang et al[49]	Y	Y	N	Y	N	N	Y	Y	N	Y	Y	6
Zheng et al[53]	Y	Y	Y	Y	N	N	N	Y	N	Y	Y	6

NOTE. 1, eligibility and source; 2, random allocation; 3, concealed allocation; 4, groups similar at baseline; 5, participant blinding; 6, therapist blinding; 7, assessor blinding; 8, >15% dropouts; 9, intention-to-treat analysis; 10, between- group difference reported; 11, point estimate and variability reported.[27,28]

Abbreviations: N, no—criterion not met; PEDro, Physiotherapy Evidence Database; Y, yes—criterion met.

* All quality scores were downloaded from the PEDro website, except for Dursun et al,[37] Qi et al,[46] and Zhang et al[49]; these are more recent studies and the evaluation was not available on the PEDro database.

† Relates to external validity and therefore does not contribute to the total score.

significant differences between the groups using a brace with or without the addition of PSSE (MD=−2.0°; 95% CI, −5.50 to 1.50) with very low-certainty evidence (downgraded because of risk of bias, inconsistency, and imprecision).

GRADE summaries

The overall certainty of evidence for each comparison can be seen in supplemental table S1 and tables 1-4. In summary, the certainty of the evidence across the comparisons ranged from very low (TE vs clinical observation/minimal intervention; TE combined with brace versus brace alone in long term) to low (PSSE vs GTE; TE vs brace) to moderate (TE combined with brace vs brace alone—short term).

Subgroup analysis

The subgroup analysis was based on scoliosis curvature severity. For individuals with mild curvatures (Cobb angle ≤24°), TE proved be superior to minimal intervention or clinical observation (MD=−3.67; 95% CI, −5.69 to −1.65). Similarly, PSSE were superior when compared with GTE (MD=−2.92; 95% CI, −5.16 to −0.68) for mild curvatures. For individuals with moderate curvatures (Cobb angle between 25° and 44°), no statistically

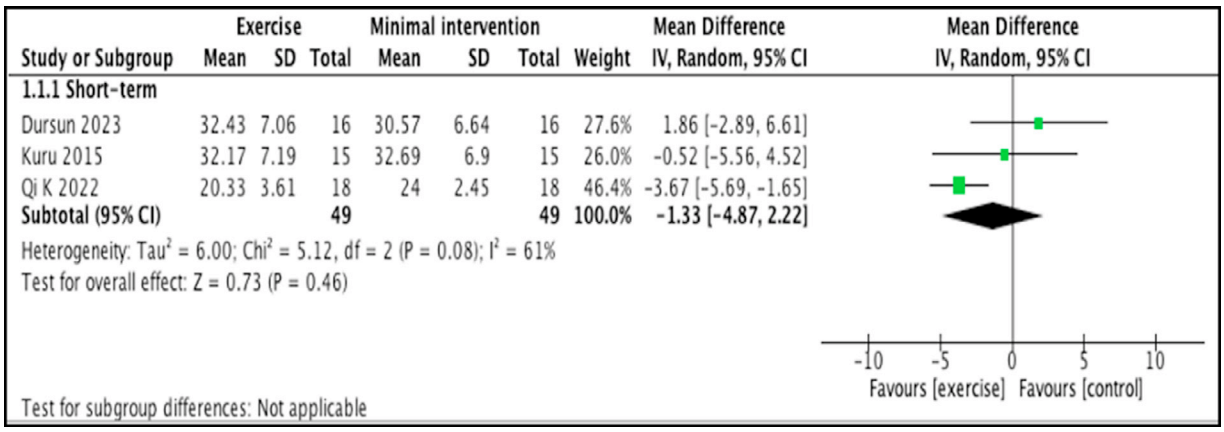

Fig 2 Meta-analysis of trials comparing therapeutic exercise (TEs) versus minimal intervention with general conservative modalities (general therapeutic exercises [GTE]) on posttreatment Cobb angle in the short term in individuals with AIS.

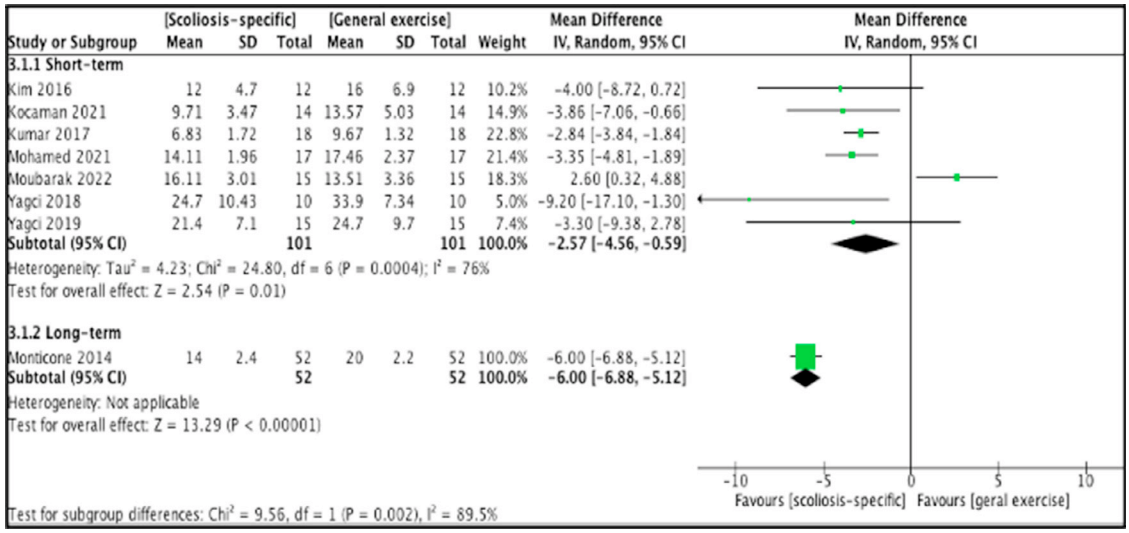

Fig 3 Meta-analysis of trials comparing PSSE versus GTE on posttreatment Cobb angle in the short and long term in individuals with AIS.

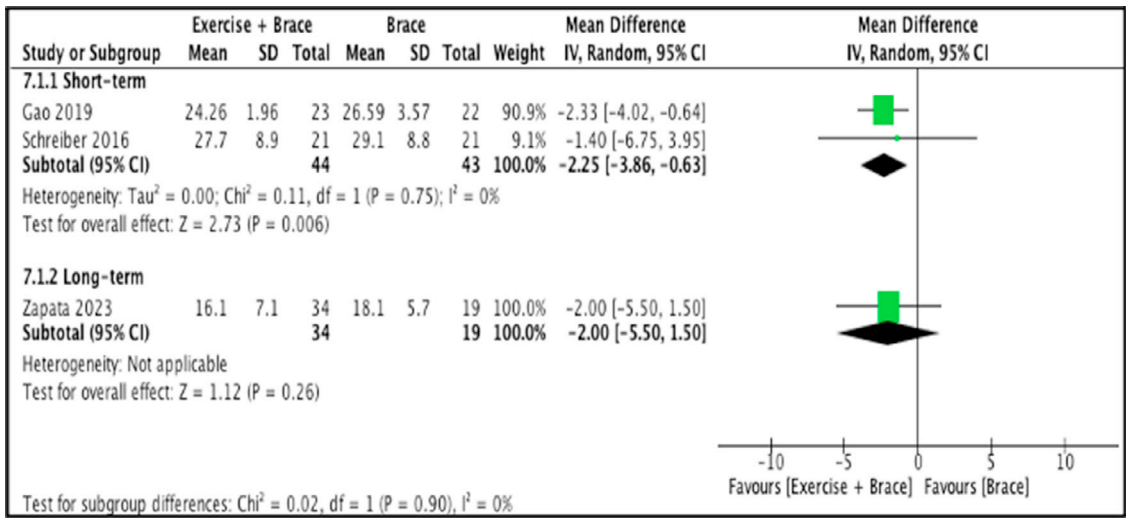

Fig 4 Meta-analysis of trials comparing TEs combined with bracing versus bracing alone on posttreatment Cobb angle in the short and long term in individuals with AIS.

significant difference was found between the TE and minimal intervention groups (MD=−0.74; 95% CI, of −2.72 to 1.24). However, the effect size favored PSSE when compared with GTE (MD=−5.69; 95% CI, −11.36 to −0.01) for moderate curvatures. No studies involving severe or very severe curvatures were included in this systematic review. For more details, refer supplemental figures S1 and S2 (available online only at http://www.archives-pmr.org/).

Three studies on Risser that evaluated the comparison between TEs and versus general conservative modalities (GTE)

All 3 studies were initially considered. However, one of these studies[46] did not report the Risser sign. The 2 studies[42,46] that explicitly provided Risser sign classifications were included, which reported Risser 0-3, and Dursun et al,[37] which included patients with Risser 0-5. Both studies included participants aged 10-18 years. The results indicated that neither of the Risser subgroups (0-3 and 0-5) showed a significant difference between groups (table 2; fig 5).

PSSE versus GTE on Risser classification

All 8 studies were initially considered and stratified according to the reported Risser sign to assess potential differences based on skeletal maturity. Three studies[39,43,45] were classified as lower Risser (0-3), whereas 2 studies[44,50] were categorized as higher Risser (Risser 2-5). The remaining 3 studies[12,41,51] did not report the Risser sign. The results indicated a significant difference favoring PSSE (MD=−3.35; 95% CI, −4.77 to −1.92) in the

Table 2 Three studies on Risser evaluated the comparison between TEs and versus general conservative modalities (general therapeutic exercises).

Author	Risser	Age Range (y)
Dursun et al[37]	0-5	10-18
Kuru et al[42]	0-3	10-18
Qi et al[46]	NR	13.7 (1.3)

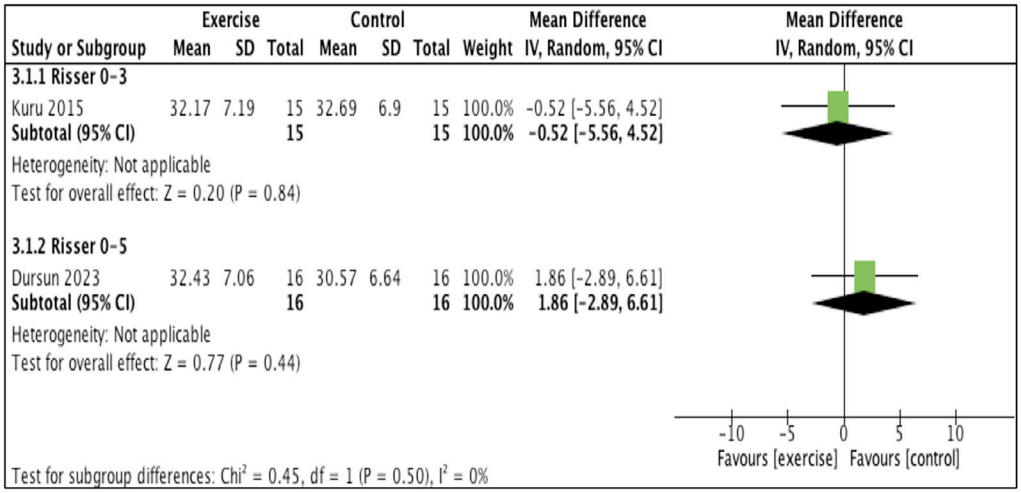

Fig 5 Meta-analysis of trials on Risser comparing TEs and versus general conservative modalities (general therapeutic exercises [GTE]) in individuals with AIS.

Table 3 Studies with exercise intervention studies that evaluated the Risser classification and age range in individuals with scoliosis.

Author	Risser	Age Range (y)
Monticone et al[45]	0-1	>10
Moubarak et al[43]	0-1	10-14
Kocaman et al[39]	0-3	10-18
Yagci et al[50]	2-3	≥12
Mohamed and Yousef[44]	2-5	14-16
Kim and Hwangbo[12]	NR	15.45 (±0.95)
Kumar et al[41]	NR	10-15
Yagci et al[51]	NR	10-16

higher Risser subgroup. Although no significant difference was found in the lower Risser subgroup (MD=−2.45; 95% CI, −8.16 to 3.26) (table 3; fig 6).

GTE versus other GTE on Risser classification

The comparison between general conservative modalities (GTE) was not summarized in a meta-analysis because of the heterogeneity of the interventions. Individual study results varied, with 1 study[36] showing a significant difference favoring direction-sensitive exercises (MD=−2.57 Cobb degrees; 95% CI, −4.56 to −0.59), whereas the other 2 studies[40,47] found no statistically significant differences (MD=−5.43 Cobb degrees; 95% CI, −13.24 to 2.38 and MD=1.00 Cobb degrees; 95% CI, −5.91 to 7.91, respectively).

Additionally, none of the 3 studies reported the Risser sign, making it impossible to perform a subgroup analysis based on skeletal maturity.

PSSE versus other PSSE on Risser classification

The comparison between PSSE versus other PSSE was evaluated by a single study.[49] This study included participants with a wide range of skeletal maturity, classified as Risser 0-4, which

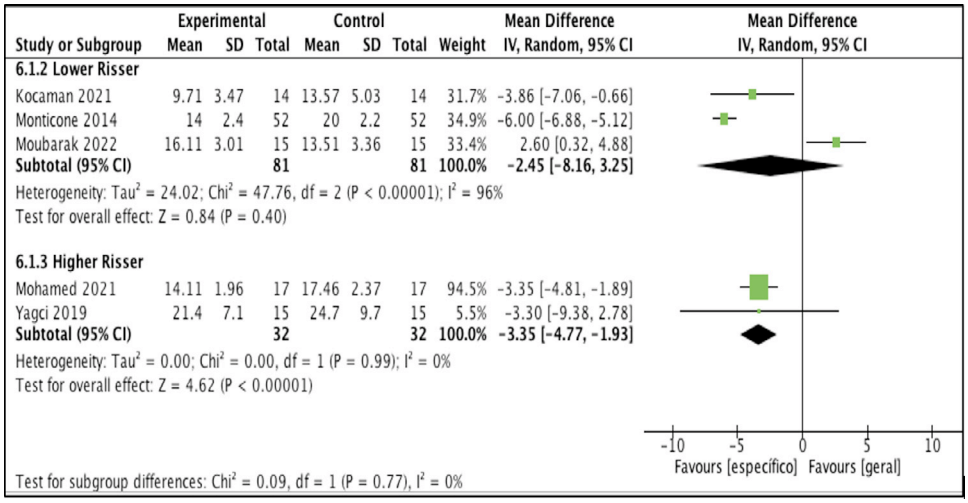

Fig 6 Meta-analysis of trials on Risser classification (lower and higher) comparing TEs and versus general conservative modalities (general therapeutic exercises [GTE]) in individuals with AIS.

Table 4 Studies on Risser in the comparison between TE combined with the use of bracing versus the use of bracing alone in individuals with scoliosis.

Author	Risser	Age Range (y)
Gao et al[38]	0-2	>10
Schreiber et al[52]	0-5	10-18
Zapata et al[54]	0-5	10-16

prevented the possibility of conducting a subgroup analysis based on skeletal maturity.

The comparison between TEs and the use of brace alone on Risser classification

The comparison between TEs and the use of a brace alone was evaluated in a single study.[53] This study included participants aged 10-17 years with Cobb angles ranging from 20° to 40° and Risser 0-2, representing individuals in the early stages of skeletal maturity. Because of the absence of additional studies in this comparison, a meta-analysis was not possible, and no subgroup analysis based on Risser classification could be conducted.

Studies on Risser in the comparison between TE combined with the use of bracing versus the use of bracing alone

All 3 studies included in the comparison between TE combined with bracing versus bracing alone (Gao et al,[38] Schreiber et al,[52] and Zapata et al[54]) were stratified based on Risser classification. The lower Risser subgroup (0-2), represented by Gao et al,[38] showed a significant difference favoring the combined intervention (MD=−2.33 Cobb degrees; 95% CI, −4.02 to −0.64). In contrast, the higher Risser subgroup (0-5), which included Schreiber et al[52] and Zapata et al,[54] did not show a statistically significant difference (MD=−1.82 Cobb degrees; 95% CI, −4.75 to 1.11) (table 4; fig 7).

Discussion

This systematic review evaluated the effectiveness of TEs in AIS, using data from 19 RCTs involving 832 participants. In general, TEs were capable of preventing Cobb angle progression. Four clinical scenarios were analyzed: the first showed very low-certainty evidence that TEs may not significantly differ from minimal intervention in overall Cobb angle reduction, yet they appear more beneficial for patients with mild curves in subgroup analysis. The second clinical scenario compared different TE modalities and found low-certainty evidence supporting the superiority of PSSE over GTE in both short and long term. The third clinical scenario questioned whether TE could replace bracing. Although no short term differences were observed between TE and the use of brace alone, long term outcomes favored the use of brace, although the low-certainty evidence supporting these finds. The fourth scenario investigated whether combining TEs with bracing improves Cobb angle reduction. This combination was more effective in the short term with moderate-certainty evidence, but not in the long term with very low-certainty of evidence.

A recent bibliometric analysis elucidates the evolution and expansion of research on exercise therapy for AIS rehabilitation, charting significant advancements from 1999 to 2023.[55] The analysis identified a total of 172 articles, showing a significant increase in publications over the last decade, reaching a peak in 2021. This trend highlights a growing recognition of TEs potential in AIS management.[55] In current clinical practice, the SOSORT guidelines specifically recommend PSSE for managing AIS to prevent the progression of Cobb angle in mild and moderate scoliosis.[1] Our data align with this approach, showing the PSSE group maintained the Cobb angle better than the GTE group in the short term (MD=−2.57 Cobb degrees) and showed a greater reduction in Cobb angle in the long term (MD=−6.00 Cobb degrees), in cases of mild to moderate curvature.

Nevertheless, the SOSORT guidelines recommend bracing either alone or in combination with PSSE, aimed to prevent surgical interventions while optimizing brace effectiveness and reduce negative impacts such as muscle weakness.[1] The latest Cochrane systematic review suggests that combining PSSE with bracing

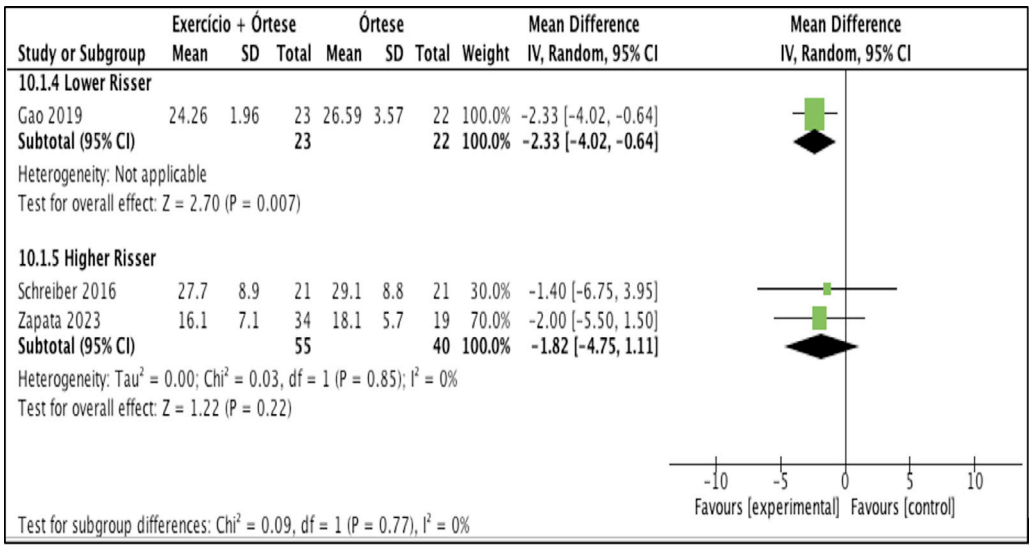

Fig 7 Meta-analysis of trials on Risser classification (lower and higher) comparing TE combined with the use of bracing versus the use of bracing alone in individuals with AIS.

compared with bracing alone may reduce the Cobb angle in the short term, although the clinical significance is not meaningful (MD= −2.2°; 95% CI, −3.8 to −0.7; 2 studies, 84 participants; low-certainty evidence, downgraded 2 levels for imprecision).[11] This finding aligns with our systematic review, which noted a very similar effect size in this comparison. However, the Cochrane review did not include the study by Zapata et al,[54] which evaluated this comparison over the long term (at 52 and 104 wk) and found no difference between groups, as reported in our systematic review (MD= −2.0°; 95% CI, −5.50 to 1.50). Nonetheless, the long term analysis was based on a single study with a high risk of bias, involving 53 participants and very low-certainty evidence.[54]

Among the systematic reviews assessing the effectiveness of TE for AIS, none included the exact comparisons and studies of this review, yet the majority have reported favorable outcomes for TEs,[17,19-25] particularly PSSE.[17,22-25] Except for Baumann et al,[56] that compared PSSE and GTE and found effect sizes similar to those in this review but concluded that there was no significant difference between the groups.[56] This was attributed to their classification of a positive effect as a reduction >5° in the Cobb angle, which they did not observe. Therefore, suggesting no significant advantage of PSSE over GTE in halting scoliosis progression.

There is no standardized threshold in Cobb angle reduction in the literature that clearly distinguishes clinical improvement in patients undergoing TEs for AIS. A decrease of 5° is often referenced by several studies as a clinically meaningful outcome that can mitigate disease progression.[12,35,56] However, because of the progressive nature of the scoliosis, stabilizing the scoliotic curvature during growth is considered a clinically satisfactory result, preventing severe deformities, reducing the effect on quality of life, and decreasing the number of surgical interventions needed. Thus, the role of TE in reducing and stabilizing scoliotic curvature until the end of adolescence is underscored.[12,13,39,41-43,45,46,48,51-53] In addition, a recent scoping review emphasizes that success in treating AIS is primarily measured by stabilization or improvement of the Cobb angle, with 61.38% of studies using this radiographic measure.[57]

For more accurate conclusions on the effects of TE on AIS progression, future research should prioritize randomized controlled trials with enhanced methodological rigor. Additionally, it is essential to investigate the supplementary effects of combining these exercises with bracing. Longitudinal monitoring is critical, as AIS can progress until the end of bone growth. Detailed descriptions of treatment protocols, including exercise frequency, dosage, and intensity are necessary to facilitate comparisons between studies and replicate results. Future research should also explore other potentially influential factors, such as genetics, hormonal levels, and physical activity to fully understand their effect on Cobb angle progression and exercise intervention outcomes.

Finally, standardizing treatment success criteria and investigating the long term effects of combined therapeutic interventions in more severe scoliosis cases are crucial to enhance treatment effectiveness and tailor approaches to individual patient needs.

The findings suggest that skeletal maturity, assessed by the Risser sign, may influence the effectiveness of physiotherapeutic interventions, particularly PSSE. Greater benefits were observed for PSSE in individuals with higher Risser scores (2-5), indicating that specific interventions may be more effective in later stages of skeletal maturation. There is a need for standardized reporting of Risser classification in studies to enable more accurate subgroup analyses. Additionally, the effectiveness of combined interventions (TEs + brace) in participants with Risser 0-2 highlights the potential of such strategies in the early stages of growth.

Study limitations

This systematic review has some limitations. First, the inclusion of RCTs with small samples (mean of 20 participants per group), and high clinical heterogeneity among the intervention and control groups, such as type of intervention, duration and frequency of treatments, characteristics of participants, and follow-up duration, may have induced variations and systematic errors. Second, the exercises reported in RCTs were predominantly either inadequate or incomplete. These limitations likely impacted the classification in the comparative analysis of "PSSE versus GTE." Moreover, the limited number of studies available for each comparison also impacted the results and restricted the ability to conduct a comprehensive meta-analysis, thereby limiting the certainty of the evidence gathered. Nonetheless, to minimize the chances of errors during this systematic review, we developed a detailed research protocol to define our inclusion and exclusion criteria, search methods, and the procedures for selecting and evaluating studies to ensure consistency and transparency at all stages. We also used the PEDro scale to assess the risk of bias in the studies and the GRADE approach to evaluate the certainty of our findings, which allowed us to identify and control potential sources of bias in the results found. Finally, we performed subgroup analyses, which enabled us to verify whether the results were consistent regardless of differences in the degrees of curvature and severity of the AIS. Third, we did not consider the risk of bias when including studies in the meta-analysis, which could be seen as a limitation. However, our initial approach focused on ensuring that studies met the inclusion criteria based on methodological design and outcomes of interest. The risk of bias was assessed after study inclusion to provide a more detailed analysis of the quality of the included studies and the certainty of the evidence. Another question was in relation to the risk of bias in studies with scored 7 or 8 points, meeting most criteria, except for subject and therapist blinding, which is a critical factor in reducing bias. The absence of such blinding increases the likelihood of performance bias and bias detection, particularly in interventions that may influence participants' behavior or expectations. This review does not consider other outcomes or look at factors such as adherence to exercise or bracing and the effect that these clinical factors can have on outcomes. In addition, future research should consider stratification by Risser and further explore less investigated comparisons, such as PSSE versus other PSSE and TEs versus brace.

Conclusions

This systematic review and meta-analysis suggest that TEs can be effective in preventing Cobb angle progression in AIS. Specifically, targeted TEs led to a greater reduction in Cobb angle compared with general exercises both in the short and long term. Although no significant difference was found between TEs and minimal intervention in the short term, combining TEs with bracing demonstrated a significant short term advantage over bracing alone. In the long term, bracing was found to be more effective than TEs in preventing Cobb angle progression. Given the varied outcomes across different interventions and time frames, further high-quality trials are needed to establish optimal treatment protocols for managing AIS.

Suppliers

a. Rayyan; Rayyan.ai.
b. Review Manager, version 5.4; Cochrane.

Keywords

Adolescents; Exercise therapy; Rehabilitation; Scoliosis; Spinal curvatures; Systematic review

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Data statements

The data extracted from included studies; data used for all analyses; analytic code and any other materials used in the review can be accessed through PROSPERO (CRD42020156639).

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