Journal of Orthopaedic Surgery and Research

SYSTEMATIC REVIEW

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The efficacy of core stabilization exercise in mild and moderate adolescent idiopathic scoliosis: a systematic review and meta-analysis

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Abstract

Background Adolescent idiopathic scoliosis (AIS) is one of the most prevalent spinal abnormalities. Core stabilization exercise (CSE) has become a common approach in the treatment of AIS. However, the efficacy of CSE in AIS remains a subject of debate.

Objective To determine the efficacy of CSE in the patients with AIS in comparison with different intervention programs.

Methods A comprehensive search was conducted across PubMed, Embase, The Cochrane Library, Web of Science, Wan Fang, Wei Pu, and CNKI databases, encompassing literature from their inception through December 31st, 2024. Two independent reviewers screened the studies, with inter-rater agreement evaluated via kappa scores. Randomized control trials that focus on the efficacy and safety of CSE in AIS population were included in this systematic review. The risk of bias assessment was performed utilizing the National Institutes of Health Quality Assessment Tools (NIH-QAT). After quality assessments and information extraction, the meta-analysis was conducted with Review manager and the standard mean difference (SMD) was pooled among the measurement data derived from different studies. Cobb angle, angle of trunk rotation, apical vertebral rotation, Walter Reed Visual Assessment Scale, Posterior Trunk Symmetry Index, forced vital capacity (FVC), forced expiratory volume in 1 s (FEV1), FEV1/FVC, SRS-22,, were focused as outcomes.

Results A total of 10 studies involving 449 subjects were included in this systematic review. The average Cobb angle was 22.86° ± 8.79°, and the intervention duration varied from 8weeks to 6months. The kappa score was 0.93. Subgroup analyses were performed based on the different control groups, National Institutes of Health Quality Assessment Tools (NIH-QAT) results, and intervention durations. The results indicated that CSE could have greater effect sizes than the blank control group on Cobb angle (MD = -4.37, $P < 0.05$), angle of trunk rotation (MD = -1.07, $P < 0.05$), apical vertebral rotation (MD = -0.44, $P < 0.05$), quality of life as SRS-22 (MD = 0.22, $P < 0.05$). Notably, the efficacy of CSE appears to be weaker than that of the three-dimensional exercise group in terms of Cobb angle

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(MD = 3.95, $P < 0.05$), angle of trunk rotation (MD = 1.69, $P < 0.05$) and WASRS scores (MD = 0.89, $P < 0.05$). Other subgroup analyses yielded no statistically significant differences.

Conclusions The present study showed that core stabilization exercise may be beneficial for the patients with mild to moderate adolescent idiopathic scoliosis, albeit less effective than three-dimensional exercises following short-term follow-up. The evidence on the efficacy of CSE is limited due to heterogeneity, small sample sizes, and multiple comparisons. The clinical trials focusing on patient compliance and training quality with long-term follow-up are warranted.

PROSPERO registration number CRD 42022367714.

Keywords Adolescent idiopathic scoliosis, Core stabilization exercise, Systematic review, Meta-analysis, Efficacy

Introduction

Scoliosis is a complex three-dimensional spinal deformity characterized by a Cobb angle of ≥ 10° and axial rotation. Approximately 80% of scoliosis cases are idiopathic [1], among which adolescent idiopathic scoliosis (AIS) is the most common [2]. Recent reviews suggest that the prevalence of scoliosis among Chinese adolescents aged 10 to 18 is 1.2%. Notably, mild (Cobb angle: 10° – 19°) and moderate (Cobb angle: 20° – 39°) cases of adolescent idiopathic scoliosis (AIS) constitute over 95% of all patient [3–5]. Given that AIS is a progressive disorder that rapidly develops during adolescence and typically stabilizes in adulthood, it necessitates heightened attention during the adolescent years. Timely and active intervention measures should be implemented when deemed necessary [6, 7].

The general treatment goals of AIS include improving respiratory dysfunctions, spinal pain, aesthetics, quality of life and stopping or even reversing the progression [8]. The treatment of AIS mainly includes surgery, brace, and exercise training [9]. Among the various exercise options, physiotherapeutic scoliosis-specific exercises (PSSE) have been extensively reported and are widely utilized for patients with mild to moderate AIS [8, 10]. Berdishevsky et al. [11] conducted a comprehensive review of the seven major schools of PSSE, each advocating a distinct technique and set of exercises. For instance, the Schroth method focuses on reshaping the thorax by activating isometric muscles around the convexities and employing a specific breathing technique known as rotational angular breathing in the concavities [12–14]. Another frequently mentioned approach is the Scientific Exercise Approach to Scoliosis (SEAS), which emphasizes educating and training patients to actively self-correct their posture and integrate these corrections into functional exercises [15]. These specialized corrective exercises require implementation by professional and certified therapists. Furthermore, the diverse classification systems of PSSE may impede the broad application in certain regions or institutions [11, 16].

Recent studies have reported the positive role of the core stabilization exercise (CSE) in patients with AIS [12, 17]. Concurrently, CSE are extensively utilized in the treatment of low back pain [18, 19]. These exercises are grounded in Manohar Panjabi's spinal stability theory [20], which posits that the fortified core muscles such as the erector spinae, multifidus, oblique and anterior abdominal muscles, and glutes could enhance their coordination in the neuromuscular control and improve trunk stability, posture, balance, and overall functionality [21, 22]. Typical CSE maneuvers include the planks, side planks, supine bridges, back bridges, side bridges, bird-dogs, and cat-camels, engage the large spinal muscles [17, 23–25]. In contrast to PSSE, the simplicity of implementation of CSE alleviates the concerns of AIS patients and their parents regarding the precision of execution and potential adverse effects from incorrect performance.

However, the efficacy of CSE is still controversial in the treatment of AIS [26–28]. Recent reviews [29–31] have underscored the critical importance of core stability in managing scoliosis, suggesting that exercise interventions centered on core strengthening yield positive results for the individuals affected by scoliosis. However, these reviews encompassed a broad range of exercise modalities, such as the Schroth method, Pilates, and yoga, without specifically focusing on CSE. Additionally, the scope of these reviews extended to all individuals with scoliosis, rather than narrowing down to those specifically diagnosed with AIS. Furthermore, the studies included in these reviews were not limited to RCTs, incorporating other types of studies as well. This heterogeneity could compromise the overall reliability of the findings. In addition, recent studies [17, 23, 24, 32, 33] have evaluated the effects of CSE on visual deformity and pulmonary function in AIS, an aspect heretofore unexplored in antecedent studies.

Therefore, the purpose of this systematic review and meta-analysis was to comprehensively review the published evidence and to evaluate the efficacy of CSE in the curve progression, spinal pain syndrome, respiratory dysfunction, visual deformity, and quality of life in the patients with mild to moderate AIS. The evidence from RCTs of CSE in this systematic review will facilitate the scientific selection of exercise programs for AIS.

Methods

This study adhered to the PRISMA statement [34] and was pre-registered on the PROSPERO platform (# CRD 42022367714) [35].

Literature searches

We retrieved PubMed, Embase, The Cochrane Library, Web of Science, Wan Fang, Wei Pu and CNKI databases to collect RCTs on the efficacy of CSE in patients with AIS. The search was conducted by combining subject words and random words, and adjustments were made according to the characteristics of each database. We also searched the references of the included studies to obtain relevant supplementary articles. The major terms used to build the search strategy included scoliosis, core stability. See the attachment for detailed search strategies and results (File S1). The time span of the search was from the establishment of the database to December 31st, 2024, and only articles written in Chinese or English were included.

Literature screening

The literature screening was independently completed by two researchers. Inclusion criteria were developed using the Population, Interventions, Comparators, Outcome, Study Designs (PICOS) qualification criteria described in PRISMA: (1) P: patients with AIS; (2) I: CSE; (3) C: usual care, traditional rehabilitation, brace, Schroth training, other exercises; (4) O: Structures: Cobb angle, angle of trunk rotation (ATR), apical vertebral rotation(AVR); Appearance: Walter Reed Visual Assessment Scale (WRVAS), Posterior Trunk Symmetry Index (POTSI); Function: forced vital capacity (FVC), forced expiratory volume in 1 s (FEV1); FEV1/FVC; Quality of life as SRS-22; (5) S: randomized controlled trial (RCT). Exclusion criteria included: (1) repeated publications; (2) unrelated study or inconsistent study types; (3) literature without full text available; (4) Studies with incomplete data or where crucial statistical measures such as the mean without accompanying standard deviations or 95% confidence intervals were not provided.

Data extraction and quality evaluation

Two researchers independently extracted and cross-checked data. In the event of any discrepancies, a third party was enlisted to moderate the discussion and facilitate consensus. The kappa statistic was employed to evaluate the level of agreement between raters. A kappa score of ≤ 0.2 indicated a poor level of agreement, 0.21–0.40 denoted a fair agreement, 0.41–0.60 was considered a moderate agreement, 0.61–0.80 signified a good agreement, and a score ranging from 0.81 to 1.00 represented an excellent agreement [36]. The content of data extraction included: (1) basic information of included studies: first author, publication year, region, sample size included in the study, etc.; (2) baseline characteristics of the study subjects (including age, gender) and interventions; (3) key elements of risk of bias assessment; (4) outcome indicators and outcome measurement data of interest. The risk of bias assessment was performed utilizing the National Institutes of Health Quality Assessment Tools (NIH-QAT) [37]. The overall quality of the studies was categorized into three levels: poor (0–4 "Yes" responses), fair (5–9 "Yes" responses), and good (10–14 "Yes" responses). Two reviewers independently assessed the quality of the included studies. Any disagreements during the assessment process or in the quality grading were addressed through group discussions. If consensus could not be reached, a third reviewer was consulted to resolve the conflicts.

Statistical analysis

Review Manager 5.4 was used for statistical analysis. When outcome indicators were continuous variables, the MD was used as the effect size. When there were significant differences in the measurements of outcomes (such as measurement instruments, and units), the SMD should be used. When outcome measures were discrete variables, risk ratio (RR) was used as the effect size. The 95% CI should be calculated at the meantime. $P < 0.05$ would indicate a statistically significant difference. The I^2 test and its p-value were used to assess the heterogeneity. If there was significant heterogeneity ($I^2 > 50\%$, $P < 0.05$), the sources of heterogeneity would be further explored using subgroup analysis or sensitivity analysis by excluding the included study one by one, or only descriptive analysis was performed. For studies that contribute to heterogeneity, we will conduct a further review to examine whether their PICOS are inconsistent. If necessary, such studies will be excluded to ensure the homogeneity of the analysis. After the elimination of the impact of significant clinical heterogeneity, a random effect model (REM) would be used for meta-analysis. Otherwise, a fixed effect model (FEM) would be used. When the number of studies included in the analysis of an outcome was greater than or equal to 10, a funnel plot would be used to estimate the publication bias.

Results

Literature screening process

The kappa score for data extraction was 0.93, indicating an "excellent" level of inter-rater agreement. A total of 803 articles were obtained from the initial database search. After the exclusion of duplicates, there were still 674 potential references remaining; after screening the titles and abstracts, 652 articles were excluded due to their failure to meet the inclusion criteria. We searched the full texts of the remaining 22 studies, of which 3 were eliminated due to failure to find the full text. According to a full-text review of 19 studies, we excluded 4 non-RCTs [26, 38–40], 2 studies that included non-AIS patients [41, 42], 1 study that included non-CSE [43], and 2 studies with incompliant interventions or outcome indicators [44, 45]. Ultimately, 10 studies were included. Figure 1 shows the PRISMA flowchart of the study selection.

Characteristics of included studies

Table 1 shows the main characteristics of the included studies. A total of 449 subjects participated in these 10

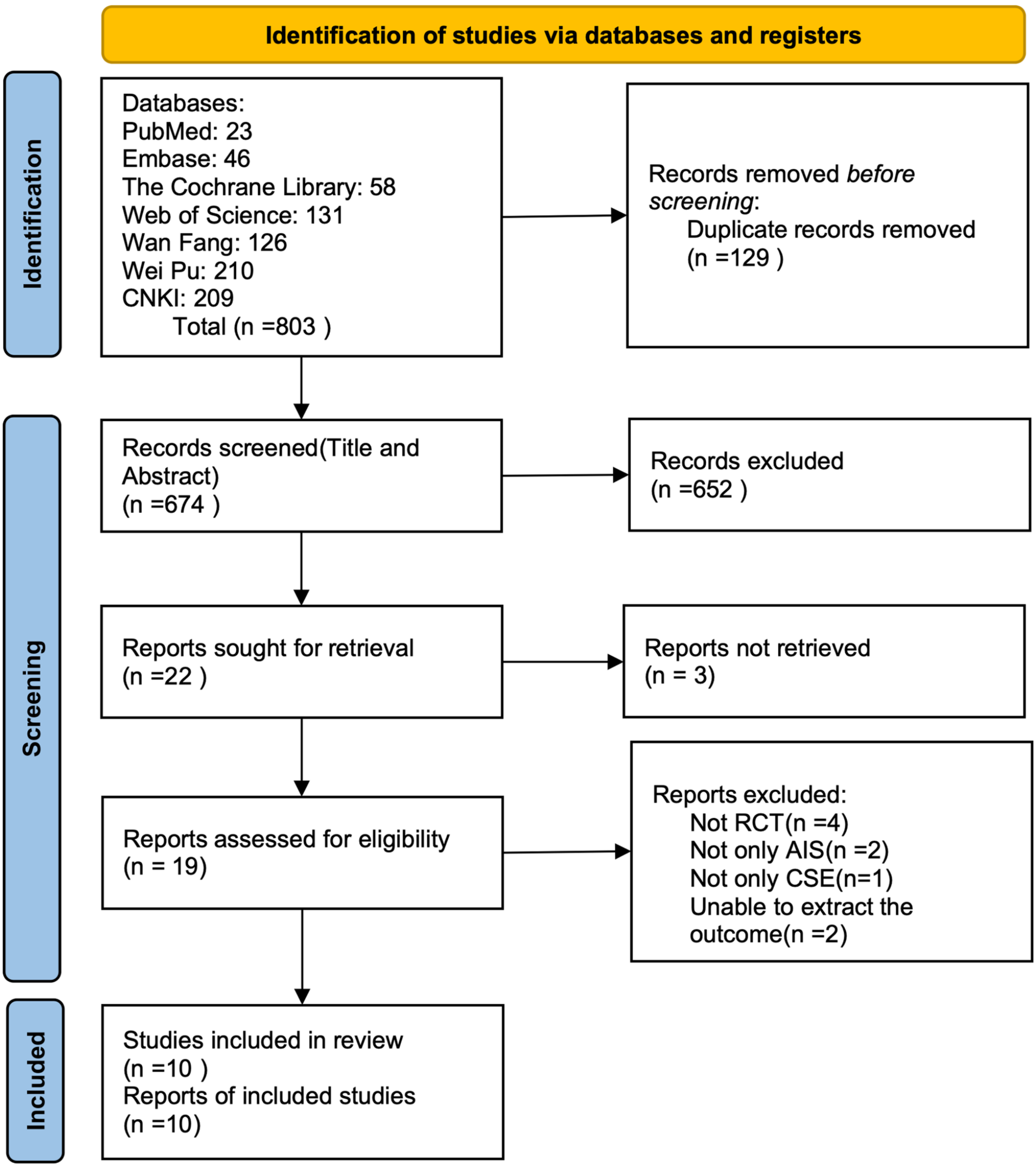

Fig. 1 PRISMA flowchart of the study selection

Table 1 Characteristics of included studies

Study	Region	No.	Age (Mean, SD)	Gender (♀, ♂)	Cobb angle (Mean, SD)	Comparisons	Outcomes	NIH-QAT
Chen 2022[47]	China	100	10.29,1.95	18,8	19.2,2.51	CS vs. CG	Cobb angle; AVR	Fair
Ji 2020[48]	China	26	13.51,0.83	29,0	15.28,2.66	CS vs. CG	Cobb angle; SRS-22(QoL); AVR	Fair
He 2024[49]	China	100	15.54,1.54	60,40	32.79,5.71	CS + ST vs. ST	Cobb angle; ATR; SRS-22(QoL)	Fair
Khaledi 2024[46]	Iran	30	16.3,1.18	0,30	15.77,4.81	CS + ST vs. ST	Cobb angle; ATR; SRS-22(QoL)	Good
Kocaman 2021[24]	Turkey	28	14.14, 2.24	21, 7	Cobb-T: 17.67,3.67 Cobb-L: 15.49,3.68	CS vs. ST	Cobb angle; ATR; WRVAS; SRS-22(QoL)	Good
Yagci 2019[23]	Turkey	30	14.1,1.38	30,0	Cobb-T: 28.8,8.61 Cobb-L: 25.4,8.38	CS + Brace vs. SEAS + Brace	Cobb angle; ATR; POTSI; WRVAS; SRS-22(QoL)	Good
Gür 2016[17]	Turkey	25	14.1, 1.67	24,1	Cobb-T: 33.14,9.57 Cobb-L: 31.77,9.04	CS + Brace + TR vs. Brace + TR	Cobb angle; POTSI; SRS-22(QoL)	Good
Yildirim 2022[32]	Turkey	30	14.84,3.29	26,4	Cobb-T: 19.73,7.21 Cobb-L: 20.40,7.14	CS + TR vs. TR	WRVAS; FVC; FEV1; FEV1/FVC	Good
Moubarak 2022[25]	Egypt	30	11.76,1.76	19,11	18.91,3.08	CS vs. ASC	Cobb angle; SRS-22(QoL)	Fair
Kisa 2023[33]	Germany	50	11.58,2.49	34,16	16.59,4.57	CS vs. 3D	Cobb angle; ATR; WRVAS; FVC; FEV1; FEV1/FVC	Good

CS: core stabilization; ASC: active self-correction; SEAS: scientific exercises approach to scoliosis; TR: traditional rehabilitation training; ST: Schroth training; 3D: three - dimensional exercise; CG: control group; ATR: angle of trunk rotation; POTSI: Posterior Trunk Symmetry Index; WRVAS: Walter Reed Visual Assessment Scale; MIP: maximal inspiratory pressure; MEP: maximum expiratory pressure; AVR: apical vertebral rotation

studies, with sample sizes ranging from 25 to100 subjects. Among them, there were 332 females and 117 males, including 224 in the test group and 225 in the control group. The average age of subjects was 13.30 ± 2.86 years. The average Cobb angle was 22.86° ± 8.79°. Most of the included studies had been conducted in Asia, of which 7 were English [17, 23–25, 32, 33, 46] and 3 were Chinese [47–49]. Among them, 6 studies involved blank controls, and 4 studies compared CSE with other exercise interventions.

Table 2 shows the details of the CSE program. The CSE intervention protocols including core stretching and activation, and auxiliary equipment have been specifically described in 8 studies [17, 23], while other two studies [17, 23] do not describe the specific intervention protocol. The CSE was mainly administrated by physiotherapists, including weekly face-to-face guidance and home-based exercise. The duration of CSE intervention ranged from 8weeks to 6 months.

Risk of bias

The evaluation of 10 studies categorized them into poor, fair, and good quality levels (poor: 0–4 "Yes", fair: 5–9 "Yes", and good: 10–14 "Yes"). Table 1 presents the NIH-QAT results for each study. Out of these 10 studies, 6 were rated as "good" [17, 23, 24, 32, 33, 46], and 4 were rated as "fair" [25, 47–49]47–49]. For the detailed scores of each item, reference should be made to Table S1. We evaluated the publication bias for outcome indicators with a relatively large number of included studies (Cobb angle and ATR). The funnel plots of Cobb angle and ATR did not suggest publication bias (Supplementary Figures S1, S2). Publication bias was not evaluated for other outcome indicators due to the limited number of included studies.

Meta-analysis

We conducted a further review of all the outcome measures included to ensure the reliability and validity of each outcome measures (File S2). In the subsequent meta-analysis, we have compared the efficacy of CSE in Structures (Cobb angle, ATR, AVR), Appearance (WRVAS, POTSI), Function (FVC, FEV1, FEV1/FVC) and Quality of life (SRS-22) with different control groups, including blank control group, 3D exercise group (the method that focuses on three - dimensional correction: Schroth training and 3D exercise), and other exercise group (active self-correction (ASC) and scientific exercises approach to scoliosis (SEAS)). The subsequent meta-analysis was also performed based on different NIH-QAT scores, and treatment durations (< 3 months or ≥ 3 months).

Cobb angle

A total of 9 studies measured the outcome of Cobb angle [17, 23–25, 33, 46–49]: 3 studies [17, 23, 24] measured the lumbar Cobb angle (Cobb-L) and thoracic Cobb angle (Cobb-T) respectively, and others only measured the main curvature Cobb angle. After summarizing

Table 2 Details of core stabilization exercise program

Study	Contents of Programs	Delivery	Duration	Adherence
Chen 2022[47]	**Core stretch**: cat camel stretching exercises. **Core strengthening**: supine bridge, side bridge, plank, dynamic bridge training, prone two-point support. **Equipment exercise**: balance pad, Swiss ball, TheraBand.	supervision by professional therapist	4 months (3x/wk.,60 min/ session)	50/50
Ji 2020[48]	**Core stretch**: cat-camel stretching exercises, side stretch, cobra stretching. **Core strengthening**: plank, side plank, back bridge, side bridge, side-lying leg lift, balance stand. **Equipment exercise**: Swiss ball.	supervision by professional therapist	12 weeks (every other day, 60 min/ session)	11/13
He 2024[49]	**Core stretch**: cat-camel stretching exercises. **Core strengthening**: plank, side bridge, prone two-point support, trunk curling.	not mentioned	6 months (3x/wk., 60 min/session)	50/50
Khaledi 2024[46]	**Core activation**: motor training and activation of core extensor muscles(4 sets × 10 to 15 s) **Core strengthening**: bird and dog, left side bridge, superman exercise, prone double - limb raise	supervision by specialists	12 weeks (3x/wk., 50–70 min/session)	15/15
Kocaman 2021[24]	**Core activation**: warm up stretching, activation of TrA and ML muscles in supine hook position. **Core strengthening**: supine bridge, side-lying leg lift, cat-camel, supine bicycles, lumbopelvic control exercise, clamshell, abdominal curl, prone bridging, side bridge. **Equipment exercise**: Swiss ball and TheraBand.	supervision by physiotherapist	10 weeks (3x/wk., 90 min/session)	14/14
Yagci 2019[23]	**Local muscle stability exercise**: transversus abdominis, multifidus, and diaphragm. **Global muscle stability exercise**: oblique abdominal muscles, psoas major, quadratus lumborum, and pelvic floor muscles. **Global muscle mobility exercise**: rectus abdominis, back extensors, and hamstring muscles. **Breathing exercises**: diaphragmatic breathing.	supervision by physiotherapist + reference booklet + daily home exercises	4 months (1x/wk., 40 min/session; daily home exercise)	15/15
Gür 2016[17]	**Local muscle stability exercise**: transversus abdominis, multifidus, and diaphragm. **Global muscle stability exercise**: oblique abdominal muscles, psoas major, quadratus lumborum, and pelvic floor muscles. **Global muscle mobility exercise**: rectus abdominis, back extensors, and hamstring muscles. **Breathing exercises**: diaphragmatic breathing	supervision by physiotherapist + daily home exercises	10 weeks (2x/wk., 60 min/session; 20 min daily home exercises)	12/12
Yildirim 2022[32]	**Core stretch**: stretching exercises. **Core strengthening**: bird and dog, pelvic tilt, hundred, bridge, cat-camel, dead bug, clamshell, abdominal strengthening, plank, rhomboid strengthening, squat. **Equipment exercise**: TheraBand. **Breathing exercises**: chest and diaphragmatic breathing exercises.	supervision by physiotherapist + daily home exercises	8 weeks (1x/wk., 30 min/session; daily home exercise 30 min in the remaining 6 days)	15/15
Moubarak 2022[25]	**Core activation**: warm up stretching, activation of TrA and ML muscles in supine hook position. **Core strengthening**: basic trunk curl from a crook lying position, bridging exercises, cat-camel exercises, single and double-leg abdominal press, and quadruped arm/leg raises. Antero-posterior and lateral pelvic control exercises (tilt).	supervision by physiotherapist + parents help (if needed)	12 weeks (3x/wk., 60 min/session; 20 min daily home exercises)	15/15
Kisa 2023[33]	**Core stretch**: spine stretch forward, stretching exercises. **Core strengthening**: posture exercises, spinal stabilization exercises, core stabilization exercises, klapp crawling exercises, core stabilization exercises with weight, lateral flexion exercise, hundred, swimming perep. **Breathing exercises**: chest and diaphragmatic breathing exercises.	supervision by physiotherapist + daily home exercises	First 6 weeks (2x/wk.). remaining 18 weeks (daily home exercise)	25/25

the data, sub - group analysis of pre - post intervention Cobb angle in CSE and control groups: control group (I^2 = 67%, $P<0.05$; MD[95% CI] = -4.37[-6.26, -2.48], $P<0.05$); 3D exercise group (I^2 = 0%, $P=0.84$; MD [95% CI] = 3.95 [2.96, 4.93], $P<0.05$); other exercises group (I^2 = 0%, $P=0.42$; MD [95% CI] = -0.98 [-2.10, 0.15], $P>0.05$) (Fig. 2). Additionally, we performed subgroup analyses considering different NIH-QAT scores and intervention

Cobb

Study or Subgroup	CSE Mean	CSE SD	CSE Total	Control Mean	Control SD	Control Total	Weight	Mean Difference IV, Random, 95% CI
1.2.1 Control group								
Chen 2022	−7.59	2.75	30	−3.63	2.9	30	8.9%	−3.96 [−5.39, −2.53]
Gür(L) 2016	−5.13	5.49	12	−1.75	3.45	13	7.4%	−3.38 [−7.01, 0.25]
Gür(T) 2016	−6.73	2.69	12	0.63	4.34	13	8.1%	−7.36 [−10.17, −4.55]
He 2024	−9.62	5.61	50	−7.56	4.91	50	8.6%	−2.06 [−4.13, 0.01]
Ji 2020	−7.85	3.79	11	0.75	6.06	13	7.2%	−8.60 [−12.58, −4.62]
Khaledi 2024	−7.44	4.55	15	−5.32	4.89	15	7.6%	−2.12 [−5.50, 1.26]
Subtotal (95% CI)			**130**			**134**	**47.9%**	**−4.37 [−6.26, −2.48]**
Heterogeneity: Tau^2 = 3.48; Chi^2 = 15.31, df = 5 (P = 0.009); I^2 = 67%								
Test for overall effect: Z = 4.54 (P < 0.00001)								
1.2.2 3D exercise								
Kisa 2023	−3	5.24	25	−7	2.75	25	8.4%	4.00 [1.68, 6.32]
Kocaman(L) 2021	−2.83	1.8	14	−6.4	2.54	14	8.8%	3.57 [1.94, 5.20]
Kocaman(T) 2021	−3.71	2.13	14	−7.93	1.76	14	8.9%	4.22 [2.77, 5.67]
Subtotal (95% CI)			**53**			**53**	**26.2%**	**3.95 [2.96, 4.93]**
Heterogeneity: Tau^2 = 0.00; Chi^2 = 0.34, df = 2 (P = 0.84); I^2 = 0%								
Test for overall effect: Z = 7.88 (P < 0.00001)								
1.2.3 Other exercises								
Moubarak 2022	−5.25	3.47	15	−2.95	2.84	15	8.5%	−2.30 [−4.57, −0.03]
Yagci(L) 2019	−4.1	2.5	15	−3.5	3	15	8.7%	−0.60 [−2.58, 1.38]
Yagci(T) 2019	−5.3	2.2	15	−4.8	2.6	15	8.8%	−0.50 [−2.22, 1.22]
Subtotal (95% CI)			**45**			**45**	**25.9%**	**−0.98 [−2.10, 0.15]**
Heterogeneity: Tau^2 = 0.00; Chi^2 = 1.74, df = 2 (P = 0.42); I^2 = 0%								
Test for overall effect: Z = 1.70 (P = 0.09)								
Total (95% CI)			**228**			**232**	**100.0%**	**−1.42 [−3.64, 0.81]**
Heterogeneity: Tau^2 = 13.86; Chi^2 = 148.20, df = 11 (P < 0.00001); I^2 = 93%								
Test for overall effect: Z = 1.25 (P = 0.21)								
Test for subgroup differences: Chi^2 = 77.58, df = 2 (P < 0.00001), I^2 = 97.4%								

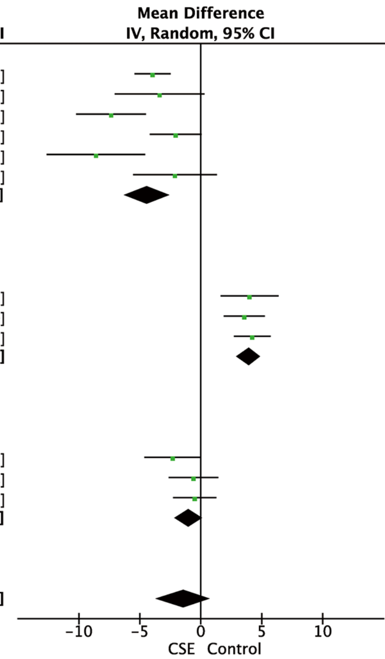

Fig. 2 Cobb angle for core stabilization exercise compared with other forms of treatment

durations (< 3 months or ≥ 3 months); however, no statistically significant results were yielded from these analyses (Figure S3 and S4).

Angle trunk rotation (ATR)

A total of 6 studies [17, 23, 24, 33, 46, 49] measured ATR, among which 3 studies [17, 23, 24] reported lumbar ATR (ATR-L) and thoracic ATR (ATR-T). Subgroup analysis revealed the differences between the CSE group and the control group: (I^2 = 10%, P = 0.34; MD [95% CI] = -1.07[-1.47, -0.66], P < 0.05). However, there was no difference between the CSE group and the other exercise group (I^2 = 0%, P = 0.35; MD [95% CI] = 0.70[-0.34,1.74], P > 0.05). Notably, the effect size of the CSE group was weaker than that of the 3D exercise group (I^2 = 15%, P = 0.31; MD [95%CI] = 1.69 [0.77, 2.61], P < 0.05) (Fig. 3). We also carried out subgroup analyses based on intervention durations (< 3 months or ≥ 3 months), yet no statistically significant findings emerged from these analyses (Figure S5).

Apical vertebral rotation (AVR)

A total of 2 studies measured AVR [47, 48]. The results showed that there was significant difference between CSE and control group (I^2 = 35%, P = 0.22; MD [95% CI] = -0.44 [-0.65, -0.22], P < 0.05) (Fig. 3).

Walter reed visual assessment scale (WRVAS)

WRVAS is a scale for assessing visual appearance deformity [50]. Four studies reported WRVAS scores [23, 24, 32, 33]. The subgroup analysis results showed that there was no difference between the CSE group and the other exercise group (I^2 = 56%, P = 0.13; SMD [95% CI] = -0.39[-1.18,0.39], P > 0.05). However, the effect size of the CSE group was weaker than 3D exercise group (I^2 = 30%, P = 0.23; SMD [95%CI] = 0.89 [0.31, 1.47], P < 0.05) (Fig. 3).

Posterior trunk symmetry index (POTSI)

POTSI is a two-dimensional surface topographic map method to assess the asymmetry of the trunk [51]. Two studies measured the POTSI scores [17, 23], and the results showed that there was no difference between the CSE group and the control group (I^2 = 49%, P = 0.16; MD [95% CI] = 0.15 [-4.29, 4.60], P>0.05) (Fig. 4).

Pulmonary function

Two studies [32, 33] measured pulmonary function indicators include FVC, FEV1 and FEV1/FVC. The results showed that after CSE, all three measures were elevated to some extent, but did not reach statistical significance compared to the control groups. The results were: FVC (I^2 = 78%, P = 0.03; SMD [95% CI] =-0.18 [-1.17,0.81], P>0.05); FEV1 (I^2 = 80%, P = 0.03; SMD [95% CI] =-0.13 [-1.15,0.90], P>0.05); FEV1/FVC (I^2 = 0%, P = 0.57; SMD [95% CI] =-0.08 [-0.51,0.36], P>0.05) (Fig. 4).

SRS-22

Six studies reported SRS-22 scores, of which 5 reported pain, self-image, function, mental health, and total scores

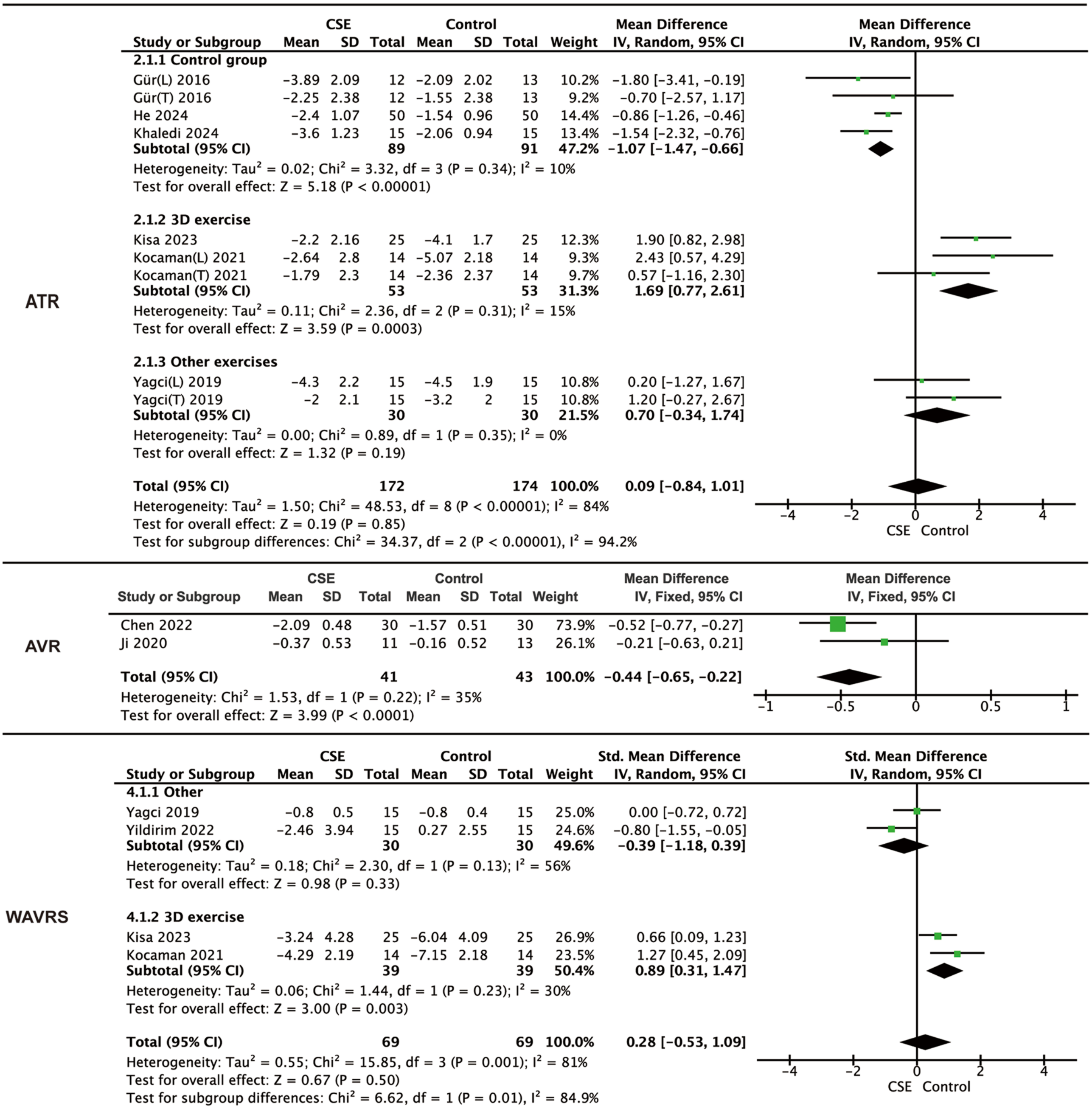

Fig. 3 ATR, AVR, WRVAS, for core stabilization exercise compared with other forms of treatment

[17, 23, 25, 47, 49], 4 reported satisfaction [23, 25, 47, 49], while one only reported total scores [24]. Two studies were removed because of their significant heterogeneity due to measurement method difference. Ji 2020 [47] calculated the total score for each dimension (function, pain, self-image, mental health, satisfaction), while others calculated the average score per dimension. Due to this measurement method difference, we excluded the Ji 2020 study from our analysis. The SRS – 22 results of Ji 2020 were: function (MD = 4.83, $P < 0.05$), pain (MD = 4.96, $P < 0.05$), self-image (MD = 1.77, $P < 0.05$), mental health (MD = 3.68, $P < 0.05$), satisfaction (MD = 2.87, $P < 0.05$). Similarly, in the He 2024 [49] calculation of the SRS – 22 Total part, they obtained the total score by summing the average scores of each dimension, unlike others. Due to this methodological inconsistency, we excluded it from the Total part analysis. The total score of SRS – 22 in He 2024 was: MD = 1.78, $P < 0.05$. We conducted a pooled analysis of pain, self-image, function, mental health, satisfaction and total score. The results showed

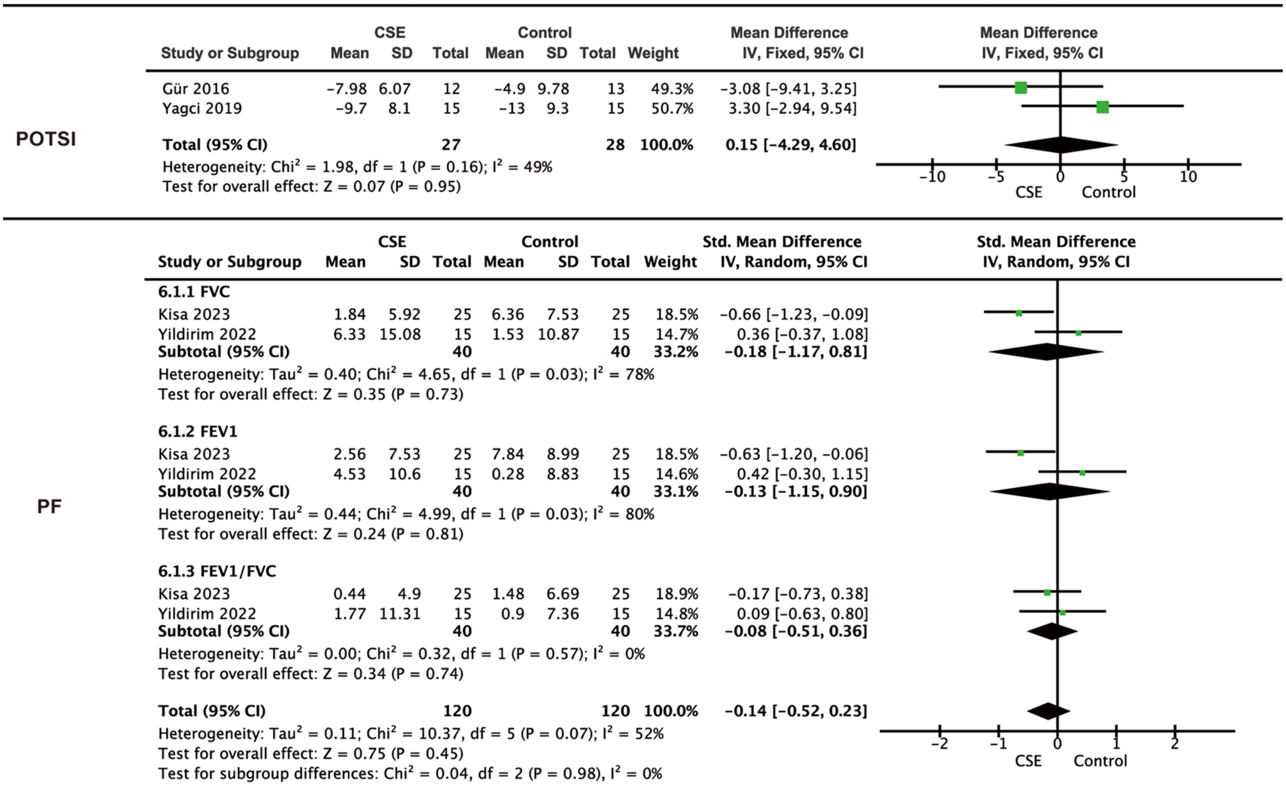

Fig. 4 POTSI and PF (FVC, FEV1, FEV1/FVC) for core stabilization exercise compared with other forms of treatment

that the quality of life in the CSE group was significantly improved compared to the control group ($I^2=60\%$, $P<0.05$; MD [95% CI] = 0.22[0.14,0.29], $P<0.05$); the difference in functional improvement was statistically significant ($I^2=0\%$, $P=0.47$; MD [95% CI] = 0.22 [0.11,0.33], $P<0.05$); a marked difference in pain improvement between the two groups ($I^2=0\%$, $P=0.76$; MD [95% CI] = 0.28 [0.16,0.40], $P<0.05$); no difference in mental health ($I^2=0\%$, $P=0.8$; MD [95% CI] = 0.08[-0.03,0.18], $P>0.05$) and satisfaction ($I^2=91\%$, $P=0.20$; MD [95% CI] = 0.22 [-0.19,0.64], $P>0.05$); statistical significance were reached in self-image ($I^2=44\%$, $P=0.14$; MD [95% CI] = 0.23 [0.04,0.42], $P<0.05$) and total score ($I^2=39\%$, $P=0.18$; MD [95% CI] = 0.20 [0.09,0.32], $P<0.05$) (Fig. 5).

Heterogeneity and sensitivity analysis

A sensitivity analysis was conducted on outcome indicators with $I^2 \geq 50\%$ to investigate the impact and potential sources of heterogeneity. The findings revealed that, after sequentially excluding each study, the effect size values of most outcome indicators remained relatively stable, indicating that the results are robust. The detailed results are shown in the File S3. It should be noted that the heterogeneity of the SRS-22 total scores was unstable in the sensitivity analysis, and such instability were derived from the study by Kocaman et al. [24]. Kocaman et al. [24] found that in terms of scoliosis and related problems in mild AIS patients, Schroth training was more effective than CSE, but in terms of improvement of peripheral muscle strength, core exercise was more effective than Schroth training. The significant difference compared to other studies may be due to the fact that Schroth training is a specific exercise targeting AIS, which has been extensively reported, and its effectiveness has been confirmed [52, 53]. A previous studies [54] determined that Schroth training programs mainly affect core muscle strength, which is similar to the mechanism of action of CSE. As the study by Kocaman et al. was unstable for heterogeneity, it was eliminated from total scores analyses. The results obtained from the meta-analysis before the elimination of this study were shown in Figure S6.

Discussions

This study included 10 RCTs investigating the efficacy of CSE in AIS patients. The results found that the CSE may may assist in enhancing the trunk structure, appearance, function, and quality of life in patients with mild to moderate Adolescent Idiopathic Scoliosis (AIS). However, the therapeutic efficacy of CSE was not found to be superior to other training groups and was less effective than the 3D training group. Furthermore, subgroup analyses based on NIH-QAT scores and intervention durations

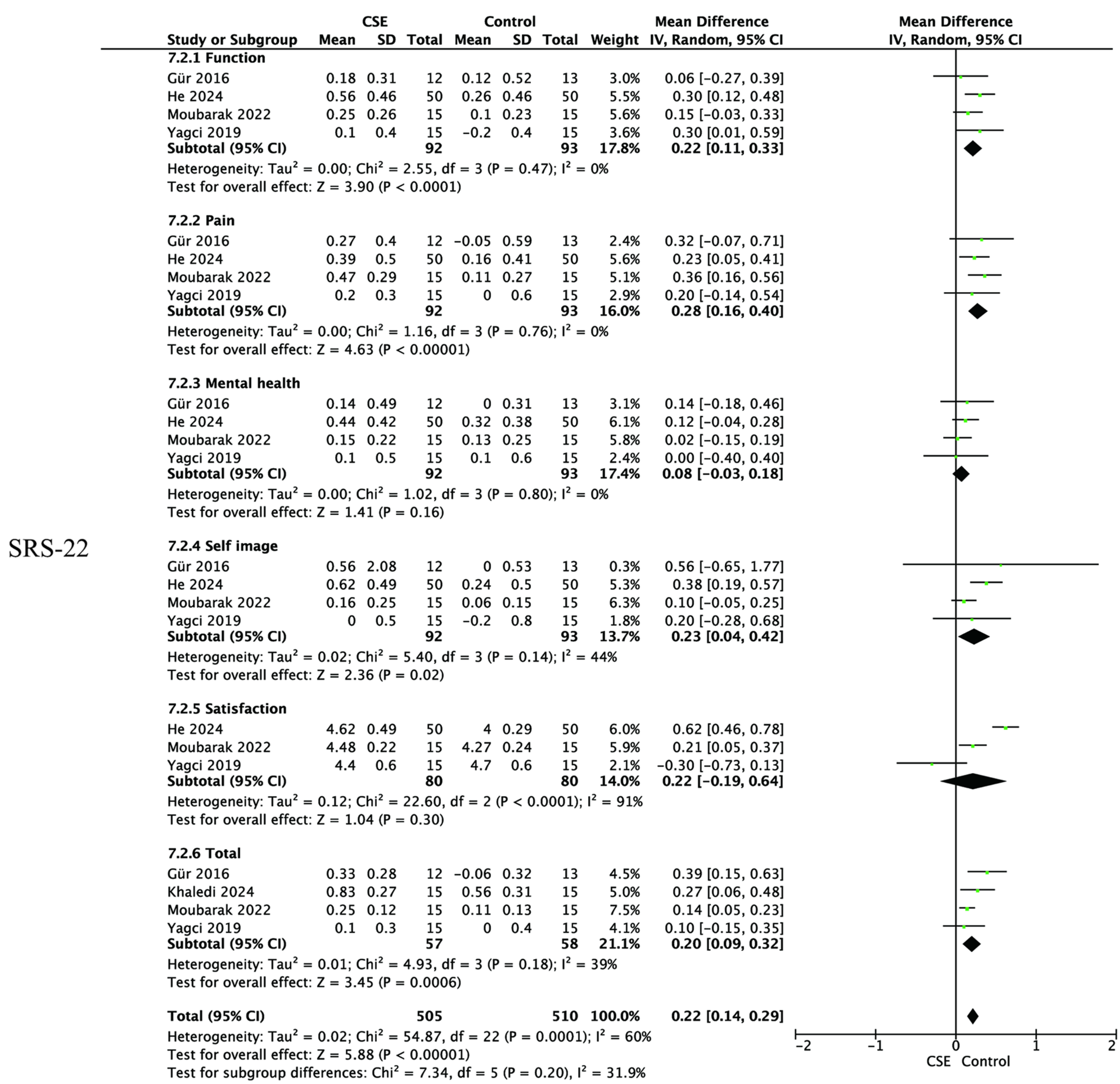

Fig. 5 Quality of Life (SRS-22) for core stabilization exercise compared with other forms of treatment

(< 3 months or ≥ 3 months) did not yield any statistically significant results. This lack of significance may be attributed to the limited number of studies included in the analysis, the heterogeneity of the interventions, and the relatively short duration of the interventions.

The reduction and control of the scoliotic curve is deemed as the success of treatment of scoliosis. Cobb angle reflects the degree of scoliotic curve in the patients with AIS, while ATR reflects the rotation of the trunk with relevance to the rotation of the spinal vertebrae [55]. The results of this systematic review show that compared with the blank control group, the Cobb angle of AIS patients in the CSE group decreased by 4.37°, reaching statistical significance, but did not reach clinical significance (Cobb angle less than 5°), which is consistent with previous studies [29]. The core muscle group mainly includes the trunk muscles surrounding the spine and abdominal organs, in which the synergistic effect of abdominal muscles, gluteus muscles, gluteus girdle, paravertebral muscles, and other muscles is of importance for the maintenance of the stability of the spine [56]. It has been shown that the asymmetry of paravertebral muscle, a member of core muscle group, may be a pathogenetic mechanism for the occurrence and progression of AIS

[57, 58]. The results of this systematic review found that CSE could reduce the asymmetry of trunk by enhancing muscle strength and endurance around the spine, thereby mitigating lateral curvature or maintaining a relatively stable state of the spine. Furthermore, the reduction in the asymmetry of the paravertebral muscles improves the rotation of the vertebral body, resulting in a decrease in AVR. In addition, AIS patients have poor posture control during walking due to the dysfunction of balance [59]. It also increases the biomechanical abnormalities of pelvis, lower limbs, and feet, which will impact the progression of scoliotic spine [60]. It has been shown that CSE may reduce their biomechanical abnormalities and postural compensation in the lower limbs by improving the trunk balance ability and stability in AIS patients, and thus alleviates the progression of scoliosis to some extent [31].

It is noteworthy that the 3D exercise group exhibited a larger effect size than the CSE group, which is consistent with the findings of Vanga et al. [30]. This could be attributed to the 3D exercise program, which places a strong emphasis on three-dimensional trunk correction [61]. For instance, the Schroth method encompasses derotation, spinal elongation, deflexion, strengthening, and rotational breathing stretching exercises to maintain vertebral alignment. These movements are tailored in combination according to the patient's specific curve type [12, 61]. In contrast to the generalized movements of large muscle groups in CSE, these meticulously designed movement combinations are adjusted to accommodate the diverse scoliosis types of different patients, demonstrating a high degree of specificity. Consequently, they may exhibit a larger effect size.

The goals of conservative treatment of AIS are related to aesthetics which was defined as one of the primary goals of treatment by SOSORT guideline [8]. The WAVRS score reflects changes in the visual appearance of the trunk, while the POTSI score reflects the symmetry of the trunk. In this study, subgroup analysis of the WAVRS revealed no statistical difference between CSE and other exercises, and the effect of CSE was less pronounced than that of 3D exercises. Regarding POTSI, the analysis showed no statistical difference between the CSE group and the control group. This may be due to the fact that both other exercise programs and CSE can enhance muscle strength and endurance, thereby improving spinal stability and functional performance through similar mechanisms of action [14, 56, 62]. However, as previously noted, scoliosis is a three-dimensional deformity, and 3D training specifically targets the three-dimensional correction of the trunk, making it highly relevant and potentially superior to CSE and other training methods in certain aspects. Moreover, the number of studies evaluating aesthetic indicators is extremely limited, indicating a need for further research to verify these aspects in the future.

In addition, the morphological aspect of the deformity is closely related to the effects on bodily function. Depending on its degree and location, the curvature may affect respiratory function. FEV_1, FVC and FEV_1/FVC reflect lung ventilation function and obstruction, which are used to evaluate the patients [63]. Previous studies have shown that the FVC, FEV_1 and FEV_1/FVC levels in AIS patients are significantly lower than those in healthy adolescents [64, 65]. The study by Mustafaoglu et al. [66] found that CSE could significantly improve lung function of drug abusing adolescent. According to our study, the FVC, FEV 1 and FEV 1 / FVC were all elevated in CSE and control groups, but did not reach statistical difference. This could be attributed to the fact that CSE enhances the strength of core muscles such as the diaphragm, external intercostal muscles, and abdominal muscles, all of which are crucial respiratory muscles. Secondly, CSE is capable of boosting the strength of the lumbopelvic muscles and regulating intra - abdominal pressure, playing a vital role in respiratory regulation, as noted in reference [67]. Finally, the enhancement of respiratory muscle strength and intra-abdominal pressure improved ventilatory function. However, the control group also underwent specific exercise training. By enhancing the muscle strength around the spine, they too improved the lung's ventilatory function, resulting in no statistically significant difference between the two groups. Additionally, the relatively short training cycle might also be a contributing factor.

Quality of life is significantly affected by aesthetic self-perception and appearance. The SRS-22 total score in the CSE group was significantly improved compared to the control group, with the most significant improvement in pain. Core stability and core strength have been widely studied, with the benefits of the training process for patients with low back pain emphasized [22, 68]. In our study, CSE significantly improved pain in AIS patients and outperformed other control groups. This may be due to improvement of core stability, which reduce excess force on the spinal structure by the limb muscles, and release early fatigue [69]. Furthermore, increased muscle strength and endurance, and reduced pain have improved the functional performance, self-image and satisfaction in AIS patients, resulting in an increase in these scores.

In this study, CSE may enhance the strength and endurance of the muscles surrounding the spine, reduce asymmetry of the trunk, and maintain a relatively stable state of the spine, which may assist in improving the trunk structure, appearance, function, and quality of life in patients with mild to moderate AIS. However, the efficacy of CSE is not superior to other exercise groups and is less effective than the 3D exercise group. The 3D exercise group appears to be more effective in treating AIS, which is in line with several previous studies [22, 68]. After short-term intensive supervised training, 3D exercise could achieve greater therapeutic effects compared to other exercises.It is noteworthy that PSSE, including 3D exercises typically require guidance from experienced and qualified certified therapists. In some areas, therapists or institutional instructors may not be able to participate in such professional training and certification courses due to various factors. These factors may hinder the promotion and application of these training methods in certain regions.

In contrast, CSE is more widespread. It has been widely applied in the fields of rehabilitation, sports competition, and public fitness. Moreover, the non-specificity of CSE reduces the regulatory needs for exercise intervention in AIS patients to some extent, as was verified by Zapata et al. [70]. They compared a supervised group and an unsupervised group after 8 weeks of CSE and found that both groups were effective in improving low back pain, with no significant difference. Similarly, Park et al. [27] found that supervised CSE was not more effective than unsupervised CSE. For regions lacking professional training institutions and AIS patients who cannot obtain professional guidance, CSE seems to provide a practical alternative. Furthermore, an excessive focus on specific exercises may exacerbate the concerns of AIS patients and their parents about the accuracy of exercise execution in the home and community environments. Given that most AIS patients are minors, they may have an aversion to certain unfamiliar movements and preferences for different exercises. Therefore, clinicians need to comprehensively assess the views of AIS patients on the applied treatment strategies and their family or community environment to select a more appropriate exercise program.

This study has several advantages. Firstly, it is the first meta-analysis that strictly limits inclusion criteria to evaluate the efficacy of CSE in patients with AIS. Secondly, we comprehensively assessed the impact of CSE on the trunk structure, appearance, function, and quality of life of AIS patients. The findings of this research are expected to offer valuable suggestions and assistance to clinicians and physiotherapists in the treatment of AIS patients, facilitating the selection of more appropriate exercise programs. Meanwhile, it also provides a reference for future research.

However, this study still has some limitations. Firstly, despite a detailed search, the number of included studies and the sample sizes of the studies are still limited, that we were unable to test for publication bias on most outcome indicators. Secondly, the included studies focus solely on short-term efficacy, which may compromise the generalizability and reliability of the results. Thirdly, the exclusive inclusion of studies in Chinese or English may result in the omission of non-Chinese/English studies, potentially introducing language bias. Moreover, most of the included studies involve Asian populations, which may limit the generalizability of the study findings. Additionally, the real-time constraints encountered during the review process may affect the reliability of the results. Lastly, due to the limited number of included articles and sample sizes, or the lack of relevant information in the articles, important confounding factors such as patient compliance, exercise quality, and spinal flexibility could not be analyzed in subgroup analyses. Future clinical trials need to focus on patient compliance and training quality and conduct long-term follow-ups to determine the impact of CSE on scoliosis curvature, appearance deformity, cardiopulmonary function, and the quality of life of patients with AIS patients.

Conclusions

This systematic review has shown that CSE could exert an effective role in controlling the scoliotic curve progression for the patients with mild and moderate AIS, albeit less than 3D exercises regarding Cobb angle, ATR, and WAVRS scores. Though the positive role of CSE has not been proved in terms of aesthetics and lung function, CSE could offer a feasible alternative for PSSE and other professional interventions in the treatment of AIS. The future investigations emphasizing on improvement of patient compliance and CSE quality are warranted.

Abbreviations

AIS	Adolescent idiopathic scoliosis
ASC	Active self-correction
ATR	Angle of trunk rotation
ATR-L	Lumbar ATR
ATR-T	Thoracic ATR
AVR	Apical vertebral rotation
CI	Confidence intervals
Cobb-L	Lumbar curvature Cobb angles
Cobb-T	Thoracic curvature Cobb angles
CSE	Core stabilization exercise
FEM	Fixed effect model
FEV1	Forced expiratory volume in 1 s
FVC	Forced vital capacity
MD	Mean difference
NIH-QAT	National Institutes of Health Quality Assessment Tools
PICOS	Population, Interventions, Comparators, Outputs, Study Designs
POTSI	Posterior Trunk Symmetry Index
PSSE	Physiotherapeutic Scoliosis-Specific Exercises
RCT	Randomized Controlled Trial
REM	Random Effect Model
RR	Risk Ratio
SEAS	Scientific Exercises Approach to Scoliosis
SMD	Standardized Mean Difference
SRS-22	Scoliosis Research Society-22
ST	Schroth Training
TR	Traditional Rehabilitation training
WRVAS	Walter Reed Visual Assessment Scale

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s13018-025-05612-7.

Supplementary Material 1: Figure S1: Assessment of publication bias for Cobb angle

Supplementary Material 2: Figure S2: Assessment of publication bias for ATR

Supplementary Material 3: Figure S3: The results of subgroup analysis based on the NIH-QAT scores (Cobb angle)

Supplementary Material 4: Figure S4: The results of subgroup analysis based on the intervention duration (Cobb angle)

Supplementary Material 5: Table S1: The detailed scores of each item of each study using the National Institutes of Health Quality Assessment Tools

Supplementary Material 6: File S1: Detailed search strategy and results

Supplementary Material 7: Figure S5: The results of subgroup analysis based on the intervention duration (ATR)

Supplementary Material 8: Figure S6: The results obtained from the meta-analysis before the elimination of Kocaman et al.

Supplementary Material 9: File S2: A further review of all the outcome measures

Supplementary Material 10: File S3: Detailed results of sensitivity analysis

Acknowledgements
Not applicable.

Author contributions
Conceptualization: Qian Wang, Min Liu; Methodology: Yanyang Wang, Xiaomei Liu; Formal analysis and investigation: Yanyang Wang, Xiaomei Liu, Yu Zhang, Qiang Wu; Writing - original draft preparation: Xiaomei Liu; Writing - review and editing: Qian Wang; Funding acquisition: Qian Wang, Min Liu; Resources: Xiaomei Liu, Min Liu; Supervision: Qian Wang. And all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Funding
This work was supported by the Beijing Natural Science Foundation-The Establishment and Promotion of an Intelligent Evaluation and Integrated Rehabilitation System for Post-Operative Spinal Deformity (No. L232022), the Rehabilitation Assistance Devices Adaptation Center Project (No. TJCZCJJK001) and 1·3·5 project for disciplines of excellence–Clinical Research Fund, West China Hospital, Sichuan University (No. 24HXFH013).

Data availability
All data generated or analyzed during this study are included in this published article (and its Supplementary Information files).

Declarations

Ethics approval and consent to participate
All analyses were based on previous published studies; thus, no ethical approval and patient consent are required.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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Received: 19 December 2024 / Accepted: 14 February 2025
Published online: 28 February 2025

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