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Factors contributing to bracing success in juvenile idiopathic scoliosis and current limitations

a systematic review and meta-analysis

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Aims
There is a general lack of guidelines on nonoperative treatment in juvenile idiopathic scoliosis (JIS). This review aims to explore factors determining bracing success in JIS and to identify limitations in current literature.

Methods
A literature search was conducted according to the PRISMA 2020 guidelines. Data extraction focused on the factors affecting bracing success, including pre-brace curve magnitude in Cobb angle, curve type, pre-brace rib vertebral angle difference, in-brace correction, brace type, brace-wear compliance, the time of brace initiation, and bracing duration. Bracing success is defined as 1) avoidance of corrective surgical intervention (curve exceeding 45° at maturity) and/or 2) major curve Cobb angle of < 5° progression at maturity. Meta-analysis was performed for individual factors.

Results
After initial and full-text screening, 16 articles were included in the review. Pooled odds ratio (OR) from eight studies and 560 patients using the threshold of Cobb angle of 30° revealed that patients with pre-brace curve < 30° were associated with bracing success (odds ratio (OR) 3.58; 95% CI 2.26 to 5.65; $p < 0.001$; $I^2 = 0.08$). Major thoracic curves were associated with reduced likelihood of bracing success compared to thoracolumbar/lumbar curves (OR 0.49; 95% CI 0.28 to 0.86; $p = 0.010$; $I^2 = 0.35$). Full-time compliance was significantly associated with bracing success (OR 5.22; 95% CI 2.24 to 12.19; $p < 0.001$; $I^2 = 0.76$).

Conclusion
This review identified that a pre-brace major Cobb angle < 30° and full-time compliance of at least 18 to 20 hours/day are prognostic factors favourable for bracing success, while presence of thoracic curves is prognostic for unfavourable brace outcome. Longer bracing duration does not translate to a higher success rate. Clinicians should devise more efforts to modify patient compliance in order to achieve optimal brace outcomes. The general lack of high-quality evidence and heterogeneity of results in existing studies indicates the need for further rigorous research on JIS.

Take home message
- A pre-brace major Cobb angle < 30° and full-time compliance of at least 18 to 20 hours/day are prognostic factors favourable for bracing success, while the presence of thoracic curves is associated with unfavourable brace outcome.
- The general lack of high-quality evidence and heterogeneity of results in existing studies regarding juvenile idiopathic

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scoliosis indicates the need for further rigorous research.

Introduction

Juvenile idiopathic scoliosis (JIS) is defined as idiopathic scoliosis diagnosed at three to ten years of age, compared to adolescent idiopathic scoliosis (AIS; 10 to 18 years).[1] A recent nationwide study reported an occurrence of 192 per 100,000 population for JIS, which was much less prevalent than AIS at 760 per 100,000 population.[2] Despite its prevalence, there is a lack of clear guidelines on JIS treatment. Most of the bracing guidelines for JIS are in accordance with AIS, which are clear and well-established.[3] Since the diagnosis is at a younger age with more growth potential, JIS has a more aggressive course and higher progression risk. This not only means that JIS patients usually have longer bracing periods, but that there would also be more patients reaching the threshold indication for surgical correction, thus leading to poorer prognosis.[4]

Given the existing knowledge gap on factors affecting bracing efficacy, the objective of this review is to explore factors determining bracing success in avoiding curve progression and surgery. Identifying the modifiable and non-modifiable factors affecting bracing success will help to set up clearer guidelines for JIS treatment, prompting better patient outcomes. It is of interest to explore if prognostic factors in JIS bracing are different from those in AIS. Additionally, it is important to identify current limitations in JIS research in order to confirm the further areas in need of future studies.

Methods

Literature search

A literature search was conducted according to PRISMA 2020 guidelines.[5] Five databases were used for the search: PubMed, Web of Science, Cochrane, Scopus, and Embase. Search terms included "(juvenile idiopathic scoliosis OR JIS)" AND "(bracing OR brace treatment)". Search results were from establishment of database up to 31 October 2024 (Figure 1). Ethical approval and informed consent were not required for this review.

Eligibility criteria and study selection

Details of inclusion criteria and exclusion criteria are described in Table I. Covidence (Covidence.org, Australia) was used to assist in the screening process. Two investigators (KHAC, EM) performed the literature search and screening independently, with any discrepancies after abstract and full-text screening discussed to reach consensus with PWHC and JPYC on final inclusion.

Data extraction

Data extraction focused on factors affecting bracing success (< 5° progression or no surgery), including pre-brace curve magnitude in terms of Cobb angle, curve type, pre-brace rib vertebral angle difference (RVAD), in-brace correction, brace type, brace-wear compliance, time of brace initiation, and bracing duration. Based on the Scoliosis Research Society (SRS) Committee on bracing and nonoperative treatment,[3] bracing success is defined as 1) avoidance of corrective surgical intervention (curve exceeding 45° at maturity) and/or 2) major curve Cobb angle of < 5° progression at maturity. Details of data extracted are shown in Tables II and III.

Table I. Inclusion and exclusion criteria for literature search.

Inclusion criteria	Exclusion criteria
• Patients with diagnosis of juvenile idiopathic scoliosis (aged ≥ 3 and ≤ 10 years) • Patients who underwent any type of brace treatment (either full-time or part-time) • Bracing of any duration (number of years/months)	• Non-English literature • Reviews, case reports, systematic reviews, and meta-analyses • Non-studies (summaries, book chapters, trial registry, meeting abstract) • Case series of sample size < 10

Critical appraisal of evidence

Quality of included studies were assessed by the Grading of Recommendations Assessment, Development and Evaluation (GRADE) approach independently by two reviewers (KHAC, EM). Randomized trials were given a high quality of evidence, while observational studies and case series were given low/very low quality. Criteria for downgrading of quality by one level were: inconsistency of results, imprecision of data, indirectness of outcome, risk of bias, and publication bias. Upgrading of evidence quality by one level was assessed by large multitude of effect and evidence of dose–response gradient. Any discrepancies were discussed until consensus was reached.

Statistical analysis

Meta-analysis was performed for individual factors if applicable. An inverse-variance method was used to combine data across studies and a random-effect model was applied. Pooled odds ratio (OR) and 95% CIs were calculated for binary outcomes. Standardized mean difference was presented with Cohen's d for continuous data. Statistical heterogeneity of pooled data was defined by I^2 test. Low, moderate, and high heterogeneity were defined as I^2 values of < 50%, 50% to 75%, > 75% respectively.[22] Two-tailed significance was set at $p < 0.05$. All statistics were generated by SPSS (v29.0; IBM, USA).

Results

We obtained 313 studies from five databases. After removing 161 duplicates, 152 studies were available for title and abstract screening, in which 110 studies were excluded. Full-text screening was performed for 42 studies, and 16 studies were included in the review (Figure 1).

Pre-brace curve magnitude

In total, 13 studies investigated the relationship between pre-brace Cobb angle and bracing outcomes.[7,9,10,12–16,18–21,23] Generally, a lower pre-brace Cobb angle was associated with reduced need for corrective surgery.[12,13,15,16,19] Eight studies stratified pre-brace curve magnitude using the 30° threshold,[7,9,10,12,18,19,21,23] while one study stratified using a threshold value of 25°.[20] Among those eight studies, four defined bracing success as prevention of surgery while four defined success as either prevention of surgery with prevention of > 5° progression at maturity. Pooled OR from eight studies and 560 patients using a threshold of 30° revealed that pre-brace curves < 30° were significantly associated with bracing success (OR 3.58; 95% CI 2.26 to 5.65; $p < 0.001$, random-effect model) with a low heterogeneity of I^2 of 0.08 (Figure 2).

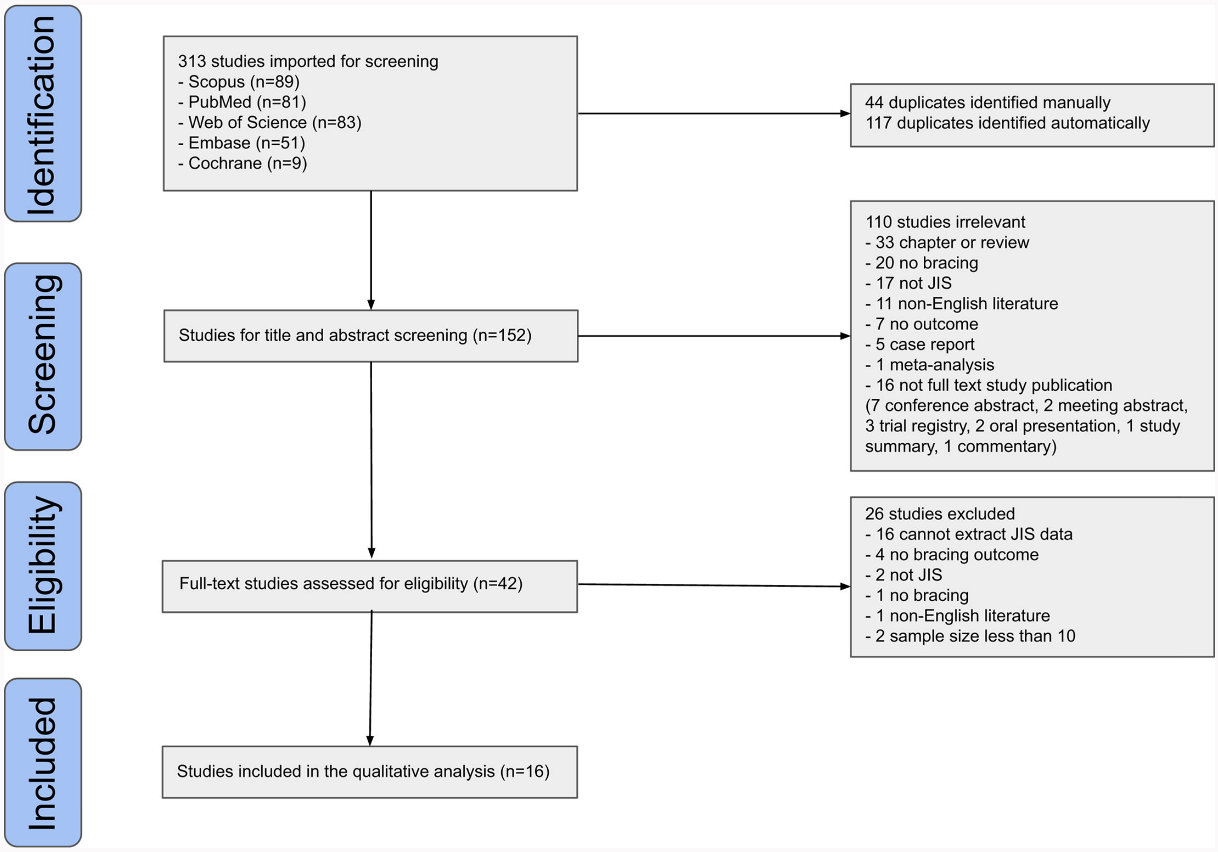

Fig. 1
PRISMA flowchart. JIS, juvenile idiopathic scoliosis.

Curve types

A total of 14 studies stratified braced patients according to curve types.[6,7,9,11,12,14–21,23] Three studies suggested that Lenke type III showed poorer prognosis.[12,18,23] Pooled OR from 526 patients in eight studies revealed that thoracic curves were associated with reduced likelihood of bracing success compared to thoracolumbar/lumbar curves (OR 0.49; 95% CI 0.28 to 0.86; p = 0.010), with a low heterogeneity of I^2 value of 0.35.[7,9,10,12,16,19–21] Double and triple major curves were excluded from analysis (Figure 3).

Brace-wear compliance

Brace compliance was defined as the adherence to bracing plan, as reflected by the amount of time patients wore the brace per day. Studies suggested at least 18 to 20 hours per day of brace-wear as good compliance and non-compliant patients were those failing to adhere to prescribed bracing plans. Four studies reported an association between compliance and brace outcome.[12,17,18,21] A meta-analysis performed from these studies with 747 patients revealed that full-time compliance was significantly associated with bracing success (OR 5.22; 95% CI 2.24 to 12.19; p < 0.001, random-effect model). However, results from studies were heterogenous with I^2 value of 0.76. It should be noted that Aulisa et al[17] presented compliance data pooled from both AIS and JIS populations (Figure 4).

Time of brace initiation and duration of bracing

Six studies investigated the relationship between age at brace initiation and brace outcomes, but without conclusion. Three studies showed that bracing success was significantly associated with older chronological age at bracing initiation,[7,12,18] with the adolescent success rate almost double that of juvenile (75% vs 34%).[7] Conversely, three studies showed patients who were braced successfully had brace initiation at a younger age compared with patients requiring surgery.[10,16] A significant association between bracing success and more mature bone age was seen in one study only.[12]

Regarding brace duration, this was the time that elapsed between brace initiation and the time iat which brace treatment was completed at skeletal maturity. Successfully braced patients were seen with shorter brace-wear duration than those with bracing failure.[7,12] However, there were four studies with a longer brace duration that was also associated with bracing success.[10,13,16,18] Pooled OR from seven studies and 517 patients showed that bracing success groups had no difference in bracing duration compared with those with bracing failure (Cohen's d 0.34; 95% CI -0.11 to 0.79; p = 0.130; I^2 = 0.86) (Figure 5).

In-brace correction

In two studies, less correction was significantly associated with bracing failure,[18,19] with Jarvis et al[19] showing notably higher in-brace correction of 101.5% in bracing success. Conversely, there was no significant difference between surgical and braced-only patients when it came to in-brace correction in

Table II. Characteristics of included studies and results.

Study	Design	Level of evidence	Sample size	Patients' characteristics	Overall curve progression rate/ surgery rate
Heemskerk et al,[6] 2020	Retrospective comparative cohort study	Low	49 JIS patients (44 F, 5 M) - Bracing only group (n = 36); Surgery after bracing group (n = 13); Control group (n = 49) (healthy patients aged between 17 and 22 with absence of spinal abnormalities)	- Age of diagnosis: 7.4 (1.5) - Age at initiation of bracing: 11.1 (2.1) - Bone age: Risser 0 (42 (86%)) Risser 1 (2 (4%)) Risser 2 (4 (8%)) Risser 3 (1 (2%)) - Menarche year for females: 13.0 (0.9) - Duration of bracing (years): 3.9 (1.8)	- No curve progression (35 (71.4%)); 5° to 10° curve progression (9 (18.4%)); > 10° curve progression (5 (10.2%))
Harshavardhana and Lonstein,[7] 2018	Retrospective comparative therapeutic clinical study (case series)	Very low	125 JIS patients (28 M, 97 F) - Bracing only group (n = 56); Surgery after bracing group (n = 69)	- Age at first visit: 8 - Age at initiation of bracing: 9.2	- Bracing success rate (not undergo surgery): 45% - Bracing success rate (SRS criteria): 41%
Mannherz et al,[8] 1988	Retrospective study	Very low	43 JIS patients (9 M, 34 F) - Observation group (n = 11); Bracing only group (n = 18); Surgery group (n = 14) (1 patient refused bracing; 1 patient with curve > 45° who had bracing; 12 patients with curve < 45° who had bracing)	- Age at presentation: 7 (4 to 9.5) - Average age at the start of orthosis: 9 (5 to 12) - Duration of bracing (years): 6 (2 to 10)	- Improved: 10 (23.3%) (average of 12°); No change: 5 (11.6%); Progressed: 28 (65.1%) (average of 21°)
Aulisa et al,[9] 2014	Prospective study based on an ongoing database	Very low	113 JIS patients (9 M, 104 F) - Bracing only group (n = 109); Surgery after bracing group (n = 4)	- Age at initiation of bracing: 8.1 (1.2) - Duration of bracing (years): 7.02 (1.39)	- Curve correction (88 (77.8%)); stabilization (18 (15.9%)); curve progression (7 (6.2%))
Kahanovitz et al,[10] 1982	Case series	Very low	15 JIS patients (6 M, 9 F) Bracing only group (n = 9); Surgery after bracing group (n = 6)	- Age at diagnosis: 6.6 - Age at brace initiation: 7.5 (5.6 to 9.4) - Bracing only group - Brace duration (years): 6.5 - Surgery after bracing group - Brace duration (years): 5.5	Surgery rate: 40%
Tolo and Gillespie,[11] 1978	Retrospective study	Very low	59 JIS patients (11 M, 48 F) Observation group (n = 18); bracing group (n = 42); surgery group (n = 16) (8 patients had surgery after bracing)	Brace duration (years): 3	Surgery rate (braced patients): 19%
Babaee et al,[12] 2020	Retrospective chart review study (case series)	Low	75 JIS patients (18 M, 57 F) Success/ stable group (n = 48); Progression/ surgery group (n = 27)	- Age at diagnosis: 6.94 (1.86), 4 to 9 - Age at brace initiation: 8.62 (2.60; 4 to 13)	Success rate (major Cobb angle at final follow-up < 50°): 64% Surgery rate: 28%

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Study	Design	Level of evidence	Sample size	Patients' characteristics	Overall curve progression rate/ surgery rate
Heemskerk et al,[13] 2023	Comparative cohort study	Very low	85 JIS patients (76 F, 9 M) Bracing only group (n = 47); Surgery after bracing group (n = 20); Physiotherapy group (n = 15); Surgery only group (n = 3)	Age at diagnosis: 7.4 (1.8)	Surgery rate: 42.6%
Donzelli et al,[14] 2014	Retrospective observational study from a prospective database	Very low	27 JIS patients (24 F, 3 M)	Mean age: 11.4 (1.2)	Change in Cobb angle: - Improved (29.6%) - Stabilized (55.6%) - Progressed (14.8%) ATR: - Improved (55.6%) - Stabilized (40.7%) - Progressed (3.7%) TRACE: - Improved (33.3%) - Stabilized (59.3%) - Progressed (7.4%) - Progression rate (to > 30°): ~ 44% - Progression rate (to > 45°): ~ 22%
Figueiredo and James,[15] 1981	Case series	Very low	98 JIS patients (33 M, 66 F) Group 1 (n = 27) (observation group): Group 1 A (stationary/slightly progressed curve) (n = 20); Group 1B (resolved curve) (n = 7) Group 2 (n = 72): Group 2 A (Bracing only group) (n = 17); Group 2B (Surgery group which 28 patients had brace before surgery) (n = 55)	Group 2 A - Age at bracing: 8.25 yrs Group 2B - Age at bracing: 7.17 yrs	Surgery rate: 62.2%
Tsirikos et al,[16] 2023	Retrospective study	Very low	45 JIS patients Bracing only group (n = 9); Surgery after bracing group (n = 36)	At brace initiation: Risser grade: 0 Triradiate cartilage open for all patients Bracing only group: Duration of bracing (years): 8.4 (4.1 to 14.4) Surgery after bracing group: Duration of bracing (years): 5 (1.6 to 9.4)	Surgical rate: 80%

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Study	Design	Level of evidence	Sample size	Patients' characteristics	Overall curve progression rate/ surgery rate
Aulisa et al,[17] 2014	Prospective study based on ongoing database	Low	127 JIS patients (116 M, 11 F) Compliance grouping: Complete group (n = 66) (brace worn as prescribed); Incomplete A group (n = 12) (brace removed for 1 month of a year); Incomplete B group (n = 25) (brace removed for 2 months of a year); Incomplete C group (n = 14) (brace removed during school hours); Incomplete D group (n = 10) (brace worn overnight only)	- Age at baseline: 9.0 (1.2) - Duration of bracing (years): 6.69 (2.18)	Mean difference in Cobb angle after bracing: -13° ($p < 0.001$)
Khoshbin et al,[18] 2015	Retrospective comparative study	Low	88 JIS patients (78 F, 10 M) Operative group (n = 44); Nonoperative group (n = 44) Progressive group (n = 63); Non-progressive group (n = 25) Compliance grouping: Full: (43 (49%)) Partial: (31 (35%)) Non-compliant: (12 (14%)) Unknown: (2 (2%))	Age at diagnosis (years): 8.4 (1.4) Age at brace initiation (years): 9.3 (1.5) Duration of bracing (years): 3.6 (1.9) Bone age: Risser 0 (80 (91%)) Risser 2+ (6 (7%)) Unknown (2 (2%)) Menarche status: Before (72 (92%)) After (5 (7%)) Unknown (1 (1%))	Progression rate: 71.6% Surgery rate: 50% Nonoperative patients Curve progression: Yes (≥ 6°) (22° (50%)) No (≤ 5°) (22° (50%)) Operative patients Curve progression: Yes (≥ 6°) (41° (93%)) No (≤ 5°) (3° (7%))
Jarvis et al,[19] 2008	Retrospective study	Very low	23 JIS patients (7 M, 16 F) Success group (n = 9); Progression group (without surgery) (n = 7); Surgery group (n = 7)	Age at referral: 8.3 yrs (5.5 to 9.9) Age at start of bracing: 10.3 yrs - Duration of bracing: 3.7 yrs (1 to 7.5)	Success rate: 39.1%
Coillard et al,[20] 2010	Prospective interventional study	Low	67 JIS patients (60 F, 7 M) At weaning point (n = 67): Success group (n = 29); Progression group (n = 9); Withdrawal from treatment (n = 4); Surgery group (n = 25) At 2 years' follow-up (n = 24): Success group (n = 18); Progression group (n = 3); Surgery group (n = 3)		At weaning Overall success rate (≤ 5°): 43.3% Progression rate (> 5°): 13.4% Rate of withdrawal: 5.97% Overall surgery rate: 37.3% At 2 years' follow-up Overall success rate (≤ 5°): 75% Progression rate (> 5°): 12.5% Overall surgery rate: 12.5%

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Study	Design	Level of evidence	Sample size	Patients' characteristics	Overall curve progression rate/ surgery rate
			91 JIS patients (83 F, 8 M)	Age at presentation: 7.6 yrs (1.5), 4.0 to 9.8	
			Bracing only group (n = 30);	Age at brace initiation: 7.9 yrs (1.41), 4.1 to 9.8	
Whitaker et al,[21] 2022	Retrospective study	Low	Surgical group (n = 61)	Duration of bracing: 4.6 yrs (1.93), 1.0 to 9.7	Surgery rate: 67.0%

Data extracted from included studies were presented as mean (SD) whenever possible.
ATR, apical trunk rotation; F, female; JIS, juvenile idiopathic scoliosis; M, male; SRS, Scoliosis Research Society; TRACE, trunk aesthetic clinical evaluation.

Table III. Data extracted from included studies regarding factors contributing to bracing success.

Study	Pre-brace Cobb angle	Curve type prevalence%	Compliance	Brace type	RVAD	In-brace correction	Time of brace initiation and duration of bracing
Heemskerk et al[6]	Pre-brace Cobb angle of largest curve 32.3° (10.0°)	Thoracic (Th): 34 (69%) Thoracolumbar (TL): 4 (8%) Lumbar (L): 11 (22%)	Full-time: ~ 20 hours per day	Boston brace			
Harshavardhana and Lonstein[7]	Pre-brace Cobb angle: 30° (20 to 60°) Bracing success rate ≤ 29°: 54% ≥ 30°: 41% (p = 0.22) Initial curve Cobb angle: - Bracing only group 23° (13° to 44°) - Surgery after bracing group 31° (10 to 60°) (p < 0.001) Pre-brace Cobb angle: - Bracing only group 30° (20 to 55°) - Surgery after bracing group 34° (20 to 60°) (p = 0.16)	Most common initial curve types: single right thoracic curve (40%) and right thoracic + left lumbar (29.6%) Bracing success rate - All other curve types excluding single right thoracic curve): 59% - Single right thoracic curve surgery rate: 72%)		- MB: 74 (59%) - TLSO: 51 (41%) - Bracing success rate (MB vs TLSO): p = 0.72			- Braced as juveniles: 93 (74%) - Braced during adolescence: 32 (25%) - Bracing success rate (juvenile vs adolescence): 34% vs 75% (p = 0.001) Bracing only group - Age at brace initiation: 9.9 (4.2 to 15.2) - Age at brace weaning: 14.4 (6.2 to 17.5) Surgery after bracing group - Age at brace initiation: 8.1 (5 to 9.7) - Age at brace weaning: 13.9 (10.6 to 23.6)
Mannherz et al[8]	Surgical progression correlated to pre-brace Cobb angle 10° to 19°: 0/3 20° to 29°: 6/16 30° to 39°: 4/8 40° to 45°: 2/3 > 45°: 1/1 Bracing only group - Pre-brace Cobb angle: 22° (10 to 40°) - Average progression of 6.7° after bracing	Th: 19 (44%) L: 5 (16%) TL: 7 (14%) Double major: 12 (28%)		Localizer jacket or MB	Bracing only and Surgery group - Initial RVAD was not predictive of progression, but 80% of patients with progression and 100% of patients required surgery despite orthosis having final RVAD > 10°		
Aulisa et al[9]	Pre-brace Cobb angle: 29.6° (7.5°) - Mean correction according to pre-brace curve magnitude < 30°: 12.6° ≥ 30°: 11.8°	L: 23 (20.3%) TL: 30 (26.5%) Th: 32 (28.3%) Double: 28 (24.8%)	Full-time: 18 to 22 hours daily	PASB for TL and L curves while MB or Lyon brace for Th or double curves			

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Study	Pre-brace Cobb angle	Curve type prevalence%	Compliance	Brace type	RVAD	In-brace correction	Time of brace initiation and duration of bracing
	- Curve correction of different pre-brace curve magnitude < 30°: 49 (83%) ≥ 30°: 39 (72.2%) - Surgery referral of different pre-brace curve magnitude < 30°: (1° (1.6%)) ≥ 30°: (3° (5.5%))	- Mean curve correction according to curve type: L: 14.7° TL: 8° Th: 10.0° Double: 12.5° - Outcome according to curve type: L and TL curves show no curve progression (> 5°); Th and double curves have higher incidence of surgery (3 (9.4%) vs 1 (3.6%))		PASB obtained better correction with 0% curve progression			
Kahanovitz et al[10]	Surgery rate for pre-brace Cobb angle ≤ 35°: 0 (0%) 35° to 45°: 3 (60%) > 45°: 2 (100%) Bracing only group: - Pre-brace Cobb angle: 32° (21° to 44°) Surgery after bracing group: - Pre-brace Cobb angle: 45° (36° to 55°)		- Full-time: 23 hours daily - Part-time: brace-wearing after school and all night, for sleep only or every other night	Custom-made MB (worn 23 hours/day for at least one year and started part-time wearing if there was reduction or stabilization)	Bracing only group - Pre-brace RVAD: 6° (2° to 20°) - End-brace RVAD: 9° (2° to 19°) Surgery after bracing group - Pre-brace RVAD: 24° (15° to 35°) - End-brace RVAD: 30° (25° to 35°)		Bracing only group - Age at diagnosis: 6 yrs - Age at initiation of bracing: 7.2 yrs - Duration of bracing: 6.5 yrs Surgery after bracing group - Age at diagnosis: 7 yrs - Age at initiation of bracing: 8 yrs - Duration of bracing: 5.5 yrs
Tolo and Gillespie[11]		Single Th: 16 (29.1%) Single L: 3 (5.5%) TL: 4 (7.3%) Double Th: 17 (30.9%) Double L: 15 (27.2%) Bracing group - Single curves more common pre-brace, while double curves become the majority after treatment - Single Th curves had the best initial correction but gradually regressed (6.5% correction); TL curves had the best response (36% correction)	Full-time: 22 hours daily (13 patients underwent only full-time bracing and 6 patients wear for more than a year) Part-time: ≤ 20 hours daily (29 patients were allowed some part-time bracing)	MB	Surgery group - Trend of RVAD for predicting poor response to bracing: persistent values of ≥ 10° (serial measurement of RVAD may be useful, as more benign curves show changes towards zero or negative)		

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Study	Pre-brace Cobb angle	Curve type prevalence%	Compliance	Brace type	RVAD	In-brace correction	Time of brace initiation and duration of bracing
Babaee et al[12]	Pre-brace Cobb angle: 34.11° (SD 11.37°, 20° to 65°) - Pre-brace curve magnitude ≤ 29°: 28 (37.3%) 30° to 45°: 31 (41.3%) ≥ 46°: 16 (21.3%) Progression/surgery rate for different pre-brace curve magnitude: ≤ 29°: 3 (11%) 30° to 45°: 9 (29%) ≥ 46°: 15 (94%) ($p < 0.001$) - Pre-brace Cobb angle: Success: 29.93° (7.62°) Progression/surgery: 45.29° (12.53°) ($p < 0.001$) - Initial Cobb angle: Success: 25.39° (9.10°) Progression/surgery: 43.59° (14.27°) ($p < 0.001$)	Lenke I: 25 (33%) Lenke II: 7 (9.3%) Lenke III: 18 (24%) Lenke V: 25 (33%) - Average best in-brace correction (BIBC): 57% (6 to 100%) - BIBC of different curves: Lenke I: 55% (6 to 100%) Lenke II: 59% (26 to 100%) Lenke III: 41% (14 to 67%) Lenke V: 62% (25 to 100%) - Progression rate in different curve types: Lenke I: 8 (32%) Lenke II: 3 (43%) Lenke III: 12 (67%) Lenke V: 4 (16%) - Surgery rate in different curve types: Lenke I: 6 (28.5%) Lenke II: 2 (9.5%) Lenke III: 10 (48%) Lenke V: 3 (14%)	Full-time: > 20 hours per day Part-time: < 20 hours per day Progression/ surgery rate according to compliance: Full (12 (24.5%)) Partial (15 (57.7%)) ($p = 0.008$)	MB: 66 (88%) TLSO: 9 (12%)			Time of brace initiation - Juvenile period: 48 (64%) - Adolescent period: 27 (36%) Effectiveness of brace treatment according to time of bracing initiation: - Juvenile period 26/48 (54%) - Adolescent period 24/27 (88%) Success/stable group - Age at initiation of bracing: 9.16 yrs (2.74) ($p = 0.01$) - Risser sign at brace initiation: 0.69 (0.85) ($p < 0.001$) - Brace wearing time (yrs): Braced at Juvenile (8.72 (2.55; 5 to 13)) Braced at Adolescent (4.52 (1.37; 2 to 8)) ($p < 0.001$) Progression/ surgery group - Age at brace initiation: 7.66 yrs (2.05) ($p = 0.01$) - Risser sign at initiation of bracing: 0.15 (0.36) ($p < 0.001$)
Heemskerk et al[13]	Pre-brace Cobb angle Bracing only group: 28° (7.4°) Surgery after bracing group: 34.9° (12.9°)		Full-time: 20 hours per day	MB: 11 (16.4%); Boston brace: 56 (83.6%)			Bracing only group - Age at initiation of bracing: 11.9 yrs (2.1) - Age at weaning of brace: 15.4 yrs (1.5) Surgery after bracing group - Age at initiation of bracing: 10.2 yrs (2.9) - Age at weaning of brace: 13.3 yrs (1.4)
Donzelli et al[14]	Pre-brace Cobb angle: 32.7° (SD 6.4°)	Single: 7.4% Th: 7.4%	Full-time: 18 to 23 hours per day	Sibilla brace: 40.7%, Sforzesco brace: 59.3%			

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Study	Pre-brace Cobb angle	Curve type prevalence%	Compliance	Brace type	RVAD	In-brace correction	Time of brace initiation and duration of bracing
	Patients with pre-brace Cobb angle above 30° (around 63%)	Double: 85.2% Th + L: 74.1% Th + TL: 7.4% Other: 3.7% Triple: 7.4%					
Figueirdo and James[15]	Group 2 A Pre-brace Cobb angle (37°) mean correction of 4° Group 2B Braced patients Pre-brace Cobb angle (43°) mean correction of 21%	In double curve pattern, mean correction at the end of bracing was 40% for thoracic and 43% for lumbar curve	Full-time brace which was removed only for bathing	Edinburgh brace			
Tsirikos et al[16]	Bracing only group - Pre-brace Cobb angle Th: 32° (13° to 56°) TL/ L: 21° (20° to 35°) - Mean improvement of 5° for both Th and TL/L Surgery after bracing group - Pre-brace Cobb angle Th: 41° (22° to 70°) TL/ L: 33.6° (17° to 54°)	Bracing only group Th 2: (22.2%) Th and L: 6 (66.7%) Double Th: 1 (11.1%) Surgery after bracing group Th: 10 (27.8%) Th and L: 21 (58.3%) Double Th: 4 (11.1%)		Boston brace			Bracing only group - Age at initiation of bracing: 7.2 (3.3 to 10) - Age at weaning of brace: 15.5 (13.6 18.1) Surgery after bracing group - Age at initiation of bracing: 7.8 (3.1 to 10) - Age at weaning of brace: 12.5 (9.8 to 16.8)
Aulisa et al[17]	Pre-brace Cobb angle: 29.5° (6.9°) Final Cobb angle: 16.5° (11.0°) with difference of -13° ($p < 0.001$)	Th: 34 (26.8%) L: 24 (18.9%) TL: 64 (50.4%) Double major: 5 (3.94%)	Full-time: max 22 hours daily, min 18 hours daily - Significant difference between compliance Complete and Incomplete B group (-9.268; $p > 0.001$), between Complete and Incomplete D group (-9.444; $p = 0.013$) Complete group Pre-brace Cobb angle: 29.4° (6.7°) - Final Cobb angle: 10.9° (9.5°) with difference of -18.5° ($p < 0.001$) Incomplete A group Pre-brace Cobb angle: 29.2° (6.9°) Final Cobb angle 21.8° (9.1°) with difference of -7.4° ($p = 0.006$) Difference over compliance with complete group: 11.1° ($p < 0.001$)	PASB (TL and L curves); Lyon and MB (Th and double major curves) PASB provides better curve correction with higher adherence to treatment, compared to Lyon or MB			

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Study	Pre-brace Cobb angle	Curve type prevalence%	Compliance	Brace type	RVAD	In-brace correction	Time of brace initiation and duration of bracing
			Incomplete B group - Pre-brace Cobb angle 29.2° (6.8°) - Final Cobb angle 24.9° (10.9°) with difference of -4.1° (p = 0.045) Difference over compliance with complete group: 14.4° (p < 0.001) Incomplete C group - Pre-brace Cobb angle 28.8° (8.1°) - Final Cobb angle 18.4° (5.5°) with difference of -10.4° (p < 0.001) Difference over compliance with complete group: 8.1°(p < 0.001) Incomplete D group - Pre-brace Cobb angle 32.6° (7.5°) - Final Cobb angle 24.2° (6.2°) with difference of -8.4° (p < 0.001) Difference over compliance with complete group: 10.1° (p < 0.001) Multiple linear regression (B coefficient) for results of Cobb angle difference with Complete group as reference ($R^2 = 0.55$): Incomplete A: 8.57 (p < 0.001) Incomplete B: 13.77 (p < 0.001) Incomplete C: 7.30 (p = 0.003) Incomplete D: 10.35 (p < 0.001)				
Khoshbin et al[18]	Pre-brace Cobb angle: 31° (20° to 71°) Progression rate according to pre-brace Cobb angle: 20° to 29°: 17 (56.7%) ≥ 30°: 46 (79.3%) (p = 0.03) - Surgery rate according to pre-brace Cobb angle: 20° to 29°: 7 (23.3%) ≥ 30°: 37 (63.8%) (p = 0.001)	Lenke I and III: 54 (61%) Lenke VI: 14 (16%) - Surgery rate according to curve types: Lenke I + Lenke III: 33 (61%) Lenke VI: 1 (14%) (p = 0.007)	Full compliance: > 20 hours per day or entire night for Charleston brace Partial compliance: < 20 hours per day or < 50% of entire night for Charleston - Non-compliant: 0 hours Progression rate according to compliance: Full: 24 (55.8%) Partial: 26 (83.9%) Non-compliant: 12 (100%) Unknown: 1 (50%) (p = 0.002)	TLSO (68%); MB (7%); Charleston (brace at night only) (10%); a combination of brace (13%) Progression rate according to brace type: TLSO: 37 (61.7%) Others: 26 (92.9%) (p = 0.03) Surgery rate according to brace type: TLSO: 25 (41.7%) Others: 19 (67.9%) (p = 0.02)		Progressive group - In-brace correction: 31.6 (24.5%) Non-progressive group - In-brace correction: 48.1 (20.0%) (p = 0.01)	Progressive group - Age of initiation of bracing: 8.9 yrs (1.5) Non-progressive group - Age of initiation of bracing: 10.3 yrs (1.3) (p = 0.001) Operative group - Age of initiation of bracing: 8.8 yrs (1.5) - Bone age: Risser 0 (38 (86%)) Risser 2+ (4 (9%)) Unknown (2 (5%)) (p = 0.14)

(*Continued*)

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Study	Pre-brace Cobb angle	Curve type prevalence%	Compliance	Brace type	RVAD	In-brace correction	Time of brace initiation and duration of bracing
			Surgery rate according to compliance: Full: 18 (41.9%) Partial: 13 (41.9%) Non-compliant: 11 (91.7%) Unknown: 2 (100%) (p = 0.006)				- Duration of bracing (years): 2.9 (1.8) Nonoperative group - Age of initiation of bracing: 9.9 yrs (1.4) (p = 0.001) - Bone age: Risser 0 (42 (95%)) Risser 2+ (2 (5%)) Unknown (0 (0%)) (p = 0.14) - Duration of bracing (years): 4.4 (1.7) (p = 0.001)
Jarvis et al[19]	Pre-brace Cobb angle: 30° (20° to 43°) Pre-brace Cobb angle according to outcome Success ≤ 5° (28.7°(22° to 37°)) Progression (26.3°(18° to 33°)) Surgery > 45° (33° (29° to 43°)) Outcome according to pre-brace Cobb angle: 20° to 29° Success ≤ 5° (5 (50%)) Progression (3 (30%)) Surgery > 45° (2 (20%)) 30 to 39° Success ≤ 5° (4 (30.8%)) Progression (4 (30.8%)) Surgery > 45° (5 (38.5%))	Right Th 9 (39.1%) Left TL 1 (4.35%) Double major 12 (52.2%) Triple 1 (4.35%) Outcomes according to curve types: Right Th + left TL Success ≤ 5° (4 (40%)) Progression (3 (30%)) Surgery > 45° (3 (30%)) Double major + triple Success ≤ 5° (5 (38.5%)) Progression (4 (30.8%)) Surgery > 45° (4 (30.8%)) Best in brace correction: 9 Th + 1 TL (94%) 12 Double major curves and 1 triple curve (76%)	Night-time wear for at least 8 hours per day	Charleston night-time bending brace		Success ≤ 5°: 101.5% Progression: 71.2% Surgery > 45°: 72.9%	
Coillard et al[20]	At weaning: Pre-brace Cobb angle 28° (10.7°) < 25° (38 (56.7%)) > 26° (29 (43.3%))	Th 35 (52.2%) TL 22 (32.8%) Double 8 (11.9%) L 2 (3.0%)	20 hours per day	- SpineCor orthosis At 2 years' follow-up: - 3 (12.5%) patients still improved from the time the orthosis was			

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Study	Pre-brace Cobb angle	Curve type prevalence%	Compliance	Brace type	RVAD	In-brace correction	Time of brace initiation and duration of bracing
	Outcomes according to pre-brace Cobb angle: < 25° Success 20 (52.6%) Progression 6 (15.8%) Withdrawal 2 (5.26%) Surgery 10 (26.3%) > 26° Success 9 (31.0%) Progression 3 (10.3%) Withdrawal 2 (6.90%) Surgery 15 (51.7%)	At weaning: Success rate according to curve type: Th 8 (22.9%) TL 17 (77.3%) Double 2 (25%) L 2 (100%)		discontinued up to 2 years' follow-up			
Whitaker et al[21]		Mid-Th 48 (5%) Double major 16 (18%) TL/L 16 (18%) Double Th 11 (12%)	Full-time: median of 18 hours per day Surgery rate for non-compliant patients: 74% (p = 0.005) - Patients who were non-compliant with bracing had 6.3 times the odds of posterior spinal fusion (OR: 6.32, 95% CI 6.12 to 18.86, p < 0.001)	- Boston brace (90%) - Charleston night brace (10%)	Bracing only group: - RVAD 8.8 (8.8) Surgery group: - RVAD 8.5 (7.8) (p = 0.88)	Bracing only group in-brace correction: 64.4 (23.6%) Surgery group in-brace correction: 55.3 (23.8%) (p = 0.11)	- Age at bracing initiation: Bracing only group: 8.2 yrs Surgery group: 7.8 (p = 0.21) - Duration of bracing (years): Bracing only group: 4.5 (2.0) Surgery group: 4.7 (1.93) (p = 0.67)

Data extracted from included studies were presented as mean (SD) whenever possible.
BIBC, Best in-brace correction; L, lumbar; MB, Milwaukee brace; OR, odds ratio; PASB, progressive action short brace; RVAD, rib vertebral angle difference; Th, thoracic; TL, thoracolumbar; TLSO, thoraco-lumbo-sacral orthosis.

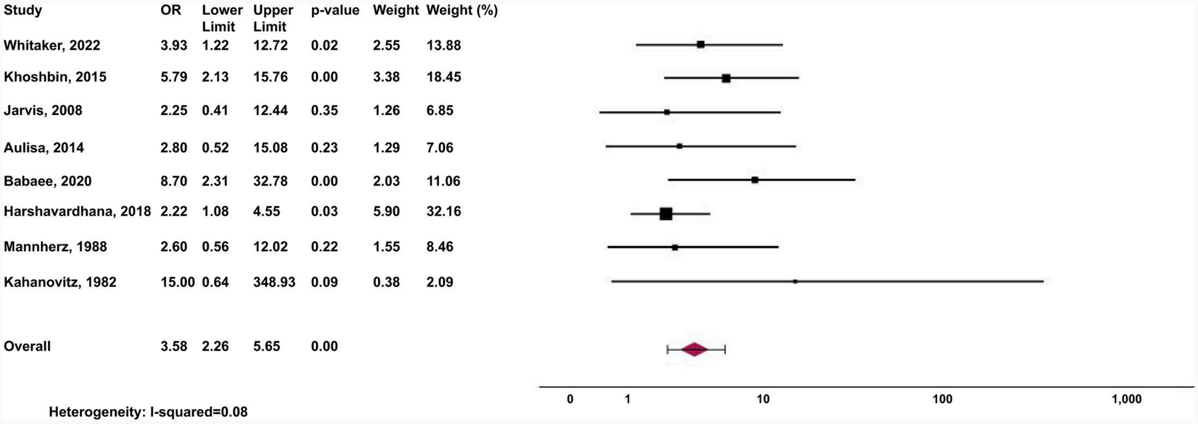


Fig. 2

Forest plot showing pooled odds ratio of bracing success in patients with pre-brace curves < 30° compared to those with pre-brace curves ≥ 30°.

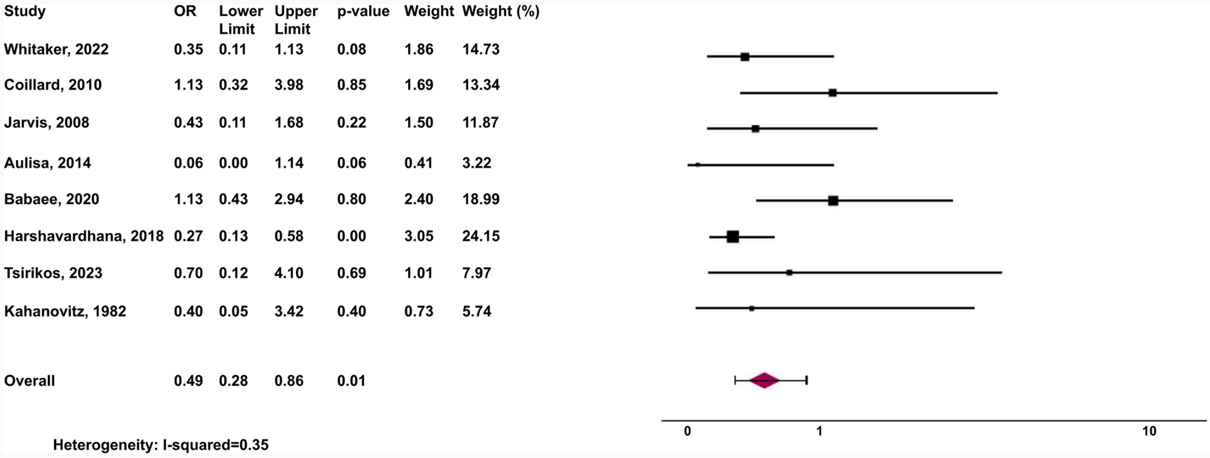


Fig. 3

Forest plot showing pooled odds ratio (OR) of bracing success in thoracic curves compared to thoracolumbar/lumbar curves.

Whitaker et al.[21] Additionally, Lenke type III was seen to have the lowest percentage correction.[12]

RVAD

There is no consensus on the significance of RVAD in predicting curve progression and surgery. Three studies were published from 1978 to 1988, with a very low level of evidence, showing an association between larger RVAD and progression or surgery.[8,10,11] In one study, increasingly positive RVAD was seen to precede curve progression in progressive single thoracic curves.[11] One recent study showed comparable initial RVAD between surgical and braced patients (8.5° vs 8.8°, p = 0.88).[21]

Current limitations of JIS research

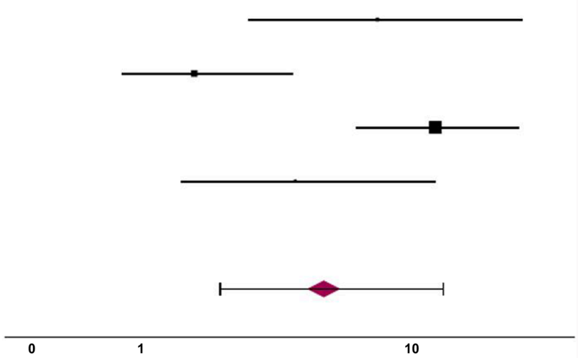
According to GRADE, the level of evidence of all included studies ranged from low to very low. Critical appraisal of included literature revealed that 12 out of 16 studies (75%) had a heterogenous patient population. Heterogeneity of patient cohort was defined as inclusion of patients with different treatment (brace types) and diagnosis (AIS/JIS) without considering any inter-group comparisons. Moreover, not all studies on JIS included multiple factors of interest. For example, only four studies had documented RVAD and only two studies compared between different brace types. None of the studies recommended brace-wear duration, and only four studies had sufficient compliance documentation for our further analysis. Five studies had a control group (patients on observation) and only one study included patient-reported outcome measures (PROMs).

Discussion

In this review, we identified a pre-brace major Cobb angle < 30° and full-time compliance of at least 18 to 20 hours/day as favourable prognostic factors for bracing success, while presence of thoracic curves act as a poor prognostic factor. Additionally, longer bracing duration did not translate to higher success rate. However, our results also highlighted insufficiencies in current JIS research.

All but one study agreed that a smaller pre-brace Cobb angle was associated with greater bracing success. Multiple studies used 30° as a cut-off Cobb angle value for comparing success rate, but studies using other cut-off values showed similar trends. Nonetheless, a similar relationship between pre-brace Cobb angle and brace treatment prognosis was well established in many studies of AIS.[24-28] Of our included

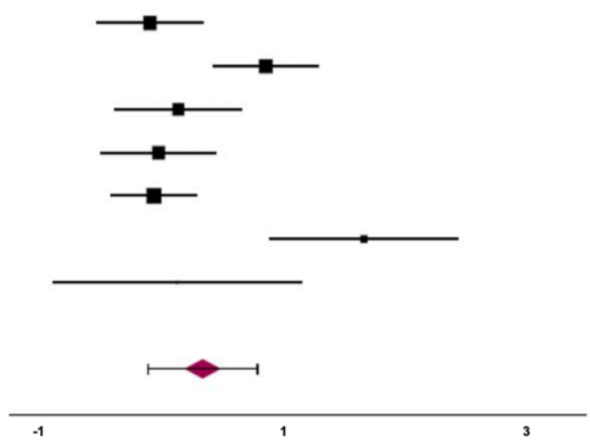
Study	OR	Lower Limit	Upper Limit	p-value	Weight	Weight (%)
Whitaker, 2022	7.73	2.87	20.82	0.00	1.23	23.03
Khoshbin, 2015	1.75	0.75	4.12	0.20	1.34	25.04
Aulisa, 2014	11.58	6.60	20.32	0.00	1.57	29.26
Babaee, 2020	4.20	1.52	11.60	0.01	1.21	22.67
Overall	5.23	2.24	12.19	0.00		



Heterogeneity: I-squared=0.76

Fig. 4
Forest plot showing pooled odds ratio (OR) of bracing success in compliant patients compared to non-compliant patients.

Study	Cohen's d	Lower Limit	Upper Limit	p-value	Weight	Weight (%)
Whitaker, 2022	-0.09	-0.52	0.35	0.70	3.02	15.80
Khoshbin, 2015	0.86	0.42	1.29	0.00	3.02	15.81
Heemsherk, 2023	0.14	-0.38	0.67	0.59	2.83	14.83
Babaee, 2020	-0.02	-0.49	0.46	0.94	2.94	15.40
Harshavardhana, 2018	-0.05	-0.41	0.30	0.76	3.19	16.68
Tsirikos, 2023	1.66	0.88	2.43	0.00	2.29	11.96
Kahanovitz, 1982	0.13	-0.88	1.15	0.79	1.82	9.52
Overall	0.34	-0.11	0.79	0.13		



Heterogeneity: I-squared=0.81

Fig. 5
Forest plot showing standardized mean difference in bracing duration between bracing success group compared with failure group.

studies, Tsirikos et al[16] showed better bracing outcomes in AIS patients (OR 2.36, p = 0.01) compared to JIS, but Donzelli et al[14] showed no difference between the two groups. Although curve magnitude cannot be modified, pre-brace Cobb angle could be used as a prognostic predictor for clinicians to decide whether to follow through with more aggressive treatment plans, possibly with the addition of physiotherapy, which was shown to reduce surgical conversion rate.[1] Patients with a greater pre-brace Cobb angle, especially those > 30° but not yet reaching the surgical threshold of 45°, should be monitored closely and be informed of the possibility of surgery if progression continues. It should be noted that while bracing success was defined as a residual curve < 45° at the end of bracing, a recent study has shown that these smaller curves of 40° to 50° could have post-maturity progression, and some patients eventually require surgical intervention.[29]

Our study identified that single thoracic curves were associated with poorer prognosis. Similarly, Robinson and McMaster[30] reported that lumbar and thoracolumbar curves generally displayed a more benign prognosis compared to major thoracic. These findings in JIS patients aligned with those in AIS, in which the severity of thoracic curves increased risk of curve progression.[24,27,31] A previous study on AIS associated poorer prognosis in major thoracic curves with more aggressive progression and less responsiveness to conservative brace treatment;[32] our results showed that curve morphology in JIS exhibited similar relationships with brace outcomes. Given the intrinsic differences in progression risk between curve types, clinicians should consider curve morphology during risk stratification of juvenile patients. For instance, more frequent follow-ups and compliance monitoring should be arranged for patients with thoracic JIS, with the aims of identifying early signs of bracing failure and progression to surgery. However, prognosis of double and triple major curves remains unclear in both AIS and JIS populations.[33] Further robust research should be performed to assess characteristics of such curve patterns and their clinical implications.

Full-time brace-wear compliance of at least 18 to 20 hours/day was identified as a favourable prognostic factor,[12,17,18,21] despite heterogeneity in included studies. Compliance is modifiable, and improving it is a reasonable approach to increase bracing success. The use of thermal or force sensors could be considered to evaluate for bracing compliance.[34,35] Moreover, treatment education, for both patients and parents, is of the utmost importance. JIS patients are relatively young and immature, and may not comprehend the true significance of bracing and the consequences of non-adherence. Parents have to intervene and ensure their children strictly adhere to treatment, hence their role should not be underestimated. Parents would have to understand the principles and importance of management as well. For instance, tertiary spine centres could consider training speciality nurses to explain the basics of bracing treatment to the whole family immediately following the doctor's consultation.[36]

Greater brace-wear duration was not associated with improved bracing outcomes. Prolonged bracing may potentially lead to problems such as reduced spinal mobility and worse health-related quality of life (HRQoL).[37] Clinicians should bear in mind that prolonged bracing may not necessarily improve treatment response, and may in fact have the opposite effect on the patient. Similarly, a recent study has shown that bracing for a longer duration in gradual weaning protocols played no effect in clinical outcomes.[38] Additionally, one study revealed that patients who braced at adolescence with half the duration of the juvenile group (4.52 vs 8.72 years) still doubled the bracing success.[12] A potential explanation for this is that curves braced at an older age could have less aggressive progression as patients were nearer skeletal maturity, and less likely to reach the surgical threshold.[39] Total treatment duration is determined by the time at which treatment commences and the time when skeletal maturity is reached with brace weaning. Clinicians should pay attention to early identification of juvenile scoliosis and initiation of treatment, instead of focusing on total length of treatment in visualizing bracing success.

Other factors with insufficient evidence include RVAD and in-brace correction. Due to the heterogeneity of studies and lack of patient data, pooled results were not available. Previously, greater in-brace correction was shown to positively correlate with bracing success in AIS,[40] and some of the studies did echo these findings.[18,19,21] Moreover, only three studies showed an association between RVAD and curve progression.[8,10,11] The lack of quantitative and qualitative evidence makes it difficult to reach clear conclusions. Future research efforts could focus on investigating these factors individually to understand their value in JIS bracing.

Although this is the first review to evaluate contributing factors to JIS bracing, it is largely limited by the availability and quality of pre-existing research. First, there is generally a lack of high-quality scientific evidence on JIS. Retrospective cohort studies, despite their value in observing trends over time, are prone to biases and confounding. More randomized controlled trials on JIS patients should be performed in the future, similar to those done previously investigating AIS patients.[41] Therefore, clinicians could isolate individual factors and study their association with bracing success in a controlled environment, translating the results to JIS management. Second, the studies lacked clear clinical recommendations. Clinicians heavily rely on evidence-based guidelines and clinical recommendations to guide treatment. They would be interested in practical aspects of JIS management, such as duration of bracing, optimal brace type, and initiation age. However, none of the previous studies on JIS made clear recommendations with robust evidence. While our systematic review has summarized major factors contributing to bracing success, it is of paramount importance for future studies to give specific recommendations to streamline clinical decision-making, given the lack of specific guidelines for JIS. Third, most studies lacked a control group for comparison. Without comparative analysis with patients on observation, it is difficult to assess the true effectiveness of JIS bracing and natural progression of JIS. Last, all but one of the studies did not include PROMs, which concluded that SRS-22r pain scores were worse in surgically treated JIS patients than braced ones.[13] A lack of PROMs in most studies limited the evaluation of patient-specific aspect of bracing effectiveness and associated HRQoL. Bracing outcomes in future studies should be assessed in a more comprehensive manner, taking mental and social aspects into account.

In conclusion, pre-brace major Cobb angle < 30° and full-time compliance of at least 18 to 20 hours/day are favourable prognostic factors, while the presence of thoracic curves acts as a poor prognostic factor for bracing success. Longer bracing duration does not translate to a higher success rate. Bracing compliance is a modifiable factor while pre-brace curve magnitude and curve types are not, hence clinicians should devise more efforts to modify patient compliance in order to achieve optimal brace outcomes. It is also essential to recognise the heterogeneity and insufficiency of current literature, highlighting the need for further rigorous investigation.

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Data sharing

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