■ SPINE

Effectiveness of bracing to achieve curve regression in adolescent idiopathic scoliosis

A SYSTEMATIC REVIEW

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Aims
To systematically evaluate whether bracing can effectively achieve curve regression in patients with adolescent idiopathic scoliosis (AIS), and to identify any predictors of curve regression after bracing.

Methods
Two independent reviewers performed a comprehensive literature search in PubMed, Ovid, Web of Science, Scopus, and Cochrane Library to obtain all published information about the effectiveness of bracing in achieving curve regression in AIS patients. Search terms included "brace treatment" or "bracing," "idiopathic scoliosis," and "curve regression" or "curve reduction." Inclusion criteria were studies recruiting patients with AIS undergoing brace treatment and one of the study outcomes must be curve regression or reduction, defined as > 5° reduction in coronal Cobb angle of a major curve upon bracing completion. Exclusion criteria were studies including non-AIS patients, studies not reporting p-value or confidence interval, animal studies, case reports, case series, and systematic reviews. The GRADE approach to assessing quality of evidence was used to evaluate each publication.

Results
After abstract and full-text screening, 205 out of 216 articles were excluded. The 11 included studies all reported occurrence of curve regression among AIS patients who were braced. Regression rate ranged from 16.7% to 100%. We found evidence that bracing is effective in achieving curve regression among compliant AIS patients eligible for bracing, i.e. curves of 25° to 40°. A similar effect was also found in patients with major curve sizes ranging from 40° to 60° when combined with scoliosis-specific exercises. There was also evidence showing that a low apical vertebral body height ratio, in-brace correction, smaller pre-brace Cobb angle, and daily pattern of brace-wear compliance predict curve regression after bracing.

Conclusion
Bracing provides a corrective effect on scoliotic curves of AIS patients to achieve curve regression, given there is high compliance rate and the incorporation of exercises.

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Introduction

Adolescent idiopathic scoliosis (AIS) is the most common type of spinal deformity in paediatric patients.[1] Untreated AIS will cause progressive back pain and poorer health-related quality of life.[2-6] Untreated patients who progress to severe thoracic curvature will suffer deformity along with cosmetic and mental health concerns, as well as compromised pulmonary function.[7-10] Common treatment for AIS includes observation, bracing, and surgery. Surgery is often reserved for patients with major curve Cobb angles greater than 50º, while bracing aims to prevent progression in patients with curves of 25° to 40°, thus avoiding surgery.[11]

The effectiveness of bracing in preventing progression has been widely recognized.[12-15] However, few studies have explored whether bracing actually achieves curve regression. Bracing exerts an external force on the spine to attain vertebral remodelling on sagittal, coronal, and axial planes.[16] Although the aetiology of AIS is unknown, its progression is explained

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Table I. Inclusion and exclusion criteria for study selection.

Inclusion criteria	Exclusion criteria
Patients with adolescent idiopathic scoliosis	Patients with non-idiopathic scoliosis
Patients underwent brace treatment	Studies reporting neither p-value nor odds ratio with confidence intervals
Studies with curve regression or curve reduction as one of the outcome measures	Animal studies
	Case reports, case series
	Systematic review and meta-analysis
	Non-English literature

by the "accordion"-like phenomenon and Hueter-Volkmann principle.[17] The glycosaminoglycans (GAGs) in the nucleus pulposus (NP) of intervertebral disc (IVD) imbibe more water when they are not loaded and expel water when they are loaded. Such traits result in a larger amount of water retained on the convex side of the IVD in the initially deformed spine. Meanwhile, diurnal variation in body height contributes to a cyclical change in loading on the IVD. As the NP on the convex side imbibes more water, it expands to withstand the intermittent loading. In contrast, the NP on the concave side is less resilient to intermittent loading due to lower water content, making it subject to continuous loading throughout the 24-hour cycle. Such continuous stress results in inhibition of growth. The above process is known as the "accordion"-like phenomenon.[17] This biomechanical phenomenon is in line with the observed initial wedging of IVD preceding vertebral body wedging observed during the adolescent growth spurt, as reported by Will et al[18] and Grivas et al.[19] With the deformity, uneven loading on both the IVD and vertebral body is subject to asymmetrical growth stimulation described by the Hueter-Volkmann principle, which states that mechanical compression decelerates growth while reduced loading accelerates it.[20,21] Hence, increased loading on the concave side suppresses growth and reduced loading on the convex side stimulates growth, and the resulting asymmetry eventually contributes to a vicious cycle of curve progression. Bracing reverses the process by exerting lateral mechanical forces opposing imbalanced loading on the scoliotic spine, restoring a symmetrical distribution of GAGs and water in the NP of the IVD.[22,23] As a result, a chondrogenic growth of the vertebral body can take place in an evenly loaded environment.[24,25] Bracing also applies forward pressure from posterior to the spine to achieve rotational correction.[26] Overall, bracing enhances resistance of the spine to a buckling phenomenon due to overgrowth induced by abnormal loading.[27] In short, bracing allows 3D remodelling of the scoliotic spine to achieve curve correction. Therefore, in theory at least, bracing is expected to produce curve regression in AIS patients by providing corrective loading.

However, no systematic review has comprehensively analyzed all the available evidence about the effectiveness of bracing on curve regression. This review aims to systematically evaluate the effectiveness of bracing to reduce curvature in patients with AIS, and to identify predictors of curve regression after bracing.

Methods

Literature search strategy and selection criteria. A literature search was performed according to the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA)[28] guidelines and was registered on PROSPERO (CRD42023446162). A comprehensive search was conducted in five databases: PubMed, Ovid, Web of Science, Scopus, and Cochrane Library, to obtain all published information about the effectiveness of bracing in achieving curve regression in AIS patients. Search terms included "brace treatment" OR "bracing" AND "idiopathic scoliosis" AND "curve regression" OR "curve reduction." Curve regression or reduction was defined as more than 5° reduction in the coronal Cobb angle of major curve upon bracing completion. The inclusion and exclusion criteria are listed in Table I. Two investigators (ST, PWHC) performed the search and screening process independently, and discussed any disagreement in study inclusion to reach a consensus. All studies published before 24 September 2023 were retrieved. Relevant articles meeting the inclusion criteria were included.

Data extraction and critical appraisal. The percentage of braced patients achieving curve regression was extracted from each study. Since some studies also analyzed factors predicting curve regression in AIS patients, predictors with statistical significance were also collected. Information about study design, sample size, patient characteristics, brace type, exercise type, and reported predictors and brace-wear compliance was summarized in relation to the rigidity of the brace (Supplementary Table i).[29]

Grading of quality of evidence in each study was divided into "high", "moderate", "low", and "very low" by the Grading of Recommendations Assessment, Development and Evaluation (GRADE) approach.[30] Initially, all studies were given low to very low quality evidence, since they were all observational studies. The quality was then upgraded if the study had a relatively larger sample size (≥ 100 participants) and obvious dose-response relationship. Dose-response relationship is determined by whether compliant patients had better outcomes than non-compliant patients. The quality was downgraded to studies with inconsistent results, indirect evidence, imprecise data, and potential reporting bias. The overall grading of the quality of evidence is listed in Supplementary Table i.

Primary and secondary outcomes. The primary outcome of this review is the effectiveness of bracing on curve regression. The secondary outcome is the predictor(s) with statistical significance for curve regression after bracing.

Search results. The PRISMA flowchart details the search results (Figure 1). The literature search was performed on 24 September 2023. In total, 487 articles were found; after duplication removal, 216 articles remained for abstract screening. Among these, 26 full texts were screened for inclusion and 11 articles met the inclusion criteria and were analyzed.[31–41]

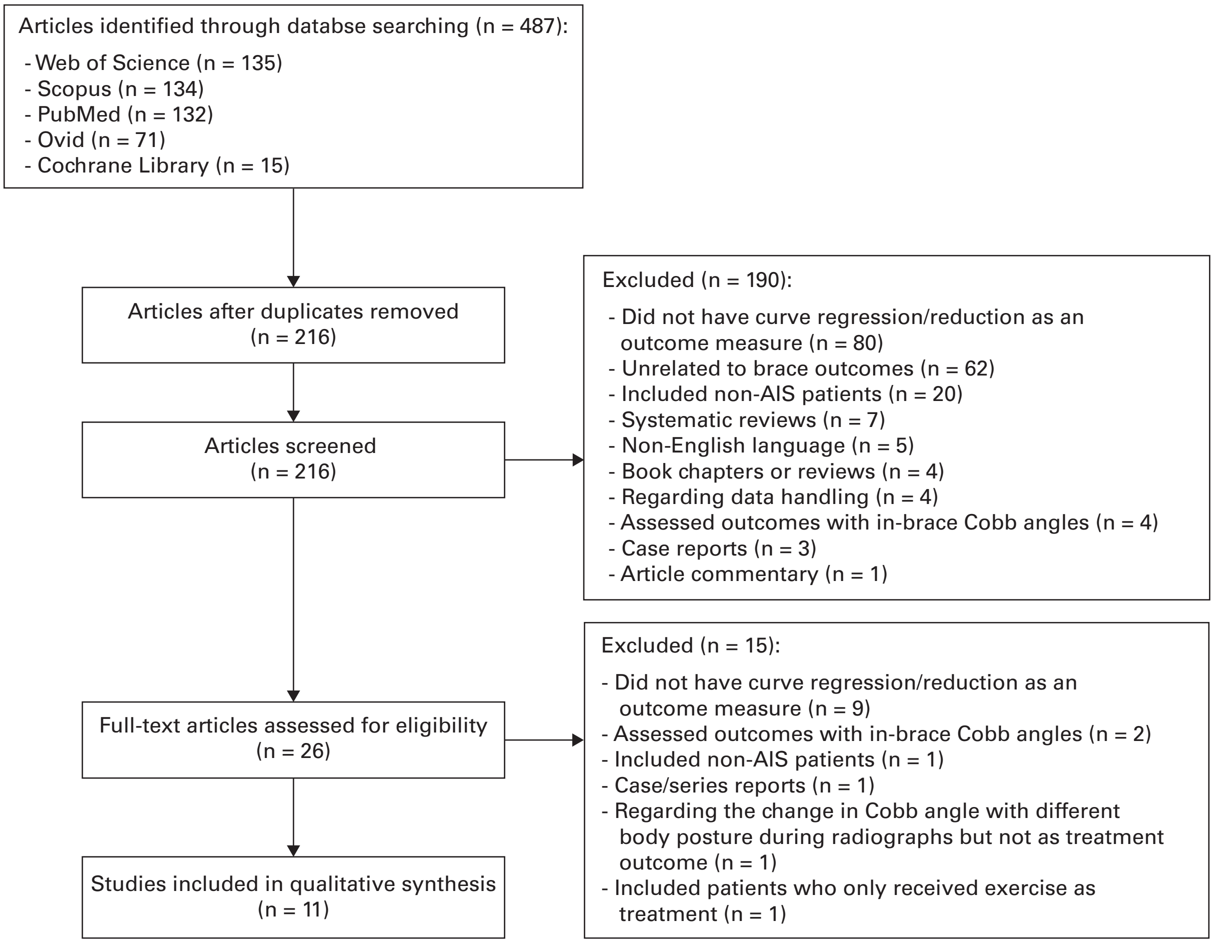

Fig. 1

Flowchart for studies included and excluded in the review. AIS, adolescent idiopathic scoliosis.

All included studies recruited AIS patients who had completed brace treatment. Regarding study design, six were retrospective cohort studies, three were prospective cohort studies, one was a retrospective cohort study with a prospective database, and one was a case-control study. For intervention, four studies had coupled bracing with exercise, and seven prescribed bracing only. Sample size across the 11 publications ranged from 16 to 586 patients, with mean age ranged from 12.6 to 14.2 years (Supplementary Table i). Among the included studies, seven evaluated the effectiveness of bracing to achieve curve regression in patients with major curves 25° to 40°. The remaining studies recruited patients with larger curve sizes ranging from 40° to 60°.

Results

Since all included studies were observational studies, only moderate evidence supporting the effectiveness of bracing in achieving curve regression was found by this review. The highest quality of evidence for curve regression came from Donzelli et al[31] and Cheung et al,[33] which were upgraded to moderate quality of evidence due to demonstration of dose-response effect and larger sample size, respectively.

There was overall moderate affirmative evidence of the effectiveness of bracing to achieve curve regression among AIS patients when using the Society of Orthopaedic and Rehabilitation Treatment (SOSORT)[11] guidelines in seven studies.[31,33–35,37,39,40] One of the studies with moderate quality of evidence investigated the effectiveness of a very rigid brace.[31] Donzelli et al[31] included AIS patients treated with a Sforzesco brace, of which 47.0% (79/168) achieved curve regression.[31] Four studies investigated the effectiveness of rigid braces.[33–35,37] Cheung et al[33] and Yang et al[34] recruited patients treated with Boston brace and found curve regression in 16.7% (98/586), and 100% (16/16), respectively. Zaina et al[35] divided the patients treated with the SPoRT brace (a family of braces following the concept of bracing: Symmetric, Patient-oriented, Rigid, Three-dimensional, active) and physiotherapeutic scoliosis-specific exercise (PSSE) into normal and overweight groups, of which the regression rate was 52% and 44%, respectively.[35] Pasquini et al[37] examined patients treated with "P" Chêneau brace and found that 29.9% (20/67) achieved regression.[37] Upadhyay et al[39] studied patients treated with either a Boston or a Milwaukee brace according to curve types and found curve regression in 68.2% (58/85) of patients.[39] Negrini et al[40] prescribed braces

Fig. 2

The "step-by-step" Sibilla Theory of Treatment of Scoliosis.[11]

of different rigidity, namely SpineCor brace, Sibilla-Cheneau brace, and Sforzesco brace, to patients of different curve sizes following the "step-by-step" Sibilla Theory of Treatment of Scoliosis (Figure 2). In addition, personalized exercises were prescribed to each patient for mobility improvement. Regression occurred in 39.1% (18/46) of them.[40]

There was inconclusive evidence for the ability of bracing to regress curvature, of a large magnitude, among AIS patients. Despite the fact that one of the Scoliosis Research Society's (SRS) bracing criteria for AIS is curve magnitude of 25° to 40°, four studies purposefully included patients with larger curves.[32,36,38,41] Three included patients treated with rigid braces.[32,36,38] Xu et al[32] included patients with curve magnitudes ranging from 40° to 45° treated with Boston brace, and 37.8% (34/90) of patients achieved curve regression.[32] Zhang et al[36] recruited patients with curve magnitudes of 40° to 60° and prescribed modified Gensingen brace and PSSE, achieving regression in 64.9% (50/77) of them.[36] Zhu et al[38] studied a cohort with curve magnitudes of 40° to 50° treated with Boston or Milwaukee brace, depending on their curve types. Only 13.0% (7/54) of the patients had their curves regressed.[38] Negrini et al[41] included AIS patients with major curves larger than 45° treated with braces of different rigidity. They studied patients with the Lyon brace (treated before 2005) or with the Sforzesco brace (treated after 2005), and who were prescribed with a scientific exercise approach to scoliosis exercises. Among these patients, 71.4% (20/28) achieved curve regression.[41]

Two of the included studies investigated the predictors for curve regression.[31,33] Cheung et al[33] found that a reduced apical ratio of 1:1 (odds ratio (OR) 0.84; $p < 0.01$) and an increased in-brace correction rate (OR 1.03, $p < 0.01$) were found having statistically significant associations with curve regression after bracing.[33] Curve regression was found not to be associated with age, Risser staging, distal radius and ulna classification,[42,43] Sanders staging,[44-46] curve type, flexibility,[47,48] or location of curve apex.[33] Donzelli et al[31] found that a pre-brace Cobb angle less than 35° ($p < 0.001$) and compliance with consistent daily patterns (OR 1.96; $p = 0.005$), where there was consistent number of brace-wear hours per day, had a statistically significant association with curve regression in braced AIS patients.[31]

Discussion

To date, there has been no review to systematically evaluate and confirm whether bracing effectively reduces Cobb angles among patients with AIS. [11] The Hueter-Volkmann principle and "accordion"-like phenomenon provided a basis for the possibility of achieving curve regression through corrective loading,[17,24,25] and several studies have investigated such potential. In this review, we found that bracing is effective in obtaining curve regression in AIS, especially for major curves of 25° to 40°, when there is strict compliance. The effectiveness of bracing for curve regression in patients with larger curves however remains controversial. Included studies in our systematic review found an apical ratio closer to 1:1, in-brace correction, and a consistent daily compliance pattern, to be predictive of curve regression after bracing.

The success of bracing in achieving regression among AIS patients with Cobb angles that are indicative of bracing is supported by moderate evidence. The strongest evidence came from studies by Donzelli et al[31] and Cheung et al[33] with moderate-quality evidence. Although all seven studies using bracing under the SOSORT guidelines demonstrated regression after bracing, the regression rate in each cohort differed. Such variation is attributable to different brace rigidities and actual brace-wear time. Regarding the rigidity of braces used, almost all studies included had patients prescribed with either very rigid brace, rigid brace, or a combination of very rigid brace and rigid brace. Only one study by Negrini et al[40] in 2009 demonstrated curve regression in patients treated with soft brace. However, no realistic comparison could be made due to difference in brace types. In 2011, Negrini et al[41] analyzed a cohort of patients treated with a similar approach as they had done in 2009,[40] but used a very rigid or rigid brace.[41] Unfortunately, the difference in age, compliance, and curve sizes made these two studies uncomparable. Nonetheless, rigid braces are proven more effective than soft braces in preventing progression. In a randomized-controlled study, Guo et al[49] found the rate of progressing more than 5° in patients treated with a SpineCor brace was 35.0%, compared to 5.6% among those treated with a rigid brace. A meta-analysis yielded consistent results, reporting that a full-time rigid brace prevented 73.2% of patients from progressing more than 5°, compared to 62.4% in patients treated with full-time soft brace.[50] In terms of brace-wear compliance, seven of the 11 studies either reported the actual compliance or excluded patients not meeting compliance requirement in the protocol.[32,35–38,40,41] Five studies included patients treated with rigid brace.[32,35–38] Compliance of included patients was at least 22 hours/day, at least 20 hours/day, 94% of prescribed dosage on average, at least 90% of prescribed dosage, and at least 75% of prescribed dosage in studies by

Pasquini et al,[37] Zhang et al,[36] Zaina et al,[35] Xu et al,[32] and Zhu et al,[38] respectively. The corresponding regression rate showed a decreasing order, except the rate reported by Pasquini et al[37] (Supplementary Table i). The remaining two studies by Negrini et al in 2011[41] and 2009[40] included patients treated with very rigid or rigid brace based on the severity of the curve. Negrini et al's 2011 paper reported 96% of patients with > 80% compliance, and the regression rate was 71.4%,[41] while the 2009 study reported 90% of the patients had > 80% compliance and regression rate was lower at 39.1%.[40] This finding is consistent with the SOSORT consensus that compliance is critical for a successful bracing outcome.[51] In addition, a similar conclusion that patients with higher compliance had a lower rate of progression and surgery referral was made by Aulisa et al.[52] Moreover, Rowe et al[53] concluded that full-time bracing for 23 hours/day was superior to any shorter duration.[53] Other studies have also demonstrated the dose-response effect of bracing.[13,54] Therefore, given the same brace rigidity, the higher the overall patient compliance, the higher is the regression rate. The effectiveness of bracing in reducing curve magnitude, however, could be underestimated by suboptimal compliance to treatment, especially in studies reporting a lower rate of regression. Developing a less lenient study protocol to include only patients with satisfactory compliance, and using a thermal sensor to measure brace-wear duration objectively, can increase the proportion of patients achieving curve regression after bracing. We, however, conclude that bracing is an effective treatment for regression in compliant AIS patients.

On the other hand, there is contradicting evidence, of low quality, of the effectiveness of bracing in regressing curves of 40° to 60° from Xu et al,[32] Zhang et al,[36] Zhu et al,[38] and Negrini et al.[41] As bracing is recommended for AIS curves of 25° to 40°, patients with larger curves are asked to consider surgical intervention because curves larger than 40° are associated with adulthood progression.[55-57] Some patients with larger curves, however, refuse to undergo surgery. Two of the studies of low quality evidence by Zhang et al[36] and Negrini et al[41] concluded that given strict compliance to bracing and PSSE, bracing is an effective treatment for patients with curves of 40° to 60°. A similar result from Wiley et al[58] is that rigid bracing is effective for patients with larger curves if the brace-wear duration is at least 18 hours a day.[58] Rigid braces for a prescribed time of 20 to 23 hours in these four studies are consistent with this finding. However, different results of the reduced effectiveness of bracing in patients with larger curves were reported by Xu et al[32] and Zhu et al.[38] They found in their studies, which were of low quality evidence, there was a use for bracing to achieve regression in patients who had severe curves. But, because of heterogeneous study protocols and treatment regimens, the effect of brace treatment in these patients cannot be pooled. Nonetheless, the use of PSSE and higher compliance in the two studies supporting bracing being effective especially in patients with larger curves[36,41] could explain the disagreement in conclusions.[32,38] Kwan et al[59] conducted a cohort study investigating the effect of PSSE on vertebral remodeling, revealing that 17% of patients treated with a rigid brace combined with PSSE achieved regression, while only 4% of braced patients treated without PSSE achieved regression.[59] In addition, a systematic review and meta-analysis by Fan et al[60] concluded from several randomized controlled studies that PSSE plays a role in curve regression. As PSSE is proven to be crucial in treating AIS patients,[61] albeit with caution, we conclude that a rigid brace with long brace-wear time and adjunctive PSSE can result in regression AIS patients with larger curves.

Moreover, there is moderate evidence for apical ratio,[33] in-brace correction,[33] a smaller pre-brace Cobb angle,[31] and consistent daily pattern compliance[31] as predictors for regression in braced AIS patients from studies by Cheung et al[33] and Donzeli et al.[31] A higher apical ratio, i.e. the ratio of convex apical vertebral body height to concave apical vertebral body height, indicates more severe wedging of the apical vertebra between convex and concave sides. An apical ratio closer to 1:1 after brace-wear was associated with curve regression after weaning off the brace.[33] A statistically significant association between in-brace correction, which is the assessment based on the immediate in-brace standing whole spine posteroanterior radiograph (i.e. the first in-brace radiograph),[62] and regression was also identified.[33] The in-brace correction rate was 54% (standard deviation (SD) 21%) among patients with curve regression after bracing, compared to 34% (SD 18%) among patients who did not achieve curve regression.[33] However, there is no clinical significance for increased in-brace correction rate[33] as it reflects mainly the brace quality,[63] without taking other determinants, namely curve characteristics and compliance, into account. Negrini et al[64] suggested the first out-of-brace radiograph assessing correction is a better predictor as it reflects the mentioned determinants.[64] Donzelli et al[31] found that patients with a pre-brace Cobb angle of less than 35° were nearly four times more likely to achieve curve regression after bracing.[31] Moreover, they identified consistent daily brace-wear patterns as a significant predictor for curve regression in addition to high daily compliance, defined as at least 90% prescribed daily brace-wear duration.[31] Among patients with high compliance and consistent daily brace-wear patterns, 67.4% achieved curve regression. A lower percentage of 50% was found in patients with the same level of compliance, but inconsistent daily patterns. Therefore, maintaining daily high compliance throughout the treatment period is crucial for curve regression.

This systematic review has several limitations. First, a meta-analysis was not done because of the heterogeneity in curve characteristics, brace types, prescribed dosage, and patient compliance with the treatment, which are important parameters affecting the outcome of brace treatment.[65] Second, this review only looked at the overall regression rate instead of the specific effect size of each study. Finally, this review cannot comment on whether curve recurrence among patients, who achieved regression at the end of bracing treatment, will nevertheless subsequently occur, since none of the included studies reported post-treatment change in Cobb angle.

This is the first systematic review evaluating the effectiveness of bracing in achieving curve regression among AIS patients. Some evidence was found to support the use of bracing to not only prevent progression of the curve, but also preclude regression in those AIS patients who have a high compliance to time wearing the brace. Moreover, bracing may produce curve regression in patients with curves larger than 40° when using a rigid brace, undertaking PSSE, and having a longer daily period of brace-wear, despite the currently low level of evidence. However, there still lacks adequate evidence of the essential factors contributing to curve regression after bracing. Future clinical studies are needed to tighten the inclusion criteria for patient compliance and adopt quantitative measurements of compliance to treatment to avoid underestimation of the effectiveness of bracing.

Take home message

- Bracing is effective in achieving curve regression in patients with adolescent idiopathic scoliosis with a major curve of 25° to 40° given good compliance.
- Among patients with adolescent idiopathic scoliosis with a major curve of 40° to 60°, bracing can be effective in achieving curve regression given incorporation of physiotherapy into treatment.
- A low apical vertebral body height ratio, in-brace correction, and daily pattern of brace-wear compliance are predictive of curve regression after bracing.

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Supplementary material

Table displaying the characteristics of included studies.

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