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Current Status of Vertebral Body Tethering for Adolescent Idiopathic Scoliosis: An Umbrella Review

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Background: Adolescent idiopathic scoliosis (AIS) is a prevalent spinal deformity among teenagers worldwide. Vertebral body tethering (VBT) is an innovative, minimally invasive technique developed to address spinal curvature by modulating vertebral growth. However, the existing body of evidence regarding the effectiveness and safety of VBT in treating AIS is fragmented and requires thorough consolidation and critical assessment.

Methods: Six databases were thoroughly examined, yielding 11 relevant systematic reviews and meta-analyses. The methodological quality of the included studies was evaluated using the Joanna Briggs Institute's critical appraisal checklist. The key findings were encapsulated using a narrative synthesis approach.

Results: The reviews indicated notable improvements in coronal plane radiographic parameters, transverse plane clinical outcomes, and health-related quality of life scores following VBT. Nevertheless, the complication rates associated warrant attention. Additionally, the variability in methodological quality across the included reviews underscores the necessity for more robust and systematic investigations in this domain.

Conclusion: This umbrella review revealed promising results for VBT as a treatment option for AIS. However, further research is needed to address knowledge gaps and limitations, focusing on long-term outcomes, patient selection, standardized techniques, and comparison with traditional treatments.

Keywords: adolescent idiopathic scoliosis, vertebral body tethering, umbrella review

Introduction

Adolescent idiopathic scoliosis (AIS) is a multifaceted spinal deformity affecting millions of teenagers globally.[1] It is characterized by a lateral curvature of the spine exceeding a Cobb angle of 10 degrees, coupled with vertebral rotation and sagittal malalignment.[2] The condition can prompt an array of physical and psychosocial complications, encompassing back pain and suboptimal mental health.[3,4] The etiology of AIS, however, has remained elusive for centuries.[5] Historically, the treatment approach for mild and moderate AIS has been centered around observation and bracing.[6] On the other hand, individuals with severe curvatures have necessitated surgical intervention.[7] Spinal fusion, despite being a non-physiological solution, is recognized for its favorable intermediate-term radiographic outcomes.[8] However, it carries potential long-term disadvantages, such as loss of motion, growth restriction, and spine stiffening in the operated segments.[9] In contrast, a novel technique has surfaced recently as an alternative surgical option.[10] This innovative method presents potential advancements in the treatment landscape of AIS.

Vertebral body tethering (VBT) is a minimally invasive surgical procedure designed to correct spinal curvature through growth modulation.[11] This technique adheres to the Hueter-Volkmann law, which proposes that compressive forces decelerate bone growth while distraction forces stimulate it, thereby modifying vertebral shape.[12] It facilitates continued spinal growth and

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natural correction.[13] Originally used off-label for approximately 15 years, VBT received approval from the United States Food and Drug Administration in 2009 as a humanitarian device exemption.[14] The inaugural case employing this procedure was documented in 2010, involving an 8-year-old boy, where it demonstrated a gradual correction over 4 years.[15] Its targeted candidates are patients still experiencing growth who require surgical intervention to correct progressive spinal curves,[16] and it is indicated that they have not shown favorable responses to bracing or are unable to tolerate it.[17] Those with a major curve ranging from 30 to 65 degrees and a bone structure capable of supporting screw fixation are suitable for VBT.[18] This groundbreaking technique has attracted considerable interest from medical professionals and researchers alike, as it offers a motion-preserving alternative that traditional surgery cannot provide.[19]

As the evidence surrounding VBT expands, it becomes vital to systematically consolidate and critically evaluate the existing literature to direct subsequent research. This umbrella review strives to deliver a thorough and rigorous synthesis of the current evidence concerning the efficacy and safety of VBT in treating AIS. By amalgamating findings from diverse systematic reviews and meta-analyses, we aim to offer valuable insights into the present state of knowledge, pinpoint knowledge gaps, and propose recommendations for future research in this rapidly progressing field.

Methods

This manuscript was prepared following the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) reporting guidelines and the Joanna Briggs Institute (JBI) manual for evidence synthesis. The review protocol has been registered in the International Prospective Register of Systematic Reviews (PROSPERO) database, with the reference number CRD42024550923.

Eligibility Criteria

Our studies of interest included (I) the population of human subjects diagnosed with AIS, (II) the intervention of surgically treated curve correction with VBT, and (III) a study design of systematic review or meta-analysis. Exclusions were made for conference proceedings, commentaries, non-English articles, scoping reviews, study protocols, and preprints.

Information Sources

A systematic search was executed across 6 online databases. These databases included Academic Search Complete and CINAHL Plus through EBSCOhost, EMBASE and MEDLINE via Ovid, Cochrane Library, and the Web of Science. The data retrieval timeframe extended from the inception of the database up to June 4, 2024.

Search Strategy

Two generic keywords, “vertebral body tethering” AND “scoliosis”, were employed to identify potential papers across all databases. An unrestricted all-text search was conducted during the literature search process. Moreover, a forward citation search was carried out to obtain further pertinent articles.

Selection Process

Initially, the principal investigator eliminated duplicates manually and verified them with another investigator. Then, a screening followed, in which the titles and abstracts of studies were evaluated to ascertain their relevance to the research question. Finally, a full-text assessment took place, wherein the full texts of potentially relevant studies were procured and appraised against the inclusion and exclusion criteria. Articles fulfilling these criteria were chosen for the present review. Two independent reviewers conducted each screening stage, and discrepancies were resolved through discussion and consensus.

Data Collection Process

The JBI data extraction form for systematic reviews and research syntheses was adapted to collect data from each included study. Data extraction was systematically recorded to enable synthesis. Two members worked independently to gather all the data, and any discrepancies were solved by revisiting the paper to reach an agreement.

Data Items

Relevant data of AIS and VBT were extracted, encompassing the institution of origin, publishing journal, protocol registry, eligibility criteria, search details, sources searched, studies included, quality appraisal, and analytical methods. Additionally, statistical results from meta-analyses were acquired.

Study Risk of Bias Assessment

The JBI critical appraisal checklist for systematic reviews and research syntheses was used to assess the methodological quality of the included reviews. This checklist comprises 11 guiding questions for appraisal. Two evaluators independently examined all reviews, and discrepancies were addressed by jointly reviewing the paper to achieve a mutual understanding.

Synthesis Methods

We intended to present the data using a narrative synthesis. This approach summarized the findings of all studies, encompassing their essential characteristics and outcome measures. The respective results were articulated descriptively.

Results

From the 6 databases examined, 555 citations were identified, of which 259 were manually removed prior to screening. The remaining 296 records underwent title and abstract screening, leading to the exclusion of 271 articles. Following this, 25 reports were evaluated for eligibility, with 10 studies being neither systematic reviews nor meta-analyses and 4 not examining the intervention of interest. Consequently, 11 reviews were confirmed for inclusion in the current umbrella review.[20–30] A flow diagram illustrating the study selection process can be found in Figure 1.

The 11 reviews originated from researchers across the United States, Spain, Australia, the United Kingdom, Hong Kong, Germany, Italy, Finland, and China. These reviews were published between 2021 and 2024, predominantly in the European Spine Journal and Spine Deformity. Among them, only 4 registered their protocols in a publicly accessible database. Regarding primary study selection criteria (apart from patients with AIS and VBT surgery), 5 teams required a minimum follow-up duration of 2 years, 3 teams opted for at least 1 year, and the remaining 3 did not specify a limit. Moreover, 2 groups specifically focused on the main thoracic curve correction. Out of the included reviews, only 7 assessed the quality of their included studies. The characteristics of each review are detailed in Table 1.

As for the number of databases searched, 1, 4, 5, and 1 teams utilized 2, 3, 4, and 8 databases, respectively. The final study inclusions varied from 7 to 26. Collectively, the 11 reviews consisted of 189 studies. Among these, 28 VBT studies were featured in 2 or more reviews, 13 were individually included in a review, 23 focused solely on posterior spinal fusion, 6 were conference proceedings, and 3 involved patients with early onset scoliosis.

Of the 6 papers claiming to employ meta-analysis, 2 used inappropriate statistical tools. Mariscal et al[21] reported significant corrections in proximal and main thoracic curves 1 year post-operation (mean difference = −10.14°, $p < 0.001$; mean difference = −22.51°, $p < 0.001$) and in thoracolumbar or lumbar curves 2 years post-operation (mean difference = −12.16°, $p < 0.001$) among VBT patients. They also demonstrated significant improvements in rib hump (mean difference = −5.26°, $p < 0.001$), lumbar prominence (mean difference = −1.20°, $p = 0.01$), and health-related quality of life score assessed by the SRS-22r questionnaire (mean difference = 1.08, $p < 0.001$).[21] No significant changes were observed in thoracic kyphosis and lumbar lordosis.[21] Similarly, Roser et al[22] showed a statistically significant correction of the major curve in the main thoracic region (mean difference = −25.77°, $p < 0.01$). Zhu et al[29] found that 65% and 74% of subjects had a residual curve smaller than 35° at follow-ups of less than and more than 3 years, respectively. Furthermore, Shin et al[30] reported a pooled complication rate of 26%, while Zhu et al[29] documented a 24% complication rate at follow-ups of less than 3 years and 52% at follow-ups of more than 3 years. They also noted unplanned reoperation rates of 4% and 16% at follow-ups of less than and more than 3 years, respectively.[29] The comprehensive results of the individual meta-analyses are listed in Table 2.

Regarding quality assessment for the included reviews, 2 papers scored 10 out of 11 points, 1 paper achieved 8 points, another 2 papers obtained 7 points, 4 papers received 6 points, and 1 paper each garnered 5 and 3 points. Common pitfalls included inappropriate criteria for evaluating studies (64%), critical appraisal conducted by fewer than 2

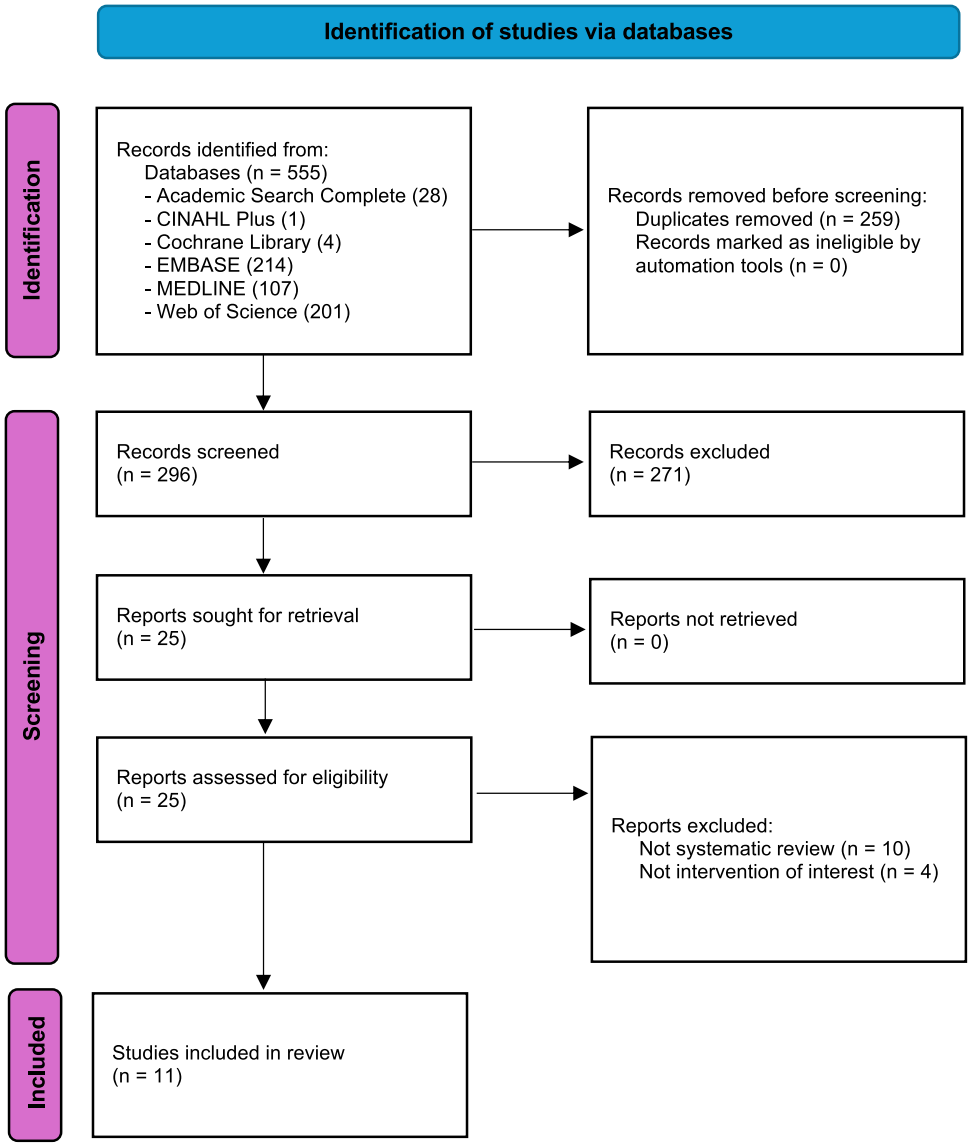

Figure 1 PRISMA flow diagram.

reviewers (36%), lack of methods to minimize errors in data extraction (27%), improper methods used to combine studies (36%), unassessed likelihood of publication bias (36%), and recommendations for practice unsupported by reported data (9%). A summary of the methodological quality of all reviews is depicted in Figure 2.

Discussion

Our umbrella review has thoroughly examined existing systematic reviews and meta-analyses on VBT among subjects with AIS. Many of these reviews have addressed similar topics, such as efficacy and complications. On the contrary, some individual reviews have explored the learning curve, skeletal maturity during surgery, and trunk range of motion. Meta-analysis results have revealed statistically significant improvements in radiographic outcomes in the coronal plane, clinical outcomes in the transverse plane, and patient-reported outcome measures. However, complication rates were as high as dissatisfaction levels. Methodological quality could benefit from stricter adherence to guidelines.

While VBT has clearly established its clinical efficacy in correcting coronal deformities, its influence on the sagittal and transverse planes appears minimal. Furthermore, it is associated with a higher complication rate compared to traditional spinal fusion procedures. Notwithstanding these concerns, the distinctive advantage of motion preservation

Table 1 Characteristics of the Included Systematic Reviews and Meta-Analyses

Included review	Institution of origin	Journal published	Protocol registry	Eligibility criteria	Search details	Sources searched	Studies included	Quality assessment	Methods of analysis
Alasadi et al,[20] 2024	Icahn School of Medicine at Mount Sinai, United States	Spine Deformity	No	- Follow-up > 2 years	vertebral body tether OR anterior vertebral body tether OR anterior vertebral tethering	- PubMed - Scopus - Web of Science	- Initial: 544 - Final: 26	No	Descriptive statistics
Mariscal et al,[21] 2023	La Fe University and Polytechnic Hospital of Valencia, Spain	European Spine Journal	No	- Follow-up > 1 year	(anterior vertebral tethering) AND (scoliosis)	- Cochrane Library - EMBASE - PubMed - Scopus	- Initial: NA - Final: 12	Risk of bias in non-randomised studies - of interventions	Meta-analysis, Review Manager version 5.4
Roser et al,[22] 2023	Queensland University of Technology, Australia	Spine Deformity	No	- Main thoracic curve only - Follow-up > 2 years	(vertebral body tethering) AND (adolescent idiopathic scoliosis)	- Cochrane Library - EMBASE - Google Scholar - PubMed	- Initial: 115 - Final: 19	National heart, lung, and blood institute quality assessment tool	Meta-analysis, R version 4.0.4
Vatkar et al[23] 2023	Nottingham University Hospitals, United Kingdom	European Spine Journal	No	- Follow-up > 2 years	(vertebral body tethering OR VBT OR growth modulation spine OR restrained differential growth) AND (scoliosis)	- EMBASE - MEDLINE - PubMed	- Initial: 259 - Final: 9	National institutes of health quality assessment tool	Meta-analysis, SPSS version 25.0
Wong et al,[24] 2023	University of Hong Kong, Hong Kong	European Spine Journal	Yes	- Outcome measures for range of motion	(adolescent idiopathic scoliosis) AND (tether OR anterior growth modulation OR anterior vertebral body growth modulation OR posterior spinal*) AND (range of motion OR flexibility OR mobility)	- Cochrane Library - EMBASE - MEDLINE - PubMed	- Initial: 493 - Final: 12	Scottish intercollegiate guidelines network	Descriptive statistics
Baroncini et al,[25] 2022	University Hospital Aachen, Germany	Zeitschrift für Orthopädie und Unfallchirurgie	No	- Follow-up > 1 year	(vertebral body tethering OR anterior vertebral growth modulation OR fusionless anterior scoliosis correction OR anterior scoliosis surgery) AND (scoliosis OR adolescent idiopathic scoliosis)	- EMBASE - Google Scholar - PubMed - Scopus	- Initial: 356 - Final: 9	Coleman methodology score	Meta-analysis, SPSS version 25.0

(*Continued*)

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Table 1 (Continued).

Included review	Institution of origin	Journal published	Protocol registry	Eligibility criteria	Search details	Sources searched	Studies included	Quality assessment	Methods of analysis
Bizzoca et al,[26] 2022	University of Bari Aldo Moro, Italy	World Journal of Orthopedics	Yes	- Follow-up > 2 years- Drop-out rate < 20%	(anterior vertebral body tethering OR tethering) AND (scoliosis) AND (growing spine OR growing child OR immature patients)	- Cochrane Library - EMBASE - Google Scholar - MEDLINE - PubMed - Springer Link - Scopus - Web of Science	- Initial: 396 - Final: 7	American Academy of orthopedic surgeons clinical practice guidelines and review methodology	Descriptive statistics
Raitio et al,[27] 2022	University of Helsinki, Finland	Journal of Clinical Medicine	No	- Follow-up > 1 year	vertebral body tethering	- EMBASE -PubMed	- Initial: 163 - Final: 20	No	Descriptive statistics
Zhang et al,[28] 2022	First Affiliated Hospital of Zhengzhou University, China	Spine Deformity	Yes	- No limits on duration of follow-up	(scoliosis) AND (vertebral body tethering OR anterior tethering OR VBT OR AVBT)	- EMBASE - PubMed - Web of Science	- Initial: 328 - Final: 25	No	Descriptive statistics
Zhu et al,[29] 2022	University of Hong Kong, Hong Kong	Journal of Orthopaedic Surgery	Yes	- Outcome measures for number of successful clinical treatments or complications or revision surgeries	(vertebral body tethering OR growth tethering OR growth modulation) AND (scoliosis)	- Cochrane Library - EMBASE - PubMed - Web of Science	- Initial: 984 - Final: 26	Modified methodological index for non-randomized studies	Meta-analysis, R version 4.1.0
Shin et al,[30] 2021	University of Pennsylvania, United States	Journal of Bone and Joint Surgery Open Access	No	- Selective thoracic fusion or Lenke 1 or 2 curves - Follow-up > 2 years	(anterior vertebral body tethering OR vertebral body tethering OR anterior vertebral body growth modulation OR anterior growth modulation OR anterior scoliosis correction) AND (spine)	- EMBASE - PubMed - Scopus	- Initial: 472 - Final: 24	No	Meta-analysis, Stata version 14.2

Table 2 Summary of Findings from Meta-Analyses

Included Review	Outcome Measure	Time Points	Pooled Results
Mariscal et al[21] 2023	Main thoracic curve correction	Pre-operation and follow-up of 1 year	Mean difference = −22.51°, $p < 0.001$, $I^2 = 89\%$
	Main thoracic curve correction	Follow-up of 1 year and 2 year	Mean difference = −0.33°, $p = 0.90$, $I^2 = 51\%$
	Proximal thoracic curve correction	Pre-operation and follow-up of 1 year	Mean difference = −10.14°, $p < 0.001$, $I^2 = 50\%$
	Proximal thoracic curve correction	Follow-up of 1 year and 2 year	Mean difference = −0.70°, $p = 0.71$, $I^2 = 39\%$
	Thoracolumbar/Lumbar curve correction	Pre-operation and follow-up of 1 year	Mean difference = −0.36°, $p = 0.90$, $I^2 = 0\%$
	Thoracolumbar/Lumbar curve correction	Follow-up of 1 year and 2 year	Mean difference = −12.16°, $p < 0.001$, $I^2 = 0\%$
	Thoracic kyphosis correction	Pre-operation and follow-up of 1 year	Mean difference = −0.29°, $p = 0.76$, $I^2 = 0\%$
	Thoracic kyphosis correction	Pre-operation and follow-up of 2 year	Mean difference = −1.04°, $p = 0.29$, $I^2 = 0\%$
	Lumbar lordosis correction	Pre-operation and follow-up of 1 year	Mean difference = −1.00°, $p = 0.40$, $I^2 = 21\%$
	Lumbar lordosis correction	Pre-operation and follow-up of 2 years	Mean difference = 0.19°, $p = 0.88$, $I^2 = 0\%$
	Rib hump correction	Pre-operation and final follow-up	Mean difference = −5.26°, $p < 0.001$, $I^2 = 0\%$
	Lumbar prominence correction	Pre-operation and final follow-up	Mean difference = −1.20°, $p = 0.01$, $I^2 = 0\%$
	Total SRS-22r score	Pre-operation and final follow-up	Mean difference = 1.08, $p < 0.001$, $I^2 = 99\%$
Roser et al,[22] 2023	Major curve of main thoracic correction	Pre-operation and final follow-up	Mean difference = −25.77°, $p < 0.01$, $I^2 = 89\%$
Vatkar et al,[23] 2023	Improper pooling of data	Improper pooling of data	Improper pooling of data
Baroncini et al,[25] 2022	Improper pooling of data	Improper pooling of data	Improper pooling of data
Zhu et al,[29] 2022	Residual curve of smaller than 35°	At follow-up more than 3 years	Proportion = 74%, confidence intervals = 69% to 79%, $I^2 = 20\%$
	Residual curve of smaller than 35°	At follow-up less than 3 years	Proportion = 65%, confidence intervals = 51% to 83%, $I^2 = 15\%$
	Unplanned reoperation rate	At follow-up more than 3 years	Proportion = 16%, confidence intervals = 13% to 20%, $I^2 = 6\%$
	Unplanned reoperation rate	At follow-up less than 3 years	Proportion = 4%, confidence intervals = 2% to 8%, $I^2 = 24\%$
	Complication rate	At follow-up more than 3 years	Proportion = 52%, confidence intervals = 34% to 71%, $I^2 = 96\%$
	Complication rate	At follow-up less than 3 years	Proportion = 24%, confidence intervals = 9% to 39%, $I^2 = 95\%$
Shin et al,[30] 2021	Complication rate	At final follow-up	Proportion = 26%, confidence intervals = 12% to 40%, $I^2 = 86\%$

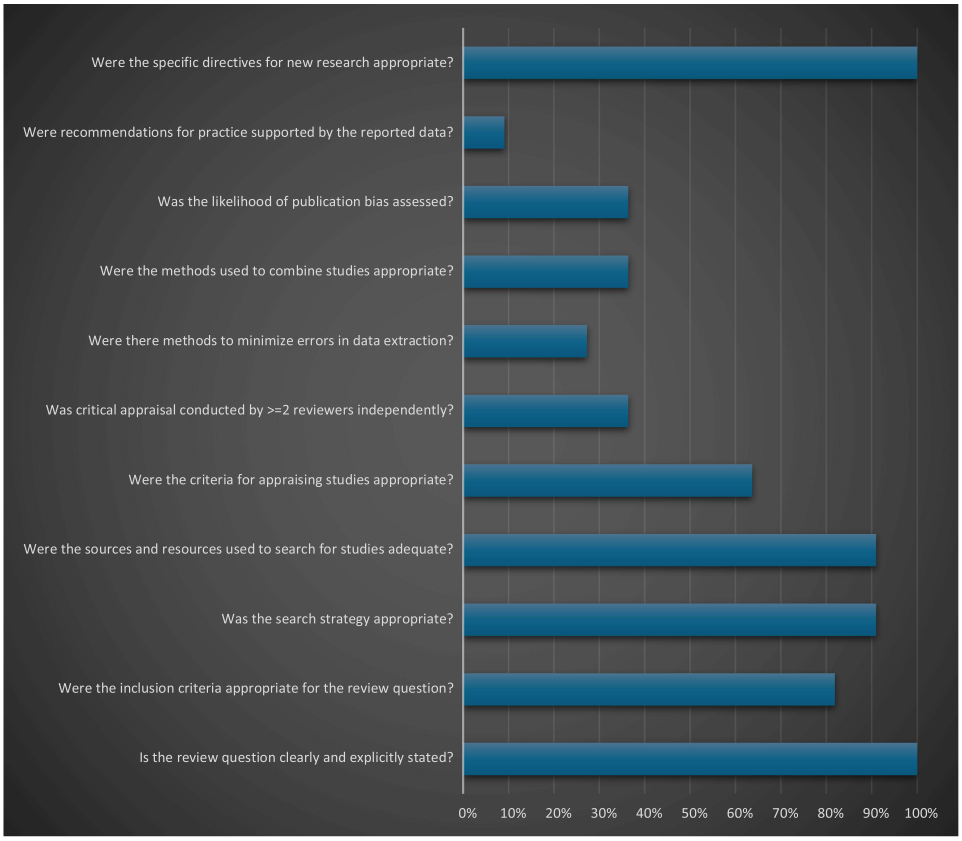

Figure 2 Overall methodological quality.

and the potential for accommodating growth should be discussed with patients and families for consideration. Careful weighing should be done by balancing the possible risks (eg, tether breakage and reoperation) against the benefits of VBT compared to conventional surgical techniques. A novel variation of VBT is anticipated to address the currently recognized limitations effectively.

Although the included meta-analyses have presented promising results, several concerns warrant attention. Notably, while the pooled data demonstrated significantly reduced Cobb angles following VBT, these were only drawn from 2 to 4 papers. Even though improvements were observed in the angles of thoracic and lumbar rotation and quality of life, these differences do not seem to exceed the minimal clinically significant difference. Intriguingly, no positive results were found for sagittal parameters. Despite the impossibility of making a direct comparison, the complication rates of VBT appeared to be relatively higher than those of spinal fusion. Several factors should be considered when interpreting these results. First, researchers should standardize the duration of follow-up across studies to facilitate appropriate comparisons. A few included reviews did not follow this essential concept, having distinct follow-up durations. Unless the judgment is based on skeletal maturity, the same follow-up duration should be applied across studies. Second, none of the comparisons have been made with the traditional spinal fusion procedure. As a result, patients and their families may still be uncertain about which surgery to opt for.

Most included reviews are generally above average in terms of methodological quality. However, improvements can be made by addressing the following items. In addition to the negative impact of not appraising the included studies, researchers should conduct critical appraisals with 2 or more individuals to minimize bias and errors. The same approach should be applied to the data extraction process. Furthermore, if researchers aim to inform clinicians about treatments, meta-analyses should be conducted to pool all available data, thereby supporting recommendations for clinical practice.

One motivation behind conducting this umbrella review was the observation that several review papers on VBT in the literature tended to overlap. Within merely 3 years, 11 systematic reviews (plus a few more narrative reviews) have

emerged, covering more or less the same topics. A possible reason for this could be that most did not register their review protocol, leading to a lack of awareness or recognition of previous reviews. Another consideration is that numerous reviews have limited their eligibility criteria to follow-up durations of 1 or 2 years. Although long-term outcomes are highly desirable, short-term outcomes should also be included to provide a comprehensive picture of longitudinal changes. Furthermore, some reviews attempted to evaluate specific curve patterns. For review purposes, researchers may initially adopt a broader inclusion of studies and then perform subgroup analyses to examine particular factors of interest. Additionally, several reviews did not assess the methodological quality of their included studies, which could affect the generalizability of the results and potentially decrease the quality of future research.

Despite advances in VBT, several knowledge gaps persist that necessitate further investigation. Given that VBT is an emerging procedure, comprehensive data on its long-term effects is limited. Ongoing research should focus on evaluating its long-term efficacy and complication profiles, particularly concerning spinal growth dynamics. Determining the ideal patient demographics for VBT continues to be a critical research area. While current recommendations suggest VBT for skeletally immature patients with moderate scoliosis, future studies should aim to refine these guidelines, for instance, by identifying the optimal curvature patterns. A lack of consensus exists regarding the clinical ramifications of tether breakage, a recognized complication of VBT. Clarifying the incidence, mechanism, and management of this issue is essential. Furthermore, comparative studies are warranted to assess VBT against traditional scoliosis treatments such as bracing and spinal fusion. These analyses should encompass assessments of efficacy, safety, cost-effectiveness, and ideal timing for surgical intervention. Variability in surgical technique execution is another challenge that needs to be addressed. Future investigations should aim to standardize VBT procedures and establish the most effective surgical approaches. Additionally, there is insufficient data on the reoperation rates following VBT and the associated factors that could prompt subsequent surgical interventions. To bridge these gaps in knowledge, it is imperative to conduct more comprehensive research, including long-term follow-up studies and thorough data collection on patient-reported outcomes.

The following further research directions are recommended. Machine learning algorithms and artificial intelligence could be explored to analyze patient data and identify potential candidates for VBT, thereby streamlining patient selection and improving treatment outcomes. Research into integrating virtual reality (VR) and augmented reality (AR) tools in surgical planning and training could allow surgeons to visualize and practice the VBT procedure in a virtual environment before performing it on patients, thus minimizing the learning curve. Investigating optimal tether material and design could minimize the risk of tether breakage and enhance the overall success of the procedure. The potential of 3D printing technology to create customized implants and anchors for VBT could be explored, which may provide a more precise fit and potentially improve surgical outcomes. It would also be interesting to collectively evaluate three-dimensional parameters of the spine to reflect a comprehensive picture of scoliosis correction resulting from VBT. Research on best postoperative care and rehabilitation practices could optimize recovery and outcomes following VBT. Using wearable devices and sensors to monitor postoperative recovery and spinal alignment in real time could improve patient follow-up and potentially enable early intervention in case of complications. These ideas have the potential to advance our understanding of VBT and contribute to the ongoing development of this promising treatment option for the scoliosis population.

The following research directions are proposed to enhance the application of VBT. Firstly, the utilization of machine learning algorithms and artificial intelligence is recommended to conduct thorough analyses of patient data, facilitating the identification of optimal candidates. This approach could streamline the patient selection process and improve overall treatment outcomes. Additionally, investigating the application of virtual reality (VR) and augmented reality (AR) technologies in surgical planning and training represents a promising avenue. Such tools could allow surgeons to simulate the VBT procedure in a controlled virtual environment, thereby reducing the learning curve and enhancing procedural accuracy prior to actual patient surgeries. A comprehensive evaluation of the three-dimensional parameters of the spine is also essential to fully elucidate the mechanics of scoliosis correction achieved through VBT.

The limitations of the current umbrella review can be delineated as follows. Due to its inherent design, several pertinent studies on VBT were inevitably excluded from the synthesis. The exclusion of non-English literature may have introduced language bias, potentially omitted relevant research, and constrained the generalizability of the results.

Furthermore, this review utilized a narrative synthesis approach, which may not effectively quantify the impact of VBT on AIS. Additionally, the included reviews demonstrated variability in methodological rigor, with some receiving low methodological scores, thus raising concerns regarding the overall reliability of the findings.

Conclusions

This umbrella review provides a comprehensive synthesis of existing systematic reviews and meta-analyses regarding VBT as a treatment modality for AIS. The findings revealed notable improvements in coronal plane radiographic outcomes, transverse plane clinical results, and overall health-related quality of life metrics. Nonetheless, the rates of complications associated with the procedure remain a significant concern. The methodological quality of the included reviews exhibited considerable variability, highlighting an urgent need for more stringent research methods in this field. Despite the encouraging findings, several critical knowledge gaps and methodological limitations have been identified, reinforcing the necessity for further investigations. Future research should prioritize long-term outcomes, patient selection criteria, standardization of surgical techniques, and comparative analyses with conventional treatment modalities.

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Disclosure

The authors report no conflicts of interest in this work.

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