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Radiographic Changes in Spinal Alignment Associated with a Dynamic Postural Support System: A Retrospective Clinical Cohort Study

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Additional Declarations: Competing interest reported. Pham Loan is the founder and director of DOCTORLOAN Clinic and is the developer and patent holder of the investigated postural support system. Robert Radics declares that he has no competing interests.

Abstract

Background

Spinal deformities such as scoliosis, abnormal sagittal alignment, and altered regional curvatures contribute to functional impairment and reduced quality of life. While surgical correction remains effective for severe cases, substantial challenges and high complication rates in traditional surgical methods drive the increasing exploration of conservative and non-invasive approaches. Dynamic postural support systems aim to induce spinal realignment through continuous adaptive biomechanical loading rather than rigid immobilization; however, robust radiographic evidence from real-world clinical cohorts remains limited.

Objective

To evaluate radiographic changes in global and regional spinal alignment associated with the clinical use of a non-invasive dynamic postural support system using paired pre–post radiographic data.

Methods

A retrospective paired pre–post analysis was conducted using anonymized radiographic data from 330 patients treated under routine clinical conditions. Outcomes included standardized measurements of Cobb angle, sagittal alignment, cervical curvature, and lumbar curvature. Analyses were performed on a pairwise-complete basis per parameter. Statistical testing employed paired t-tests or Wilcoxon signed-rank tests as appropriate. Individual-level consistency was examined using boxplots, spaghetti plots, and pre–post scatterplots.

Results

Across all analyzed parameters, post-treatment values shifted toward improved physiological alignment. Mean Cobb angle decreased by 2.01° (N = 189), sagittal alignment increased by 9.60° (N = 96), cervical curvature increased by 13.14° (N = 51), and lumbar curvature increased by 11.35° (N = 41). Visual analyses demonstrated consistent directional change across individuals despite heterogeneous baseline presentation.

Conclusions

In a large real-world clinical cohort, non-invasive dynamic postural support was associated with consistent radiographic improvement in spinal alignment. However, prospective controlled studies are required to establish causality and long-term clinical effectiveness.

Introduction

Spinal deformities represent a critical clinical and socioeconomic challenge, contributing to chronic pain, significant functional disability, and diminished quality of life(Franceschini et al., 2025; Kyrölä et al., 2022). In the United States alone, the annual economic burden of low back and neck pain is estimated at $134.5 billion(Manchikanti, 2020), with back pain serving as a primary cause of years lived with disability globally(Wu et al., 2020). Adult spinal deformity is now recognized as having one of the highest disease burdens among common long-term disorders, with disability levels directly correlating to the severity of sagittal and coronal imbalance(Kieser et al., 2021). These conditions disrupt fundamental biomechanical stability and postural symmetry, often precipitating a cycle of progressive neuromuscular decline and compensatory strain(Bae et al., 2021). The multifaceted etiology of spinal deformities, encompassing congenital, degenerative, and idiopathic factors, underscores the complexity of their clinical management and the critical need for effective intervention strategies(Chan et al., 2021).

Historically, management strategies for spinal deformity have relied on surgical correction for severe cases or static bracing and physiotherapy for milder presentations(Kotwicki et al., 2013). However, surgical interventions for ASD are associated with high complication rates, reaching up to 55% in some cohorts(Scheer et al., 2023), and significant healthcare costs(Christiansen et al., 2016). Conversely, traditional rigid bracing is often limited by poor patient adherence(Li et al., 2022) and the risk of muscle atrophy or accelerated degeneration due to forced immobilization(Lim et al., 2024); evidence suggests that conservative treatments often yield indeterminate results, as they frequently fail to target the global postural imbalance that drives symptomatic progression(Mizutani et al., 2024). This highlights a significant gap in treatment modalities that effectively address the underlying biomechanical dysregulation without necessitating invasive procedures(Mizutani et al., 2024).

In response to these limitations, dynamic postural support systems have emerged as a non-invasive alternative designed to promote realignment through continuous, adaptive biomechanical loading. Unlike rigid constraints, these systems leverage proprioceptive feedback to modulate postural control and optimize musculoskeletal function (Bouisset et al., 2022). Research indicates that restoring sagittal alignment can significantly improve neurophysiological function and sensorimotor control by optimizing the relationship between the spinal column and the nervous system (Oakley et al., 2021). By providing enhanced proprioceptive input, dynamic devices may assist patients in perceiving their spinal position, which could influence muscle activity and spinal loading. This approach moves beyond the limitations of conventional rigid orthoses, which, despite their efficacy in preventing curve progression in conditions like adolescent idiopathic scoliosis when worn consistently, often lead to discomfort, skin breakdown, and potential bone deformation due to prolonged static pressure and restricted movement (Ali et al., 2020).

Dynamic postural support systems differ conceptually from rigid immobilization approaches by aiming to facilitate adaptive spinal realignment through sustained low-load biomechanical guidance rather than static fixation. Proposed mechanisms described in the rehabilitation and sagittal alignment literature

include altered proprioceptive input, redistribution of mechanical loading, and progressive neuromuscular adaptation associated with prolonged physiological positioning. This dynamic intervention contrasts with traditional rigid spinal stabilization systems, which, while effective in achieving segmental fusion, can impose significant mechanical stress on adjacent segments, potentially leading to degenerative changes and persistent pain (Akgün et al., 2025).

Unlike passive support systems, dynamic corrective approaches may encourage active postural engagement while simultaneously applying gentle body-weight-assisted counterforces to promote sagittal restoration. This active engagement, facilitated by continuous proprioceptive feedback, enables gradual, adaptive changes in spinal alignment and muscular recruitment patterns (Li et al., 2025).

Despite these theoretical advantages, systematic radiographic evidence of anatomical change in real-world clinical cohorts remains sparse (Moustafa et al., 2022). The present study evaluates the **DOCTORLOAN patented postural support system**, which uses a cervical pillow with a calibrated rigid core and specialized sitting and reclining chairs. These devices are designed to generate controlled counterforces using the user's own body weight to guide the spine toward physiological alignment.

This study aims to contribute additional real-world radiographic evidence regarding spinal alignment changes associated with dynamic postural support interventions in routine clinical practice.

Our analysis of 330 patients suggests that this dynamic approach is associated with quantifiable spinal realignment across both global and regional parameters. Key findings include a mean reduction in Cobb angle of 2.01°, a 9.60° improvement in global sagittal alignment, and substantial increases in regional lordosis, with cervical curvature improving by 13.15° and lumbar curvature by 11.35°. This study seeks to bridge the gap between biomechanical theory and clinical radiographic outcomes by providing additional observational evidence on the magnitude of anatomical response to dynamic corrective loading in a routine clinical setting.

Research Goals and Hypotheses

Research Goals

Exploratory Objective: To evaluate whether radiographic changes demonstrate directional consistency across patients within the cohort.

1 **Quantify changes** in coronal deformity and global sagittal alignment using paired pre- and post-treatment radiographic data.

2 **Assess the restoration of regional curvatures, specifically cervical and lumbar lordosis, following standardized clinical application of the support system.**

3 **Establish external validity by determining the consistency of individual**-level responses across a large, heterogeneous routine clinical cohort (Perna et al., 2021).

Hypotheses

● **Primary Hypothesis (H_1)**: Consistent use of the dynamic postural support system will result in statistically significant improvements in regional sagittal curvatures (cervical and lumbar lordosis) toward normative physiological alignment.

● **Secondary Hypothesis (H_2)**: Dynamic corrective loading through body-weight counterforces will be associated with a measurable reduction in global coronal deformity as measured by the Cobb angle across diverse baseline presentations.

● **Mechanistic Hypothesis (H_3)**: The observed spinal realignment will demonstrate a high degree of directional consistency across the cohort, supporting the presence of directional consistency across the cohort.

Methods

Study Design and Setting

This study utilized a retrospective, observational cohort design to evaluate radiographic changes in patients undergoing treatment with a dynamic postural support system. Data were extracted from a routine clinical registry of 330 patients treated between 2023 and 2025. The study was designed and reported in accordance with STROBE recommendations for observational cohort studies. The retrospective nature of this study, similar to other investigations into spinal pathologies (Skaggs et al., 2020), allows for the analysis of existing clinical records to identify patterns and outcomes associated with the intervention(Guo et al., 2020).

Participants

The study cohort consisted of 330 adult and pediatric patients with documented spinal malalignment who sought conservative treatment.

● **Inclusion Criteria**: Baseline radiographic diagnosis of spinal deformity, defined as a Cobb angle > 10° or a significant deviation from normative sagittal parameters; completion of at least one follow-up radiographic assessment following intervention; and documented clinical utilization of the prescribed support protocol based on routine clinical records.

● **Exclusion Criteria**: Patients were excluded if they had a history of spinal fusion surgery, acute spinal fractures, active spinal malignancies, or neuromuscular conditions (e.g., Duchenne muscular dystrophy) that would preclude the use of body-weight-based corrective forces.

The resulting dataset represents a heterogeneous "real-world" population, which is increasingly recognized as essential for obtaining meaningful results in musculoskeletal modeling and clinical outcomes research(Fernandez et al., 2020). This inclusive approach aimed to capture a representative

sample of patients presenting with diverse forms of postural imbalance and non-structural postural deformities(Kim et al., 2022).

Intervention

The intervention centered on **a commercially available dynamic postural support system**, a non-invasive approach designed to induce spinal realignment through dynamic corrective loading. The system comprises two primary components:

1 **Cervical Support**: A specialized pillow with a calibrated rigid core designed to facilitate the restoration of cervical lordosis through controlled extension and gravity-assisted loading(Moustafa et al., 2021).

2 **Dynamic Seating/Reclining**: Specialized chairs engineered to utilize the user's own body weight as a corrective counterforce. By positioning the apex of the spinal deformity against the system's support structures, a persistent but gentle corrective pressure is applied to guide the spine toward its physiological neutral position. The intervention differs from rigid immobilization approaches by applying sustained low-intensity support forces during seated or reclining positioning(Ali et al., 2020).

The intervention was designed to utilize the patient's own body weight and gravitational loading as components of the corrective biomechanical stimulus. Rather than rigid external immobilization, the system applies sustained low-intensity counterforces through anatomically contoured support surfaces intended to encourage gradual postural adaptation and restoration toward physiological alignment. This approach is conceptually consistent with adaptive biomechanical responses to sustained low-intensity loading described in musculoskeletal literature(Warden & Thompson, 2017). The sustained corrective forces were meticulously calibrated to ensure patient comfort and adherence, while simultaneously providing an effective biomechanical stimulus for spinal remodeling. This includes addressing decreased disc height and promoting cervical lordosis restoration, which are important for alleviating chronic neck pain and disability(Katz et al., 2026; Meng et al., 2017).

This conceptual framework is broadly consistent with mechanobiological principles underlying adaptive responses to sustained loading in musculoskeletal tissues(Kim, 2026). This dynamic approach also differentiates it from passive orthotic devices by integrating active patient engagement in the corrective process(Igawa et al., 2023). This method aims to leverage the body's natural restorative capabilities, aligning with contemporary conservative approaches that focus on restoring normal sagittal plane alignment (Moustafa et al., 2024).

Unlike rigid immobilization approaches, the system was designed to provide sustained low-intensity support forces during seated or reclining positioning. Patients were instructed to use the system for standardized intervals of approximately 45–60 minutes daily.

Imaging and Measurement

Standardized full-spine standing radiographs were obtained at baseline and at follow-up intervals. All images were analyzed using validated medical imaging software to ensure measurement precision.

● **Coronal Deformity**: The **Cobb method** was used to quantify the degree of scoliosis or coronal tilt, identifying the most tilted vertebrae at the cranial and caudal ends of the curve(El-Fiky et al., 2020).

● **Sagittal Parameters**: Global and regional sagittal alignments were measured using the **Harrison Posterior Tangent Method**. This method has demonstrated superior reliability and a lower standard error of measurement compared to traditional four-line Cobb methods, particularly in the assessment of regional lordosis(Katz et al., 2019).

● **Regional Curvatures**: Cervical lordosis was defined as the angle between the lines tangent to the posterior aspect of the C2 and C7 vertebral bodies (Katz et al., 2019). Lumbar lordosis was measured from the superior endplate of L1 to the superior endplate of S1.

Statistical Analysis

Change scores (post–pre) were assessed for distributional characteristics. Paired t-tests were utilized for parameters meeting normality assumptions, while Wilcoxon signed-rank tests were applied to non-parametric data. Statistical significance was evaluated at $\alpha = 0.05$. Given the large sample size and the retrospective nature of the study, interpretive emphasis was placed on the magnitude and directional consistency of change rather than p-values alone(Nakagawa et al., 2017).

Individual-level response patterns were visualized using spaghetti plots to connect paired observations and scatterplots to compare pre- and post-treatment values against identity lines, helping to distinguish systematic treatment effects from random variation. Primary analyses focused on paired pre–post comparisons of radiographic parameters. Descriptive visualization techniques were additionally used to assess directional consistency across individuals.

Results

Descriptive Statistics

Baseline and post-treatment radiographic parameters were evaluated using paired analyses for patients with complete pre–post imaging data available for each parameter. Descriptive statistics for the primary radiographic outcomes are presented in Table 1.

The normality of the data was verified using the Shapiro-Wilk test, and subsequent comparisons between pre-operative, post-operative, and follow-up measurements were conducted using either Student's paired t-test or the Wilcoxon signed-rank test, contingent upon the outcome of the normality assessment (Langlais, 2022).

Table 1
Descriptive Summary of Radiographic Parameters

Parameter	N	Pre-Treatment Mean (°)	Post-Treatment Mean (°)	Mean Change (Δ)
Cobb Angle	189	14.96	12.95	-2.01
Sagittal Alignment	96	18.32	27.92	$+9.60$
Cervical Curvature	51	9.56	22.71	$+13.15$
Lumbar Curvature	41	31.45	42.80	$+11.35$

Note: Negative values indicate a reduction in coronal deformity, while positive values indicate an increase toward physiological sagittal curvature profiles.

Evidence Addressing Primary Hypothesis (H_1): Regional Sagittal Curvature

The primary hypothesis predicted significant improvements in regional sagittal curvatures. The data strongly support this:

● **Cervical Lordosis**: Among 51 patients, mean curvature increased by **13.15°**. This shift represents directional movement toward more physiological sagittal alignment profiles. Similarly, the observed mean increase of 11.35° in lumbar lordosis across 41 patients further substantiates the efficacy of the intervention in restoring more favorable sagittal alignment. These findings highlight the intervention's capacity to induce favorable alterations in spinal alignment beyond coronal plane correction alone, emphasizing its holistic impact on spinal biomechanics. The mean increase in sagittal alignment of 9.60° across 96 patients further underscores the comprehensive impact of the treatment on overall spinal posture, extending beyond localized changes, promoting a more balanced spinal equilibrium.

● **Lumbar Lordosis**: Among 41 patients, mean curvature increased by **11.35°**. This finding is particularly relevant due to the established link between adequate lumbar lordosis and spinal biomechanical efficiency and load distribution. The comprehensive improvements in lumbar lordosis, alongside reductions in Cobb angles, highlight a holistic, positive impact on spinal alignment. This comprehensive sagittal plane correction is critical, as aberrations in sagittal alignment are increasingly recognized as determinants of treatment outcomes and quality of life in adolescent idiopathic scoliosis (Wang et al., 2022). The improvement in sagittal parameters is crucial, especially considering that a negative impact on the sagittal profile for C7 and SI has been noted in some complete conservative treatments, even with significant reductions in Cobb degrees(Negrini et al., 2009). Conversely, the progressive reduction of lumbar hyperlordosis and associated forward thoracic translation has been documented to correlate with symptomatic relief in pediatric patients (Kallan et al., 2022).

The magnitude of the observed sagittal changes exceeded the magnitude of coronal changes within this cohort, suggesting that sagittal parameters may respond differently to dynamic postural support interventions.

Evidence Addressing Secondary Hypothesis (H_2): Global Coronal Deformity

The secondary hypothesis predicted a measurable reduction in the Cobb angle.

● The mean Cobb angle decreased from 14.96° to 12.95°, corresponding to a mean paired reduction of 2.01°. While smaller in magnitude than the sagittal changes, this reduction was directionally consistent across a large population, supporting the system's ability to modulate coronal deformity. It is noteworthy that other studies have documented a more pronounced reduction in Cobb angles, with some reporting in-brace corrections exceeding 70%(Guy et al., 2024). This disparity in Cobb angle reduction might be attributable to variations in brace design, patient population characteristics, or the specific biomechanical principles employed in different corrective systems.

Evidence Addressing Mechanistic Hypothesis (H_3): Systematic Biomechanical Effect

The study sought to determine if these changes represented a systematic effect rather than random variation.

● **Directional Consistency**: Visualization through spaghetti plots confirmed that the majority of patients across all parameters moved toward normative alignment. This consistent directional change, observed across a large cohort, suggests a consistent radiographic response. This finding is further corroborated by evidence that specific brace designs can substantially reduce both thoracic kyphosis and lumbar lordosis, with immediate significant reductions observed in both sagittal parameters after bracing(Fan et al., 2024), although the ultimate impact on sagittal alignment can vary with brace characteristics and duration of wear. This systematic biomechanical influence is also reflected in the immediate in-brace correction of the Cobb angle, which has been shown to be a reliable prognostic factor for the effectiveness of brace treatment and a significant factor for predicting positive long-term outcomes(Razeghinezhad et al., 2021).

● **Scatterplot Analysis**: Specifically, researchers observed enhancements in lumbar lordosis and pelvic tilt under conditions incorporating resistive force orthoses, indicating a functional biomechanical adjustment to the imposed external forces. However, it is crucial to consider that while bracing has demonstrated significant coronal plane correction, a satisfactory apical vertebral derotation rate has been observed immediately after bracing, indicating a positive impact on the axial plane, particularly (Fan et al., 2024). This highlights the complex, multi-planar nature of scoliosis correction and the need for brace designs that can address all three planes of deformity effectively, often through individualized and active corrective strategies.

Discussion

Principal Findings

The central finding of this study is that a non-invasive, dynamic postural support system was associated with quantifiable radiographic changes in spinal alignment. Specifically, the observed improvements in both coronal and sagittal plane parameters, as evidenced by reductions in Cobb angle and enhancements in cervical and lumbar lordosis, suggest that the intervention was associated with multidimensional radiographic changes. These radiographic changes align with contemporary bracing philosophies that advocate for active, patient-oriented strategies to address the complex biomechanics of adolescent idiopathic scoliosis.

The most pronounced improvements were observed in regional sagittal parameters—cervical and lumbar lordosis—both of which exceeded 11°. These findings are of high clinical relevance, as sagittal imbalance is more strongly correlated with disability and poor health-related quality of life than coronal deformity alone(Scheer et al., 2023). This emphasis on sagittal plane correction aligns with contemporary understanding that optimal sagittal alignment is paramount for biomechanical efficiency and long-term spinal health.

The substantial increase in lumbar lordosis is particularly noteworthy, given that other interventional approaches, such as surgical corrections for adolescent idiopathic scoliosis, have been observed to result in an undesirable loss of lumbar lordosis below instrumented levels(Chilakapati et al., 2023). In contrast, the present study's findings suggest a favorable impact on lumbar lordosis, which is crucial for maintaining spinal balance and reducing compensatory mechanisms(Cheung, 2020).

Comparison with Traditional Bracing and Dynamic Alternatives

Our results offer a compelling alternative to traditional rigid bracing. While rigid braces are effective at "holding" a curve, they often lead to reduced quality of life and poor long-term adherence(Li et al., 2022). In contrast, the DOCTORLOAN system was associated with directional radiographic change. This included an observed 2.01° reduction in Cobb angle. However, our findings distinguish themselves by documenting significant restoration of sagittal lordosis, a parameter routinely studied in scoliosis-focused bracing protocols(Fan et al., 2024). Furthermore, the documented improvement in sagittal plane alignment, particularly lumbar lordosis, is critical given its established correlation with overall spinal balance and patient comfort, underscoring the potential clinical relevance of this dynamic approach(Wang & Sun, 2019). This is particularly significant given that conventional rigid braces, while effective in the coronal plane, frequently fail to adequately address sagittal plane deformities, and can lead to flatback syndrome(Guan et al., 2020).

Neurophysiological and Mechanistic Implications

Previous rehabilitation literature has proposed several possible mechanisms that may contribute to postural adaptation, including altered proprioceptive input, modified muscular recruitment patterns, and

redistribution of spinal loading. However, these mechanisms were not directly evaluated in the present study and therefore remain speculative.

Restoring normal sagittal configuration has been shown to reduce mechanical tension on the spinal cord and improve neurophysiological function(Koeppen et al., 2017). The 13.15° improvement in cervical lordosis is particularly noteworthy; cervical malalignment is increasingly recognized as being associated with chronic neck pain(Lee et al., 2025). This suggests that the system's ability to positively influence both coronal and sagittal parameters could offer a more comprehensive therapeutic approach compared to interventions focusing solely on coronal plane correction (Sohn et al., 2021). The pronounced changes observed in sagittal parameters may be clinically important because sagittal alignment has been increasingly associated with functional status, energy expenditure, spinal loading efficiency, and health-related quality of life(Cirillo et al., 2021). Restoration of more physiological cervical and lumbar curvature profiles may therefore have implications that extend beyond radiographic appearance alone, although the current investigation did not evaluate functional outcomes. However, given the documented correlation between improved spinal alignment and better functional outcomes in other studies, future research should integrate validated patient-reported outcome measures and functional assessments to more fully evaluate the broader impact of this dynamic intervention. Such investigations would be crucial to substantiating the long-term clinical utility and patient benefits of this innovative scoliosis treatment. It is imperative that future studies also rigorously evaluate potential improvements in spinal compressive forces and overall spinal loading efficiency, particularly considering the biomechanical advantages of dynamic bracing in modulating vertebral growth through the Hueter-Volkmann law (Shen et al., 2024).

This active proprioceptive retraining may therefore promote sustained postural correction and reduce neurological sequelae(Aman et al., 2015). Moreover, the continuous corrective tension provided by the bracing system, configured to pull or apply tension to the patient in a unique corrective movement, may contribute to adaptive postural responses, leading to gradual improvements in spine alignment and posture (Oakley, 2018).

Clinical and Methodological Implications

For clinicians, these data suggest that dynamic loading via body weight can be a viable component of conservative management for spinal deformities. The use of a routine clinical registry can provide a level of "real-world" evidence that is often absent from smaller, idealized pilot studies. The findings suggest that dynamic postural support systems may warrant further investigation as adjunctive conservative management approaches for selected patients with spinal malalignment. Furthermore, the observed reductions in Cobb angle, although modest, underscore the potential for simultaneous coronal plane correction associated with non-invasive bracing (Coillard et al., 2008). This comprehensive approach offers significant potential for enhancing long-term clinical outcomes in adolescent idiopathic scoliosis. The dose-response effect of brace-wearing time on treatment outcomes observed in other studies further supports the need for consistent, long-duration application of corrective forces in AIS management (Négrini et al., 2025).

Limitations and Future Directions

This study is limited by its retrospective nature and the absence of a randomized control group. While the large sample size and within-subject consistency provide robust evidence of an association, we cannot definitively rule out the influence of concurrent therapies. Additionally, while immediate and short-term radiographic changes are documented, long-term longitudinal data (e.g., 2–5 years) are necessary to confirm the permanence of these realignments and their impact on long-term clinical outcomes. Future research should incorporate patient-reported outcome measures to correlate these radiographic improvements with changes in pain and functional capacity, as spinal imbalance has been shown to affect patient function and quality of life (Kieser et al., 2021).

Several limitations should be acknowledged. First, the retrospective observational design limits causal inference. Second, the absence of a control group prevents differentiation between intervention-associated change and natural variation or concurrent therapies. Third, the study evaluated radiographic parameters only and did not include pain, functional outcomes, quality-of-life, or long-term follow-up outcomes. Finally, compliance with device utilisation was based on routine clinical documentation rather than objective monitoring.

Declarations

Ethics approval and consent to participate

This retrospective observational study utilised anonymised radiographic and clinical data collected during routine clinical practice at DOCTORLOAN Clinic, Ho Chi Minh City, Vietnam. Only participants who had provided written informed consent for participation in the research study were included in the analysed dataset.

Participants were informed that anonymised clinical and radiographic data could be used for scientific research, publication in scientific journals, conference presentations, and educational purposes. All data were anonymised before analysis, and the authors conducting the statistical analysis did not have access to personally identifiable patient information.

Ethical oversight for participant consent, data governance, anonymisation procedures, and release of the retrospective research dataset for the purposes of this study was conducted through the Hội đồng Đạo đức trong nghiên cứu y sinh học cấp cơ sở (Institutional Biomedical Research Ethics Committee) of Phòng khám Nội tổng hợp thuộc Hộ kinh doanh Phòng khám Chuyên khoa Cột sống Đức Phúc DOCTORLOAN, Ho Chi Minh City, Vietnam, established pursuant to Decision No. 00065/2025/DPDL-1 dated 31 October 2025.

The study was conducted in accordance with the ethical principles for medical research involving human participants as outlined in the Declaration of Helsinki.

Consent for publication

Not applicable. The manuscript does not contain identifiable individual participant data.

Availability of data and materials

The datasets generated and/or analyzed during the current study are not publicly available due to clinical confidentiality considerations but may be available from the corresponding author on reasonable request and subject to ethical and privacy considerations.

This retrospective observational study utilized anonymized radiographic and clinical data collected during routine clinical practice. Only participants who had provided consent for inclusion in the retrospective research dataset were included in the analysis. The dataset was anonymized prior to transfer for statistical analysis and manuscript preparation, and the authors did not access personally identifiable patient information. Ethical oversight for the retrospective clinical data review process was coordinated through a collaborating medical ethics structure in Ho Chi Minh City, Vietnam.

Competing interests

Pham Loan is the founder and director of DOCTORLOAN Clinic and is the developer and patent holder of the investigated postural support system. Robert Radics declares that he has no competing interests.

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The study received no external funding.

Authors’ contributions

Robert Radics contributed study design, methodological framework development, statistical analysis, interpretation of findings, and manuscript preparation.

Pham Loan contributed clinical treatment oversight, participant consent coordination, radiographic data acquisition, and clinical interpretation.

Both authors reviewed and approved the final manuscript.

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Authors’ information

Robert Radics, PhD, is a researcher and academic affiliated with Lincoln University, New Zealand, with expertise in quantitative analysis, systems research, and applied observational studies.

Pham Loan is a clinician involved in conservative spinal and postural rehabilitation practice in Vietnam.

References

1. Akgün MY, Savasci M, Durmus N, Günerbüyük C, Öktenoğlu T, Ateş Ö, Özer AF. Evaluating the performance of a novel double-threaded dynamic stabilization system: a finite element study. J Orthop Surg Res. 2025;20(1). https://doi.org/10.1186/s13018-025-06130-2.
2. Ali A, Fontanari V, Fontana M, Schmölz W. Spinal Deformities and Advancement in Corrective Orthoses. Bioengineering. 2020;8(1):2–2. https://doi.org/10.3390/bioengineering8010002.
3. Aman JE, Elangovan N, Yeh I-L, Konczak J. The effectiveness of proprioceptive training for improving motor function: a systematic review [Review of *The effectiveness of proprioceptive training for improving motor function: a systematic review*]. Frontiers Hum Neuroscience 8 Front Media. 2015. https://doi.org/10.3389/fnhum.2014.01075.
4. Bae J, Sathe A, Lee S-M, Theologis AA, Deviren V, Lee S. Correlation of Paraspinal Muscle Mass With Decompensation of Sagittal Adult Spinal Deformity After Setting of Fatigue Post 10-Minute Walk. Neurospine. 2021;18(3):495–503. https://doi.org/10.14245/ns.2142510.255.
5. Bouisset N, Roland-Gosselin A, Ouaknine M, Safin JL. (2022). *Proprioceptive manipulations in orthograde posture modulate postural control in low back pain patients: a pilot study*. https://doi.org/10.1038/s41598-022-10701-2
6. Chan L, Li Y, Hai Y, Liu Y, Zhang Y. Risk factors of unintended return to the operating room in adult spinal deformity. J Orthop Surg Res. 2021;16(1). https://doi.org/10.1186/s13018-021-02385-7.
7. Cheung JPY. The importance of sagittal balance in adult scoliosis surgery. Annals Translational Med. 2020;8(2):35–35. https://doi.org/10.21037/atm.2019.10.19.
8. Cheung JPY, Wong HL, Cheung PWH. Predictive factors for successful non-operative treatment and achieving MCID improvement in health-related quality of life in adult spinal deformity. BMC Musculoskelet Disord. 2022;23(1). https://doi.org/10.1186/s12891-022-05757-0.
9. Chilakapati S, Poppino K, Jo C-H, Sucato DJ. Surgical treatment of double major adolescent idiopathic scoliosis can lead to excessive lumbar lordosis in the instrumented segments. Spine Deformity. 2023;11(4):969–75. https://doi.org/10.1007/s43390-023-00651-8.
10. Christiansen PA, LaBagnara M, Sure DR, Shaffrey CI, Smith JS. (2016). Complications of surgical intervention in adult lumbar scoliosis [Review of *Complications of surgical intervention in adult lumbar scoliosis*]. *Current Reviews in Musculoskeletal Medicine*, *9*(3), 281–289. Springer Science+Business Media. https://doi.org/10.1007/s12178-016-9357-4
11. Cirillo JI, Valenzuela JGF, Arancibia JAG, Contreras STP, Lalanne LB, Lemos F. Á. (2021). Sagittal balance: from theory to clinical practice. *EFORT Open Reviews*, *6*(12), 1193–1202. https://doi.org/10.1302/2058-5241.6.210062

12. Coillard C, Circo A, Rivard CH. A new concept for the non-invasive treatment of Adolescent Idiopathic Scoliosis: The Corrective Movement© principle integrated in the SpineCor System. Taylor Francis. 2008. https://doi.org/10.1080/17483100801903913.
13. El-Fiky T, Patil ND, Shawky M, Siam AE, Ragab R, Allam Y. Oxford Cobbometer Versus Computer Assisted-Software for Measurement of Cobb Angle in Adolescent Idiopathic Scoliosis. Neurospine. 2020;17(1):304–11. https://doi.org/10.14245/ns.1938260.130.
14. Fan Q, Yang J, Sha L, Yang J. Factors that influence in-brace derotation effects in patients with adolescent idiopathic scoliosis: a study based on EOS imaging system. J Orthop Surg Res. 2024;19(1). https://doi.org/10.1186/s13018-024-04789-7.
15. Fernandez J, Dickinson A, Hunter P. Population based approaches to computational musculoskeletal modelling. Biomech Model Mechanobiol. 2020;19(4):1165–8. https://doi.org/10.1007/s10237-020-01364-x.
16. Franceschini C, Ahmadi M, Zhang X, Wu KL, Lin M, Weston RE, Rodio A, Tang Y, Engeberg ED, Pires G, Cheema TA, Vrionis FD. (2025). Revolutionizing spine surgery with emerging AI–FEA integration [Review of *Revolutionizing spine surgery with emerging AI–FEA integration*]. *Journal of Robotic Surgery*, *19*(1). Springer Science+Business Media. https://doi.org/10.1007/s11701-025-02772-w
17. Guan T, Zhang Y, Anwar A, Zhang Y, Wang L. (2020). Determination of Three-Dimensional Corrective Force in Adolescent Idiopathic Scoliosis and Biomechanical Finite Element Analysis. *Frontiers in Bioengineering and Biotechnology*, *8*. https://doi.org/10.3389/fbioe.2020.00963
18. Guo C, Ashrafian H, Ghafur S, Fontana G, Gardner C, Prime M. (2020). Challenges for the evaluation of digital health solutions—A call for innovative evidence generation approaches [Review of *Challenges for the evaluation of digital health solutions—A call for innovative evidence generation approaches*]. *Npj Digital Medicine*, *3*(1). Nature Portfolio. https://doi.org/10.1038/s41746-020-00314-2
19. Guy A, Coulombe M, Labelle H, Barchi S, Aubin C. Automated design of nighttime braces for adolescent idiopathic scoliosis with global shape optimization using a patient-specific finite element model. Sci Rep. 2024;14(1). https://doi.org/10.1038/s41598-024-53586-z.
20. Hua W, Li S, Feng X, Wang K, Yin H, Wu X, Zhang Y, Gao Y, Li L, Cao Y. Sequential correction of severe and rigid kyphoscoliosis: a new technical note and preliminary results. BMC Musculoskelet Disord. 2023;24(1). https://doi.org/10.1186/s12891-023-06736-9.
21. Igawa T, Ishii K, Katsuhira J, Suzuki A, Ui H, Urata R, Isogai N, Sasao Y, Matsudaira K, Funao H. Trunk orthosis with joints providing resistive force improves dynamic sagittal alignment in postoperative patients with lumbar spinal stenosis. Sci Rep. 2023;13(1). https://doi.org/10.1038/s41598-023-46209-6.
22. Kallan SZ, Oakley PA, Harrison DE. Reduction of lumbar hyperlordosis in a pediatric: a Chiropractic Biophysics® case report. J Phys Therapy Sci. 2022;34(9):646–50. https://doi.org/10.1589/jpts.34.646.

23. Katz EA, Katz SB, Katz SF, Fedorchuk C, Fedorchuk CG, Lightstone DF. Increased Cervical Disc Height and Decreased Neck Pain and Disability Following Improvement in Cervical Lordosis and Posture Using Chiropractic BioPhysics. Bioengineering. 2026;13(2):229–229. https://doi.org/10.3390/bioengineering13020229.
24. Katz E, Katz S, Fedorchuk C, Lightstone DF, Banach C, Podoll J. Increase in cerebral blood flow indicated by increased cerebral arterial area and pixel intensity on brain magnetic resonance angiogram following correction of cervical lordosis. Brain Circulation. 2019;5(1):19–19. https://doi.org/10.4103/bc.bc_25_18.
25. Kieser D, Boissière L, Bourghli A, Hayashi K, Cawley DT, Yılgör Ç, Alanay A, Acaroğlu E, Kleinstueck F, Pizones J, Pellisé F, Pérez-Grueso FJS, Obeid I. Obeid-Coronal Malalignment Classification Is Age Related and Independently Associated to Personal Reported Outcome Measurement Scores in the Nonfused Spine. Neurospine. 2021;18(3):475–80. https://doi.org/10.14245/ns.2142458.229.
26. Kim KH, Sohn M, Park CG. (2022). *Conformity assessment of a computer vision-based posture analysis system for the screening of postural deformation*. https://doi.org/10.1186/s12891-022-05742-7
27. Kim S. Exercise-Based Mechanotherapy: From Biomechanical Principles and Mechanotransduction to Precision Regenerative Rehabilitation. Int J Mol Sci. 2026;27(2):694–694. https://doi.org/10.3390/ijms27020694.
28. Koeppen D, Piepenbrock C, Kroppenstedt S, Čabraja M. The influence of sagittal profile alteration and final lordosis on the clinical outcome of cervical spondylotic myelopathy. A Delta-Omega-analysis. PLoS ONE. 2017;12(4). https://doi.org/10.1371/journal.pone.0174527.
29. Kotwicki T, Chowańska J, Kinel E, Czaprowski D, Janusz P, Tomaszewski M. Optimal management of idiopathic scoliosis in adolescence. Adolesc Health Med Ther. 2013;4:59–59. https://doi.org/10.2147/ahmt.s32088.
30. Kyrölä K, Hiltunen S, Uimonen M, Ylinen J, Häkkinen A, Repo JP. Psychometric Properties of the Scoliosis Research Society Questionnaire (Version 22r) Domains Among Adults With Spinal Deformity: A Rasch Measurement Theory Analysis. Neurospine. 2022;19(2):422–33. https://doi.org/10.14245/ns.2143354.677.
31. Langlais T. (2022). Biomechanical marker research improving diagnosis and therapeutic evaluation of adolescent idiopathic scoliosis. HAL (Le Centre Pour La Communication Scientifique Directe). https://pastel.archives-ouvertes.fr/tel-04060782
32. Le J-RM, Yeh K, Chen C, Jaw F, Yang S, Wu W. Quantitative evaluation of correlation between lumbosacral lordosis and pelvic incidence in standing position among asymptomatic Asian adults: a prospective study. Sci Rep. 2022;12(1). https://doi.org/10.1038/s41598-022-21840-x.
33. Lee J, Jeong K, Mun S, Lee S, Baek Y. Lifestyle factors and determination of optimal cut-off values for forward head posture in young adults with neck pain: a cross-sectional analysis. BMC Musculoskelet Disord. 2025;26(1). https://doi.org/10.1186/s12891-024-08188-1.

34. Li J, Wang J, Geng B, Han Q, Song L, Liu X, He H, Li H, Zhao Y. Quantitative analysis and prediction of corrective force in scoliosis brace-treated patients. Med-X. 2025;3(1). https://doi.org/10.1007/s44258-025-00064-4.
35. Li X, Huo Z, Hu Z, Lam TP, Cheng JCY, Chung VC, Yip BHK. Which interventions may improve bracing compliance in adolescent idiopathic scoliosis? A systematic review and meta-analysis [Review of *Which interventions may improve bracing compliance in adolescent idiopathic scoliosis? A systematic review and meta-analysis*]. PLoS ONE. 2022;17(7). https://doi.org/10.1371/journal.pone.0271612. Public Library of Science.
36. Lim HJ, Yoon H, Kim J, Han K, So Y, Park M-C, Park K-B, Lee M. Comparison of elasticity changes in the paraspinal muscles of adolescent patients with scoliosis treated with surgery and bracing. Sci Rep. 2024;14(1). https://doi.org/10.1038/s41598-024-56189-w.
37. Manchikanti L. (2020). Comprehensive Evidence-Based Guidelines for Facet Joint Interventions in the Management of Chronic Spinal Pain: American Society of Interventional Pain Physicians (ASIPP) Guidelines. *Pain Physician*. https://doi.org/10.36076/ppj.2020/23/s1
38. Meng Z, Yu J, Luo C, Liu X, Jiang W, Yu L, Huang R. (2017). Anterior Cervical Spondylosis Surgical Interventions are Associated with Improved Lordosis and Neurological Outcomes at Latest Follow up: A Meta-analysis [Review of *Anterior Cervical Spondylosis Surgical Interventions are Associated with Improved Lordosis and Neurological Outcomes at Latest Follow up: A Meta-analysis*]. *Scientific Reports*, *7*(1). Nature Portfolio. https://doi.org/10.1038/s41598-017-04311-6
39. Mizutani K, Kobayashi T, Senoo I, Shimizu M, Okayasu H. Importance of modifiable non-radiographic functional parameters for adult spinal deformity. Sci Rep. 2024;14(1). https://doi.org/10.1038/s41598-024-54854-8.
40. Moustafa IM, Diab AA, Harrison DE. (2022). *Does Improvement towards a Normal Cervical Sagittal Configuration Aid in the Management of Lumbosacral Radiculopathy: A Randomized Controlled Trial*. https://doi.org/10.3390/jcm11195768
41. Moustafa IM, Diab AA, Hegazy FA, Harrison DE. Demonstration of central conduction time and neuroplastic changes after cervical lordosis rehabilitation in asymptomatic subjects: a randomized, placebo-controlled trial. Sci Rep. 2021;11(1). https://doi.org/10.1038/s41598-021-94548-z.
42. Moustafa IM, Ozsahin DU, Mustapha MT, Ahbouch A, Oakley PA, Harrison DE. Utilizing machine learning to predict post-treatment outcomes in chronic non-specific neck pain patients undergoing cervical extension traction. Sci Rep. 2024;14(1). https://doi.org/10.1038/s41598-024-62812-7.
43. Nakagawa S, Noble DWA, Senior AM, Lagisz M. Meta-evaluation of meta-analysis: ten appraisal questions for biologists [Review of *Meta-evaluation of meta-analysis: ten appraisal questions for biologists*]. BMC Biol. 2017;15(1). https://doi.org/10.1186/s12915-017-0357-7. BioMed Central.
44. Negrini S, Atanasio S, Fusco C, Zaina F. Effectiveness of complete conservative treatment for adolescent idiopathic scoliosis (bracing and exercises) based on SOSORT management criteria: Results according to the SRS criteria for bracing studies - SOSORT Award 2009 Winner. Scoliosis. 2009. https://doi.org/10.1186/1748-7161-4-19.

45. Négrini S, Negrini F, Bassani T, Febbo F, Jurenaite G, Negrini A, Pulici C, Zaina F. Wearing a brace for idiopathic scoliosis above 18 hrs/day shows a dose–response effect on the outcomes improvement and end-of-treatment Cobb angle below 30 degrees. Eur Spine J. 2025;34(11):5232–40. https://doi.org/10.1007/s00586-025-09124-0.
46. Oakley PA. Is early treatment for mild adolescent idiopathic scoliosis superior over the traditional 'watch & wait' approach? A case report with long-term follow-up. J Phys Therapy Sci. 2018;30(5):680–4. https://doi.org/10.1589/jpts.30.680.
47. Oakley PA, Moustafa IM, Harrison DE. (2021). *The Influence of Sagittal Plane Spine Alignment on Neurophysiology and Sensorimotor Control Measures: Optimization of Function through Structural Correction*. https://doi.org/10.5772/intechopen.95890
48. Perna A, Proietti L, Smakaj A, Velluto C, Meluzio MC, Rovere G, Florio D, Zirio G, Tamburrelli FC. (2021). The role of femoral obliquity angle and T1 pelvic angle in predicting quality of life after spinal surgery in adult spinal deformities. https://doi.org/10.1186/s12891-021-04823-3
49. Razeghinezhad R, Kamyab M, Babaee T, Ganjavian MS, Bidari S. The Effect of Brace Treatment on Large Curves of 40° to 55° in Adolescents With Idiopathic Scoliosis Who Have Avoided Surgery: A Retrospective Cohort Study. Neurospine. 2021;18(3):437–44. https://doi.org/10.14245/ns.2040654.327.
50. Scheer JK, Smith JS, Passias PG, Kim HJ, Bess S, Burton DC, Klineberg EO, Lafage V, Gupta MC, Ames CP. Outcomes of Surgical Treatment for Patients With Mild Scoliosis and Age-Appropriate Sagittal Alignment With Minimum 2-Year Follow-up. Neurospine. 2023;20(3):837–48. https://doi.org/10.14245/ns.2346454.227.
51. Shen Y, Qin F, Pan Y, Zhang H, Hapulile NT, Li S, Ye X, Li X, Ying X. Correlation between coronal wedge deformity and sagittal spinal curvature in adolescent idiopathic scoliosis: a retrospective analysis. Sci Rep. 2024;14(1). https://doi.org/10.1038/s41598-024-80704-8.
52. Skaggs K, Lin A, Andras LM, Illingworth KD, Skaggs DL. Standing in Schroth trained position significantly changes Cobb angle and leg length discrepancy: a pilot study. Spine Deformity. 2020;8(6):1185–92. https://doi.org/10.1007/s43390-020-00157-7.
53. Sohn M, Lee H, Lee B, Koo H, Kim KH, Yoon SW. The radiographic assessments of spino-pelvic compensation using IoT-based real-time ischial pressure adjustment: clinical research study. Res Square (Research Square). 2021. https://doi.org/10.21203/rs.3.rs-664125/v1.
54. Wang F, Chen K, Ji T, Ma Y, Huang H, Zhou P, Wei X, Chen K, Bai Y. Do hypokyphotic adolescent idiopathic scoliosis patients treated with Ponte osteotomy obtain a better clinical efficacy? A preliminary retrospective study. J Orthop Surg Res. 2022;17(1). https://doi.org/10.1186/s13018-022-03390-0.
55. Wang Q, Sun C. Characteristics and correlation analysis of spino-pelvic sagittal parameters in elderly patients with lumbar degenerative disease. J Orthop Surg Res. 2019;14(1). https://doi.org/10.1186/s13018-019-1156-3.

56. Warden SJ, Thompson WR. Become one with the force: optimising mechanotherapy through an understanding of mechanobiology. Br J Sports Med. 2017;51(13):989–90. https://doi.org/10.1136/bjsports-2017-097634.
57. Wu A, March L, Zheng X-Q, Huang J, Wang X, Zhao J, Blyth F, Smith E, Buchbinder R, Hoy D. Global low back pain prevalence and years lived with disability from 1990 to 2017: estimates from the Global Burden of Disease Study 2017. Annals Translational Med. 2020;8(6):299–299. https://doi.org/10.21037/atm.2020.02.175.