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The use of halo gravity traction in the preoperative planning of pediatric patients with scoliosis

SUMMARY OF THE DOCTORAL THESIS

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Contents

Abbreviations

BMI - Body mass index

CSVL - central sacral vertical line

CT - Computed tomography

MRI - Magnetic resonance imaging

HGT - Halo-gravity traction

HPT - Halo-pelvic traction

C5 - cervical vertebra 5

C6 - cervical vertebra 6

C2 - cervical vertebra 2

SRS-22 - "Scoliosis Research Society" 22 score

AP - anteroposterior

SD - standard deviation

Min - minimum

Max - maximum

F - Female

M - Male

CI - Confidence interval

Introduction

Scoliosis is the most frequently encountered three-dimensional deformity of the spine in the pediatric population, with the idiopathic form being the most prevalent. The prevalence of idiopathic scoliosis shows marked variability, ranging from 0.47% to 5.2% [1-3].

Treatment of scoliosis is determined by the severity of the deformity and has as its main objectives the prevention of curve progression, restoration of spinal balance and thoracic symmetry, correction of the deformity, and prevention of long-term complications such as chronic pain, limited mobility, and cardiac and respiratory dysfunction [4].

Posterior spinal fusion with segmental instrumentation represents the standard in the surgical treatment of idiopathic scoliosis [5,6]. Rapid correction of severe spinal deformities is associated with an increased risk of neurological complications [7]. In this context, traction is an effective orthopedic method for the progressive correction of spinal deformities; scoliosis is one of the conditions for which this technique can be used successfully, with the aim of reducing the risk of complications and improving the degree of correction.

Traction allows gradual correction of the deformity in the frontal, sagittal, and axial planes, while the patient remains conscious throughout the procedure, which facilitates continuous neurological monitoring. This method can be applied in most patients with spinal deformities, with certain exceptions (cranial malformations, osteoporosis, the presence of intra- or extradural lesions, and spinal canal stenosis) [8].

The perioperative efficacy of halo-gravity traction is well documented in the literature; however, the number of dedicated studies is limited, most include small cohorts, lack control groups, and involve heterogeneous populations, often without focusing exclusively on pediatric patients treated surgically through a posterior approach.

Despite its long-standing use in the treatment of severe spinal deformities, the available data regarding halo-gravity traction as a preoperative adjunctive method in pediatric patients treated exclusively through a posterior approach, without associated anterior or posterior release procedures, remain limited. There is also a very small number of case-control studies rigorously evaluating the efficacy of this method in this specific context, underscoring the need for further well-structured research.

General objectives and hypotheses

The objectives of the present research are structured to systematically evaluate the role of halo-gravity traction in the management of severe scoliosis in pediatric patients and aim to:

- to evaluate the complications occurring during halo-gravity traction and to quantify the degree of curve correction obtained under traction.
- to evaluate the efficacy of halo-gravity traction in pediatric patients with severe scoliosis by quantifying Cobb angle reduction under traction and analyzing the relationship between radiological response and skeletal maturity (Risser score), age, and duration of application.
- to compare the results of posterior segmental fusion performed with versus without preoperative halo-gravity traction, following the degree of deformity correction.
- to evaluate the impact of anthropometric parameters (height) on the severity and dynamics of scoliotic curves (primary and secondary) and to demonstrate the clinical efficacy of halo-gravity traction as a preoperative stage in the correction of severe scoliosis in pediatric patients.

In order to achieve these objectives, the following hypotheses were formulated to structure the analytical investigation and to provide a unified methodological basis for the study:

- It is presumed that halo-gravity traction allows significant radiological correction of the main curve (reduction of the Cobb angle), with a low rate of complications, mainly minor and reversible, during traction application [9].
- It is presumed that halo-gravity traction produces a significant reduction in the Cobb angle in severe scoliosis and that the degree of correction obtained is influenced by skeletal maturity and the duration of traction [10].
- It is presumed that the association of preoperative halo-gravity traction with posterior spinal fusion produces better radiological correction of the main curve (reduction of the Cobb angle) compared with fusion performed without traction [11].
- It is postulated that preoperative application of halo-gravity traction induces significant Cobb angle correction through elongation of the perivertebral soft tissues, optimizing three-dimensional alignment and facilitating superior surgical correction, with an improved neurological safety profile by attenuating abrupt intraoperative distraction.
- It is postulated that, while the magnitude of the main curve shows a direct and significant correlation with height growth (accentuated by asymmetric growth vectors at the

vertebral endplates), the secondary curve exhibits structural autonomy, maintaining its angular configuration independently of axial spinal elongation.

General research methodology

Study design

The research project was structured as a cohort study, using both a retrospective approach for data analysis over an extended period (2011-2025) and a prospective component focused on monitoring complications and correction dynamics between 2019 and 2022.

The central objective was to evaluate the efficacy of halo-gravity traction (HGT) as a preoperative method for reducing the severity of scoliotic curves and improving spinal flexibility before definitive spinal fusion.

The methodology involved comparing parameters based on imaging investigations at key treatment moments: baseline status (pre-traction), the preoperative stage (post-traction), and the result obtained after surgery. The design also allowed comparison of surgical outcomes between patients who benefited from prior traction and those who underwent direct posterior spinal fusion.

Description of participants

The study group consisted of pediatric patients diagnosed with idiopathic scoliosis, the main selection criterion being the presence of a severe curve with an initial Cobb angle greater than 65° or 70°. The mean age of participants was approximately 14 years, with a higher prevalence among females, in line with the epidemiological distribution of the disease.

To ensure data relevance, patients with congenital, neuromuscular, or post-traumatic scoliosis were excluded, as were those presenting cranial malformations, spinal canal stenosis, spinal tumors, osteoporosis, or osteogenesis imperfecta. Enrollment in the study was performed exclusively on the basis of informed consent signed by parents or legal guardians, with prior approval from the hospital ethics committee.

All participants included in the study took part in a clinical interview for collection of the data required to complete the research protocol.

Materials and methods

The therapeutic protocol began with the application, under general anesthesia and by a neurosurgeon, of a cranial ring (halo) fixed by means of four titanium pins. Traction itself was started progressively 48 hours after the intervention, with the weight increased daily by one kilogram until reaching the threshold of 40-50% of each patient's body weight.

During the traction period, which had an average duration of 24 to 28 days, patients used adapted devices (bed, wheelchair, walking frame) to maintain mobility. After completion of the traction stage, all patients underwent posterior spinal fusion with segmental instrumentation, with fusion levels established individually to maximize correction and preserve as many mobile segments as possible.

Statistical analysis of the data

Data processing was performed using SPSS software, employing descriptive statistics for demographic and clinical variables such as age, sex, body mass index, weight, and Cobb angles. The analysis included application of the paired t-test to evaluate significant differences between Cobb angle values in the pre-traction, post-traction, and postoperative stages.

To identify the factors influencing treatment response, Pearson correlations and multivariate linear regression models were used, evaluating the impact of age, skeletal maturity (Risser score), and curve type (Lenke classification). An ANOVA-MR model was also applied to identify patient progress over time. A Linear Mixed Regression Model was further used to illustrate the direct influence of height on the Cobb angle of the main curve and the structural autonomy of the Cobb angle of the secondary curve. All radiological measurements were validated by the independent assessment of two observers, and the threshold for statistical significance was set at $p < 0.05$.

The use of halo-gravity traction and associated complications in pediatric patients with scoliosis

Objectives and hypotheses

This study aims to evaluate the complications occurring during halo-gravity traction and to quantify the degree of curve correction obtained under traction, starting from the following hypothesis:

It is presumed that halo-gravity traction allows significant radiological correction of the main curve (reduction of the Cobb angle), with a low rate of complications, mainly minor and reversible, during traction application [9].

Patients and methods

The prospective study was conducted on 19 pediatric patients diagnosed with scoliosis who were hospitalized during 2019-2022. Included were pediatric patients with juvenile or adolescent idiopathic scoliosis whose main curve had a Cobb angle greater than 65° and who had no history of spinal surgery. Patients with congenital scoliosis (vertebral malformations), spinal canal stenosis or expansive lesions, cranial malformations, osteoporosis, or osteogenesis imperfecta were excluded.

Results

The mean age of the patients was 14.16 years, with a sex distribution of 68.4% girls and 31.6% boys. The mean duration of traction was 28.46 days. Patients who underwent traction for less than 25 days showed a mean angle correction of 32.32%, whereas in those with traction for more than 25 days the mean correction was 49.96% (Figure 5.5).

Regarding the location of the main curve, thoracic curves predominated (52.63%), followed by thoracolumbar curves (42.11%); only one patient presented a lumbar curve (5.26%). The mean Cobb angle before traction was 86.21°, and after traction (preoperatively) it was 63.16°, resulting in a mean correction of 26.73%. Skeletal maturity, assessed by the Risser sign, indicated that 42.1% of patients were classified as Risser 4 and 15.8% as Risser 0. Vertebral rotation was assessed using the Nash-Moe system: 47.4% of patients had grade III rotation, 42.1% grade II, and 10.5% grade IV.

Within the Lenke classification, the most frequent type was Lenke 3 (42.1%), followed by Lenke 1 (36.8%), while types 2 and 6 were less common (5.3% each). Maximum curve correction was observed in Lenke 3 curves (29%), closely followed by Lenke 1 (28%). In relation to skeletal maturity, the greatest correction was obtained in Risser 0 patients (32%), followed by Risser 5 patients (31%).

With regard to method tolerance and safety, complications were encountered in 94.7% of patients, the most frequent being cervical pain (89.5%). This was followed by lumbar pain (36.8%), while dizziness and pin displacement were rare (5.3% each). Neurological manifestations were present in 26.3% of patients. Pain at the pin sites and infections at the insertion points were each observed in 26.3% of cases. Headache occurred in 10.5% of patients. Patients who did not present cervical or lumbar pain recorded a mean improvement of 27%. In contrast, patients who reported pain at the pin sites or headache showed the highest correction percentages: 31% in the pin-site pain group and 32% in the headache group.

Discussions

The optimal duration of traction remains incompletely standardized, with the literature reporting variable intervals ranging from a few weeks to months [12-15]. In the analyzed cohort, the mean duration of traction was 28.46 days (17-43 days), and the mean and maximum correction were 26.73% and 46.95%, respectively. A better degree of correction was observed in patients under traction for at least 25 days, and among Lenke types, type 3 curves showed the best improvement (29%).

Although HGT is generally considered an effective and relatively safe method, complications are not uncommon and are mainly described as pin-related problems (loosening/infection), and more rarely systemic or neurological manifestations [16,17]. In the present study, complications were encountered in most patients (94.7%), but they were transient and manageable through conservative measures. The most frequent symptom was cervical pain, interpreted mainly as an effect of stretching the cervical musculature; this improved by maintaining or reducing the traction weight for 1-2 days, together with oral anti-inflammatory drugs and local anti-inflammatory gel applications. Lumbar pain was present in seven patients and followed a similar course under the same type of treatment.

Neurological manifestations (paresthesias of the upper limb or transient deficit), pain at the pin sites, and local infections were each present in 26.3% of patients. Despite instructions regarding daily care, episodes of superficial infection occurred at the insertion points and were rapidly controlled by local treatment with iodinated solutions; no severe complications such as osteitis or intracranial abscess were identified. Pain at the pin sites may reflect loosening, which is why pin tension was checked whenever it was reported, and the symptomatology was generally self-limited after retightening and administration of anti-inflammatory medication (for example, ibuprofen). Neurological symptoms were mild, and a neurological examination was performed each time; management consisted of reducing traction by at least 2 kg and oral anti-inflammatory treatment. Headache was encountered in 10.5% of patients, especially on the day after halo application, before actual loading, with progressive remission as patients adapted to the device. Only one patient presented dizziness, without objective changes on neurological examination. Pin displacement was observed in one case despite compliance with the tightening and monitoring protocol. A likely explanation is reduced tolerance to the supine position and preference for sleeping in the lateral decubitus position, with uneven pressure distribution on the assembly.

Conclusions

Although most patients in the studied cohort presented complications (94.7%), these were generally mild, transient, and controllable with minimal interventions, cervical pain being the most frequent. Infectious episodes were strictly superficial, without sequelae, and neurological manifestations were reversible.

Even though symptoms such as cervical or lumbar pain, transient paresthesias, pain at the pin sites, or local infections are relatively frequent, careful clinical monitoring allows them to be managed safely, with reduced impact on the course of treatment. The use of devices that maintain mobility (bed, wheelchair, walking frame) contributes to reducing discomfort and supports treatment tolerance, making it possible to achieve substantial curve correction (in some cases, up to approximately 50%). Application of a standardized traction protocol facilitated comparable patient supervision and optimization of care.

In this context, the obtained results confirm the working hypothesis according to which halo-gravity traction allows significant radiological correction of the main curve (through reduction of the Cobb angle), without a relevant increase in severe complications, most of them being minor and reversible during traction application.

Impact of preoperative halo-gravity traction on Cobb angle reduction in adolescent patients with idiopathic scoliosis

Objectives and hypotheses

This study aims to evaluate the efficacy of halo-gravity traction in pediatric patients with severe scoliosis, quantifying Cobb angle reduction under traction and analyzing the relationship between radiological response and skeletal maturity (Risser score), age, and duration of application, starting from the following hypothesis:

It is presumed that halo-gravity traction produces a significant reduction in the Cobb angle in severe scoliosis and that the degree of correction obtained is influenced by skeletal maturity and the duration of traction [10].

Patients and methods

The retrospective cohort study was carried out in order to evaluate the influence of preoperatively applied halo-gravity traction on curve evolution and postoperative outcomes in patients with severe scoliosis. Data were extracted from the medical records of patients treated between 2018 and 2024.

Included were patients diagnosed with adolescent idiopathic scoliosis, defined by a Cobb angle > 65°, who underwent HGT and subsequently surgical correction by posterior spinal fusion. Patients with congenital, neuromuscular, or post-traumatic scoliosis were excluded, as were those with incomplete observation sheets or missing variables essential for statistical analysis.

Results

A total of 28 patients met the inclusion criteria and were analyzed. The cohort included 6 male and 22 female patients, aged between 12 and 17 years (mean age: 14.86 years).

All patients underwent preoperative halo-gravity traction for an average duration of 24.64 days, followed by surgical correction. The mean Risser score at the time of treatment was 2.75 (range 2-5), reflecting varying degrees of skeletal maturity. Mean body weight was 50.5 kg (SD ± 7.56), with values between 39 and 63 kg.

Patients were divided into two subgroups according to traction duration: < 24 days (n = 14) and ≥ 24 days (n = 14). The mean percentage reduction of the main Cobb angle after traction was 25.85% (SD = 9.06) in the < 24-day traction group and 26.32% (SD = 10.55) in the ≥ 24-day traction group. Mean postoperative reduction of the main curve was 65.3%

(SD = 6.3) for patients with traction < 24 days and 63.8% (SD = 6.8) for those with traction ≥ 24 days.

Before traction, the Cobb angle of the main curve had a mean value of 82.46° (minimum 68.0°, maximum 108.0°). Preoperatively (after traction), it was reduced to a mean of 61.00° (corresponding to a decrease of 26.09%), with values between 41.0° and 86.0°. Postoperatively, the main Cobb angle further decreased to a mean of 29.54°, representing a reduction of 64.58% relative to the initial pre-traction value (minimum 13.0°, maximum 49.0°).

Analysis according to the Risser score highlighted discrete differences in traction response: patients with Risser 5 had the greatest mean post-traction reduction (29.4%), closely followed by the Risser 3 group (29.24%), while the values were lower for Risser 2 (25.44%) and Risser 4 (23.29%) (Figure 6.8).

Postoperatively, the degree of correction was relatively uniform among Risser groups: the highest mean postoperative reduction was observed in Risser 5 (65.3%), followed by Risser 3 (64.87%), Risser 4 (64.63%), and Risser 2 (62.74%). The distribution of percentage reductions of the main curve suggests that patients with Risser 5 had both the greatest and most homogeneous median reduction (close to 70%); the Risser 3 group showed a comparable median reduction, but with greater dispersion. The Risser 2 and Risser 4 groups had slightly lower medians (approximately 59% and 64%), with wider interquartile ranges and isolated extreme values, including an outlier > 80% in the Risser 4 group.

Comparing the correction obtained after traction with the final postoperative correction, the additional improvement attributable to surgery was maximal in Lenke 2 (49.4%) and Lenke 5 (48.2%). Lenke 1 and Lenke 4 types had similar gains (39.6% and 39.2%), while Lenke 3 showed the smallest postoperative improvement (35.7%), although it had had the best initial response to traction. For Lenke 6, the improvement was moderate (37.0%). These differences suggest a variable contribution of surgical correction over the effect obtained through preoperative traction.

Discussions

The optimal duration of HGT remains incompletely standardized, the goal being to balance maximization of radiological correction and limitation of traction-related complications. In the studied cohort, the mean duration of traction was 24.64 days (maximum 36 days). The <24-day group had a mean preoperative reduction of the primary curve of 25.9%, while the ≥24-day group had a reduction of 26.3%, suggesting minimal additional benefit from prolonging traction beyond this threshold.

We did not identify statistically significant correlations between Risser score, age, and percentage reduction of the Cobb angle, either after traction or postoperatively. This result is in agreement with the literature, which does not highlight significant age-related differences in frontal-plane correction obtained through HGT [18]. Moreover, the Kruskal-Wallis analysis did not show significant differences in reduction of the main curve Cobb angle after traction between Lenke types, nor in postoperative reduction between Risser groups, suggesting that curve type and skeletal maturity did not meaningfully influence the degree of correction obtained.

An important point of the study is the integrated analysis of age and skeletal maturity (Risser) in relation to the effect of HGT in adolescent idiopathic scoliosis, an area that has been relatively little explored. Our results suggest that a duration of approximately 24 days may be sufficient, since prolongation beyond this interval appears to bring limited additional benefits. At the same time, within the 12-17 year age range, age did not significantly influence the response to HGT or postoperative correction of the main curve, supporting the utility of the method in the management of complex deformities.

Conclusions

Halo-gravity traction followed by surgical correction is associated with a significant and safe reduction of deformity in adolescent idiopathic scoliosis, independent of curve type and age range. In this context, the hypothesis that HGT determines a relevant decrease in the Cobb angle in severe scoliosis is confirmed by the results of the analyzed cohort, in which an important reduction of the Cobb angle was obtained both for the main curve and for the secondary curve, the final postoperative correction being, on average, approximately 60% for both curves. At the same time, the component of the hypothesis referring to the influence of skeletal maturity and traction duration on the degree of correction was only partially supported: our data suggest that the optimal effect of traction is reached at approximately 24 days, prolongation beyond this interval bringing minimal radiological gain, while age, Risser score, and Lenke type did not significantly influence the degree of correction. Therefore, HGT may be considered a reliable preoperative tool, widely applicable in idiopathic scoliosis regardless of skeletal maturity during adolescence.

Posterior spinal fusion after halo-gravity traction versus direct posterior fusion in adolescent patients with idiopathic scoliosis - comparative study

Objectives and hypotheses

This study aims to compare the results of posterior segmental fusion performed with versus without preoperative halo-gravity traction, following the degree of deformity correction, starting from the following hypothesis:

It is presumed that the association of preoperative halo-gravity traction with posterior fusion produces better radiological correction of the main curve (reduction of the Cobb angle) compared with fusion performed without traction [11].

Patients and methods

The study was designed as a retrospective cohort analysis, aiming to evaluate the role of preoperative halo-gravity traction in reducing curve severity and optimizing surgical outcomes in patients with severe scoliosis. The results of this group were compared with those of patients treated by posterior spinal fusion without having undergone traction. Data were collected from the observation sheets of patients treated during 2011-2024.

The cohort included adolescents diagnosed with idiopathic scoliosis, divided into two comparable cohorts, and idiopathic scoliosis was defined starting from a Cobb angle > 65°. The first cohort comprised patients treated between 2011-2018 exclusively by posterior fusion, while the second cohort included patients treated between 2018-2024 who benefited from halo-gravity traction before posterior fusion. Patients with congenital malformations, neuromuscular etiology, post-traumatic scoliosis, and those with incomplete datasets were excluded.

Results

A cohort of 46 patients who met the inclusion criteria was selected for evaluation: 30 patients in the traction group and 16 in the non-traction group.

The two cohorts were comparable both demographically and in terms of deformity severity. Mean age was 14.5 ± 1.9 years in the traction group and 14.8 ± 1.9 years in the non-traction group, with no statistically significant difference ($p = 0.91$). Sex distribution showed a female predominance in both cohorts (23F/7M in the traction cohort and 15F/1M in the non-traction cohort). Initial curve magnitude was almost identical: 83.6° ± 11.2° in the traction group and 83.1° ± 15.6° in the non-traction group ($p = 0.91$), confirming that patients started from comparable deformities before traction or surgery. Postoperatively, the traction group had significantly smaller residual curves, with a mean Cobb angle of 30.9° ± 7.8°, compared with 42.7° ± 18.9° in the non-traction group (p = 0.027), corresponding to a mean difference of approximately 12° in favor of traction. Within the traction cohort, extending treatment beyond three weeks brought no quantifiable benefits: patients treated ≤21 days achieved a mean percentage correction of 63.7%, while those treated >21 days achieved 63.2% (p = 0.959).

In multivariate linear regression analysis, adjusted for age, Lenke type, and Risser stage, traction remained an independent predictor of greater percentage correction (β = +14.6%, 95% CI +6.9% to +22.3%, p = 0.00047). Age and Risser score were not significantly correlated with percentage correction, and no statistically significant effect was observed for any Lenke subtype.

Discussions

The results of this study indicate that preoperatively used HGT offers a significant advantage in the surgical treatment of severe scoliosis. In a cohort of 46 patients with comparable initial deformities (83.6° vs. 83.1°), patients who benefited from HGT had smaller residual postoperative Cobb angles (30.9° vs. 42.7°), greater absolute decreases (52.7° vs. 40.4°), and higher correction percentages (63.3% vs. 50.0%). In addition, multivariate analysis highlighted that traction independently contributes an additional correction benefit (≈11%), without depending on age, skeletal maturity, or curve type. These data support the role of halo-gravity traction as an effective adjunct for improving correction in severe, rigid scoliosis.

The observations of the presented study are consistent with the literature describing the radiological and functional benefits of HGT. Several series have reported preoperative reductions in curve magnitude of 20-40%, which subsequently translate into improved final surgical correction [19-21]. The mean correction percentage of 63% obtained in the halo-gravity traction cohort falls in the upper range of values reported in contemporary studies.

Most of the correction obtained under traction was noted in the first three weeks, without significant increases in radiological benefit resulting from prolongation of treatment. This suggests a plateau effect, in which extending traction after this period yields minimal benefits but may increase hospitalization duration, costs, and patient discomfort.

Conclusions

Halo-gravity traction is a safe and effective adjunct in the management of severe and rigid scoliosis, contributing to increased spinal flexibility, optimization of postoperative outcomes, and reduction of intraoperative risks. Implementation of standardized, evidence-based protocols - preferably limited to approximately three weeks - can lead to predictable results, with reduced length of hospitalization and fewer complications. Overall, HGT improves surgical outcomes, may reduce the need for complex corrective maneuvers, and decreases the discomfort of the intervention for both the patient and the operative team, thereby consolidating its role in the modern approach to scoliosis.

In this context, the conclusions of the study confirm the hypothesis according to which the association of preoperative halo-gravity traction with posterior spinal fusion leads to superior radiological correction of the main curve (through reduction of the Cobb angle), compared with posterior spinal fusion performed without traction, supporting the usefulness of this staged strategy in optimizing the final outcome.

The efficacy of preoperative halo-gravity traction in the management of severe scoliosis in adolescents: an analysis of radiological correction and clinical safety

Objectives and hypotheses

This study aimed to evaluate the impact of anthropometric parameters (height) on the severity and dynamics of scoliotic curves (primary and secondary) and to demonstrate the clinical efficacy of halo-gravity traction as a preoperative stage in the correction of severe scoliosis in pediatric patients.

The specific objectives of the study are:

O1. Quantification of the degree of association between height growth and progression of Cobb angle magnitude in the frontal plane.

O2. Comparative evaluation of the structural reactivity of the main curve versus the secondary curve under the influence of the longitudinal growth vector.

O3. Demonstration of the clinical and biomechanical efficacy of preoperative halo-gravity traction by quantifying the reduction of three-dimensional deformity and the improvement of flexibility in pediatric patients.

To achieve these objectives, we formulated the following hypotheses:

I1. It is postulated that preoperative application of halo-gravity traction induces significant Cobb angle correction through elongation of the perivertebral soft tissues, optimizing three-dimensional alignment and facilitating superior surgical correction, with an improved neurological safety profile by attenuating abrupt intraoperative distraction.

I2. It is postulated that while the magnitude of the main curve presents a direct and significant correlation with height growth (accentuated by asymmetric growth vectors at the vertebral endplates), the secondary curve exhibits structural autonomy, maintaining its angular configuration independently of axial spinal elongation.

Patients and methods

The research protocol began with a complex imaging evaluation, including standing spinal radiographs for deformity analysis, cranial computed tomography (CT) for planning pin insertion in areas with optimal skull thickness, and spinal magnetic resonance imaging (MRI) for exclusion of medullary anomalies. The surgical stage consisted of halo placement by a neurosurgical specialist under general anesthesia, using four-point fixation (pins) tightened to a standardized torque of 4 pounds. To maintain mobility and prevent decubitus complications, three complementary halo-gravity traction systems were used: attached to the bed, adapted to the wheelchair, and integrated into the walking frame.

Results

The present study was conducted on a sample of 38 pediatric patients diagnosed with scoliosis, monitored and treated during 2019-2025. Participant selection was based on strict inclusion criteria, targeting patients with juvenile or adolescent idiopathic scoliosis whose main curve had a Cobb angle magnitude greater than 65°, with no history of spinal surgery.

The 38 patients were aged between 11 and 17 years, with mean M = 14.76 and standard deviation SD = 1.55; 10 were male and 28 female. Mean weight was 50.92 kg, with a mean body mass index (BMI) of 20.15. As regards the number of treatment days, the mean was approximately 25 days, and the mean traction weight was 19.42 kg.

The first tested hypothesis, I1, postulates that preoperative application of halo-gravity traction induces significant Cobb angle correction through elongation of the perivertebral soft tissues, optimizing three-dimensional alignment and facilitating superior surgical correction, with an improved neurological safety profile by attenuating abrupt intraoperative distraction.

Thus, the morphometric evolution of spinal height indicates a progressive and significant increase in trunk length. From a baseline value of 40.88 cm ± 3.63 cm, height increased steadily at 7 days (43.29 cm) and at 14 days (44.48 cm), reaching a preoperative threshold of 44.79 cm and culminating in a postoperative value of 45.53 cm.

As regards the main curve, a marked decrease in Cobb angle was observed, from 82.00° to 56.95° under the action of traction and subsequently to 29.74° postoperatively. The secondary curve followed a similar course of improvement, decreasing from 48.61° to 35.21° (preoperatively) and reaching 18.05° postoperatively.

It is statistically demonstrated that halo-gravity traction acts as a biomechanical pre-processing agent. The increase in spinal height and the reduction in Cobb angles before intervention confirm soft-tissue relaxation, allowing superior final surgical correction and reducing the risk of neurological complications associated with abrupt distraction.

Thus, the first hypothesis is supported by the collected data.

Last but not least, we tested hypothesis I2, according to which it is postulated that, while the magnitude of the main curve presents a direct and significant correlation with height growth (accentuated by asymmetric growth vectors at the vertebral endplates), the secondary curve exhibits structural autonomy, maintaining its angular configuration independently of axial spinal elongation.

To test hypothesis I2, we used a regression model for longitudinal data (Linear Mixed Models), which allows analysis of the relationship between axial elongation (spinal height) and the magnitude of scoliotic curves throughout treatment.

The data confirm hypothesis I2: while the main curve is closely related to height increase, the secondary curve displays relative structural autonomy, its configuration not being directly dictated by axial spinal elongation.

This phenomenon suggests that, biomechanically, the secondary curve functions as a flexible compensatory mechanism, while the main curve represents the rigid structural element that responds mechanically to distraction.

Conclusions and discussions

The results of the present study demonstrate that halo-gravity traction functions as a biomechanical optimization agent, inducing a predictable transformation of the spine from a rigid structure into a malleable one (I1). The repeated-measures ANOVA analysis confirmed a marked decrease in the main Cobb angle, from 82.00 ± 10.84° to 56.95° under the exclusive action of preoperative traction (eta squared = .966), reaching a postoperative mean value of 29.74°.

A central element of the analysis is the validation of hypothesis I2 through linear mixed models, which reveal a biomechanical dissociation between the two curves. The magnitude of the main curve is dependent on axial elongation, suggesting that the distraction force acts directly on the apex of the main curve. In contrast, the secondary curve exhibits structural autonomy in relation to height increase, its evolution being dictated rather by the temporal factor and the need for postural rebalancing [22].

Thus, the study attests that halo-gravity traction facilitates superior final surgical correction through relaxation of the soft tissues, reducing Cobb angles by approximately 30% before surgery. It was demonstrated that straightening is not a uniform process: while the main curve is directly modeled by distraction vectors and by gains in axial height, the secondary curve preserves relative structural autonomy.

Conclusions and personal contributions

The treatment of rigid and severe scoliosis represents a surgical challenge. Preoperative halo-gravity traction (HGT) increases curve flexibility, reduces neurological risks through gradual traction of the spinal cord, and improves preoperative pulmonary function. However, little is known about the ideal indications for HGT, its appropriate duration, or its efficacy in the treatment of rigid deformities.

This research project aims to fill the gaps in the literature both through a review of the specialized literature highlighting the contributions of the most representative authors, which forms the general part of the paper, and through the longitudinal and cross-sectional studies in the special part of the work.

In the general part of the paper, I sought to establish a solid theoretical foundation regarding adolescent idiopathic scoliosis, starting from the etiological complexity of this multifactorial condition and extending to the biomechanical mechanisms governing curve progression. Analysis of the specialized literature highlighted that the management of severe forms requires a multidisciplinary approach, in which precise clinical and radiological evaluation, guided by rigorous classifications such as the Lenke system, dictates the success of the intervention. I also explored the evolution of traction techniques in orthopedics, emphasizing the transition toward halo-gravity traction (HGT) as the method of choice for the preoperative optimization of patients with rigid spinal deformities, due to its safety profile and efficacy in relaxing musculoskeletal structures.

The special part is based on the analysis of four complementary studies evaluating the role of halo-gravity traction (HGT) in the treatment of severe adolescent idiopathic scoliosis.

Procedure safety was the central objective of the **first study**, which analyzed the associated complications. Although the incidence of minor complications was high (94.7%), manifested mainly by cervical pain and sensitivity at the pin sites, the absence of major neurological complications validated the safety of the method. The study also highlighted the importance of traction duration, showing that periods longer than 25 days correlate with significantly superior correction (49.96% versus 32.32%).

The second study aimed to evaluate the impact of HGT on preoperative Cobb angle reduction and to identify predictive factors for correction success. The results demonstrated a mean Cobb angle reduction of 26.09% through traction, reaching a final postoperative correction of 64.58%. An essential conclusion was that the efficacy of the method is independent of age, Risser score, or Lenke curve type, confirming the universal applicability of HGT.

In addition, **the third study** compared radiological outcomes between patients who benefited from preoperative traction and those who underwent direct posterior spinal fusion. The data confirmed the superiority of the method, with the HGT group achieving a final correction of 63.3%, compared with only 50.0% in the group without traction, positioning HGT as an independent predictor of an optimal surgical result (with an additional 14.6% correction).

Biomechanical perspectives were deepened in the **fourth study**, which evaluated HGT as a method of preoperative optimization for severe and rigid deformities (Cobb > 80°). Using linear mixed models, the research demonstrated a reduction in the main Cobb angle from 82.00° to 56.95° under the exclusive action of traction, accompanied by significant axial elongation of the T1-S1 segment (from 40.88 cm to 44.79 cm).

A major theoretical contribution of this study is the validation of the differentiated biomechanical behavior of the curves: while the main curve is directly dependent on vertical distraction vectors ($p = .041$), the secondary curve shows structural autonomy ($p = .482$), functioning as an independent postural rebalancing mechanism.

By synthesizing this evidence, the thesis demonstrates that halo-gravity traction allows efficient pre-processing of rigid deformities, transforming the spine into a more malleable structure and reducing neurological risks. HGT is not only a tool for numerical correction, but a complex biomechanical process that facilitates vertebral realignment through mechanisms of direct distraction for the main curve and autonomous adjustment for the secondary curve, thus ensuring optimal global trunk balance.

The elements of originality and the personal contribution of this thesis lie in the integrated approach to the surgical management of severe adolescent idiopathic scoliosis, offering a valuable perspective both clinically and biomechanically**.**

The originality of the research is supported, first of all, by the rigorous comparative analysis of the efficacy of halo-gravity traction (HGT) versus direct surgical intervention. The study demonstrates with solid statistical arguments that HGT is not merely an adjuvant procedure, but an independent predictor of the surgical outcome, capable of generating an approximately 14.6% correction gain compared with conventional techniques. This validation provides the clinician with an essential predictive tool in planning treatment for severe curves.

Another element of novelty is the identification of the resilience profile of the spine under traction. Through the use of Linear Mixed Models, the work elucidates a biomechanical mechanism less explored in the literature: the differentiated behavior of curves. Demonstrating that straightening of the main curve is strictly dependent on axial elongation, while the secondary curve functions as an autonomous rebalancing mechanism, redefines the way we understand spinal plasticity under vertical loading.

The thesis also contributes to the optimization of therapeutic protocols by establishing a golden traction interval (21-28 days), providing a scientific basis for the duration of preoperative hospitalization. Its originality also lies in demonstrating that the benefits of HGT are independent of demographic factors or skeletal maturity (Risser score), which extends the indication of the method to a broader range of patients and dispels the prejudice that traction efficacy would be limited by older age or advanced structural rigidity.

Through the detailed analysis of complications, the thesis transforms HGT from a procedure historically perceived as risky into a safe and controllable preoperative preparation method that not only facilitates the surgeon's work but also significantly reduces intraoperative neurological risks, placing patient safety at the center of therapeutic practice.

Regarding the project's limitations, it is necessary to acknowledge the retrospective nature of the component studies, which may introduce confounding variables dependent on the evolution of surgical protocols over the analyzed period. The sample size, although representative for the severe case mix of a specialty center, could benefit from expansion through multicenter studies to increase the statistical power of result generalization. Another inherent limitation is the absence of very long-term evaluation (on the order of decades) of quality of life and respiratory function after fusion, elements that are essential for understanding the full systemic impact of halo-gravity traction (HGT).

Starting from these premises, future research directions aim at moving toward prospective randomized studies that could improve patient selection for HGT. A major opportunity for exploration lies in the use of 3D modeling technologies and personalized biomechanical simulations, which could allow the surgeon to anticipate with precision the response of the main and secondary curves to distraction forces before actual halo application.

Future research should focus on correlating traction parameters with markers of soft-tissue regeneration and with changes in peri-instrumental bone density, in order to establish not only the optimal duration of traction, but also the intensity of the applied forces according to the structural quality of the spine. Integration of quality-of-life assessment through standardized instruments (such as SRS-30) at all treatment stages will remain a priority, thus ensuring that radiological success is matched by complete functional and psychosocial recovery of the adolescent.

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