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ORIGINAL ARTICLE

NEW PERSPECTIVES IN SCOLIOSIS AND SPINAL DEFORMITIES:
AN UPDATE FROM THE 2023 ANNUAL SOSORT MEETING

Long-term outcome after brace treatment of Scheuermann's kyphosis: an observational controlled cohort study

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ABSTRACT

BACKGROUND: In the literature, there are several papers on Scheuermann's kyphosis. It is a structural deformity of the spine that is characterized by anterior wedging of 5° or more of 3 adjacent thoracic vertebral bodies with kyphosis measuring greater than 45° between T5 and T12. Bracing treatment is able to obtain, during skeletal growth, remodeling of the deformed vertebrae.
AIM: The aim of this study was to evaluate the effectiveness of conservative treatment in Scheuermann's kyphosis at a minimum follow-up of 10 years.
DESIGN: This is an observational controlled cohort study nested in a prospective clinical on-going database in patients with Scheuermann kyphosis.
SETTING: Inpatients and outpatients in Rome.
METHODS: From a consecutive series of patients included in a prospective database, we selected 158 patients with thoracic Scheuermann's kyphosis who were treated using an anti-gravity brace: 93 males and 65 females. The mean age at the beginning of the treatment was 14 years. The time bracing prescribed was a max of 20 hours daily and a min of 16 hours daily. Weaning was started when a full recovery of vertebral geometry was seen on a lateral radiograph view or when growing was ended. Radiographical measurements were performed on radiographs from a lateral projection at baseline (t1), at the end of the treatment (t2) and at 10 years of minimum follow-up (t3). To avoid the great variance in the range of curve angles in thoracic kyphosis (TK) that rely on the radiological position, X-rays were performed observing the following position: standing with head straight, arms bent at 45° and hands lightly placed on a support. The anterior wedging angle (Alpha) of the apex vertebra and the degrees of the curve (Cobb methods) were analyzed using statistical analysis.
RESULTS: The results from our study showed that in 158 patients with TK curves, the mean Cobb angle was 57.6±6.3 SD at baseline, 43.3±7.8 SD at the end of treatment and 44.49±7.4 SD at ten years of follow-up. The alpha angle was 14.43±2.535 SD at baseline and 8.571±3.589 SD at the end of treatment, and after ten years of follow-up, it was 8.654±3.57 SD. The mean duration of treatment was 28.42±12.07 months, and the mean follow-up was 128.3±11.07 months. The difference between baseline and end of treatment, tested with the one-way ANOVA comparisons test, was significant ($P<0.0001$) for both Cobb angle and alpha; instead, the difference between the end of treatment and follow-up was not significant ($P=0.3277$).
CONCLUSIONS: The results confirm that conservative treatment in Scheuermann's kyphosis during skeletal growth is effective. Bracing treatment can remodel the deformed vertebrae.
CLINICAL REHABILITATION IMPACT: At the 10-year follow-up after bracing, kyphosis curve correction was stable over time.

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KEY WORDS: Scheuermann disease; Conservative treatment; Follow-up studies.

Scheuermann's disease is an idiopathic structural deformity of the thoracic spine in the sagittal plane. It was first described by Scheuermann in 1920 as a condition distinct from postural kyphosis based on spine stiffness; he used the term "osteochondritis juveniles dorsi,"[1] but the condition is universally known today as Scheuermann's kyphosis. The typical radiologic criteria of Scheuermann's kyphosis include wedging of three consecutive vertebrae (more than 5°) with no evidence of congenital, infectious, or traumatic disorders of the spine.[2] These criteria are extensively acknowledged and used today. In addition, there are other pathologic changes, such as endplate irregularity, loss of disc space height, Schmorl's nodes (in some cases), and anterior detachment of the epiphyseal region of the vertebra.[3] The disease has a prevalence ranging from 4% to 10% of the population.[4, 5] The etiology of Scheuermann disease remains unclear; however, multiple theories have been suggested. Scheuermann thought that osteonecrosis of the vertebral ring apophysis caused longitudinal growth arrest of the anterior vertebral plate, thus causing wedging of the vertebrae.[1] Schmorl postulated that disk material herniated through the vertebral end plates leads to weakening of the vertebral plate and disk height, vertebral body wedging, and node formation.[6] Other authors hypothesized that the softness of the vertebral endplate is likely due to predisposing genetic factors that influence the quality of matrix components (collagen types II and IX) and chondrocytes.[6, 7] Fotiadis *et al.* proposed that mechanical stress influences the severity of spinal impairment associated with Scheuermann's deformity.[8]

Clinically, the pathology is manifested by uncorrectable hyperkyphosis and may be associated with back pain.

Vertebral geometry changes in Scheuermann's kyphosis and the results of orthopedic treatment have been evaluated by radiographic measures of both curve magnitude and vertebral wedging on lateral X-ray projection.[9-13] However, in some cases, the clinical evolution of the deformity is not correlated with radiographic parameters.

Orthopaedic treatment aims to reduce pressure on the front part of the vertebral endplates and alleviate pain. It may also help in healing certain localized lesions. Consequently, bracing is indicated for painful Scheuermann's disease and/or mild kyphosis (between 45° and 65°).[5] Although positive results have also been shown in curves up to 70° Cobb,[14] there is a lack of robust data to support conservative treatment in these larger curves. Despite the apparent benefit of bracing treatment, the effect on the natural history and progression of disease remains under scrutiny.[15, 16] In a recent systematic review, Huq *et al.*[17] suggested that bracing provides less correction and might be less durable than surgery. This suggestion could be explained by recognizing that all available studies investigating bracing treatment have been small, retrospective, and limited to level IV evidence.[18] Therefore, the aim of this study was to evaluate the effectiveness of conservative treatment with an antigravity brace in Scheuermann's kyphosis with a long-term follow-up of a minimum of 10 years.

Materials and methods

We observed 158 consecutive patients with thoracic Scheuermann's kyphosis from our database treated with an antigravity brace between 2004 and 2010. Ethical clearance was obtained from our centre's clinical research ethics (prot. n.599), as per the 1964 Declaration of Helsinki. All patients and their parents gave informed consent for enrolment in the study.

Ninety-three patients were male, and 65 were female. The mean age at the beginning of the treatment was 14.2±1.8 years.

Inclusion criteria: thoracic kyphosis (TK) greater than 45°; Risser score between 0 and 2 at baseline; apex T7 or lower; and no contraindication to brace treatment.

Exclusion criteria: TK greater than 75°; BMI>25; concomitant musculoskeletal diseases; neurological diseases; metabolic diseases; the presence of congenital spine deformities; and previous spinal surgery.

The mean curve magnitude before treatment, measured by Cobb's method, was 57.8°, which falls within the guidelines for conservative treatment.[19] All cases were treated with anti-gravity braces (Figure 1).

The antigravity brace consists of a plastic valve structure, a front opening and an adjustable sternal metal structure. The profile is shaped posteriorly below the scapulae, and at the height of the midline, the valve is extended up to the apex of the kyphosis. The principle that makes the brace is the three-point concept. The mechanical efficacy is obtained through a direct push on the kyphosis apex and a counterthrust on the sternum obtained with a sternal plate connected to the valve *via* two adjustable rods placed at the level of the sternoclavicular junction. The third point consists of the reduction of hyperlordosis, obtained with pressure on the abdominal cavity.

The time spent in the brace was a minimum of 18 hours per day. Clinical review was conducted every 3 months. These frequent visits aimed to facilitate and verify compliance by establishing an open and friendly relationship with

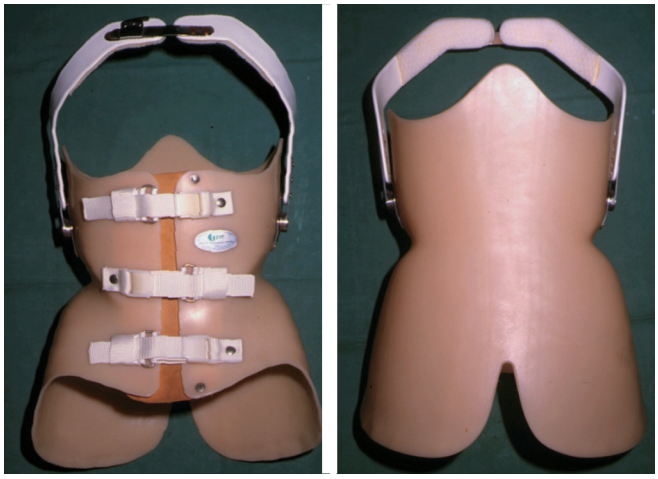

Figure 1.—Antigravity brace.

the patients. Frequent checks were also made to increase bracing efficacy over time. Weaning was started when a full recovery of vertebral geometry was seen on a latero-lateral radiograph view or when growth was finished. No exercises were performed.

Lateral X-rays were performed at our radiology department, and patients were evaluated in a standing position with their head straight, arms bent at 45° and hands placed on a support. Radiographic measurements were recorded at the beginning (t1) at the end of the treatment (t2) and at 10 years of minimum follow-up (t3).

Vertebral geometry at t1, t2 and t3 was evaluated according to the following parameters: Cobb degrees for kyphotic curve magnitude and anterior wedging angle (ALFA) of the apex vertebra. All parameters were measured by two independent observers. The ALFA angle was determined by measuring the angle between two lines along the superior and inferior vertebral endplates. These parameters were chosen because they were shown to be the most significant in a previous study.[20]

Statistical analysis

The mean and standard deviation of the kyphosis degree as the Cobb and ALFA angles at baseline (t1), at the end of treatment (t2) and at follow-up (t3) were calculated.

A repeated measures mixed model was used to investigate the treatment effect on both Cobb and alpha parameters and whether this effect was moderated by the duration of the treatment. A P value of less than 0.05 was considered significant, and Bonferroni correction was applied when necessary.

Statistical analysis was carried out using Stata® (Version 17, StataCorp LLC).

Data availability

The data associated with the paper are not publicly available but are available from the corresponding author on reasonable request.

Results

The results from our study with 158 patients showed that the mean thoracic curve magnitude was 57.6±6.3° SD at baseline, 43.3±7.8° SD at the end of treatment and 44.49±7.4° SD at the ten-year follow-up. The alpha angle was 14.43±2.535° SD at baseline, 8.571±3.589° SD at the end of treatment and 8.654±3.57° SD at ten years of follow-up. The mean duration of treatment was 28.42±12.07 months, and the mean follow-up was 128.3±11.07 months (Table I).

Regarding the treatment effect on alpha, after Bonferroni correction (0.05/3=0.017), there was a significant difference between T1 and T3 (P<0.001) and T2 (P<0.001). No significant differences were found between T2 and T3 (P=0.614) (Figure 2).

Regarding the treatment effect on thoracic Cobb magnitude, after Bonferroni correction (0.05/3=0.017), there was a significant difference between T1 and T3 (P<0.001) and T2 (P<0.001) and between T2 and T3 (P=0.002) (Figure 3).

The effect of treatment on alpha was significantly (P<0.001) moderated by the duration of the treatment itself. In fact, the effect of the treatment on Alpha was not the same at different treatment durations (Figure 4). In this case, the treatment duration was treated as a continuous variable, in which case the developed model would be considered to be a cubic growth model. The likelihood-ratio test was used to test the difference between nested models (*i.e.*, linear, quadratic, cubic).

Accordingly, the effect of treatment on Cobb angle was significantly (P<0.001) moderated by the duration of the

TABLE I.—*Radiographic and main data.*

	Time of treatment in months	Cobb t1	Cobb t2	Cobb t3	Follow-up in months	Alpha t1	Alpha t12	Alpha t3
Mean	28.42	57.6°	43.28°	44.49°	128.3	14.43°	8.571°	8.654°
SD	12.07	6.31	7.871	7.421	11.07	2.535	3.589	3.573
SE of Mean	0.9698	0.502	0.6262	0.5904	0.8809	0.203	0.2873	0.2861

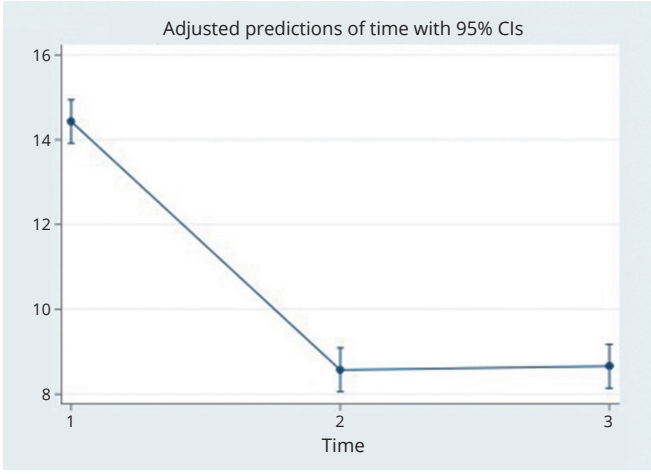

Figure 2.—Alpha degrees at baseline t1, end of treatment t2 and at follow-up t3.

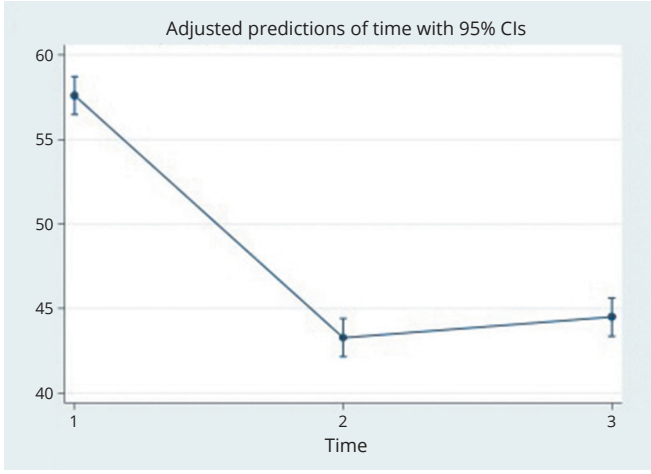

Figure 3.— Cobb degrees at baseline t1, end of treatment t2 and at follow-up t3.

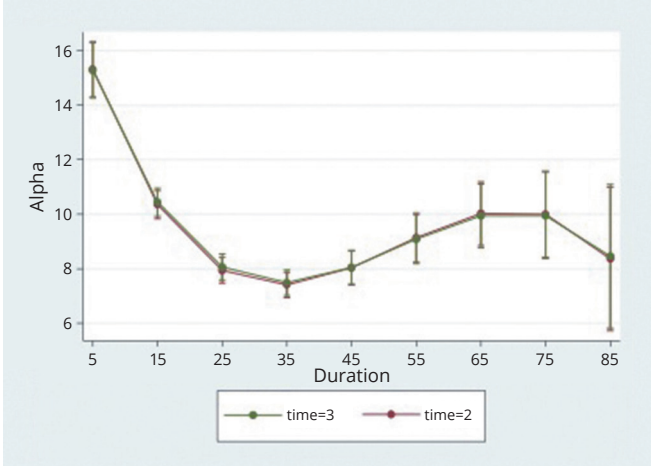

Figure 4.—Prediction curve of Alpha related to duration of treatment.

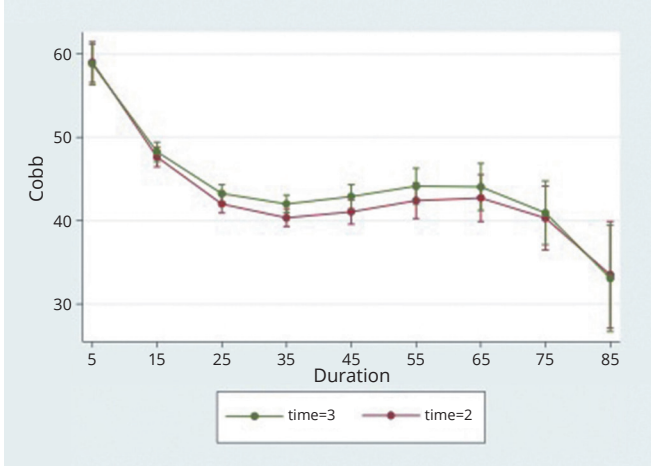

Figure 5.—Prediction curve of Cobb related to duration of treatment.

treatment itself. However, the treatment duration magnitude effect was observed, and the effect of the treatment on Alpha was not the same at different treatment durations (Figure 5).

Both Figure 4, 5 demonstrate a moderate correlation of correction with the duration of treatment. This can be attributed to the varying severity of hyperkyphosis, as there are instances that achieve correction in a shorter time.

Discussion

The aim of our study was to evaluate the effectiveness of conservative treatment in Scheuermann's kyphosis at a minimum follow-up of 10 years.

While the prognosis of untread Scheuermann disease has been suggested to be benign, there is a lack of consensus in the literature. In fact, many authors report that structural hyperkyphosis in adolescents causes back pain and body image dissatisfaction during sensitive developmental ages. It has also been reported that curves greater than 65° may continue to progress even after skeletal maturity, thus leading, in adulthood, to very severe deformity, chronic back pain, lower quality of life and poorer general health compared with the general population.[5] Brace treatment of Scheuermann's kyphosis is indicated for painful and/or mild kyphosis (45°<TK°<65°), while its efficacy in the management of severe kyphosis, greater than 70°, remains unclear and lacks consensus.[14-17]

Murray *et al.* found that untreated patients, with Cobb <85° at 32 years follow-up, suffer more from back pain than the general population, but without differences in the number of days absent from work for back pain and no interference with activities of daily living or for recreational activities. Additionally, the patients reported little concern with their physical appearance.[22] Ristolainen *et al.*, in a study performed on 19 patients with moderate Scheuermann disease who were followed for 46 years, observed a moderate worsening in the Cobb degree and in the mean vertebral wedge angle. They also reported back pain, but this was not correlated with curve magnitude and progression. Restrictive lung disease was observed only when kyphosis was >100°.[21]

In the literature, there are few articles regarding the impacts of bracing on Scheuermann's disease, and in most cases, they concern Milwaukee braces. Predictors of a promising outcome include improved flexibility of kyphosis, early instigation of bracing, Cobb angle <65°, initial improvement of the curve by >15° with brace, and skeletal immaturity. Rigid kyphosis >65°, vertebral wedging >10°, and limited or no remaining spinal growth are predictors of poor outcome. With correct patient selection, conservative treatment can achieve an improvement in kyphosis and the reversal of vertebral wedging. However, once brace wear ceases, the correction is partly lost in at least 30% of patients.[22-28] Bradford *et al.* studied 155 patients with Scheuermann's disease who were treated with the Milwaukee brace, and they reported an average kyphosis decrease from 59° to 39° after 34 months,[23] while Montgomery[25] and Erwin encompassed part-time bracing with an average of 18 hours for 18 months in regard to Scheuermann's treatment. Thirty-nine participants were studied who completed brace wearing. The average curve improved from 62° to 41°. In their study, where the initial patients numbered 62, only 39 completed the treatment, and furthermore, in those who underwent part-time treatment, at the longer-term follow-up (over 18 months), 15 degrees of correction was lost. A recent study by Sharifi *et al.* reported poor compliance with the Milwaukee brace, and they found that the brace was worn less often than reported by the patients and/or their parents.[29]

All our patients were treated with antigravity full-time braces. The average duration of brace wearing was 28 months for a mean of 20 hours a day, and the mean follow-up was 128 months. The improvement in the kyphotic angle was 14°, and it was stable at the ten-year follow-up. Only two patients discontinued the brace early due to poor compliance. This study confirms that conservative treatment in Scheuermann's kyphosis during skeletal development is effective and facilitates remodeling of the wedged vertebrae. The biomechanical principles of the antigravity brace and its action on wedged vertebrae have been described previously.[30, 31] Based on this long-term follow-up, we confirm that using the ALFA angle of the apex vertebra to study vertebral reconstruction allows us to achieve a better knowledge of the response to anti-gravity brace treatment.

The strengths of this study undoubtedly lie in its extended follow-up period and the measurements conducted by two operators.

Limitations of the study

The study limitations include the young age of patients at follow-up, the hours of compliance, only by the oral confirmation of the patients, and the low BMI, which could potentially lead to an overestimation of the effectiveness of the brace.

Conclusions

The results confirm that conservative treatment in Scheuermann's kyphosis during skeletal growth is effective. Furthermore, bracing treatment can remodel the wedged vertebrae, and the correction is stable over time. We reiterate that vertebral remodeling is a complex mechanism and that ALFA angles allow us to reach a better understanding of the Scheuermann spine response to anti-gravity brace treatment.

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Conflicts of interest
The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

Authors' contributions
All authors read and approved the final version of the manuscript.

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