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Research Article

Adolescent Idiopathic Scoliosis: Effects of Brace on Orthostatic Postural Control

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Abstract

Purpose: Adolescent Idiopathic Scoliosis (AIS) is associated with neurosensorial disorders that perturb orthostatic posture control. A spinal brace worn for up to 23 hours per day is the main treatment for AIS. The impact of brace-induced correction of scoliotic curvature on orthostatic posture control is unknown. We use posturography recordings to evaluate the effect of wearing the CTM brace on orthostatic postural control in AIS.

Methods: This is a single-center retrospective analysis of routine clinical data. Routine posturography recordings were made in 83 patients with AIS (mean age 14.45±1.77 y; median Cobb angle 31°) using a force plate. The position of the center of pressure and its displacement were recorded in the standing position with and without the anti-scoliosis CTM brace under three test modalities: eyes open on hard plate or on soft plate; eyes closed on hard plate. Patients were their own controls.

Results: Center of pressures way area was significantly increased in all three modalities when the patients wore their CTM brace, particularly in modality "eyes closed" (363 mm^2 with brace vs 307 mm^2 without brace, $p<0.001$). For all conditions, center of pressure velocity was also significantly increased with brace. Posturographic parameters were aggravated most with braces that reduced the scoliotic curvature more than 40%.

Conclusion: This study demonstrated that posturographic parameters are aggravated in patients with AIS when they wear their brace. This finding should be taken into consideration for planning rehabilitation programs to improve orthostatic posture control and for the design of future anti-scoliosis braces.

INTRODUCTION

Adolescent idiopathic scoliosis (AIS) is a tridimensional structural deformity of the spine. Prevalence of AIS is 0.5% to 2% in the population aged 8-15 years [1]. There are many complications – altered body image, psychological disorders (anxiety, depression), musculoskeletal pain, respiratory disorders, neurological disorders – warranting medical or eventually surgical treatment [1]. The pathogenesis of AIS is probably multifactorial. There is a confirmed genetic factor and a probable neurosensorial factor, notably perturbed orthostatic posture control [2]. Orthostatic posture control, i.e. the capacity to achieve, sustain or restore balanced posture in the standing position, is required for bipedal movement [3]. Multisensorial input from vestibular, visual and somesthetic receptors is used to construct the spatial referential required to maintain balance. Several studies have shown that AIS is associated with neurosensorial disorders and perturbed orthostatic posture control, particularly perturbed dynamic proprioception, vestibular disorders, biased perception of the gravitational vertical [4-6]. Posturographic recordings using a force platform provide an objective quantifiable assessment of orthostatic posture control [5]. This method is particularly well adapted for AIS [7].

Orthopedic care using a spinal brace is currently the gold standard medical treatment for AIS [8]. The purpose of this restrictive device is to correct the scoliotic deformity and thus, ideally, reduce the Cobb angle by at least 50% [9]. Rigid braces providing tridimensional correction that are worn for 12-24 h per day appear to be the most effective, in particular the Chêneau-Toulouse-Munster (CMT) brace [9]. Nevertheless, evidence is lacking concerning the impact wearing a spinal brace has on orthostatic posture control in AIS. Indeed, it is unknown whether brace-induced correction of the spinal curvature would improve orthostatic posture control or on the contrary would aggravate it because of the imposed rigidity.

The purpose of this work was to use posturographic recordings to evaluate the effect of wearing the CTM brace on orthostatic posture control in adolescents with AIS.

MATERIAL AND METHODS

Hypothesis

In AIS, wearing a brace induces modification of orthostatic postural control.

Design

This was a single-center study designed to analyze retrospectively data collected prospectively.

Participants

The study population was recruited among patients attending our pediatric outpatient clinic devoted to spinal disease. Inclusion and non-inclusion criteria are described in Table 1. The clinical and radiological features of our population are presented in Table 2. The scoliotic adolescents and their legal guardian were given written information about use of their medical charts for research purposes. Data were examined anonymously, in compliance with the Helsinki Declaration of patients' rights. Our center has a permanent authorization for retrospective studies (CNIL-MR003). Our AIS patients received routine care and there were no supplementary invasive explorations performed for the purpose of this study.

Outcome measures

- Posturography recordings were made within the framework of routine follow-up care for AIS patients. One trained clinician with several years of experience in posturography recordings used the same SATEL® (Figure 1), force plate for all patients. This platform has four captors that monitor the force applied on the plate with 2.0 ±0.1 mV/V sensitivity, 51.2s acquisition time, and 40Hz sampling frequency. There were three test modalities: eyes open (EO) on a hard plate; eyes closed (EC) on a hard plate; EO on a soft plate (Podialène Evalène, Orthomic® pad: thickness 3 mm, shore 40, density 250). For each test, the subject stood barefoot on the force plate placed 90cm in front of a bare white wall, heals 2 cm apart with feet forming a 30° angle (Figure 2). The instructions were "do not move your feet", "leave your arms along the side", "look straight ahead" or "close your eyes" depending on the testmodality, and "count outloud slowly". Recordings were made with and without the CTM brace for each test modality, with two runs for each test, the results of the second run being retained for data analysis. Tests with and without the CTM brace were made in random order to avoid learning bias, although for convenience all tests with the brace were run in a single sequence. Subjects could wear corrective lenses during the tests. For the tests with the CTM brace, the device was worn tight as usual. The subject stepped off the platform after each test to walk around during a 1-min rest interval. Three posturographic parameters were recorded: center of pressure (COP), COP sway area, and COP velocity. The COP, defined by the mean medial-lateral value (x-axis) in the frontal plane and the mean antero-posterior value (y-axis) in the sagittal plane, was expressed in millimeters (mm). COP sway area, defined as the surface area of the ellipse containing 90% of the sampled COP positions, was expressed in mm^2. COP velocity, which reflects the dispersion of COP positions providing information on orthostatic posture control, was expressed in mm/s.

Table 1: Inclusion and non-inclusion criteria for patients with adolescent idiopathic scoliosis (group AIS).

Inclusion criteria all criteria necessary for inclusion	**Non-inclusion criteria** one criterion sufficient for exclusion
1. Adolescent ≥ 12 years and < 18 years. 2. Idiopathic scoliosis defined by the presence of a three-dimensional deformity of the spine, associating criteria (a), (b), (c) and (d): (a) frontal scoliosis angle (radiographic Cobb) ≥ 20° without brace, measured on a recent anteroposterior view of the spine in the upright weight-bearing position (EOS X-ray <3 months), (b) the principal curvature is thoracic with right convexity, (c) vertebral rotation defined as a clinical gibbous deformity measuring on the forward bending test, with scoliometer, (d) absence of other causes of scoliosis. 3. First wearing of CTM brace 4. Wearing CTM brace for at least 1 month and less than 3 months, and at least 12 hours / 24. 5. The minor and legal guardians informed, in writing and orally, that the data recorded in the medical chart may be used anonymously and retrospectively for research purposes.	1. Subject with neurological disorder (signs of pyramidal irritation, signs of cerebellar disorder…) 2. Visual deficiency 3. Known vestibular disorder 4. Pathological hyperlaxity compatible with secondary scoliosis (Beighton's score ≥5/9) 5. Secondary scoliosis (tumor, malformation, neurological ...) 6. Leg length discrepancy > 20 mm at the physical examination 7. Major balance disorder with risk of falling 8. Evaluation impossible due to psychic, social or geographical problems, or inability to understand.

Table 2: Baseline population.

Group AIS (n = 83)	
Age (mean ± standard deviation)	14.4 years ± 1.7
Sex ratio male/female	15/68
BMD (median ± intervalle interquartile)	18.5 kg/m² (3.9)
Cobb angle of main curvature without brace (median ; intervalle interquartile)	31,5° (14)
Cobb angle of main curvature with brace (median ; intervalle interquartile)	19° (15.8) (for 45 subjects)
% correction main curvarture with brace (median ; intervalle interquartile)	35.7% (28.6) (for 45 subjects)
Main curvature	
Lumbar and thoraco-lumbar curvature	42%
Thoracic curvature	58%

AIS : Adolescent Idiopathic Scoliosis

Table 3: Results of posturographic measures, with and without brace. Results are presented in median with, in brackets, interquartile range.			
	Posturographic results without brace	Posturographic results with brace	p
COP sway area EO (mm^2)	307 (iq 253)	363 (iq 248)	p < 0.001*
COP sway area EC (mm^2)	349 (iq 237.5)	389 (iq 312.5)	p < 0.01*
COP sway area YO/SP (mm^2)	295 (iq 197.5)	353 (iq 280.5)	p < 0.005*
X EO (mm)	5.4 (iq 8.9)	5.6 (iq 8.2)	p = 0.871 NS
X EC (mm)	5.7 (iq 9.7)	5.2 (iq 9.9)	p = 0.774 NS
X EO/SP (mm)	5.7 (iq 9.5)	6 (iq 6.1)	p = 0.58 NS
Y EO (mm)	-34.4 (iq 25)	-35.4 (iq 21.9)	p = 0.807 NS
Y EC (mm)	-33.2 (iq 21.2)	-30.4 (iq 23.1)	p = 0.239 NS
Y EO/SP (mm)	-36.7 (iq 23.4)	-34.8 (iq 22.3)	p = 0.038*
COP Velocity EO (mm/sec)	10.9 (iq 4.3)	11.6 (iq 2.9)	p < 0.001*
COP Velocity EC (mm/sec)	12.6 (iq 4.2)	13.8 (iq 5.3)	p < 0.005*
COP Velocity EO/SP (mm/sec)	10.8 (iq 3.5)	11.6 (iq 3.8)	p < 0.0005*

COP: Center of Pressure; EO: Recording Modality « Eyes Open (EO) on a Hard Plate; EC: Recording Modality « Eyes Closed (EO) on a Hard Plate; EO/SP: Recording Modality « Eyes Open (EO) on a Soft Plate »; X: Mean Medial-Lateral Value (X-Axis) in the Frontal Plane; Y: Mean Antero-Posterior Value (Y-Axis) in the Sagittal Plane; Mm: Millimeter; Sec: Second; Iq: Interquartile Range; *: Significant Difference; NS: No Significant Difference

Table 4: Results by correction with brace: group with correction of Cobb angle < 40%, group with correction of Cobb angle ≥ 40%. Result are presented in percentage difference of posturographic measures between the 2 groups.		
	Group with correction of Cobb angle < 40% (n = 27)	Group with correction of Cobb angle ≥ 40% (n = 18)
COP sway area EO (mm^2)	+ 27.9%	+ 30.8%
COP sway area EC (mm^2)	+ 12.3%	+ 29.1%
COP sway area EO/SP (mm^2)	+ 31.9%	+ 25.6%
COP Velocity EO (mm/sec)	+ 7.2%	+ 50.7%
COP Velocity EC (mm/sec)	+ 7.6%	+ 8.4%
COP Velocity EO/SP (mm/sec)	+ 9.4%	+ 16.3%

COP: Center of Pressure; EO: Recording Modality « eyes open (EO) on a hard plate »; EC: Recording Modality « eyes closed (EO) on a hard plate »; EO/SP: Recording Modality « eyes open (EO) on a soft plate »; mm: millimeter; sec: second

Clinical and radiological assessments

Clinical and radiological data were collected during routine medical check-ups conducted by the same physician specialized in care for patients with AIS. Cobb angles were measured on EOS radiographs to limit radiation exposure [10]. No supplementary radiographic examination was required for the purpose of this study since patients had EOS explorations without the brace every six months as part of their standard AIS follow-up [8]. Anti-scoliosis CTM braces were prescribed as needed (first or revision brace). The prescribed brace was delivered within a delay of two to four weeks. One month after delivery of the CTM brace, an EOS radiograph was obtained with the brace to evaluate its efficacy [9]. The posturography recordings were made at this time. Thus, the two EOS radiographs (with and without brace) used for the purpose of this study were obtained less than three months before the posturography recording.

The following clinical and radiological data were collected for each subject: age, gender, body mass index in kg/m^2, Cobb angle of the braced and unbraced primary curvature, brace efficacy expressed in percentage, i.e. ($Cobb_{braced}$ – $Cobb_{unbraced}$) / $Cobb_{braced}$ x 100. With this formula, posturography results can be expressed as a function of brace-induced correction. Data for this variable were available for 45 patients. Two subgroups were defined according to the degree of Cobb angle correction: <40% correction (n=27 patients); ≥ 40% correction (n=18 patients).

Data analysis

Statistical analysis was carried out using IMB SPSS® Statistics V22.0.0. The Shapiro-Wilks test was used to check normal data distributions. Variables with a non-normal distribution were analyzed with the Wilcoxon non-parametric test and described with the median value and interquartile range (Q1 - Q3). Variables with a normal distribution were analyzed with Student's *t* test and described with the mean and standard deviation (SD).

Data were considered significant with a 5% alpha risk ($p<0.05$).

Due to the small sample size, the statistical analysis could not be performed on variables expressed as a function of brace-induced correction. These results are presented as percent variation in posturographic parameters between braced and unbraced conditions.

RESULTS

Results are summarized in Tables 3 and 4.

COP on x-axis and y-axis

For the EO and EC modalities, the COP was displaced to the right and posteriorly in the unbraced condition (no significant difference with braced condition). For the EO on soft plate modality, there was a significant difference between the braced and unbraced conditions ($p<0.05$), with a smaller mean posterior displacement with the brace.

COP sway area

In all test modalities (EO, EC, EO on soft plate) COP sway area was greater in the braced condition. The difference is significant with the unbraced condition ($p < 0,01$).

COP velocity

There was a significant increase in COP velocity in the braced condition for all test modalities ($p < 0.01$).

Results expressed as a function of Cobb angle correction

The posturographic parameters tended to reflect less satisfactory balance in the braced condition when the Cobb angle correction was less than 40%.

DISCUSSION

Our study demonstrated that wearing the CTM spinal brace can induce less satisfactory balance with an increase instanding posturographic parameters, specifically COP sway area and COP velocity. A recent review of the literature analyzed ten studies focusing on this topic [11]. Most of these studies reported findings similar to ours although two did find that postural control was improved by wearing a spinal brace [12,13]. Unfortunately, these two studies included less than 15 subjects and did not evaluate the impact of wearing the brace on standing postural control as a function of the percentage of improvement in the scoliosis curvature. Not with standing, it is difficult to extrapolate our findings to a general hypothesis because of the retrospective nature of our study and the fact that certain measurements (braced Cobb angle) were not available for some patients. Further large-scale prospective studies would be needed. Furthermore, our decision to retain for analysis only the second run for each posturography test and to consider only static posturographic parameters could be debated. We made these methodological choices because of clinical considerations: our posturography recordings were made as part of routine follow-up procedures for AIS patients conducted on a static force plate and experience has shown that AIS patients tire quickly during multiple recordings. Nevertheless, taken together, our results are quite similar to those provided by other teams measuring standing posturographic parameters in unbraced AIS patients [5]. Indeed, earlier publications have reported greater postural instability in AIS, with a larger COP sway area and a mean medial-lateral displacement to the right and a mean antero-posterior displacement backward in unbraced AIS subjects compared with normal-development subjects [5]. Moreover, our results all go in the same direction, making protocol bias unlikely.

The less satisfactory posture control reflected by the increase in posturographic parameters observed when AIS patients wore their CTM brace could be interpreted in several ways.

First it is possible that the corrective brace has a direct perturbing effect on postural control. Indeed, it is known that human beings control bipedal locomotion on the basis of a spatial stabilization of the pelvis [14]. But for most orthopedic spinal braces, including the CTM brace, the necessary support is provided by the pelvis, leading to an inevitably more rigid trunk-pelvis complex [9]. This loss of freedom of movement and the compensatory reorientation of the pelvis limits the possibilities for stabilizing the pelvis in space [15]. In the healthy subject, other postural strategies can be used for balance, e.g. stabilization of the head in space [14]. But in the AIS patient, this compensatory mechanism is limited due to perturbed spatial stabilization during locomotion [16]. Thus, it is quite possible that standing postural control could be impaired by the CTM brace per se.

Second, perturbed balance in the standing position is a well-known feature of AIS, suggesting that a primary cause not necessarily simply implying mechanisms adapting balance control to the trunk deformity could be involved [6]. This would be in agreement with the finding that brace-induced improvement in the scoliosis curve does not improve standing postural control [11]. The same observation was noted when comparing posturography recordings before and after arthrodesis surgery for AIS [17,18]. The reduction of the spinal deformity by arthrodesis does not lead to improvement in posturographic parameters [17,18].

Third, our findings might be explained by perturbed central integration of sensorial information in AIS [19]. It is known that AIS patients have difficulty re-weighting sensorial information in conflicting situations (sensorial conflict, transient suppression of one sensorial modality…) [20]. And the brace obviously has a "sensorial perturbation" effect. In our study, all of the patients were wearing a new CTM brace that had been delivered less than three months before the test. The "learning" curve may have been too short for these AIS patients to adopt an optimal postural control strategy adapted to their new situation, especially since some of the patients wore their brace only 12 h a day.

Our results also reveal that postural control was inversely related to CTM brace effectiveness in reducing the spinal deformity. Like all corrective braces, the CTM brace treats the consequences of a pathophysiological process and not its cause. Thus, the patient's postural control system has to learn how to cope with the perturbing effect of the causal mechanism. This learning process would thus be reflected in the perturbed posturographic parameters as the body attempts to re-establish its prior postural status. This would explain why increased brace efficacy is associated with increased perturbation of postural control.

Though our findings cannot be explained by one straightforward mechanism, there are important practical implications.

Less effective standing postural control when wearing the CTM brace could have negative implications for the AIS patient, especially since neurosensorial alterations are already present [4-6,20]. Several studies have demonstrated a significant association linking disc-related lower back pain with perturbed orthostatic postural control [21]. But in AIS, discal involvement is seen as an alteration of the annulus fibrosus [22]. The combination of these two phenomena, perturbed orthostatic postural control and discopathy, could have a deleterious potentializing effect in AIS, resulting in greater pain.

Our findings, together with those of others [8], raise the practical question of how long the spinal brace should be worn. It would be important to leave the spine unbraced several hours every day in order to avoid excessive degradation of orthostatic postural control. At the present time, most clinicians propose that AIS patients wear their spinal brace 12 hours a day [9]. To limit the impact of the brace on posture control, part of these 12 hours could be during the night when the subject is in a reclining position not implicating the mechanisms of standing postural control. It is also important to note that the bracing effect is maximal at night [23]. Indeed, deep sleep is accompanied by a peak in growth hormone [24,25]. To achieve the at least 12h/d goal, the brace could be worn at home, leaving the patient free during school and recreational activities. This would be favorable for social and sports activities. In addition, rehabilitation exercises specifically designed to enhance postural control are also indispensable [6,8].

The design of future spinal braces should also be revisited in order to achieve appropriate correction of spinal curvature yet preserve spinal mobility. Combining different materials with various characteristics – resistant yet highly flexible (carbon), or resistant, pliable and plastic (intelligent textiles) - would be helpful in achieving this goal. The challenge is significant, but we should be able to limit the impact of conventional spinal bracing on orthostatic postural control. The problem of limited freedom of movement for the pelvis would also be resolved.

CONCLUSION

Despite its limitations our study demonstrated spinal brace-induced aggravation of posturographic parameters. This would suggest that AIS involves a primary anomaly of orthostatic postural control. Moreover, this complication of orthopedic treatment should be taken into account for rehabilitation programs and for the design of future spinal braces.

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