"Effect of long-term orthotic treatment on gait biomechanics in adolescent idiopathic scoliosis"

Mahaudens, Philippe ; Raison, Maxime ; Banse, Xavier ; Mousny, Maryline ; Detrembleur, Christine

Abstract

Background context A previous study showed subtle biomechanical changes in the gait of unbraced adolescent idiopathic scoliosis (AIS) patients such as a reduction of pelvic, hip, knee, and ankle displacements. However, lumbopelvic muscles' timing activity was bilaterally increased during gait and correlated to excessive oxygen consumption as compared with healthy subjects. Usually, a brace, when indicated, is worn strictly for 22 hours every day in skeletally immature idiopathic scoliotic girls. To our knowledge, no study has assessed the long-term brace effect (6 months) on functional activities such as level walking. Purpose To assess the stiffening effects of 6 months' brace wearing on instrumented gait analysis in girls with thoracolumbar/lumbar adolescent idiopathic scoliosis. Study design/setting Clinical prospective study. Patient sample Thirteen girls diagnosed as progressive adolescent idiopathic scoliosis with left thoracolumbar/lumbar curves (curves ranging 25°...
Clinical Study

Effect of long-term orthotic treatment on gait biomechanics in adolescent idiopathic scoliosis

Philippe Mahaudens, PhD a,b,*, Maxime Raison, PhD c, Xavier Banse, MD, PhD d, Maryline Mousny, MD, PhD e, Christine Detrembleur, PhD b

a Rehabilitation and Physical Medicine Unit, Cliniques Universitaires Saint-Luc, Université Catholique de Louvain, 12, Ave. Hippocrate, 1200 Brussels, Belgium
b Institute of Neuroscience, Université Catholique de Louvain, 53, Ave. Mounier, Bte B1.53.04, 1200 Brussels, Belgium
c Institute Research Chair in Pediatric Rehabilitation Engineering, Ecole Polytechnique and Centre de Réadaptation Marie Enfant (CRME) Bureau GR-123, 5200 rue Bélanger Est, HIT 1C9 Sainte-Justine, Montréal QC, Canada
d Orthopaedic Research Laboratory, Cliniques Universitaires Saint-Luc, Université Catholique de Louvain, 53, Ave. Mounier, Bte B1.53.04, 1200 Brussels, Belgium
e Service d’Orthopédie et de Traumatologie de L’Appareil Locomoteur, Cliniques Universitaires Saint-Luc, Université catholique de Louvain, 12, Ave. Hippocrate, 1200 Brussels, Belgium

Received 7 January 2013; revised 9 July 2013; accepted 26 August 2013

Abstract

BACKGROUND CONTEXT: A previous study showed subtle biomechanical changes in the gait of unbraced adolescent idiopathic scoliosis (AIS) patients such as a reduction of pelvic, hip, knee, and ankle displacements. However, lumbopelvic muscles’ timing activity was bilaterally increased during gait and correlated to excessive oxygen consumption as compared with healthy subjects. Usually, a brace, when indicated, is worn strictly for 22 hours every day in skeletally immature idiopathic scoliotic girls. To our knowledge, no study has assessed the long-term brace effect (6 months) on functional activities such as level walking.

PURPOSE: To assess the stiffening effects of 6 months’ brace wearing on instrumented gait analysis in girls with thoracolumbar/lumbar adolescent idiopathic scoliosis.

STUDY DESIGN/SETTING: Clinical prospective study.

PATIENT SAMPLE: Thirteen girls diagnosed as progressive adolescent idiopathic scoliosis with left thoracolumbar/lumbar curves (curves ranging 25°–40°).

OUTCOME MEASURES: All patients underwent a radiographic and instrumented gait analysis, including assessment of kinematics, mechanics, electromyography (EMG), and energetics of walking.

METHODS: The scoliotic girls were prospectively studied at S1 (before bracing) and 6 months later at S2 (out-brace: treatment effect). The gait parameters were compared with those of 13 matched healthy girls. A paired test was conducted to evaluate the effect of the 6-month orthotic treatment in AIS girls. Student t test was performed to compare the scoliotic group at S2 and the healthy subjects to identify if the observed changes in gait parameters meant improvement or worsening of gait.

RESULTS: After 6 months of orthotic treatment in AIS, thoracolumbar/lumbar curves and apical rotation remained reduced by 25% and 61%, respectively. During gait, frontal pelvis and hip motions increased, contributing to an improvement of muscular mechanical work during walking. EMG activity duration of lumbopelvic muscles did not change except for the erector spinae muscles.

CONCLUSIONS: After 6 months of orthotic treatment, in an out-brace situation, the main structural thoracolumbar/lumbar curve remained partly corrected. Frontal pelvis and hip motion increased, contributing to an improvement of muscular mechanical work during walking. EMG activity duration of lumbopelvic muscles did not change except for the erector spinae muscles.
Introduction

Bracing is commonly prescribed for skeletally immature adolescent idiopathic scoliosis (AIS) with progressive curves greater than 25° [1–4]. Most braces are strictly worn (22/24 hours every day) [5,6] until the end of the residual growth, which corresponds to a period of 1 to 3 years. Several studies have investigated the immediate biomechanical effects of bracing on the spine, such as the interface pressure generated at the compression pads [7], radiological correction [1,8,9], and intragastric pressure [10]. Walking, which is the most common functional activity, has been previously analyzed in experimental protocols for the study of functional disabilities in AIS with a brace. Thus, the Milwaukee brace lowers energy expenditure during walking [11] by reducing chest mobility. Both rigid and more flexible braces reduce pelvis and hip kinematics [12]. Back muscle electromyography (EMG) patterns while walking are not changed with the brace as compared without the brace [13].

So far, long-term (>6 months) follow-up of orthotic-treated AIS patients have been limited to assessing the effectiveness of brace treatment in terms of radiographic curve progression, pain, quality of life, and psychological effects [14–22].

Many AIS patients reported that this long-term, daily restricting orthotic treatment forces them to greatly limit social activities [23] or habitual relations with others because of early fatigability and mobility restrictions [12]. However, no study, to our knowledge, has assessed the long-term effects of strictly worn braces on walking and its spatiotemporal, kinematic, mechanical, EMG, and energetic parameters in AIS.

Furthermore, considering the effect of scoliosis progression on gait parameters, our two previous studies [24,25], performed on scoliosis patients before any treatment, have shown that the scoliosis deformity generated changes in gait parameters compared with healthy subjects. These changes included a reduction of the frontal pelvic, hip, and shoulder motion; a decrease in muscular mechanical work; and an increase of EMG activity duration of the paravertebral muscles associated with the excessive energy cost of walking with as consequence poor muscle efficiency. The scoliosis patients included in these studies who were treated with orthotics were retested after 6 months of brace-wearing to assess the long-term effects of orthotic treatment on these gait parameters. Because it is logical that the radiological scoliosis curve correction would no longer be influenced by the orthotic treatment as soon as the brace (currently worn 22 hours per day) is removed for 18 hours, we expected to observe the same phenomenon on the gait parameters.

The objective of this study was therefore to assess the effect of orthotic treatment on gait variables (kinematic, EMG, mechanical, and energetic variables) in females with thoracolumbar/lumbar AIS after wearing a brace for 6 months. We hypothesized that the long-term effect of bracing treatment could induce a stiffening of the body, affecting functional daily walking.

Material and methods

Study population

Thirteen progressive [26] girls with AIS (14 [12–15] years, 157±8 cm, 48.5±8.4 kg, 19.5±1.9 body mass index) with a left thoracolumbar/lumbar primary structural curve according to the Lenke classification [27] were enrolled in the study. Patients presenting with leg-length discrepancy greater than 1 cm, locomotor disorders, back pain, neurological abnormalities, or any previous treatment for their back were excluded. Inclusion criteria for the indication of brace in AIS were [4,5]: skeletal immaturity, Risser 0 to 2, premenarcheal or postmenarcheal by less than 1 year, and a 25° to 40° Cobb angle on posteroanterior view radiographs.

Patients were instructed to wear (22 hours per day) a custom-made rigid underarm thoracolumbosacral orthosis (Chêneau brace) [28] molded by an experienced orthotist. Marks were made on the straps of the brace to ensure that the correct pressure was applied.

Each subject signed a consent form and participated freely in the study as approved by the local ethics board. Compliance was estimated by the orthopedic surgeon reviewing the patient at the 6 months’ clinical follow-up. A questionnaire to assess compliance was not administered.

The patients underwent radiographic examination without the brace (removed for 18 hours) and gait assessment (Fig. 1).

Radiological assessment

A posteroanterior full-spine standing radiograph was performed to evaluate the main Cobb angle curve [29], frontal body balance [30], and Risser sign [31] as described previously.

Instrumented gait analysis

The gait was assessed using a three-dimensional analysis, including synchronous kinematic, EMG, mechanical,
and energy variables. All data were simultaneously acquired on a motor-driven treadmill (Mercury LTmed, HP Cosmos, Germany) [32].

Segmental kinematics and spatiotemporal parameters (step length, cadence, and stance phase duration) were measured with the Elite system (BTS, Italy). Six infrared cameras measured, at 100 Hz, the three-dimensional (3D) coordinates of 22 reflective markers located on specific anatomical landmarks [33]. Measurements allowed computation of the 3D angular displacement and angular speed of the shoulder, pelvis, hip, knee, and ankle [34]. On each segmental angular displacement and speed curve expressed as a function of normalized stride (as a percent), the maximum and minimum angular positions were measured as well as the segmental range of motion, which was calculated as maximum angular position minus minimum angular position.

The electrical activity (EMG) of the quadratus lumborum, erector spinae, gluteus medius, rectus femoris, semitendinosus, tibialis anterior, and gastrocnemius muscles was bilaterally recorded by an EMG telemetry system (Telemg, BTS) using surface electrodes (Medi-Trace, Graphic Controls Corporation, NY, USA). The signals were digitized at 1,000 Hz, full-wave rectified, and filtered (bandwidth 25 to 300 Hz). The onset and cessation of muscle activity were determined as described by Van Boxtel et al. [35].

Kinematic and EMG data were normalized to 100% of stride, with 0% corresponding to the initial contact of left foot.

The total muscular mechanical work ($W_{tot}$) was the sum of the external work performed by the muscles of the body to move the center of body mass ($\text{COMb}$) relative to the surroundings, and the internal work performed by the muscles to move the body segments relatively to the $\text{COMb}$ [36].

The external work was computed from strain gauges measuring 3D-ground reaction forces according to Cavagna [37]. The internal work was computed from kinematic data [36,38]. The metabolic cost of walking was determined by the subject’s oxygen consumption ($\dot{V}O_2$) and carbon dioxide production ($\dot{V}CO_2$) both measured with an ergospirometer (Quark b2, Cosmed, Italy) [39]. The net energy cost was calculated as “the metabolic cost of walking minus the metabolic cost of standing” divided by speed [40]. The efficiency of positive work production by the muscles of the body was calculated as the ratio between $W_{tot}$ and the net energy cost [40].

Protocol

Radiographs and gait analysis were performed 6 months after having worn the brace for 22/24 hours daily (session 2=S2).

During this session, radiographs and walking assessments were performed without the brace, which had been removed for approximately 18 hours.

Each gait analysis session began with a resting period, during which the subjects stood barefoot on the treadmill [41] for the static calibration of kinematic variables. Thereafter, the subjects were asked to walk at a constant speed of 4 km/h for a few minutes until a steady state was reached. Then, the energy variables were computed for 2 minutes and the other variables were simultaneously recorded for 20 seconds and averaged for 10 successive strides. The mean value for each variable was used for statistical analysis.

Statistical analysis

All variables, in terms of the normal distribution and equality of variance, were presented in mean (±standard deviation). Statistical analysis was performed using the software SigmaStat version 2.0 (SPSS Sciences Software GmbH, Erkrath, Germany). The significance level was at $p<.05$.

Because no asymmetry was previously observed for the bilateral gait variables (kinematics and EMG) in normal subjects and the group of AIS patients addressed for the orthotic treatment [24], only variables of the convex side in patients were used for these statistical analyses.

A $t$ paired test was conducted to evaluate the effect of the 6-month orthotic treatment on radiological data and gait variables in the AIS sample (session 2=S2) as compared...
with the data obtained earlier, before treatment, for the same scoliosis group (session 1 = S1).

In a previous study, we demonstrated altered gait parameters in this scoliosis group prior to treatment as compared with healthy subjects [24,25]. Therefore, to identify if the observed changes in gait parameters meant improvement or worsening of gait, a second comparison using a Student t test was performed for the significantly changed gait variables between the scoliosis group at S2 and the healthy subjects included in the previous study. The power analysis was calculated for each parameter not significantly changed for which the p value was between .1 and .05.

Results

Demographic and radiographic results

Scoliosis patients did not show any significant changes in height, weight, body mass index, and age (Table 1). After 6 months of brace treatment, scoliosis patients did not have a statistically significant change in frontal balance (S1: −0.2±17.0 mm vs. S2: −4.9±18.0 mm; p = .27). However, the main structural thoracolumbar/lumbar curve was on average reduced by 25% (S1: 26.6±9.8° vs. S2: 19.8±12.9°; p = .025).

As orally reported to the surgeon during the consultation, all patients attested they wore the brace 22/24 hours as prescribed.

Effect of brace treatment on gait variables in AIS

With regard to the spatiotemporal variables at S2, the step length and stance phase were significantly increased, although the cadence showed a significant decrease (Tables 2 and 3). At S2, the frontal pelvic motion was significantly increased by 1.5° (p = .04), although the transversal shoulder motion was significantly reduced by 1.8° (p = .01).

After 6 months of brace treatment, the duration of EMG activity (expressed in percentage of gait cycle) was only bilaterally reduced in the erector spinae (decrease of 36%; p < .001) and tibialis anterior (decrease of 21%; p = .007) muscles.

At S2, the internal, external, and total mechanical work were significantly increased (p = .04, p < .001, and p = .014, respectively). The energy cost of walking and muscle efficiency increased but not significantly.

With regard to the not significantly changed parameters, the power of the performed tests was noted for each variable of which the p value of the statistics was higher than .05 and below .1. Only the muscle efficiency comparison showed a p value less than .1 (p = .09). For this statistical test, the power was moderate (0.29).

When comparing the significantly changed gait variables in the S2 scoliosis patients with those of the healthy subjects, we observed that the increase in the stance phase did not normalize the decreased stance phase observed in scoliosis patients before any treatment (S1). The frontal pelvic motion became normal after the 6-month bracing, but the frontal and transverse shoulder motions decreased. The lack of difference between scoliosis patients after 6 months of bracing and the healthy no-braced subjects for the frontal pelvic motion parameter showed a moderate statistical power (0.30).

The EMG activity duration of the erector spinae muscles was significantly increased in untreated AIS when compared with that of healthy subjects [24]. This duration was reduced after 6 months of orthotic treatment and became similar to that of healthy subjects [24].

The increase in external work did not compensate for the decrease previously described in S1 scoliosis patients and remained decreased when compared with that of the healthy subjects. Although the internal work was normalized to the healthy subjects’ values, the total work remained decreased.

Table 1

Comparison of demographic and radiographic variables between S1 (before bracing) and S2 (after 6-month bracing) AIS patients

<table>
<thead>
<tr>
<th>Variables</th>
<th>Scoliotic patients (N=13)</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>S1 mean (± SD)</td>
<td>S2 mean (± SD)</td>
</tr>
<tr>
<td></td>
<td>[minimum–maximum]</td>
<td>[minimum–maximum]</td>
</tr>
<tr>
<td>Demographic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Height (cm)</td>
<td>157 (8)</td>
<td>160 (6)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>48.5 (8.4)</td>
<td>49.1 (7.9)</td>
</tr>
<tr>
<td>BMI (kg m⁻²)</td>
<td>19.5 (1.9)</td>
<td>19.4 (1.6)</td>
</tr>
<tr>
<td>Radiologic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thoracolumbar/lumbar Cobb angle (°)</td>
<td>26.6 (9.8) [15–40]</td>
<td>19.8 (12.9) [7–40]</td>
</tr>
<tr>
<td>Balance (mm)</td>
<td>−0.2 (17.0) [−31 to 26]</td>
<td>−4.9 (18.0) [−30 to 30]</td>
</tr>
</tbody>
</table>

AIS, adolescent idiopathic scoliosis; NS, not significant; SD, standard deviation.

Note: Significant differences are shown in bold and are accepted for p ≤ .05.

* Median and quartile [25%–75%].

† Negative value represents a left trunk imbalance.
The energy cost of walking remained excessive in scoliosis patients even after 6 months of brace treatment as a consequence of persistent decreased muscle efficiency.

Discussion

Because wearing a brace in AIS is restrictive because of the constant pressure on the body, strict daily wear, long duration of treatment, and mobility restriction, bracing may affect long-term functional activities such as walking.

Although the aim of the study was not to analyze the effect of brace treatment on scoliosis curves, our results showed a 25% reduction of the lumbar curve on the radiograph assessment after 6 months of treatment. Prolonged efficacy of brace on reduction of scoliosis curves remains controversial. The Maruyama review study in 2011 reported that, compared to observation, bracing is more potent in preventing the progression of scoliosis but not correcting [42]. In addition, most patients attempt to imitate a cervical traction by pulling their head up and pushing their convex scoliotic spinal side to the the concave side during the radiological assessment. They are currently taught this by the physical therapist. These temporary postural adaptations are likely to modify the natural upright position as observed in the Krejci study[43]. Thus, the improvement observed in our study could be partly explained by the patient’s effort to maintain a corrected position during the radiological examination, which may have been learned during the physical treatment combined with the orthotic treatment.

In regard to the spatiotemporal parameters, the stance phase was bilaterally reduced by 1% to 1.5% in AIS patients, regardless of the session (before and after 6 months of orthotic treatment).

Table 2

<table>
<thead>
<tr>
<th>Variables</th>
<th>Healthy subjects</th>
<th>Scoliotic patients</th>
<th>S2 mean (±SD), N=13</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (±SD), N=13</td>
<td>S1 mean (±SD), N=13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spatiotemporal variables</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Speed (km/h⁻¹)</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Step length (m)</td>
<td>0.70 (0.02)</td>
<td>0.64 (0.02)</td>
<td><strong>0.69 (0.04)</strong></td>
<td></td>
</tr>
<tr>
<td>Cadence (step/min⁻¹)</td>
<td>111 (7)</td>
<td>117 (8)</td>
<td><strong>109 (7)</strong></td>
<td></td>
</tr>
<tr>
<td>Stance phase (%)</td>
<td>64.9 (1.0)</td>
<td>63.4 (0.8)</td>
<td><strong>64.0 (0.9)</strong></td>
<td></td>
</tr>
<tr>
<td>Segmental kinematic variables</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PPA frontal pelvis motion (°)</td>
<td>8.4 (1.5)</td>
<td>6.0 (1.1)</td>
<td><strong>7.5 (1.5)</strong></td>
<td></td>
</tr>
<tr>
<td>PPA sagittal pelvis motion (°)</td>
<td>2.6 (0.9)</td>
<td>2.7 (0.7)</td>
<td>2.7 (0.9)</td>
<td>0.05</td>
</tr>
<tr>
<td>PPA transversal pelvis motion (°)</td>
<td>7.3 (1.1)</td>
<td>7.6 (2.0)</td>
<td>7.5 (2.9)</td>
<td>0.05</td>
</tr>
<tr>
<td>PPA frontal hip motion (°)</td>
<td>13.0 (1.7)</td>
<td>9.6 (1.6)</td>
<td>11.4 (2.7)</td>
<td>0.36</td>
</tr>
<tr>
<td>PPA sagittal hip motion (°)</td>
<td>42.4 (3.3)</td>
<td>42.2 (4.0)</td>
<td>42.3 (3.9)</td>
<td>0.05</td>
</tr>
<tr>
<td>PPA transversal hip motion (°)</td>
<td>17.3 (2.7)</td>
<td>12.5 (2.6)</td>
<td>15.2 (4.4)</td>
<td>0.12</td>
</tr>
<tr>
<td>PPA frontal shoulder motion (°)</td>
<td>9.3 (1.3)</td>
<td>7.0 (1.8)</td>
<td>7.4 (1.6)</td>
<td>0.12</td>
</tr>
<tr>
<td>PPA sagittal shoulder motion (°)</td>
<td>3.1 (1.0)</td>
<td>3.8 (1.4)</td>
<td>4.0 (2.4)</td>
<td>0.05</td>
</tr>
<tr>
<td>PPA transversal shoulder motion (°)</td>
<td>4.7 (1.9)</td>
<td>4.8 (2.4)</td>
<td><strong>3.0 (1.6)</strong></td>
<td></td>
</tr>
<tr>
<td>PPA sagittal knee motion (°)</td>
<td>62.2 (3.8)</td>
<td>56.8 (6.8)</td>
<td>54.0 (6.3)</td>
<td>0.05</td>
</tr>
<tr>
<td>PPA sagittal ankle motion (°)</td>
<td>31.4 (6.1)</td>
<td>27.5 (7.1)</td>
<td>27.9 (6.9)</td>
<td>0.21</td>
</tr>
<tr>
<td>PPA transversal ankle motion (°)</td>
<td>16.0 (4.0)</td>
<td>16.2 (2.3)</td>
<td>16.4 (5.5)</td>
<td>0.05</td>
</tr>
<tr>
<td>EMG variables</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>QL duration (%)</td>
<td>34.5 (7.1)</td>
<td>43.8 (9.0)</td>
<td>42.8 (12.8)</td>
<td>0.05</td>
</tr>
<tr>
<td>ES duration (%)</td>
<td>31.4 (7.7)</td>
<td>42.9 (10.0)</td>
<td><strong>28.4 (5.5)</strong></td>
<td><strong>0.05</strong></td>
</tr>
<tr>
<td>GM duration (%)</td>
<td>40.4 (5.2)</td>
<td>48 (4.0)</td>
<td>46.9 (5.9)</td>
<td>0.21</td>
</tr>
<tr>
<td>RF duration (%)</td>
<td>34.6 (11.9)</td>
<td>43.4 (13.4)</td>
<td>48.8 (9.2)</td>
<td>0.05</td>
</tr>
<tr>
<td>ST duration (%)</td>
<td>36.1 (3.9)</td>
<td>46.1 (7.3)</td>
<td>44.5 (12.7)</td>
<td>0.07</td>
</tr>
<tr>
<td>TA duration (%)</td>
<td>50.1 (7.5)</td>
<td>55.8 (9.6)</td>
<td><strong>43.8 (5.7)</strong></td>
<td></td>
</tr>
<tr>
<td>G duration (%)</td>
<td>35.1 (3.2)</td>
<td>36.3 (3.1)</td>
<td>36.6 (3.7)</td>
<td>0.05</td>
</tr>
<tr>
<td>Mechanics</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wext (J/kg⁻¹ per m⁻¹)</td>
<td>0.27 (0.02)</td>
<td>0.25 (0.02)</td>
<td><strong>0.26 (0.03)</strong></td>
<td><strong>0.001</strong></td>
</tr>
<tr>
<td>Wint (J/kg⁻¹ per m⁻¹)</td>
<td>0.27 (0.06)</td>
<td>0.24 (0.02)</td>
<td><strong>0.26 (0.02)</strong></td>
<td></td>
</tr>
<tr>
<td>Wtot (J/kg⁻¹ per m⁻¹)</td>
<td>0.55 (0.02)</td>
<td>0.50 (0.03)</td>
<td><strong>0.53 (0.03)</strong></td>
<td></td>
</tr>
<tr>
<td>Energetics</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy cost (J/kg⁻¹ per m⁻¹)</td>
<td>1.8 (0.3)</td>
<td>2.3 (0.3)</td>
<td>2.5 (0.9)</td>
<td>0.05</td>
</tr>
<tr>
<td>Muscle efficiency (%)</td>
<td>30.2 (3.9)</td>
<td>22.7 (5.8)</td>
<td>24.7 (4.6)</td>
<td>0.29</td>
</tr>
</tbody>
</table>

EMG, electromyography; ES, erector spinae muscle; G, gastrocnemius muscle; GM, glutaeus medius muscle; PPA, peak-to-peak amplitude; QL, quadratus lumborum muscle; RF, rectus femoris muscle; SD, standard deviation; ST, semitendinosus muscle; TA, tibialis anterior muscle; Wext, external work; Wint, internal mechanical work; Wtot, total muscular mechanical work.

Note: Comparison was performed between S1 and S2 scoliotic patients. Significant differences in the scoliotic group between S1 and S2 sessions are shown in bold.

**p<.001; *p<.05."
The stance phase characterizes the floor contact period of one limb. This period equals the swing phase of the other limb. The reduction of the contralateral limb swing period could be explained as a strategy to ensure a better dynamic balance that is often reduced in AIS [44].

This result did not agree with the Kramer de Quervain’s study [45], in which no difference was found for the stance phase between idiopathic scoliosis patients characterized by left-lumbar and right-thoracic curve components and published norms. Nevertheless, the reduction of the stance phase found in our study does not appear clinically relevant.

The increase in step length in S2 scoliosis patients compared with S1, which was associated with a decrease of cadence, may be explained by residual growth of the lower limbs that occurred between the S1 and S2 sessions. This residual growth was not evaluated in this study.

In untreated AIS, the shoulder, pelvis, and hip motions as well as the muscular mechanical work were slightly reduced, inducing an abnormal gait compared with that of normal subjects [24,25]. In this study, after 6 months of brace treatment, the pelvis and hip became more mobile by almost 20% and were similar to that of healthy subjects. The results showed a moderate power analysis only for the frontal pelvic motion. This could be mainly explained by a large standard deviation (20% of the mean value) and a small difference between the mean of frontal pelvic motion and hip abduction-adduction on both sides after long-term bracing.

Note: Comparison between S1 and S2 scoliotic patients is summarized in the second column. Comparison results between S2 scoliotic patients and healthy subjects are presented in the third column. The p value of the comparison is indicated in brackets.

The results showed a moderate power analysis only for the frontal pelvic motion. This could be mainly explained by a large standard deviation (20% of the mean value) and a small difference between the mean of frontal pelvic motion and hip abduction-adduction on both sides after long-term bracing.
1-year follow-up [12], whereas our results were analyzed at the 6-month follow-up. Our study included the thoracolumbar/lumbar scoliosis curves, whereas the thoracic, lumbar, and double major curves were studied in the Wong et al. study. There is no information in regard to the length of time without the brace before the gait assessment in Wong et al. A very short time between the brace removal and the gait examination may influence pelvis and hip mobility.

There is a first hypothesis to explain the increase of pelvis and hip motions observed in our study relative to the muscular mechanical work.

During walking, human beings not only move their lower legs and pelvis, but also lift their COMb up and down at each step. Pelvic and hip frontal motion are major determinants that minimize the vertical displacement of the COMb [46]. This vertical displacement of the COMb plays an important role in optimizing the Wtot (i.e., the work in pelvic and hips motions [25]. This latter one also correlated positively with the decrease of COMb minants that minimize the vertical displacement of the body segments relative to the COMb [40,47] and the energy expenditure resulting from oxygen consumption [48,49] allow assessment of locomotion efficiency.

Disturbances of the vertical displacement of the COMb in normal conditions (e.g., walking on sand or carrying loads) [50,51] or conditions of pathologic gait (e.g., stiff-knee gait after a stroke or walking with a prosthesis) [38,52–54] increase the mechanical work and metabolic cost of gait [49,55].

Further, the muscular mechanical work during walking can be decreased compared with during normal walking only when the vertical displacement of the COMb is excessively reduced. This was observed in Massaad’s study, where the vertical displacement of the COMb has been voluntarily decreased by asking the normal subjects to walk keeping both knees lightly flexed [55]. Consequently, the metabolic cost of the gait increased because this way of walking provided important co-contractions of flexor and extensor muscles of the knees. In conclusion, to walk with a muscular mechanical work that is lower or higher than the norms increases the metabolic cost of the gait. Human beings adapt their gait strategy to limit excessive energy expenditure during walking [56].

In terms of the muscular mechanical work in AIS (before orthopedic or surgical treatment), it was lower than in healthy adolescents [25], although we expected to observe an increase of muscular mechanical work as is currently observed in pathologies. Further, in AIS, the low muscular mechanical work correlated positively with a decrease of the vertical displacement of the COMb. Moreover, this latter one also correlated positively with the decrease of pelvic and hips motions [25].

After 6 months of bracing, with the trunk being enclosed 22/24 hours in the brace and the lower limbs providing already normal motion, only the pelvis and the hips, providing small amounts of motion in untreated AIS and that were not enclosed in the brace in treated AIS, could increase their motion to increase the vertical displacement of the COMb [57]. They could also increase the muscular mechanical work closer to normal values, allowing the prevent more excessive cost of gait.

Another hypothesis for the improved frontal pelvic motion, observed in our studied patients after 6 months of brace treatment, was an increased pelvic mobility subsequent to the decrease of prolonged erector spinae muscle co-contractions. Indeed, after 6 months of orthotic treatment, bilateral EMG duration activity of both erector spinae muscles was reduced during gait in AIS (Fig. 2). The lower EMG activity of the erector spinae muscles could be due to the long-term wear of the rigid brace that greatly limits back and pelvis mobility [58,59].

Effectively, long-term bracing may induce stiffening of the spine and a subsequent reduction of the compensatory EMG activity of the muscles surrounding the spinal deformity because muscles are no longer recruited to move these joints. For example, after 4 weeks of leg immobilization, the normal quadriceps muscles showed a 50% atrophy resulting from the drastic reduction of the afferent input arising from muscle spindles to the nervous system as well as a decrease of the efferent EMG activity [60–62]. This explanation however must be considered with caution because spinal stiffness resulting from surgical arthrodesis and instrumentation [63] was not shown to induce reduction of lumbopelvic muscle-timing EMG activity. Furthermore, the improvement in Cobb angle after 6 months of orthotic treatment may have reduced the compensatory activity of the back muscles.
However, previous results of untreated AIS presenting similar curves (ie, Cobb curve <20°) to the 6-month bracing AIS showed the persistence of prolonged EMG activation up to 40% when compared with normal subjects [24]. Further studies are necessary for a more consistent explanation on the erector spinae muscle changes.

Our current results have showed after 6 months of AIS brace treatment, an increase in Wtot which was closer to the normal values [53], although still significantly lower, inducing a significant improvement of muscular efficiency. However, muscular efficiency remained lower than that of healthy subjects, probably because of the excessive oxygen consumption already observed in AIS patients before any treatment (S1).

The oxygen consumption necessary for AIS patients to walk was excessive in untreated AIS. It was 30% above that of normal subjects. It means that a normal subject, to consume the same metabolic energy, would have to walk at a speed of 6 km/h⁻¹ instead of walking to self-selected gait speed (4 km/h⁻¹ in this study), which is closer to running. After 6 months of brace treatment, this excessive oxygen consumption did not decline (Fig. 3) despite both an optimization of the muscular mechanical work consecutive to a greater pelvic mobility and the decrease of EMG duration activity of both erector spinae muscles.

This excessive oxygen consumption could impair physical performance in AIS early. For example, walking induces oxygen consumption equal to 32% of the maximal capacity of aerobic energy in healthy subjects [64]. For AIS patients, with their 30% higher oxygen consumption than normal subjects, they approach 43% of the VO₂ max. Moreover, as observed by the Barrios study, maximal aerobic capacity was a 23% below the average value obtained in controls [65]. It could be expected that AIS patients will quickly approach their maximal aerobic capacity for efforts only a little higher than just walking. These results suggest that it could be helpful to intensively train AIS patients with endurance exercises such as those practiced by athletes [66] in order to reduce oxygen consumption during effort and limit functional disabilities.

Perhaps the excellent compliance of the AIS patients with the orthotic treatment influenced the results. In terms of the scoliosis curves, the Rowe et al. study showed that the weighted mean proportion of success was 0.93 for bracing for 23 hours per day, but only 0.62 for bracing for 16 hours per day [19].

In terms of the improvements of pelvic mobility, muscular mechanical work, and EMG activity of paravertebral muscles, it is more likely to depend on the amount and duration of movements specifically performed within the brace. It could be expected that the braced hours without any activities would have no effect on the gait parameters, but further studies should evaluate the effect of the amount and the duration of physical activities on the gait parameters in braced AIS.

Further clinical studies for specific overall body reconditioning and training regimen will be conducted to evaluate whether the excessive energy cost of walking is due to poor physical condition or muscular disease. More studies will be necessary to determine the causes of these unadapted scoliosis muscle activities and the excessive oxygen consumption.

Conclusion

In conclusion, our results show some radiological and functional benefits from long-time orthopedic treatment for AIS patients.

After 6 months of orthotic treatment, in an out-of-brace situation, a 25% improvement of the main structural thoracolumbar/lumbar curve was observed. During gait, the frontal pelvis and hip motions increased despite a slight reduction of the shoulder rotation. Consequently, the Wtot and muscular efficiency during walking increased, approaching values observed in normal subjects. EMG activity duration of the erector spinae muscles decreased but energy expenditure remained 30% above the normal values as soon as the AIS patients practiced basic functional activities, such as walking at their most comfortable speed. Thus, contrary to our hypothesis, long-term orthopedic treatment in AIS does not significantly stiffen the body or deteriorate functional daily walking observed before treatment.

References


[Image 46x107 to 281x281]
REFERENCES


