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Gait in adolescent idiopathic scoliosis. Kinematics, electromyographic and energy cost analysis

MAHAUDENS P.[a,⊗] and MOUSNY M.[b]
[a] *Rehabilitation and Physical Medicine Unit, Université Catholique de Louvain, Brussels, Belgium*
[b] *Orthopaedic Research Laboratory, Université Catholique de Louvain, Brussels, Belgium*

Abstract.
Introduction: Adolescent idiopathic scoliosis (AIS) can affect spine mobility and gait mechanisms. Nowadays little is known about the effects of scoliosis on gait.
Objectives: To evaluate the effects of untreated scoliosis on gait.
Materials and Methods: Fifty-four females (13 healthy girls and 41 AIS with thoracolumbar/lumbar curve) were assessed by gait analysis. Xrays allowed classifying AIS patients into three groups, depending on the scoliosis severity. Gait analysis included synchronous bilateral kinematic and electromyographic (EMG) measurements, assessment of external (W_{ext}), internal (W_{int}), total mechanical work (W_{tot}), oxygen consumption ($\dot{V}O_2$), energy cost (C) and muscular efficiency (W_{tot}/C).
Results: Shoulder, pelvis and hip motions were significantly reduced in all AIS patients. The reduced motion correlated with decreased W_{tot}. $\dot{V}O2$ and C were increased by 30 %. Muscle efficiency was decreased by 29 %. Increased C correlated with prolonged timing activity of lumbo-pelvic muscles (LPMTA).
Discussion: Reduction of W_{tot} can be explained by decrease of external work. Increase of $\dot{V}O_2$ and energy cost could be due to bilateral increase of LPMTA.
Conclusion: Similar gait alterations were observed in all AIS patients, whatever the severity of the scoliosis. The observed alterations may be considered as the manifestation of an underlying neuromuscular disease or as a consequence of the stiffening effect of scoliosis. The observed "careful walking" strategy could also be a compensatory mechanism to minimize energy expenditure.

Keywords. scoliosis, gait, energy cost, muscular efficiency, lumbopelvic muscles activity

1. Introduction

Adolescent Idiopathic Scoliosis (AIS) is a progressive growth disease that can affect spine morphology, mobility [7] and trunk symmetry [19]. Therefore, it is intended that

⊗ Corresponding Author: P Mahaudens, Rehabilitation and Physical Medicine Unit, Université Catholique de Louvain, 53, Avenue Mounier, 1200 Brussels, Belgium; E-mail: Philippe.Mahaudens@uclouvain.be

AIS can modify bilaterally body kinematics [12] and muscular electromyographic activity (EMG) during human locomotion [18]. Kramers de-Quervain et al. [12] showed a decrease in shoulder rotation on the convex side of thoracic scoliotic curves. This decrease correlated with the severity of the scoliosis [9]. Wong et al.'s study [24] did not showed any gait asymmetry for pelvis and lower limbs when comparing the convex and concave sides. The EMG measurements of the erector muscles were found being asymmetric in scoliotic patients in the Guth et al.'s study [9]. This asymmetry was less marked when patients were walking with a brace [9]. Such observation was also made in patients after surgery in Hopf et al.'s study [10].

It has been demonstrated that the alterations in gait kinematics and electromyography could influence energy expenditure [21, 22]. Such energy expenditure alterations have been observed in scoliotic patients but only during cardiorespiratory performance tests [2]. The energy expenditure allows to compute the energy cost (C) of walking which is normally linked to the muscular mechanical work necessary to move the body [11]. This muscular mechanical work (W_{tot}) can be divided in two parts: the internal work (W_{int}), that is the work needed to move the shoulders and the lower limbs relative to the centre of mass of the body (COM_b) and the external work (W_{ext}), that is the additional work needed to accelerate and lift up the COM_b relative to the ground [4]. Usually, the vertical displacement of COM_b goes up and down by 3 cm with every step. An increase in W_{tot} is frequently observed in patients with a pathological gait, usually due to an increased vertical displacement of the COM_b [21, 22]. This increased W_{tot} induces an increase in energy cost.

Nowadays little is known about the effects of scoliosis on mechanics and energy cost of walking as well as the effects of the curves severity on these gait mechanisms.

The purposes of this study were first to evaluate the effects of untreated scoliosis and scoliosis severity on gait mechanisms and second, to look for any asymmetry in kinematic and EMG variables during walking.

2.Materials and Methods

Fifty-four females (13 healthy girls and 41 untreated AIS with thoracolumbar/lumbar curve) were assessed by gait analysis. Xrays allowed to classify AIS patients into three groups, depending on the scoliosis severity (group 1 <20° Cobb, group 2 between 20° and 40° Cobb, and group 3 >40° Cobb).

Gait analysis included synchronous bilateral kinematic and electromyographic (EMG) measurements, assessment of vertical COM_b displacement, external work (W_{ext}), internal work (W_{int}) and total mechanical work (W_{tot}), oxygen consumption ($\dot{V}O_2$), energy cost (C) and muscular efficiency (W_{tot}/C). The subjects walked on a treadmill at 4 km/h (comfortable speed) (Figure 1). The tridimensional (3D) shoulder, pelvis and lower limb motions were measured using 22 reflective markers tracked by 6 infrared cameras at 100 Hz [8]. The EMG timing activity was measured using bipolar surface electrodes on *quadratus lumborum*, *erector spinae*, *gluteus medius*, *rectus femoris*, *semitendinosus*, *tibialis anterior* and *gastrocnemius* muscles [20]. W_{int} was calculated from the kinematics. The displacements of the COM_b were derived from the ground reaction forces, and W_{ext} was calculated from the force signal. W_{tot} was equal to $W_{int} + W_{ext}$ [23]. Oxygen consumption ($\dot{V}O_2$) was measured with a mask to calculate energetic cost (C) and muscular efficiency (W_{tot}/C) [17].

Figure 1. Frontal viewi of a patient equipped with the cutaneous markers, the bipolar muscular electrodes, and the mask linked to the ergospirometer. The patient is walking on the motor-driven treadmill, attached to the ceiling by a harness.

3. Results

Vertical displacement of the shoulders, pelvis and hips in the coronal plane (i.e. drop and rise) and hips rotation in the transverse plane were significantly reduced in all scoliotic patients (respectively, 21%, 27% 28% and 22% less). The EMG recording during walking showed that the *quadratus lumborum*, *erector spinae*, *gluteus medius*, and *semitendinosus* muscles (i.e. lumbo-pelvic muscles) contracted during a longer part of the stride in scoliotic patients (46% of the stride) compared with normal subjects (35% of the stride)(Figure 2b). There was no significant difference between scoliotic groups 1, 2 and 3 for any of the kinematic and EMG parameters. Scoliosis was not associated with any kinematic or EMG left-right asymmetry. The external work (W_{ext}) and internal work (W_{int}) were both reduced from 7 to 22 % depending on the severity of the scoliotic curve. Overall, the total muscular mechanical work (W_{tot}) was reduced from 7% to 13 % in scoliotic patients. No significant difference was found in W_{tot} between the three scoliotic groups. The reduced shoulders-pelvis-hips motion correlated with the decreased W_{tot}. The energy cost (C) and $\dot{V}$O2 were increased by about 30% (Figure 2a). Muscle efficiency was decreased by 29% without any significant differences related to the severity of the scoliosis [15]. Increased C correlated with prolonged timing activity of lumbo-pelvic muscles.

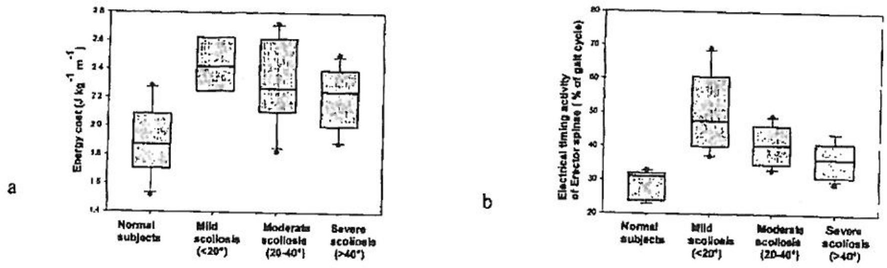

Figure 2 – **a)** Distribution of energy cost values (expressed in J kg^{-1} m^{-1}) in normal subjects and in the three groups of AIS patients. **b)**. Electrical timing activity of the Erector spinae muscle (expressed in % of gait cycle) in normal subjects and in the three groups of AIS patients. A significant difference was found for both parameters only between normal subjects and each of the scoliotic groups. No significant differences were observed between scoliotic subgroups.

4. Discussion

Patients with adolescent idiopathic scoliosis showed a slight but significant decrease in shoulders, pelvis and hips vertical displacement in the coronal plane and in hips rotation, whatever the severity of the scoliosis. This was responsible of a decrease in COM_b vertical displacement and in muscular mechanical work.

Surprisingly, no asymmetry was noted for kinematics and EMG. These results are concordant with others studies on lower limb kinematics in scoliotic patients [5, 12, 13], but are in contradiction with Kramers de-Quervain et al.'s study [12]. These authors have shown an asymmetrical trunk rotation, called ''torsional offset'', in right-thoracic idiopathic scoliosis during walking. This "torsional offset" correlated with the angle of the thoracic curve, with a lack of rotation on the thoracic curve's convex side, most likely caused by the structural deformity [12]. This ''torsional offset'' was not observed in our scoliotic populations [14]. It must nevertheless be noted that our patients groups included only thoracolumbar/lumbar curves.

The bilateral symmetric increase in EMG duration observed in our study does not agree with data from other studies [1, 9, 10, 18], that have shown asymmetry in back muscle activity between scoliosis concave and convex sides. Allenbach and Wiest [1], and Riddle and Roaf [18] described a higher paravertebral EMG on the convex side of the curvature when patients were examined in the static position, suggesting stronger contraction in the convexity. In both static and dynamic EMG measurements, asymmetric activity has been reported by Güth et al. [9] in non-progressive scoliosis. This muscular asymmetry was described by these authors as a biomechanical consequence of the scoliotic curvature rather than its cause. Hopf et al. [10] also showed a significant asymmetry in paravertebral muscle activity in severe scoliotic patients before spinal arthrodesis surgery. They concluded that this asymmetrical muscle activity resulted from the spine deformations. It must nevertheless be noted that it is difficult to evaluate the force of the muscles in dynamic situations such as locomotion, as noted by Basmajan [3]. Therefore, we decided to analyse the timing and duration of EMG muscular contraction expressed as a percentage of the gait cycle, instead of analysing the "muscle strength" as it was proposed in the other studies.

Our results are in agreement with our previous study on AIS patients with mild Cobb angle curves (less than 30°) [16], showing a symmetric increase of muscle duration by 21 to 61%.

The observed bilaterally prolonged muscle contraction time of lumbo-pelvic muscles may partly explain the weak muscle efficiency because it induces an increase of $\dot{V}O2$ and an excessive energy cost of walking. The increase of $\dot{V}O2$ and energy cost by 30 % in scoliotic patients compared to healthy subjects is comparable to a gait at a speed of 6 km h^{-1} in normal subjects [6]. During comfortable walking, scoliotic patients had to elevate their levels of physical effort. Scoliotic patients require about 35% of their $\dot{V}O2$ max (that is 50 % more than healthy subjects) just for walking [2]. Therefore, it seems that in scoliotic patients, walking is a more demanding physical effort than in healthy subjects. It is thus expected that scoliotic patients must have difficulty in tolerating significant increase of physical effort. This excessive energy cost of walking correlated to the prolonged bilateral contractions of lumbo-pelvic muscles, whatever the severity of the scoliosis. To our knowledge, this observation has never been reported in the literature.

The observed alterations may be considered as the manifestation of an underlying neuromuscular disease or as a consequence of the stiffening effect of scoliosis. The observed "careful walking" strategy could also be a compensatory mechanism to minimize energy expenditure.

5. Conclusion

This study confirms that patients with thoracolumbar/lumbar adolescent idiopathic scoliosis demonstrate significant alterations in gait kinematics, whatever the severity of the scoliosis. Lumbo-pelvic muscles activity was also found altered. Muscle efficiency during walking was reduced, when compared to normal subjects. For the first time, energy cost was evaluated in scoliotic patients during physiological gait and was found altered. These alterations in energy cost correlated with the alterations in lumbo-pelvic muscles activity. Further studies are needed to evaluate the origin and consequences of these observations.

6. Significance

First study comparing gait in healthy individuals with gait in AIS patients.

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