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Effect of natural sagittal trunk lean on standing balance in untreated scoliotic girls

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ABSTRACT

Background: Generally, scoliotic girls have a tendency to lean further back than a comparable group of non-scoliotic girls. To date, no study has addressed how standing balance in untreated scoliotic girls is affected by a natural backwardly or forwardly inclined trunk.

Methods: 27 able-bodied young girls and 27 young girls with a right thoracic curve were classified as leaning forward or backward according to the median of their trunk sagittal inclination. Participants stood upright barefoot. Trunk and pelvis orientations were calculated from 8 bony landmarks. Upright standing balance was assessed by 9 parameters calculated from the excursion of the center of pressure and the free moment.

Findings: In the anterior-posterior direction, backward scoliotic girls had a greater center of pressure range ($P = 0.036$) and speed ($P = 0.015$) by 10.4 mm and 2.8 mm/s respectively than the forward scoliotic group. Compared to their matching non-scoliotic group, the backward scoliotic girls stood more on their heels by 14.6 mm ($P = 0.017$) and display greater center of pressure speed by 2.5 mm/s ($P = 0.028$). Medio-lateral center of pressure range ($P = 0.018$) and speed ($P = 0.008$) were statistically higher by 8.7 mm and 3.6 mm/s for the backward group. Only the free moment RMS was significantly larger ($P = 0.045$) for the backward scoliotic group when compared to the forwardly inclined scoliotic group.

Interpretation: Only those with a backward lean displayed statistically significant differences from both forward scoliotic girls and non-scoliotic girls. Untreated scoliotic girls with an exaggerated back extension could profit more from postural rehabilitation to improve their standing balance.

1. Introduction

Idiopathic scoliosis is a three-dimensional deformation of the spine and trunk occurring in around 3% of the population with an occurrence 8 times higher in girls (Sharma et al., 2011; Weinstein, 1989). Scoliosis increases risk for health problems in adult life, such as reduced quality of life, pain, functional impairments and balance disorders (Dalleau et al., 2007; Pehrsson et al., 1992; Weinstein et al., 2003). Standing imbalance in adolescent idiopathic scoliosis (AIS) has been well documented (Byl and Gray, 1993; Herman et al., 1983; Sahlstrand et al., 1978). It is related in part to an altered body posture characterized by body segment rotations in both frontal and horizontal planes (Nault et al., 2002) resulting from a well-known complex interaction between spine, trunk and pelvis (Burwell et al., 1992). Generally, scoliotic girls prior to bracing have a tendency to lean further back than a comparable group of non-scoliotic girls (Dalleau et al., 2012; Nault et al., 2002). The observed increase in the neuromuscular demand in AIS girls to compensate a posteriorly displaced center of pressure (CoP) is assumed to come from a backward trunk lean to maintain standing balance (Dalleau et al., 2010). But not all scoliotic girls fully extend their trunk (Nault et al., 2002) and these girls could display less postural sway in standing and a better quality of postural balance than those leaning backwards.

Asymmetrical body postures were reported in AIS (Burwell et al., 1992; Goldberg et al., 2001; Ramirez et al., 2006) but only a few authors have associated standing imbalance to curve type and severity

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(Gauchard et al., 2001; Haumont et al., 2011), body morphology (Allard et al., 2004) and body posture (Nault et al., 2002; Sawatzky et al., 1997). In these studies, no distinction was made between girls with a natural tendency to lean their trunk backward from those who tilt their trunk forward and how their standing balance is modified accordingly. Natural trunk sagittal inclinations in standing (Fortin et al., 2015) as well as in voluntarily forward leaning prior to gait initiation (Crenna and Frigo, 1991) were shown to modify the electromyographic activities of the foot and ankle muscles. Young adults who present a forward leaning of the trunk display different gait initiation and walking characteristics compared to backward leaners (Leardini et al., 2013; Leteneur et al., 2013). In scoliotic patients, perturbed walking patterns were also reported. They had a shorter stride length, variations in the timing of muscle activation (Haber and Sacco, 2015) and less trunk stability than a control group (Park et al., 2015). These observations could be attributed in part to the imposing mass of the head, neck and trunk which corresponds to more than half of the total human body (de Leva, 1996). Combined morphologic transformations resulting from spine and rib cage deformation and trunk inclination modify the inertial properties of the scoliotic trunk (Damavandi et al., 2015) and exacerbate gait patterns irregularities and conceivably increase standing imbalance.

Trunk lean and its effects on standing balance were reported in scoliotic and able-bodied girls. Poorer postural performance was detected in scoliotic girls than non-scoliotic girls (Nault et al., 2002) or in scoliotic patients with a Cobb angle of < 15° (Haumont et al., 2011). The Cobb angle allows to quantify coronal plane spine deformity. Sawatzky et al. (1997) also observed a direct relationship between the trunk imbalance and the extent of sway area of the CoP. However, no significant difference in the quality of standing balance was reported between a group of girls with a mild scoliosis and a group of moderately severe scoliosis who maintained a slightly greater backward trunk lean by 1.9° (Dalleau et al., 2012). Here, the extent of the spinal deformity and the backward or forward trunk sagittal orientations were not considered as classification variables.

To date, no study has addressed how standing with a natural backwardly or forwardly inclined trunk affects standing balance, especially in untreated scoliotic girls. It is hypothesized that the neuromuscular control is altered to maintain standing balance according to trunk lean. The objective of this study is to test if a natural backward (BW) or forward (FW) trunk inclination affects standing balance of scoliotic and non-scoliotic girls. Furthermore, we wish to determine if scoliotic girls with a FW or BW trunk lean have greater standing imbalance than non-scoliotic girls with similar trunk inclination orientation. Finally, we wish to verify if trunk sagittal inclination is related to any of the standing balance parameters and sagittal pelvic tilt in each group of subjects since the pelvis orientation could modify trunk inclination (Burwell et al., 1992; Chung et al., 2010).

2. Methods

Fifty-four girls participated to this study. Half of them were adolescent idiopathic scoliosis patients. They were randomly selected by an orthopedic surgeon from the hospital scoliosis clinic according to the criteria given by Bunnell (1986). They all had a right thoracic curve that averaged 27.2° (SD 9.4°) and varying between 11° and 42°. The right thoracic curve was quantified by the Cobb angle on coronal radiographs, between the 2 vertebrae which endplates are the most tilted at the extremities of the curve deformity. The intersection angle of the lines drawn along these endplates defined the Cobb angle. All scoliotic girls were under observation and none was wearing a body brace at the time of the experiment. Their average age was 12.0 years (SD 1.5 years) while their height and mass were 1.54 m (SD 0.09 m) and 44.0 kg (SD 8.8 kg), respectively. The remaining 27 girls formed the control group. They were selected from a nearby school on a voluntary basis. Any subject having a limb length discrepancy of > 1 cm, wearing foot orthoses, displaying any signs of postural, orthopedic or neurological disorders were excluded from the study. Their mean age 13.0 years (SD 1.5 years), height 1.56 m (SD 0.07 m) and mass 46.2 kg (SD 7.1 kg) were comparable to the scoliotic group ($P = 0.742$, $P = 0.06$, $P = 0.432$, respectively) The experimental procedure was explained to each girl and her parents. Both signed a written consent approved by the Sainte-Justine Hospital Ethics Committee.

Body posture and standing balance measurements were taken while participants stood barefoot on a force plate (AMTI force plate, Model OR6-5, Newton, MA) with their heels spaced by 23 cm and feet pointing externally by 15° (Nault et al., 2002), with the upper limbs at the side. During the experiment, girls focused on a target positioned at 1.2 m ahead them and located at eye level. Trunk and pelvis orientations were calculated from 8 bony landmarks. These were the right and left anterior, posterior and superior tip of the iliac crests as well as the first sacral (S1) vertebra and the seventh cervical (C7) spinous processes. The three-dimensional coordinates of the body landmarks were measured by means of Flock of Bird system (Ascencion Technologies, Burlington, VT, USA). These were obtained by lightly touching the skin lying over the anatomical landmarks with the tip of a stylus. Even if the Flock of Bird system is precise, it is possible that the subject slightly moves between two non-synchronous measures. To minimize this effect, all measurements were taken by a trained and experience technician. Furthermore, errors of < 1° between two set of 20 angles measurements in scoliotic girls were reported with this technique (Dao et al., 1997). The estimated linear and angular resolution of this electromagnetic system is 0.76 mm and 0.1° respectively (Bellefleur et al., 1994). The origin was set at S1 with positive axes to the right, anterior and upwards using a subject-centered coordinate system. Trunk and pelvis sagittal orientations were calculated according to Nault et al. (2002).

The quality of upright standing balance was determined from the excursion of the CoP calculated from forces and moments obtained by the force-plate with respect to the force plate' origin (positive along the left and forward axes). Each subject performed three trials of 64 s sampled at 64 Hz. In all, 9 parameters were calculated: the mean antero-posterior (AP) and medio-lateral (ML) CoP positions which reflect the center of mass location, the CoP range, being the difference between the maximal and minimal CoP values in each direction, and representing maximum standing sway, the CoP speed (sum of CoP displacements over acquisition time in both AP and ML directions) corresponding to the neuromuscular system demand (Maki et al., 1994) and the mean, range and RMS values of the free moment, T_z which are indicative of an asymmetric control of the trunk around the vertical axis during standing (Dalleau et al., 2007). The free moment values were normalized with respect to the subject body mass (Nm/kg). Values obtained from the 3 trials of each subject were averaged for further analysis. Afterwards, scoliotic and non-scoliotic participants were classified as leaning forwards (FW) or backwards (BW) according to the median of their trunk sagittal inclination of their respective subject groups as previously performed in similar types of studies (Leardini et al., 2013; Stylianides et al., 2012).

Multivariate analyses (Manova) were used for statistical comparisons between the scoliotic and non-scoliotic groups and trunk inclinations. When the Manovas reached a significant level ($P \leq 0.05$), planned comparisons were used to examine the specific effect of trunk inclination. A Bonferroni correction procedure was applied to control Type 1 error by adjusting the P values in the analysis of the parameters (Holland and Copenhaver, 1988). Pearson coefficients of correlation were performed to identify any relationships between trunk inclination and standing balance parameters and sagittal pelvis tilt for each group.

3. Results

Results for the Cobb angle, trunk sagittal inclination and pelvic tilt are given in Fig. 1. There was no significant difference in the Cobb