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Acute postural adaptations induced by a shoe lift in idiopathic scoliosis patients

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Abstract The objective of this study was to identify acute spinal and three-dimensional postural adaptations induced by a shoe lift in a population of idiopathic scoliosis (IS) patients. Forty-six IS patients (mean age: 12 ± 2 years) were evaluated radiologically and with a stereovideo-graphic system for pelvic obliquity. Based on the initial postural and radiological evaluation, a pertinent shoe lift height was chosen for each with the result that 12 patients were tested with 5-mm (S5) lifts, 20 patients were tested with 10-mm (S10) lifts, and 14 patients with 15-mm (S15) lifts. The posture for all 46 patients was then re-evaluated and a spinal radiograph obtained for 14 patients. The implementation of a shoe lift independent of the type of curve and amplitude significantly decreased the Cobb angle. As expected there was a change in the vertical height of the left tibial plateau and greater trochanter that induced a change in pelvic tilt. There was also a significant increase in the vertical

height of S1 and T1. There was a significant change in the left and right iliac bone version, as well as a decrease in the difference in version between these two bones. The implementation of the shoe lifts also changed the lateral shift of the pelvis. A relative change between the shoulders and pelvis for tilt and anteroposterior shift was also found to be significant. In conclusion, using a shoe lift resulted in acute postural adaptations which specifically affected the spine and the three-dimensional position and orientation of the pelvis and shoulder girdle.

Keywords Orthopaedics · Posture · Scoliosis · Sacral tilt · Biomechanics

Introduction

Obliquity of the sacrum in the frontal plane is associated with lumbar and thoracolumbar idiopathic scoliosis [14, 15, 22]. The origin of this obliquity may be related to a deformity and disorientation of the sacrum relative to the pelvis, a lower leg length discrepancy (LLD) [17, 25], disorientation of the pelvis due to an asymmetric formation of the iliac bones [17, 25], or muscular imbalance [17,

25]. Its presence represents a potential aggravating factor for idiopathic scoliosis (IS) patients, where vertebral alignment and postural control is challenged. However, the effectiveness of a shoe lift in decreasing sacral tilt and maintaining spinal correction has not been well established [11, 13, 19], nor is the mechanism completely understood. Using noninvasive evaluation techniques [3, 7, 21], a number of authors have suggested that the movement associated with the correction of sacral tilt as noted in the frontal plane is also accompanied by postural

changes that occur in the sagittal and transverse planes. These changes may be attributed to the position, alignment and mobility of the hip joint, the mobility of the sacroiliac joint and the various actions of the passive and active components of the neuromuscular system. Given its ability to assess changes that may occur to body segments in three dimensions, the postural geometry model [3, 8, 18] has been presented as a unique compliment to conventional radiographic evaluations.

The objective of this study is to identify acute spinal and three-dimensional postural adaptations induced by a shoe lift in a population of IS patients. A description of the relationships between these adaptations will serve as a means to identify possible corrective mechanisms contributing to the spinal correction.

Materials and methods

Subjects

The data presented in this prospective study were collected between 1995 and 1999 at the Spinal Pathology Evaluation Center at Sainte-Justine Hospital in Montreal. The patients visiting the clinic were evaluated for their IS and underwent standardized clinical, postural geometry and radiological exams. For the patients with a pelvic obliquity, with or without a leg length inequality, a shoe lift was placed under the side of obliquity, and its effect on the patients' posture evaluated. In cases where it was deemed necessary, a posteroanterior spinal radiograph was obtained, and a shoe lift prescribed. In all, 46 patients, 37 females and 9 males, with a mean age of 12 years (SD, 2 years) were included in this study.

Procedures

The radiological evaluation consisted of a posteroanterior radiograph of the trunk, including the pelvis, and when necessary a sagittal plane radiograph. The patients were placed with their feet in a standardized foot template [8], with the elbows and arms slightly flexed. The frontal plane radiograph was used to describe the scoliosis characteristics: number of curves, apex location and curve magnitude as measured by the Cobb angle technique [9], presented in Table 1. Additional variables were assessed: apical vertebral rotation [20] and the tilt of S1 in the frontal and sagittal planes. The presence of a wedged vertebra was defined as an asymmetric formation of the vertebral body as identified in the frontal plane radiograph. These initial radiological characteristics are presented in Table 1.

The three-dimensional postural geometry of each patient was obtained using a noninvasive stereovideographic approach [3, 8, 18]. First, 56 anatomical landmarks were palpated and identified with reflective markers. The patients were then asked to place their feet within a standardized template [8] and remain in a quiet standing position with their arms slightly abducted. A motion analysis system was used to record the image of the anatomical markers needed to reconstruct their three-dimensional position. The mean of two or three trials was used to describe the postural geometry of the patient. The postural parameters calculated in this study were the orientation (rotation, tilt, version) and position (anteroposterior and medial-lateral shift, vertical height) of the pelvis and shoulders, sagittal spinal curvatures (kyphosis, lordosis), and the height of the lower extremities (tibial plateau and great trochanter) [3, 8, 18]. All angular measures were positive counterclockwise from a posterior (frontal plane), right (sagittal plane), and apical (transverse) point of view. The linear measures were positive to the left of the mid-distance between the two heels and anteriorly from a line joining the two heels. To facilitate the interpretation of the postural characteristics, a threshold was chosen to define the absence and direction of a postural abnormality. This threshold is based on the inter-session variability of each postural parameter as identified by De la Huerta et al. [8] among control and scoliosis patients.

All patients received a postural geometry evaluation with a shoe lift that was fitted under the left foot with a height of 5 mm for 12 patients (S5), 10 mm for 20 patients (S10) and 15 mm for 14 patients (S15). For 14 patients, it was deemed necessary to obtain a PA radiograph with a shoe lift to make a clinical decision regarding its prescription as a compliment to treatment for IS.

A *t*-test for dependent groups was performed between the without-shoe- and with-shoe-lift conditions for the postural parameters so that changes in the posture of the patient could be identified. Since previous studies on control subjects show wide variability and individual postural adaptations with a shoe lift [3, 6], the results are presented to reflect the different trends among patients.

Results

Initial postural and radiological characteristics

The initial radiological parameters for each type of curvature are listed in Table 1. The mean counterclockwise tilt of the sacrum for all of the patients was 5°, ranging from 0° to 17°. There was a mean Cobb angle for the lumbar and thoracolumbar curves of 22°, ranging from 6° to 40° for all of the patients. The apex of the lumbar and thoracolumbar curves had a rotation that ranged from 0° to 25°.

Table 1 Initial radiological characteristics

	<i>n</i>	Apical vertebra				Cobb (°) mean (SD)	Sacral tilt	
		Level	Side	Rotation (°) Mean (SD)	Wedge (<i>n</i>)		Frontal (°) Mean (SD)	Sagittal (°) Mean (SD)
Left lumbar	5	L2-L4	Left	12 (3)	3	21 (10)	3 (3)	46 (13)
Left thoracolumbar	22	T11-L1	Left	12 (7)	18	20 (8)	5 (4)	44 (10)
Right thoracic, left lumbar	5	T7-T10, L2-L4	Right, Left	11 (7)	3	26 (15), 26 (12)	6 (5)	45 (11)
Right thoracic, left thoracolumbar	14	T7-T10, T11-L1	Right, Left	13 (6)	11	16 (9), 23 (8)	5 (4)	48 (9)

Table 2 Induced change in postural parameters measured by the shoe lift

Postural parameter	Initial evaluation		Difference with shoe lift		P value
	Mean (SD)	Range	Absolute mean value (SD)	Range	
Difference left-right tibia (mm)	-3 (5)	-18 to 7	11 (4)	3 to 19	$P<0.05$
Difference left-right trochanter (mm)	-10 (10)	-30 to 18	15 (6)	3 to 31	$P<0.05$
Pelvic tilt (°)	3 (1)	0.1 to 7	3 (1)	-6.2 to -0.8	$P<0.05$
Pelvic rotation (°)	0.4 (4)	-7 to 11	2 (2)	-8 to 9	
Version right iliac bone (°)	-10 (4)	-18.9 to -0.8	2 (1)	-7 to 2	$P<0.05$
Version left iliac bone (°)	-11 (4)	-21.9 to -2.0	1 (1)	-6 to 5	$P<0.05$
Difference in version right and left (°)	-0.5 (2)	-6 to 5	2 (1)	0.2 to 5	$P<0.05$
Lateral shift of S1 (mm)	1 (10)	-26 to 28	9 (6)	-24 to 14	$P<0.05$
Anteroposterior shift of S1 (mm)	12 (19)	-20 to 60	7 (5)	-15 to 18	
Vertical height of S1 (mm)	897 (84)	682 to 1037	5 (3)	1 to 12	$P<0.05$
Shoulder rotation (°)	1 (4)	-8 to 11	2 (2)	-7 to 7	
Shoulder tilt (°)	0.4 (2)	-3 to 4	0.8 (0.6)	-1 to 2	$P<0.05$
Lateral shift of T1 (mm)	13 (15)	-23 to 59	9 (7)	-27 to 24	
Anteroposterior shift of T1 (mm)	32 (20)	-19 to 89	7 (7)	-14 to 29	$P<0.05$
Vertical height of T1 (mm)	1279 (117)	978 to 1464	6 (3)	-1 to 14	$P<0.05$
Kyphosis (%)	7 (3)	0.1 to 12	0.6 (0.6)	-2 to 2	
Lordosis (%)	4 (2)	1 to 11	0.5 (0.5)	-2 to 2	
Rotation shoulders/pelvis (°)	1 (4)	-7 to 9	1 (1)	-5 to 5	
Tilt shoulders/pelvis (°)	-2 (2)	-7 to 3	3 (2)	0 to 9	$P<0.05$
Lateral shift of shoulders/pelvis (mm)	12 (10)	-9 to 38	4 (3)	-7 to 13	
Anteroposterior shift shoulders/pelvis (mm)	20 (18)	-15 to 58	6 (5)	-13 to 19	$P<0.05$

with a wedged vertebra either immediately superior or inferior to the apical vertebra in 35 patients. There was a weak correlation between sacral tilt and the Cobb angle ($r=0.30$), and the sacral tilt and the rotation of the apical vertebra ($r=0.37$). The initial postural characteristics of the scoliosis patients are listed in Table 2. The vertical height of the right trochanter was greater than the left one for 36 of the 46 patients. For five patients the difference was minimal (-2 to 0 mm), and five had a greater vertical height for the left trochanter than for the right trochanter (3 to 18 mm, respectively). The counterclockwise pelvic tilt ranged from 0.1° to 7.3°. The angular parameters of rotation and version and the linear parameters of medial lateral shift for the pelvis and shoulders were variable in direction. The frequency according to the direction of the postural abnormality are presented in Figs. 1 and 2.

Changes induced by the shoe lift

Fourteen of the 46 patients were evaluated radiologically with and without the left shoe lift on the same day. With a shoe lift there was a mean decrease in the frontal plane sacral tilt of 5° (range 0° to 10°), a mean decrease of the lumbar and thoracolumbar Cobb angles of 7° (range 1° to 14°), and for the patients who had an additional thoracic

curve, a change of 4° (range 1° to 6°). These amplitudes represent approximately 41% and 32% of the initial Cobb angle, where four of the patients had a decrease that was 5° or less. The correlation between the change in Cobb angle and the change in tilt of S1 in the frontal plane was $r=0.10$.

The postural changes induced by the shoe lift are presented in Table 2. There were a number of significant changes that were largely systematic in direction and amplitude. This included a change in the vertical height of the left tibia, fibula, and trochanter, S1 and T1 ($P<0.05$). This had a direct impact on the tilt of the pelvis with a mean absolute decrease in pelvic tilt of 2.9° (range -6.2° to -0.8°), and a decrease in the difference in version between the left and right iliac bones (0.2° to 4.8°). Due to the change in pelvic tilt, there was also a relative change in the tilt of the shoulders in reference to the pelvis (3.4°). There was a significant correlation between the height of the shoe lift used and the change in the difference in vertical height of the tibia and fibula (0.77), trochanter (0.67), the tilt of the pelvis (-0.71), and a difference in version between the two iliac bones (0.64), the vertical height of S1 (0.60) and T1 (0.67) and the tilt of the shoulders in relation to the pelvis (0.67).

The postural parameters that changed significantly and were variable in direction include the version of the left

Fig. 1 Initial angular postural parameters

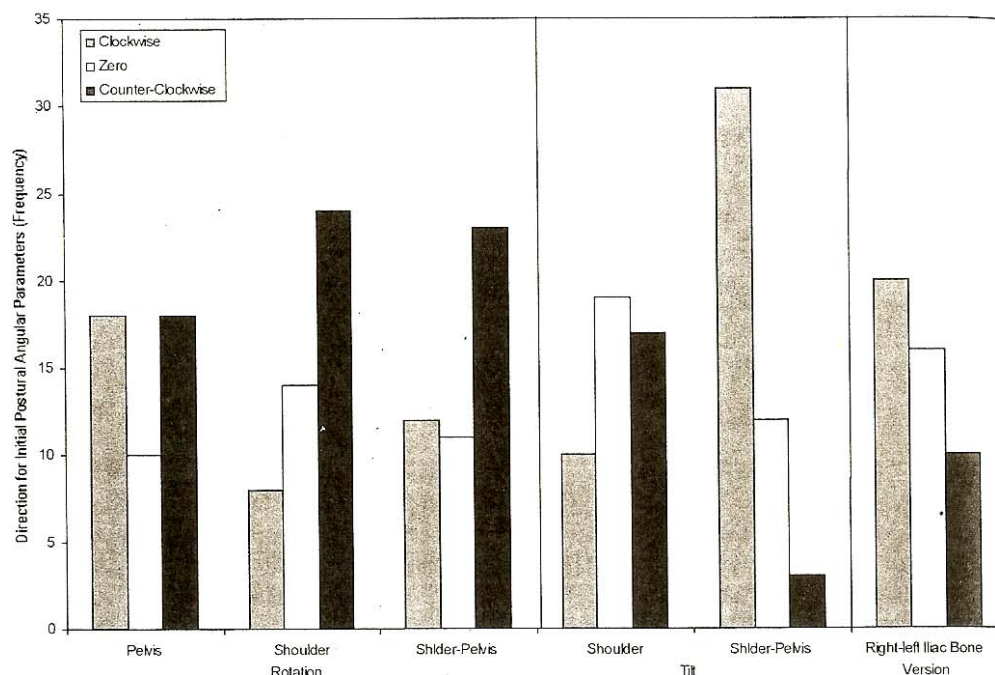
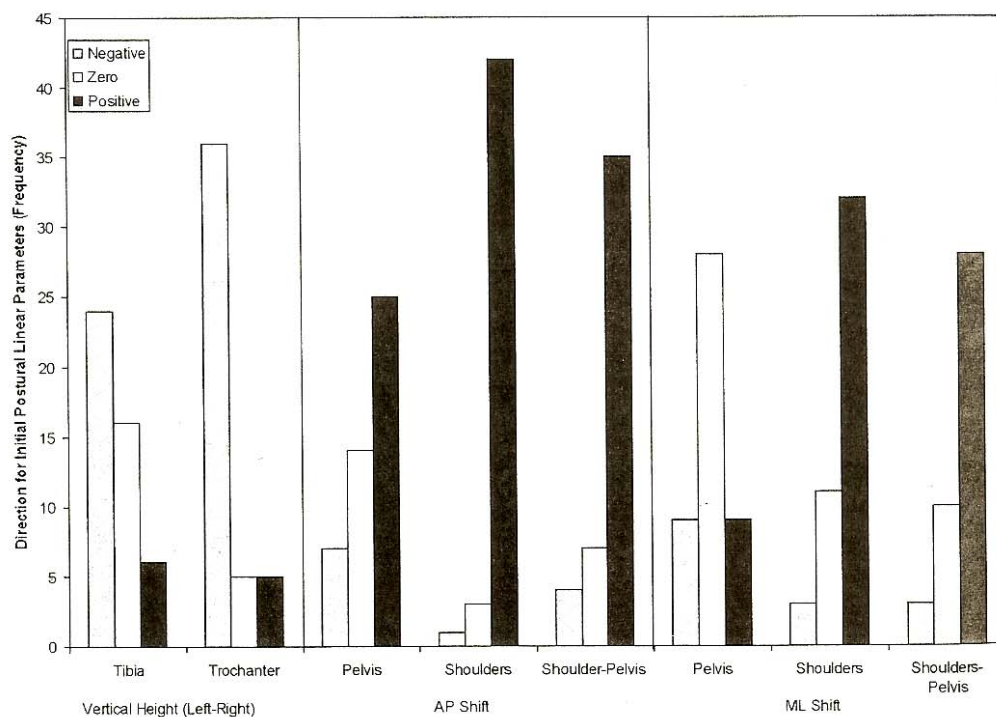


Fig. 2 Initial linear postural parameters. Positive is defined as anterior and to the left; negative is defined as posterior and to the right.



and right iliac bones, the lateral shift of the pelvis, the tilt of the shoulders, the anterior shift of T1 and the anterior shift of T1 in reference to S1. For the pelvis, there was a significant change in the right iliac bone (RIB) version (-6.6° to 2.2°) and the left iliac bone (LIB) version (-6.2° to 4.9°). There was a retroversion of the right and left iliac bones noted for 5 patients (11%), an anteversion of the right iliac bone and a retroversion of the left iliac bone

for 31 patients (68%) and an anteversion of the left and right iliac bones for 9 patients (20%). The change in the lateral shift of the pelvis ranged from 14 to -24 mm with a shift to the right for 18 patients, a negligible shift for 20 patients and a shift to the left for 8 patients. The actual change in shoulder tilt was rather small: 38 patients had a tilt that ranged between -1.1° and 1.1° , with only 8 ranging between 1.2° and 2.5° . The amplitude of the antero-

posterior shift for the pelvis and the shoulders ranged from -15 to 18 mm, and -14 to 29 mm, respectively, and for T1 in reference to S1 from -13 to 19 mm.

A number of parameters did not show a significant change; however, the amplitude of the individual postural reactions should be recognized. There was a variable impact on pelvic rotation with an induced change ranging from -7.9° to 9.9° (18 clockwise, 20 zero, 8 counterclockwise) and shoulder rotation ranging from -7.3° to 6.8° (16 clockwise, 18 zero, 12 counterclockwise) and the relative measure between the two body segments ranged from -4.6° to 4.6° (6 clockwise, 27 zero, 11 counterclockwise). The lateral shift of the shoulders ranged from 24 mm to -27 mm, with an medial-lateral shift to the right for 18 patients, no change for 18 and a shift to the left for 10. The relative lateral shift of T1 in reference to S1 was -7 mm to 13 mm with 4 to the right, 34 no change, and 8 to the left. This change was not statistically significant. There was no change for the anteroposterior shift of the pelvis.

Discussion

The primary objective of this study was to identify acute three-dimensional postural and spinal adaptations induced by a shoe lift in a population of IS patients. As expected with a shoe lift, there was an increase in the vertical height of the left lower limb decreasing the tilt of the pelvis. There was also a change in the global and relative version between the left and right iliac bones, lateral shift, and vertical height of the pelvis. The shoulder tilt decreased, with an increased anterior shift, and in consequence the anteroposterior shift of the shoulders in reference to the pelvis changed along with the relative tilt. For the 14 patients evaluated radiologically, the shoe lift induced an overall decrease in sacral tilt (90%) in the frontal plane, and a decrease in the version of the sacrum in the sagittal plane. This was accompanied by a decrease in the amplitude of the lumbar and thoracolumbar curves (41%), and for the patients who had an additional thoracic curve (32%). These results are in concordance with previous research that has identified systematic postural adaptations induced by a shoe lift in control subjects [3, 7, 21] and positive associations between the change in spinal curvature and the correction of leg length inequality [11, 13, 19]. However, the correlation between these changes and the spinal correction ($r=0.10$) in the scoliosis patients was weak. This suggests that the corrective mechanism induced by the shoe lift cannot be solely described by a horizontalization of S1, but involves an interaction of the muscular system, and the mobility of the skeletal system.

The height of the shoe lift was strongly related to the parameters that quantified changes in reference to the vertical axis (correlation 0.60–0.77). These included the increased vertical height of the tibia, fibula, trochanter, S1 and T1, the decrease in pelvic tilt, the tilt of the shoulders

and the relative tilt between the shoulders and pelvis. There was also a change in the version of the iliac bones. The movement measured for the pelvis included anteversion of the RIB and a retroversion of the LIB, which is similar to the movements noted by an induced leg length inequality in control subjects [3, 7, 21]. The systematic nature of these adaptations are strongly influenced by the direct mechanical interaction between the shoe lift and the common skeletal characteristics of each patient. Adding a shoe lift will induce changes in the height of the shank and thigh. This will increase the height of the left acetabulum, decreasing the tilt of the pelvis. However, additional movements of the pelvis were noted, which include version and rotation. Consequently the horizontalization of the adjacent structures (vertebrae) has a less direct link associated with the shoe lift height. The strength of this association decreases in the cranial direction, which is associated with the increased degrees of freedom of the vertebral joint. The shoulders which articulate with the spine show a change in tilt, which is not necessarily the same as the pelvis.

There was a smaller relationship between the height of the shoe lift used and the angular measures of rotation and the linear measures of anteroposterior and medial-lateral shift. These parameters had greater variability noted for the direction and amplitude of the postural changes induced by the shoe lift. This variability can be attributed to a change in the point of force application within the acetabulum, which would have an impact on the position and orientation of the pelvis [4]. This point of force application would most likely be caused by the orientation of the femur in space which is defined by the internal or external rotation of the femur as well as the femoral neck shaft angle and femoral anteversion angle [4]. This orientation could be different from patient to patient, as well as undergo changes with ageing and pathology development. The result will be a movement that occurs in relation to the constraints imposed by the morphology and degrees of freedom of each joint, as well as the elasticity and architecture of the surrounding soft tissue. For example, within this group of patients there were three patterns of the relative movement between the right and left iliac bones. These movements included (a) the retroversion of the right and left iliac bones (11%), (b) an anteversion of the RIB and a retroversion of the LIB (68%) and (c) an anteversion of the LIB and RIB (20%). This contrast may principally be related to the morphology of the coxal bone (composed of three bones fused early in life: the pubis, ischium, and ilium) which is different between patients and known to differ with age and gender [1]. The majority of the patients included in this study (60%) had a Risser sign 0, and 90% a Risser less than 4. This indicates that they were not mature and undergoing growth and changes in morphology of the coxal bone and sacroiliac joint. Other variable postural adaptations such as rotation and lateral shift of the pelvis and shoulders are changes that occurred in the transverse plane outside the axis of principal cor-

rection. These adaptations may be specific to the constraints imposed by muscle tissue in reference to a new skeletal geometry and in consequence affect the overall geometry. They may reflect a strategy used by the neuromuscular system to move the centre of gravity over the sacral base and within the base of support, providing a horizontal vestibular and visual frame of reference.

At the time of the initial patient evaluation, the majority of the patients in this study had a discrepancy between the height of the lower limbs and they all had a tilt of the pelvis, accompanied by a curvature of the spine. These patients also had vertebral rotation and wedging of the apical vertebra of the major curve. The strongest relationship with the spinal curvature was the rotation of the apical vertebra (0.62) followed by sacral tilt (0.30). The impact of pelvic obliquity as a secondary or aggravating factor for specific types of scoliosis curves has been identified by previous authors [14, 15, 22]. The mechanism, although not clearly defined, may be principally related to the consequent tilt of S1 that affects the tilt of adjacent vertebra, destabilizing the vertical alignment of the spine, changing the functionality of each muscle, and in the end an asymmetrical distribution of forces on the vertebral body. This asymmetric force distribution could then affect the geometry and orientation of the vertebral body [12, 16, 24], contributing to the structural deformity of the pathology. As a result, the horizontalization of the sacrum is used as a technique to reduce the scoliotic curve. The literature suggests that this is a successful treatment approach for functional scoliosis curves, but ineffective for structural curves, with some controversy over the possibility of functional curves becoming structural. Within the context of this study, the acute impact of the shoe lift was investigated on the spine and posture of the patient. These changes may be sufficient for an acute correction, but not sufficient to reduce the scoliosis curve over the short and long term. This may be attributed to individual adaptive

sequences associated with the maturation, mobility and morphology of the sacroiliac joint [1], the growth phase that the patient is in [10], the presence of asymmetric vertebral deformation [2, 23, 24] and the mechanical stresses induced on the vertebra through adjacent anatomical structures. In these instances, the shoe lift may provide the basis for correcting the spinal base (horizontal sacrum) from which a brace or surgical treatment may be pursued more effectively. In this study 23 of the 46 patients were fitted with a brace to complement the shoe lift treatment. Through a combined approach, an optimal spinal correction may be pursued initially with the shoe lift, then followed by brace or surgical techniques. However, the potential to judge the prognostic nature of the postural reactions and the efficacy of short-term and long-term spinal correction should be more clearly defined. The systematic and individual postural adaptations suggest the importance of considering the impact of a shoe lift on the spine, but also the necessity of recognizing that acute postural adaptations are present and need to be taken into consideration.

Conclusion

Use of a shoe lift results in acute postural and spinal adaptations. These changes are three-dimensional in nature, involving the position and orientation of the pelvis and shoulder girdles as well as the spine and are the product of a mechanism that is involved in acute spine correction. This mechanism has a systematic component common to all patients, as well as a component that is related to the initial skeletal morphology of each patient.

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