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Balance Control and Plantar Pressure Distribution in Hyperkyphotic Adolescent and Young Adults

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ABSTRACT

AIM: To assess differences in static/dynamic balance and plantar pressure distribution (PPD) in hyperkyphotic adolescents and young adults based on sagittal spinopelvic alignment changes.

MATERIAL and METHODS: Twelve hyperkyphotic patients and 12 normal subjects were included in the study group and control group, respectively. Lateral spine X-rays were used to evaluate spinopelvic parameters, thoracic kyphosis, lumbar lordosis (LL), and sagittal vertical axis offsets. A Balance Master device was used to evaluate the balance and postural control of subjects, and an EMED pedobarography device was used to record dynamic PPDs. Radiologic parameters, center of pressure (COP) velocity, COP alignment, and PPDs were compared in both groups to determine significance.

RESULTS: A positive correlation was found between kyphosis and lordosis ($r = 0.573$, $p=0.03$) in the study group. No significant difference was found in COP alignment and mean sway velocity between the two groups ($p>0.05$). Statistically significant differences were found in the endpoint excursion values in the forward direction between groups in terms of dynamic balance measurement ($p=0.09$). The dynamic pedobarographic measurements did not reveal any intergroup differences ($p<0.05$).

CONCLUSION: Delayed balance control may be observed during forward reach in hyperkyphotic adolescents and young adults. Compensatory LL may be effective to maintain normal gravity projections, static balance control, and PPDs as a response to thoracic hyperkyphosis.

KEYWORDS: Body balance, Kyphosis, Plantar pressure distribution, Postural control, Sagittal spinopelvic alignment

ABBREVIATIONS: COP: Center of pressure, **PPD:** Plantar pressure distribution, **TK:** Thoracic kyphosis, **LL:** Lumbar lordosis, **PI:** Pelvic incidence, **PT:** Pelvic tilt, **SVA:** Sagittal vertical axis, **LOS:** Limits of stability, **RT:** Reaction time, **MVL:** Movement velocity, **EPE:** Endpoint excursion, **MXE:** Maximum excursion, **COM:** Center of mass

INTRODUCTION

Hyperkyphosis is the most common cause of sagittal spinal malalignment in adolescents and young adults. It is characterized by increased thoracic kyphosis (TK) angle, which is measured using Cobb's method. Hyperkyphosis is most often caused by Scheuermann's kyphosis (SK) and round back deformity (18).

An erect posture achieved by healthy spinopelvic alignment is necessary to maintain the body's balance and postural control in an energy-efficient way. The body's center of mass (COM) can be safely maintained within the base of support by keeping the spinal curvature within physiologic borders on the sagittal plane, straight and symmetric column alignment on the coronal plane, and well-balanced paravertebral musculatures. Balance control is affected in different spinal

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deformities, such as adolescent idiopathic scoliosis (AIS) and age-related kyphosis (9). Displacement of the center of gravity and its ground projection (center of pressure [COP]) on the anteroposterior and lateral planes has been postulated to cause poor stability control in patients with AIS (7). Furthermore, neurosensory alterations and related balance control dysfunction may play a key role in the development and progression of coronal plane deformities in adolescents (9, 23). Currently, the mechanisms behind the postural control and balance of hyperkyphotic adolescents and young adults remain unclear. More information regarding the possible underlying mechanisms of spinal deformities is needed to improve treatment strategies.

In addition, trunk asymmetry in spinal deformities may lead to COP displacements, which reflect potential alterations in plantar foot pressure. Several studies have been conducted to evaluate plantar pressure distributions (PPDs) in coronal plane spinal deformities (17). To our knowledge, no previous studies have examined PPD in hyperkyphotic adolescents and young adults. The present study was conducted to investigate the influence of hyperkyphosis on static/dynamic balance and foot PPDs in adolescents and young adults.

MATERIAL and METHODS

Participants

Twelve hyperkyphotic patients (five females and seven males) aged between 13 and 32 years (mean 19.7 years, SD 5.5) with a mean height of 170 cm (SD 9) and a mean body mass index of 22.7 kg/m² (SD 5.6) were recruited as the study group. The inclusion criteria for hyperkyphotic subjects were age between 15 and 35 years, TK angle greater than 50°, no previous surgical or conservative treatment, and no other known musculoskeletal or neurological disorder. Ten of the cases had SK, and two cases had round back deformity. These patients had a mean TK angle of 68.3° (between 52° and 88°, SD 12.51).

Twelve patients (four females and eight males) aged between 14 and 29 years (mean 18.7 years, SD 5.2) with no spinal deformities on full-length posteroanterior and lateral spine X-rays in standing position were recruited as the control group. These subjects were referred to the outpatient clinic of the orthopedics department of the university hospital for consultation by their family physician or pediatrician to rule out spinal deformities. The mean height and body mass index of the control group were 168.7 cm (SD 10.2) and 27.5 kg/m² (SD 3.1), respectively. No significant differences were observed for age, height, and body mass index between both groups. The study protocol was approved by the local research ethics committee, and informed consent was obtained from each participant or parent.

Radiographic Evaluation

All patients were evaluated by full-length posteroanterior and lateral 36–in X-rays in a standardized position (knees and hips in full extension, arms in a forward direction at 90°) (13). If established, sagittal spinal parameters (Figure 1) and frontal plane deformities were measured using Cobb's method. The Cobb angle between the upper end plate of the T4 vertebra and the lower end plate of the T12 vertebra was used to measure TK, and the Cobb angle between the upper end plate of the L1 vertebra and the lower end plate of the L5 vertebra was used to measure lumbar lordosis (LL). The S1 superior endplate was not used to measure lordosis because L1–L5 Cobb measurement methods are reliable for measuring global LL in adult scoliosis (11). The angle between the line perpendicular to the sacral plate at its midpoint and the line connecting this point to the middle axis of the femoral heads was used to measure pelvic incidence (PI). Pelvic tilt (PT) was determined by the angle between the line connecting the midpoint of the sacral plate and the middle axis of the femoral heads (16). Sagittal vertical axis (SVA) offset was defined as the distance between the C7 plumb line (originating from the center of the C7 vertebral body) and the posterosuperior corner of the S1 vertebra. SVA and its perpendicular distance from the posterosuperior corner of the S1 vertebral body were recorded as negative when the plumb line shifted posteriorly and positive when the plumb line shifted anteriorly as a measurement in millimeters of sagittal spinal alignment (14).

Posturographic Balance and Postural Control Evaluation

A force plate system (Balance Master balance and performance device, NeuroCom System Version 8.1.0, B 100718, 1989–2004 NeuroCom® International Inc., USA) was used to evaluate balance and postural control in the present study.

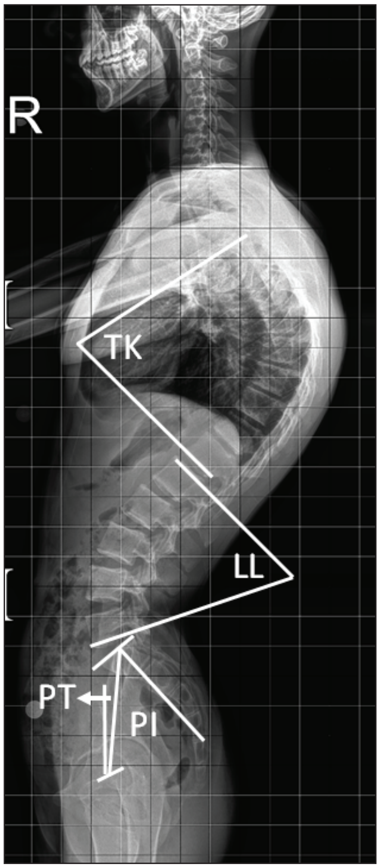

Figure 1: Sagittal spinopelvic measurements on full-length lateral X-rays. Thoracic kyphosis (TK), lumbar lordosis (LL), pelvic tilt (PT), and pelvic incidence (PI) measurements can be seen.

The participants were asked to stand relaxed, immobile, and barefoot on the force plate with their eyes open, feet at shoulder width, and arms hanging freely at the side for 30 s (Figure 2A). The measurements were repeated three times, and subjects were allowed to rest once. COP alignment was recorded as anterior, within the normal range, and posterior according to the measurement of the device (Figure 2B). The average COP sway was recorded in degrees per second to indicate static balance. The limits of stability (LOS) test was used to evaluate the dynamic balance of subjects. The LOS test is a reliable tool to evaluate functional stability and assess dynamic balance during the performance of specific tasks with visual feedback (15). It quantifies the maximum distance that a person can lean in a given direction without losing balance or reaching for assistance. During the LOS test, subjects were required to shift their COP in the direction of four cardinal and four diagonal targets as soon and accurately as possible after the visual signal was triggered on screen (Figure 3A). Three consecutive trials were performed for each experimental condition. Four dynamic control parameters were measured and evaluated (Figure 3B). The reaction time (RT) was defined as the time measured from the presentation of a start cue to the onset of the voluntary shifting of the subject's COP toward the target position. Movement velocity (MVL) is referred to as the average speed of COP movement displacement measured in degrees per second. Endpoint excursion (EPE) was defined as the percentage of the distance achieved toward a target on the initial movement, and maximum excursion (MXE) was defined as the value indicating the furthest on-axis distance of COP traveled from the center target (10).

Pedobarography

Dynamic plantar pressure measurements were performed using an EMED pedobarography device (Novel Inc., Munich, Germany) embedded in a wooden platform. This device pro-

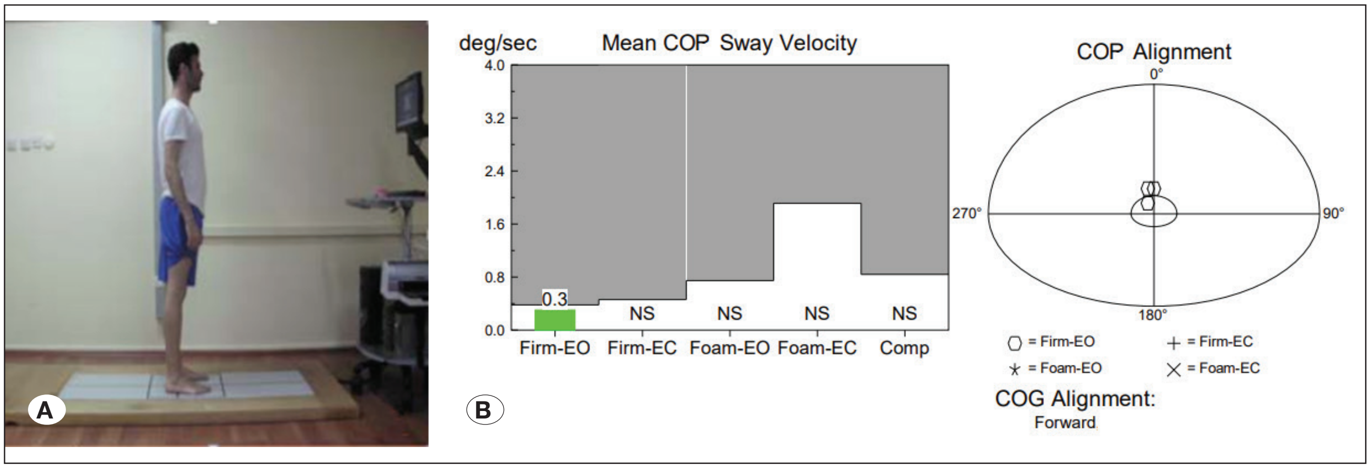

Figure 2: Standing position of a volunteer on the force plate to compute static balance and center of pressure (COP) alignment **(A)**. Sample of COP sway velocity and COP alignment test result **(B)**.

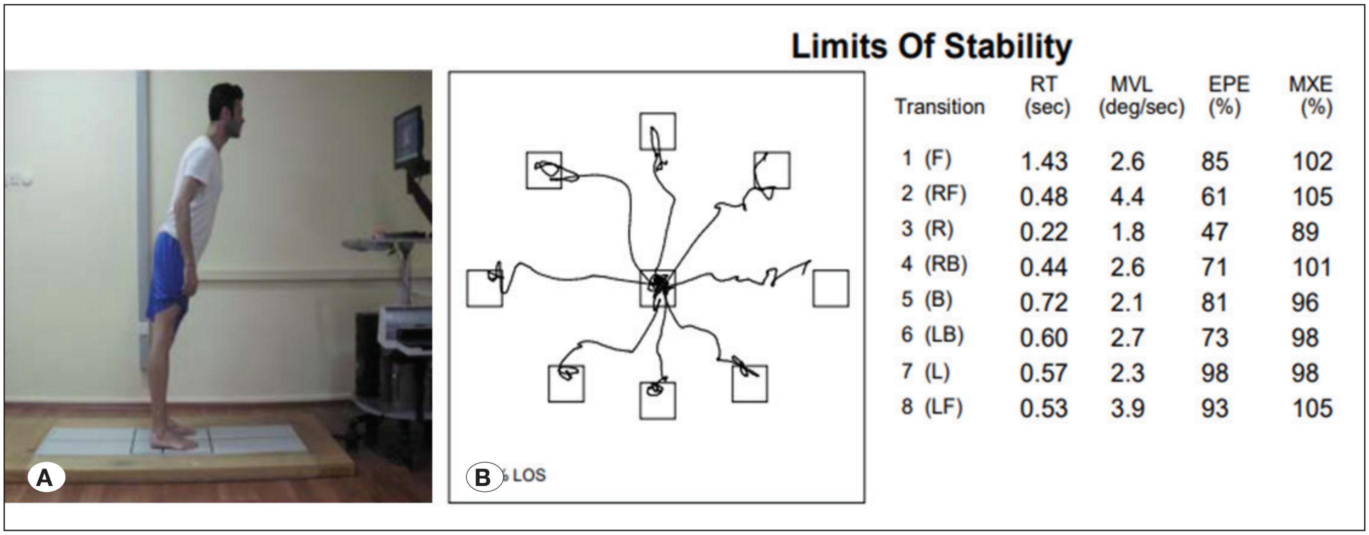

Figure 3: For dynamic balance evaluation, the volunteer was asked to shift his center of pressure (COP) by reaching in the direction of different targets as soon as possible after the visual signal was triggered on the computer screen **(A)**. Test result of dynamic balance assessment (Limits of stability test) **(B)**.

vides information regarding foot posture to measure the plantar contact area and plantar load distribution during bipedal posture and walking. It measures PPDs objectively with a total area of 610 mm × 323 mm, enclosing a 240 mm × 380 mm sensor area with a total of four sensors/cm^2 and a sampling rate of 60 Hz. Three trials were performed with the two-step gait initiation protocol. The footprints were divided into 10 regions by the software according to the manufacturer's guidelines, and the mean values of peak pressures in each region (kPa) of the left foot were recorded.

Statistical Analysis

Dynamic balance studies can make subjects uncomfortable. For this reason, the number of samples should be kept to a minimum. The estimation of the sample size was based on a previous study (8). The Power Analysis and Sample Size software (trial version, NCSS, Kaysville, UT, USA) calculated that a minimum sample size of 24 people would be required for an alpha level of 0.05 and 80% power. The group results for raw data are expressed as means and standard deviations. Pearson correlation coefficients were calculated to analyze the correlation between quantitative variables. The Mann–Whitney U test was used to compare ordinal data, and the chi-squared test was used to compare categorical data between groups. Statistical significance was set at p<0.05 for all comparisons with data analyzed using SPSS 15.0 software for Windows.

RESULTS

The TK angle was 68.3° ± 12.51° (52°–88°) in the study group and 35.9° (24°–46°) in the control group. Mild thoracic scoliosis curves were detected in three cases in the study group. Among them, two had right thoracic curves and one had left thoracic curves. All subjects in the study group were right hand dominant, and only two subjects in the control group were left hand dominant.

Table I shows a comparison of the sagittal spinopelvic parameters between groups. The TK and LL angles were significantly higher in the study group than in the control group (68.3° vs. 35.9°, p=0 for TK; 51.1 vs. 41.1°, p=0.05 for LL). TK was found to be strongly positively correlated with LL (r=0.573, p=0.03). Although relatively higher PI and PT values were noted in hyperkyphotic subjects, they were not statistically significant. The mean SVA offsets were not different between groups (–17 mm, SD 39.3 vs. –3.9 mm, SD 43.13, p>0.05), and C7 plumb lines tended to be placed posterior to the posterosuperior corner of the S1 vertebra in both groups.

The COP mean sway velocity data showed no significant difference in terms of static balance between groups (0.36 ± 0.07 °/s in the control group and 0.34 ± 0.07 °/s in the study group). No significant differences in COP alignment between groups were determined (p>0.05).

Table II shows the LOS test results. The EPE in the anterior direction was significantly higher (p=0.01) in the study group than in the control group. In other directions, the EPEs were almost similar. A lower MXE in the posterior direction and a higher MXE in the anterior direction were detected in the study group, but they were not statistically significant (p>0.05). The differences in dynamic peak pressures on plantar regions between groups were not statistically significant (p>0.05, Table III).

DISCUSSION

Spinal deformities are thought to be associated with various balance disorders and postural control disorders. In posturographic analysis of patients with AIS, significant differences were observed in COP-based postural sway measures during static standard stance and perturbation tests (5). Such findings in patients with AIS have been suggested to result from somatosensory changes and three-dimensional deviation of the spine as a biomechanical factor, along with the associated changes in COM of the body (21). Furthermore, deficits in nervous system components responsible for postural control have been hypothesized to be involved in the etiology of AIS (23).

The effects of sagittal plane deformities of the spine on balance and postural control have been studied mostly in adult patient groups. Osteoporosis-related hyperkyphosis and accompanying weakness of the back extensor muscles have been shown to lead to inadequate postural stability and impaired body sway control in adults (21). There is insufficient data in the literature regarding the effect of hyperkyphosis on postural stability and balance in adolescent and young adult age groups, which is caused by different etiological factors than age-related kyphosis.

Table I: Comparison of Sagittal Spinopelvic Parameters Between Groups. Sagittal Spinopelvic Parameters Show No Statistically Significant Differences Between Groups

	Normal (n=12)	Hyperkyphosis (n=12)	p value
TK (°)	35.9 (7.1)	68.3 (12.5)	**<0.01**
LL (°)	41.1 (5.9)	51.1 (14.1)	**0.05**
PI (°)	37.9 (8.9)	42.3 (11.1)	0.224
PT (°)	10.1 (5.2)	14.2 (8.6)	0.182
SVA offset (mm)	-17 (39.3)	-3.9 (43.13)	0.487

***p:** Mann-Whitney U Test, **TK:** Thoracic kyphosis angle, **LL:** Lumbar lordosis angle, **PI:** Pelvic incidence angle, **PT:** Pelvic tilt angle, **SVA:** Sagittal vertical axis (negative when C7 plumbline was shifted posteriorly and positive when C7 plumbline shifted anteriorly).*

Table II: Comparison of Limits of Stability Between Groups. Anterior Endpoint Excursion (EPE Forward) is Statistically Different Between Groups

	Normal (n=12)	Hyperkyphosis (n=12)	p value
RT Forward (sec)	1.304 (0.543)	1.288 (0.400)	0.862
RT Backward (sec)	0.680 (0.410)	0.760 (0.340)	0.418
RT Right (sec)	1.370 (0.637)	1.230 (0.615)	0.453
RT Left (sec)	0.805 (0.387)	0.916 (0.441)	0.453
MVL Forward (deg/sec)	3.225 (1.359)	2.866 (0.896)	0.840
MVLForward (deg/sec)	3.225 (1.359)	2.866 (0.896)	0.840
MVL Backward (deg/sec)	2.325 (1.389)	2.433 (1.103)	0.451
MVL Right (deg/sec)	3.533 (1.861)	3.650 (1.948)	0.773
MVL Left (deg/sec)	4.016 (1.440)	4.516 (2.063)	0.908
EPE Forward (%)	62.16 (21.41)	82.25 (16.94)	**0.01**
EPE Backward (%)	57.83 (20.54)	48.50 (12.05)	0.418
EPE Right (%)	59.50 (20.90)	68.00 (15.39)	0.355
EPE Left (%)	74.66 (16.73)	74.66 (20.01)	0.840
MXE Forward (%)	94.50 (13.08)	99.91 (9.31)	0.340
MXE Backward (%)	70.08 (22.38)	66.50 (16.03)	0.525
MXE Right (%)	81.16 (8.70)	82.25 (8.92)	0.954
MXE Left (%)	94.00 (10.54)	91.58 (10.57)	0.729

***p:** Mann-Whitney U Test, **RT:** Reaction time, **MVL:** Movement velocity, **EPE:** End point excursion, **MXE:** Maximum excursion.*

Table III: Comparison of Plantar Peak Pressures within Each Region Between Groups. No Statistically Significant Differences in Plantar Pressure Distribution were Observed Between Groups

Peak Pressure, kPa	Normal (n=12)	Hyperkyphosis (n=12)	p value
Total Object	275 (132)	369 (125)	0.065
Hindfoot	240 (61)	243 (81)	0.954
Midfoot	150 (95)	163 (77)	0.525
MH 1	140 (71)	146 (77)	0.729
MH 2	110 (84)	139 (106)	0.506
MH 3	113 (99)	125 (92)	0.707
MH 4	101 (39)	119 (63)	0.908
MH 5	122 (74)	127 (76)	0.750
Big Toe	81 (81)	60 (69)	0.483
Second Toe	113 (127)	176 (142)	0.435
Toes 3,4,5	72 (58)	57 (35)	0.451

***p:** Mann-Whitney U Test, **MH:** Metatarsal head.*

In the present study, COP parameters were examined by posturographic analysis to evaluate balance under static and dynamic conditions. The time domain sway velocity parameter of COP is reliable in evaluating static balance (3). Increased sway velocity values indicate that the body's static balance is disturbed; requiring high sway magnitudes to maintain balance (9). The mean COP sway velocities in the static standing position were found to be similar in the study and control groups. Based on this finding, it can be assumed that individuals in the study group do not have difficulty maintaining body balance in the standing position. Similarly, Eshraghi et al. reported that patients with SK were not different from normal individuals in achieving static balance (8). A possible explanation is that hyperkyphotic individuals are capable of maintaining their center of gravity and associated ground projection (COP) within the limits of their base of support in the standing position, similar to normal individuals. The similarity of the mean COP alignments recorded under static conditions in both groups in our study supports this hypothesis.

In an attempt to achieve the forward visualized gaze, thoracic hyperkyphosis is compensated with increases in the lordosis angle in other spinal segments in adolescents and young adults having a flexible spine structure (4). Previously, significant compensatory increases in LL and posterior placement of the C7 plumb line (negative SVA offsets) were observed, especially in patients with SK (6). Consistent with the literature, thoracic hyperkyphosis was significantly compensated by increased LL in the study group. Furthermore, these patients had negative SVA offset values similar to the control group. Compensation of hyperkyphosis may enable the healthy maintenance of static balance. Similarly, a study on patients with AIS observed that static balance control could be better achieved in patients with double major curvatures compared to patients with thoracic major, thoracolumbar major, and lumbar major curvatures. This is because double major scoliosis is a well-balanced scoliosis with minimum or no lateral COP displacements compared with single major curve scoliosis (9).

Due to its high reliability, the LOS test has been used in various studies to perform a posturographic analysis of the dynamic component of balance (15, 20). In the present study, the EPE values were significantly higher in the study group compared with the control group, indicating that patients in the study group achieved delayed balance control during forward reach. Moreover, the EPE values were higher in the anterior direction but lower in the posterior direction in the study group compared with the control group. However, the differences were not statistically significant. Contrary to our results, Eshraghi et al. found shorter reach distances in all directions in patients with SK compared with healthy subjects, and this finding was explained by the intervertebral ligament stiffness (8). The heterogeneity of subjects in the study group, including patients with thoracic SK, thoracolumbar SK, and patients with round back deformity, may have contributed to the emergence of different results in the present study. However, anterior longitudinal ligament stiffness is present in SK (19), which may explain the short reach distance in the posterior direction. Basically, the human body can maintain postural stability with a complex integration of neurologic, sensory, and biomechanical factors. Although perturbation test conditions (e.g., eyes closed, unstable floor, and tendon vibratory stimulation) during posturographic test procedures may provide information about the proprioceptional, visual, and vestibular components of postural control (21), it is difficult to distinguish the effect of biomechanical factors. Delayed control and the long distance of forward reach in hyperkyphotic individuals may result from the diminished strength of posterior muscles, which is a probable mechanical theory in the pathogenesis of SK (22). Considering that the RT and MVL in all directions were similar in both groups, it could be suggested that differences in dynamic balance and postural control in hyperkyphotic patients might be due to biomechanical factors (low muscle strength and uncontrolled and fast center of gravity transfer) rather than central neurosensory factors.

To the best of our knowledge, no studies have conducted pedobarographic evaluations on adolescent and young adult patients with hyperkyphosis. The analysis of dynamic pedobarographic data in this study revealed similar peak pressure distributions at different plantar regions of the left foot between groups. Although the changes in foot anatomy developing in parallel to advancing age affect the standardization of pedobarographic examinations, adult pressure distribution patterns are observed in adolescents and children over the age of seven years (1). The effect of spinal deformities on PPD has been evaluated in a limited number of studies. Aydin et al. have shown that impaired sagittal spinopelvic alignment in adult patients with ankylosing spondylitis can cause changes in pressure distributions in the metatarsal region and midfoot under dynamic conditions (2). However, a relatively rigid sagittal spinopelvic alignment in patients with ankylosing spondylitis may have led to this situation. Similarly, in another study, no PPD differences were observed in patients with AIS in general, but statistically significant plantar pressure changes were observed in patients with significant loss of lordosis in the sagittal plane. Again, PPD differences were not observed in six patients with SK in the same study compared with normal cases (12). Undoubtedly, dynamic PPDs are associated with bipedal gait, and gait balance requires a more complex integration of neurosensory systems compared with static–dynamic balance conditions. Moreover, the evaluation of sagittal spinopelvic alignment on X-ray images of patients in a standing position may be inadequate to predict body inclination during walking. However, after reviewing the information in current literature and our study results, it can be concluded that a flexible lumbar spine may play a key role in center of gravity compensation during walking in hyperkyphotic adolescents and young adults, resulting in normal PPD.

The limitations of the study were the low number of patients in the control and study groups and the inclusion of hyperkyphotic patients having different diseases. Simultaneous measurements on X-ray and posturographic images could help achieve a more reliable comparison. In future studies, perturbation conditions and somatosensory evoked potential tests should be integrated into posturographic analysis to comprehensively evaluate the neurosensory pathways in these patient groups.

CONCLUSION

The static balance, COP alignment, and PPD in hyperkyphotic adolescents and young adults are similar to those in healthy individuals, probably because of the effect of increased compensatory LL. Delayed balance control may be observed during forward reach in these patients.

AUTHORSHIP CONTRIBUTION

Study conception and design: HC, OA, AE, IES
Data collection: HC, AE
Analysis and interpretation of results: HC, OA, AE, IES
Draft manuscript preparation: HC, OA
Critical revision of the article: HC, OA, AE, IES
Other (study supervision, fundings, materials, etc...): OA, IES
All authors (HC, OA, AE, IES) reviewed the results and approved the final version of the manuscript.

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