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The effect of foot hyperpronation on spine alignment in standing position

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Abstract

Background: According to clinical observations, foot hyperpronation is very prevalent and may cause malalignment of the lower extremity, leading to structural and functional deficits in standing and walking. This study aimed at investigating the effect of foot hyperpronation on spine alignment in the standing position.

Methods: Thirty-five healthy males with an age range of 18-30 years participated in this cross-sectional study. Evaluation was performed with two examiners in four standing positions (on the floor, and on the wedges angled at 10, 15, and 20 degrees) using a motion analysis system (Zebris). Moreover, each of the measurement methods was repeated for three short times. Paired t- test and repeated measures ANOVA test were used for statistical analysis.

Results: Significant differences were observed between all modes in the sacral angle, pelvic inclination, lumbar lordosis, and thoracic kyphosis variables (except between the first and second mode). Finally, a positive correlation was obtained for the examiners and all the variables with an increasing slope of the angle of wedge.

Conclusion: The results of the present study revealed sacral angle, pelvic inclination, lumbar lordosis, and thoracic kyphosis were increased with an increase in bilateral foot pronation. In fact, each one of them is a compensatory phenomenon.

Keywords: Biomechanics, Hyperpronation, Motion Analysis System, Spine Alignment, Wedges, Zebris System.

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Introduction

Understanding the biomechanical structure of each part of the body is important for preventing and treating the musculoskeletal system (1). The normal biomechanics of the foot might be disrupted because of abnormal function of the subtalar joint. In a closed kinematic chain, pronation of the subtalar joint is characterized by adduction and plantar flexion of the talus and eversion of the calcaneus (2). Excessive pronation of the foot may cause malalignment of the lower extremity, frequently leading to structural and functional deficits in both standing and walking. The bilateral presence of excessive calcaneal eversion generates internal rotation of the hips, and consequently, may lead to increased pelvic anteversion (3) and to the presence of lumbar hyperlordosis (4). Thus, the presence of excessive calcaneal eversion may be related to the occurrence of pathological conditions of the lumbar spine (5). However, several researchers suggest a relationship between hyperpronation and alignment of the pelvis and lumbar spine (4-8). Hyperpronation causes more proximal biomechanical dysfunction. The current research suggests that the dysfunction of the musculature of the lumbopelvic-hip complex may lead to lower extremity functional changes and developing some pathology traditionally attribut-

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ed to excessive foot pronation. Good posture is often idealized as the perfect alignment of the weight-bearing segments (9, 10). Pelvic position is an important key in appropriate postural alignment and acts as an intermediary between the lower extremities; moreover, spine is responsible for the anatomic connection and transmission of forces between the lower limbs and the upper body. Pelvic position is associated with lumbar vertebrae position (4,11). When the center of the body is deviated from the ideal alignment, the body may use compensatory postural strategies until the center of gravity (COG) returns within the base of support and obtains a stable position (12). According to clinical observations, hyperpronation is highly prevalent. Several authors have suggested the possibility of excess pronation during a two-legged stance and gait, affecting the posture of the pelvis (3,13) and lumbar spine (5,14). Few studies have described the relationship between bilateral hyperpronation and alignment of the spine in the standing position. Thus, this study aimed at investigating the immediate effect of induced hyperpronation of the feet on the spine alignment in the standing position using an ultrasound-basis motion analysis system.

Methods

Participants

Thirty-five healthy males, aged 18-30 years participated in this cross-sectional study. All participants were evaluated and selected in School of Rehabilitation Clinic at Iran University of Medical Sciences (Tehran, Iran) according to the following inclusion criteria: 1) No history of lower limb or spine surgery, musculoskeletal injuries, and neurological diseases; 2) No pain or pathology in the ankle, hips, pelvis, and spine for at least 1 year. Furthermore, those participants with structural lower limb abnormalities (e.g., arthritis, leg length discrepancy (>5mm), known muscle atrophic diseases, acute or chronic back pain, and postural abnormalities) were also excluded. The institutional ethics committee at University of Iran approved this study, and all participants signed an informed consent form. Moreover, approval was obtained from the Research Ethics Committee of Iran University of Medical Sciences. Research Ethics Board approvals were kept current for the duration of the study. Furthermore, the present study was conducted according to the Declaration of Helsinki, the Australian NHMRC National Statement on Ethical Conduct in Human Research 2007 (15) the Notes for Guidance on Good Clinical Practice as adopted by the Australian Therapeutic Goods Administration 2000 CPMP/ICH/135/95 (16) and the ICH GCP Guidelines. The study was conducted in a biomechanical laboratory.

Measures and Procedures

Three-dimensional motion analysis system (Zebris Medical GmbH, Germany), with ultrasonic pointer and basic system (CMS20) was applied for analyzing the spine (Fig. 1). To analyze with the pointer, we attached the triple reference marker to the participant's body using a Velcro strip. It was used to eliminate fluctuations of the body's position during the pointer measurement. First, the position of the measuring device was calibrated to define its position to the ground. Four points were indicated on the floor for calibration by the pointer. The points were fixed by pushing the button on the pointer and sensors of the pointer were facing the measuring unit. A new calibration was necessary only if the measuring unit or the reference marker had slipped. Initially, the barefoot participants were asked to stand in a relaxed position with their weight evenly distributed on both feet to obtain the same base of support considering their pelvic width and the same natural foot alignment. Then, the participants stood on the posture wedge angled at 10, 15, and 20 degrees, which was designed to induce hyperpronation (Fig. 2). Tracing was then made of the participant's feet so that all measurements would be made with the participant in the same standing position. Each measurement was taken 3 times

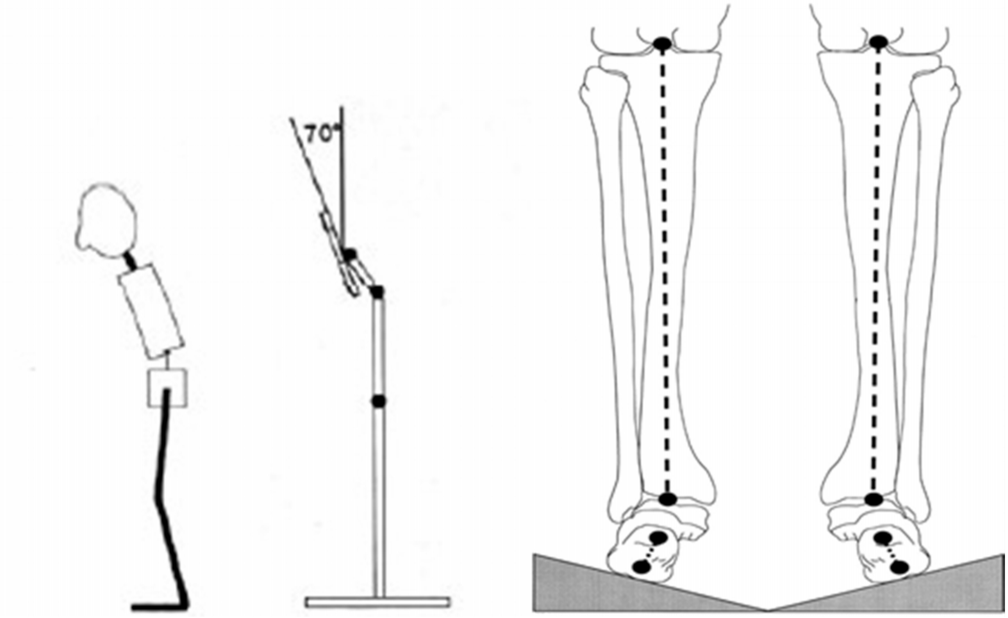

Fig. 1. Basic System CMS20, Ultrasonic Pointer

Fig. 2. (A) The Participant Standing on a Wedge, (B) Position of the Measuring Unit

during a normal relaxed standing position. Each participant remained in a standing position with his back turned to the device, and the position of the examiner was preferably on the side opposite to the applied reference marker. While the participant was standing, the first examiner palpated the right and left ASIS, and PSIS, left and right acromions, and the spinous processes of C7 and S3, and marked them with a marker. The top of the pointer was put on the anatomical points and the key-button of the pointer was pressed for approximately one second until the point appeared on the screen and a short acoustic signal was given. After all pointers were entered, the spinal crest line was scanned with the tip of the pointer from C7 to S3. A line was drawn from C7 to S3 using an ultrasonic pointer. This measurement, like others, was taken 3 times by the same examiner without rest between the measurements. Each of the measurement methods was repeated 3 times. The second examiner took the measurements 3 times on each participant to determine the average of these measurements. The first examiner was not aware of the original values, and thus, could not be influenced by them, so reliability assessment was not compromised. The second examiner recorded the measurement without allowing the first examiner to be informed about those measurements.

Data Reduction

Data were processed through the 3D Motion Analysis Software (WinSpine Pointer Program for analyzing the posture, shape and mobility of the spine). Layouts of the program were database, real time measurement, signal viewer, and report. Sacral angle was defined by the angle between the tangent through S1 and the frontal plane. Pelvic inclination was described by the angle between the line drawn through the anterior superior iliac spine and posterior superior iliac spine and the line drawn through the transverse plane in the sagittal plane. Thoracic kyphosis (the abnormally excessive convex kyphotic curvature of the spine) and lumbar lordosis (the normal inward lordosis curvature of the lumbar and cervical regions of the spine) angles were formed from all the thoracic vertebrae angles. The angles of the vertebrae were calculated using 3 points as described in the Annex. The means and standard deviations of the position of the spine were computed using the three trials for each participant in each study condition.

Statistical Analysis

Statistical analysis and graphic presentation were prepared using software SPSS Version 17. Significance of the change in the segmental alignment between modes was determined using paired t-test. Cumulative influence of the increasing wedge angle on the segmental alignment change was examined using repeated measure ANOVA. Significance level was adjusted by Bonferroni's equation for multiple comparisons. Significance level was set at $P < 0.0083$.

Results

The mean (SD) age, height, and weight of the participants was 22.8 (28.9) years, 1.77 (4.98) m, and 78 (7.77) kg, respectively. The physical status of the participants is demonstrated in Table 1. Repeated measures were used for statistical analysis. No significant differences were found in the variables and examiners. A strong correlation was found for examiners and sacral angle between standing directly on the floor and three wedges angled at 0.929°, 0.931°, and 0.940°, respectively. The spaces added for examiners and pelvic inclination were as follow: Between standing directly on the floor and the first wedge (r=0.862), second wedge (r=0.871), and the third wedge (r=0.903). The spaces added for examiners and lumbar lordoses were as follow: Between standing directly on the floor and the first wedge (r=0.817), second wedge (r=0.856), and the third wedge (r=0.871). The spaces added for examiners and thoracic kyphosis were as follow: Between standing directly on the floor and the first wedge (r=0.807), second wedge (r=0.842), and the third wedge (r=0.844). The results demonstrated a positive correlation with the increased slope of the angle of the wedges, which was obtained for the examiners and variables. The means and standard deviations for each variable in the 4 standing positions provided by the 2 examiners are demonstrated in Table 2.

No statistically significant difference was

Table 1. The Physical Status of the Participants

Variable	Mean±SD	Maximum	Minimum
Age	22.8±2.89	18	28
Weight (kg)	78.0±7.77	61.8	93.5
Height (cm)	177.0±4.98	168	187
BMI*	24.8±2.73	19.8	31.2

* Body Mass Index (BMI) was calculated by the following formula: Weight (kg) / height (m). This index was used to define the nutritional status.

Table 2. The Means and Standard Deviations of the Variables in the Four Standing Positions (on the Floor, on the Wedges Angled at 10, 15, and 20 Degrees) in the Sagittal Plane Determined by 2 Examiners (Mean±SD).

Variable	Examiner	Floor Mean±SD	First Wedge (10 Angle) Mean±SD	Second Wedge (15 Angle) Mean±SD	Third Wedge (20 Angle) Mean±SD
Sacral angle	Examiner 1	30.2±5.21	32.8±5.45	34.5±5.50	36.8±5.56
	Examiner 2	30.5±5.75	32.7±5.31	34.7±5.65	36.9±5.78
Pelvic inclination	Examiner 1	34.6±5.24	37.3±5.33	39.0±4.94	40.0±5.23
	Examiner 2	34.7±5.23	37.3±5.36	39.0±4.92	40.2±5.40
Lumbar lordosis	Examiner 1	33.9±4.75	35.7±4.15	38.0±4.30	40.5±4.61
	Examiner 2	33.9±4.71	35.9±4.06	38.2±4.25	40.4±4.62
Thoracic kyphosis	Examiner 1	31.2±5.32	31.9±5.19	33.4±5.78	34.8±5.52
	Examiner 2	31.0±5.00	32.1±5.15	33.4±5.77	34.8±5.66

Table 3. Changes in Sagittal Spine Alignment between the Modes

Variable	Sacral Angle	Sacral Angle P-value (paired t-test)	Pelvic Inclination	Pelvic Inclination P-value (paired t-test)
Floor and Wedge 1	-9.828	<0.001	-7.987	<0.001
Floor and Wedge 2	-17.394	<0.001	-14.113	<0.001
Floor and Wedge 3	-28.282	<0.001	-19.807	<0.001
Wedge 1 and 2	-8.960	<0.001	-7.257	<0.001
Wedge 1 and 3	-15.539	<0.001	-8.444	<0.001
Wedge 2 and 3	-16.694	<0.001	-4.486	<0.001

Variable	Lumbar Lordosis	Lumbar Lordosis P-value (paired t-test)	Thoracic Kyphosis	Thoracic Kyphosis P-value (paired t-test)
Floor and Wedge 1	-5.962	<0.001	-2.448	<0.001
Floor and Wedge 2	-14.387	<0.001	-6.198	<0.001
Floor and Wedge 3	-23/346	<0.001	-10.315	<0.001
Wedge 1 and 2	-9.993	<0.001	-6.032	<0.001
Wedge 1 and 3	-17.959	<0.001	-8.365	<0.001
Wedge 2 and 3	-14.829	<0.001	-7.646	<0.001

found between the examiners. An increase of 2.4, 1.8, and 2.2 in sacral angle demonstrated the transition from the floor to Wedge 1, Wedge 1 to Wedge 2, and Wedge 2 to Wedge 3.

Table 3 demonstrates a statistically significant increase in sacral angle, pelvic inclination, lumbar lordosis, and thoracic kyphosis in all modes ($p<0.0083$), except between the first and second mode of the thoracic kyphosis variable ($p>0.0083$).

Discussion

In terms of biomechanics, the human body has a multisegmental structure, initiating major and powerful interactions between adjacent segments. Interaction between segments that are further apart may also hold a high significance for symptom-free musculoskeletal function. The pelvis bone is an important segment situated in the center of the body (4) and connects the movement of the lower limbs to the segmental motion of the spine, and is a functional link through which loads are transferred in a proximal and distal manner. Although suggested often, its position and movement as related to foot posture was mostly hypothesized (13). When postural alignment is optimal, little or no muscle activity is required to maintain medial-lateral stability. The gravitational torques acting on each body is opposed by equal torques, acting on the other side of the body (17). When the center of the gravity exits the ideal alignment, the body may use compensatory postural strategies until the COG returns within the base of support and obtains a stable position. Therefore, according to the body components such as interlocking rings that each affects the other (18, 19), it is likely that changes of foot alignment may lead to the presence of postural alterations and instability of the spine, balance disorders, and structural abnormalities (20,21). Our results suggest that during the pronation of the subtalar joint, the calcaneus everts, causing the talus to slide medially and inferiorly. This medial downward movement of the talus induces an internal rotation of the tibia (14,22), and this may affect the knee joint function (23). Medial rotation of the femur causes the head of the femur to exert pressure on the posterior portion of the acetabulum (3,24). It has been hypothesized that internal rotation at the femur causes the head of the femur to exert pressure on the posterior portion of the acetabulum. This backward push on the posterior aspect of the pelvis would cause the pelvis to tilt anteriorly (15,25,26). Because pelvis is tightly connected to the lumbar spine at the sacro-iliac joint by an extensive fibrous connection, an anterior tilt of the pelvis could increase the lumbar lordosis (27,28). Excessively tilted anteriorly may lead to an increase in the lumbar anterior convexity. The line of gravity is at a greater distance from the lumbar joint axes than the optimal distance, and therefore, the extension moment in the lumbar spine is increased. The posterior convexity of the thoracic curve increases and becomes kyphotic to balance the lordotic lumbar curve and maintain the head over the sacrum (17). The change in thoracic kyphosis was smaller than the changes occurring in the segments below, as the segment was located further away from the wedge. The most significant alteration in spine alignment occurred in the transition from standing directly on the floor to standing on a 10 wedges. No significant difference was found between the examiners ($p>0.0083$), but there was a significant difference ($p<0.0083$) between the variables in all modes. The present study used the wedges to alter foot alignment in the standing position. Considering these findings, the transition from standing directly on the floor to standing on 10, 15, and 20 wedges led to additional significant changes in spine alignment. Therefore, we hypothesize that hyperpronation may play an important role in an abnormal posture etiology, specifically in babies. However, longitudinal studies are necessary to find the long-term effects of excessive foot pronation and its possible influence on the body posture. Postural abnormalities may lead to pain of the musculoskeletal system; however, correcting and training the posture is a method of reducing pain and has been used by physical therapists as a therapeutic approach (6,29,30). In the present study, the participants with excessive foot pronation used short-term compensatory mechanisms to prevent imbalance and change their body posture.

Conclusion

The results of this study revealed that sacral angle, pelvic inclination, lumbar lordosis, and thoracic kyphosis increased with an increase in bilateral foot pronation. In other words, each one of them is a compensatory phenomenon.

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