Symmetry Comparison balance Performance and Plantar pressure Distribution in Active Adolescent's Girls with Ankle Pronation While Standing and Stance Phase of Gait

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Abstract

Introduction: The foot-ankle ankle has the capability to perform specific functions such as the weight bearing of body in the standing position against the gravity, moving the body to the front and creating stability to keep the balance and control the posture. The purpose of the present study was to evaluate symmetry comparison of balance performance and plantar pressure distribution in active adolescent's girls with ankle over pronation while standing and during stance phase of gait. **Materials and Methods**: In this quasi- experimental study, 34 active adolescent girls between 14 and 17 were selected as simple. The navicular drop measurement by Bordy method, the plantar pressure distribution by foot pressure device (PT-Scan4452F100), and the symmetry between the two limbs and balance function by symmetry Index and Balance performance formula were used. Mean and Deviation was used to describe data, Shapiro-Wilk Test to verify the normality od the data, and independent t-test to compare the variable of the two groups at significance level of $P \leq 0.05$. **Results**: The symmetry comparison of balance performance and plantar pressure distribution showed that a significant difference in symmetry of rear foot pressure distribution (P=0.04), symmetry of rear foot impulse (P=0.04), symmetry of medial heel (P=0.04), symmetry of tars 1 (P=0.04) and symmetry of ankle rotation (P=0.03) between two groups, indicating more symmetry in healthy girls than those ankle hyperpronation, indicating more symmetry in healthy girls than those ankle hyperpronation. **Conclusion:** The current study's findings showed that the girls with the hyperpronation had less asymmetry on the medial heel foot and increased pressure distribution on the 1st tarsus. Also, the symmetry of balance function of heel rotation around the ankle's axis and the impulse of rear foot in the healthy group were more than in the hyperpronation group. Furthermore, because of more contact of the inner surface of the soles with the ground in the people with hyperpronation, the pressure level on the inner edge and 1st metatarsus was increased and the medial heel symmetry in the pronation group was decreased compared to the healthy group. Hence, more scientific evidence is needed to generalize the results.

Keyword: Active; Female Adolescents; Pronation; Pressure Distribution; Symmetry

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Introduction

The ankle is the last segment at the end of the closed kinetic chain and the foot sole is the common boundary of force distribution between the lower limb and the ground, which has a determining role in the absorption and distribution of reaction forces, maintaining balance, and transmitting forwarding forces [1]. The anatomical structure of the ankle acts as a rigid lever when bearing the body weight and moving [2]. One of the most important and variable structural features of the foot is the reduction of medial longitudinal arch height when bearing the bodyweight, causing deformation and disruption of the anatomical structure of the ankle and the pronation [3]. In this anomaly, the head of talus and navicular bones rotates inwards-downwards and the direction of gravity center rotates inwards, which causes an early contact of the medial part of the sole with the ground when walking, thereby resulting in a lack of effective absorption, distribution, and transmitting the reaction force from the ground to the ankle [4]. Most researchers believe that since the movement axis of the talus bone in the ankle tends inwards, it bears half of the body weight

Figure1. Navicular drop evaluation device; *A*) non-weight bearing position; *B*) weight bearing position)

when standing on both limbs, half of the force to the talus bone is transmitted by the subtalar joint to the heel, and the rest through medial and lateral longitudinal arch of foot to the forefoot [3, 14]. Therefore, any deformities of the ankle's anatomical structure may disrupt the distribution of forces on the sole, alter muscle functions, cause damage to the lower limb, and make difficulties in maintaining posture control and balance function [1, 4]. In general, symmetry includes a complete match between two halve of an object or a body and any deviation from this ideal structure causes asymmetry in the object or body. Asymmetry in people is often due to differences between limbs length and imbalances between the dominant and non-dominant limbs, leading to the body's systematic tendency toward a specific limb and biomechanical changes in the skeletal structure, articular forces, muscular functions, posture control, and balance [7, 12].

Previous studies have shown that the ankle structure displays more structural changes in comparison with other body parts and people with hyperpronation often have problems such as inflammation of the calf tendons and plantar fascia, pain in the metatarsal area, bunion deformity, and inappropriate absorption and distribution of the forces on the foot sole [2, 13,15,18]. On the other hand, some researchers have considered the plantar abnormalities as an important factor in changing the distribution patterns of the pressure on the sole when walking and standing [2,6]. They believe that the plantar abnormalities can result in changes in the center of pressure, causing changes in the range of motion, muscle torque, and distribution of plantar pressures. In people with ankle hyperpronation, the action of inverter muscles (including tibia posterior) is less than healthy people, and this leads to increased plantar flexors torque and disruption in maintaining posture control and their balance function [2,5,30]. Jahani and Jalalvand and Esmaeili *et al.* reported that the amount of ankle plantar flexion in the stance phase of walking and the peak pressure on the 2nd to 5th metatarsus in those with hyperpronation was more than normal people. However, Jafarnejad *et al.* stated a small difference in the pressure distribution between healthy people and people with ankle hyperpronation [9, 15, 19].

Figure2. Placement of sensors and regional foot classification

Finally, as most researchers have worked on the comparison and analysis of the human foot's biomechanical behaviors when standing and walking, there very few biomechanical studies to investigate the symmetry of the distribution of plantar pressures and ankle's balance function between healthy people and those with the pronation anomaly. Therefore, the purpose of the current study was to compare the symmetry of plantar balance function and pressure distribution between healthy active adolescent girls and those with ankle hyperpronation when standing and at the stance phase of walking.

Material and Methods

The study was conducted as quasi-experimental. Participants were active teenage girls in the city of Tehran and the statistical sample consisted of 32 individuals with the age between 14to 17 years. The confirmation of the ethics committee from sport science institution (IR.SSRI.REC.1400.1181) was received. The statistical samples were divided into two groups of healthy and those suffering from ankle hyperpronation. After the evocation and invitation to cooperation according to the diagnosis of the Orthopedist or the Correctional movement's expert, a written consent form was filled by all of the participants. The

Table1. Mean (SD) of descriptive measures of demographic parameters in two groups of healthy and hyper pronation girls

Group	Age (Year)	Height (m)	Weight (m)	BMI (kg.m^2)
Hyperpronation	17.16 (1.54)	1.67 (0.02)	62.38 (5.63)	22.17 (2.46)
Healthy	16.07 (1.16)	1.64 (0.18)	56.30 (6.06)	20.67 (2.46)
***P*-value**	0.516	0.184	0.03*	0.05

**significant differences at P≤0.05*

Table2. Mean (SD) of results of the independent T-test in symmetry comparison of static balance between healthy and hyperpronation girls (Kpa)

Variables	Group	Mean (SD)	Mean difference	T	Df	*P*-value
Total symmetry of foot pressure distribution	Healthy	-4.72 (3.12)	-1.97	-0.40	31.00	0.68
	Hyperpronation	1.24 (4.71)				
symmetry of forefoot pressure distribution	Healthy	-1.78 (3.14)	1.18	0.74	32.00	0.46
	Hyperpronation	-10.96 (3.54)				
symmetry of rear foot pressure distribution	Healthy	-1.43 (2.59)	-1.73	-0.65	32.00	0.04*
	Hyperpronation	-7.70 (4.16)				
symmetry of contact surface with ground	Healthy	-0.21 (1.36)	1.14	0.33	32.00	0.74
	Hyperpronation	-2.36 (2.26)				
Mean symmetry of pressure distribution	Healthy	-3.01 (1.47)	-1.30	-0.56	32.00	0.58
	Hyperpronation	-4.71 (2.37)				
Mean symmetry of rear foot pressure distribution	Healthy	-4.82 (2.32)	1.21	0.28	32.00	0.78
	Hyperpronation	-7.03 (2.79)				
Mean symmetry of rear foot pressure distribution	Healthy	-11.21 (1.79)	-1.62	-0.55	32.00	0.58
	Hyperpronation	3.57 (3.57				

**significant difference at P≤0.05*

condition of entry into subjects with pronation was higher than 10 mm of navicular drop and eversion of the calcaneus were higher than 4 degrees. At first the height of the test subjects' height was measured using stadiometer (26SM) with 0.1CM accuracy and their weight using a digital calibrated scale (Bs101) with 0.5-kilogram accuracy and also, in order to determine the dominant and none-dominant leg, the fall test in blindfolded condition and Waterloo's dominant limb questionnaire were used.

Ankle evaluation method

In order to evaluate the ankle hyperpronation, anthropometric kit and navicular drop test (NDT) of Brody method with navicular drop device were used. The final coefficient of the Brody test was reported by Muller *et al.* with R=0.80, Evans *et al.* with R=0.76, and Jay Hertel *et al.* with R=0.70, Shultz *et al.* with R=0.80 (21, 22). In this method, the individuals were firstly asked to sit on a chair with barefoot, and position of their foot was in non-weight bearing position in which the angle between the knee and the thigh was 90 degrees with no abduction or adduction movement in ankle joint. At first, the navicular bone prominence of the subjects was marked in seated position and its distance from the ground was measured by digital navicular drop device Collis in a non-weight bearing position (Figure1A).Then, the individual was asked to stand up so that the distance between the navicular bone prominence and the ground could be measure in the bearing-weight position (Figure1B). To estimate the drop degree of navicular bone, the navicular prominence in the seated position was subtracted from the standing position. If the discrepancy between these two positions is between 5 to 9 millimeters, the individual's foot arch is in normal position, more than 10-millimeter is flatfoot and hyperpronation, and less than 4 millimeter is considered as high arch and hyper supination (21).

Data Processing

To examine the symmetry of variables, formula 1 was used. In this formula, x2 is the variable of dominant limb and x1 is the variable of non -dominant limb. The symmetry between two legs was determined using zero - symmetry index. If the symmetry index is more than 11 %, it represents the asymmetry between the dominant and non-dominant feet. A positive sign indicates a larger variable in the dominant limb and a negative sign indicates a larger variable in the non-dominant limb [26].

Statistical analysis

Mean and Deviation was used to describe data, Shapiro-Wilk Test applied to verify the normality od the data, and independent t-test was compare the variables of the two groups at significance level of *P*≤0.05 using SPSS software, version 24.

Table3. Mean (SD) of results of the independent T-test of symmetry comparison of dynamic balance between healthy and hyper pronation girls (Kpa)

Variables	Group	Mean (SD)	Mean difference	t	DF	*P*-value
Symmetry of hallux stiffness	Healthy	42.33 (1.09)	-6.19	-0.11	31.00	0.91
	Hyperpronation	48.53 (1.59)				
Symmetry of ankle rotation	Healthy	-48.44 (1.63)	-1.38	-2.34	30.00	0.03*
	hyperpronation	80.93 (1.29)				
Symmetry of fore foot balance pressure distribution	Healthy	-31.18 (3.01)	-2.75	-0.79	27.00	0.44
	hyperpronation	44.57 (1.95)				
Symmetry of ankle balance performance pressure distribution	Healthy	10.78 (2.36)	-2.01	-0.19	31.00	0.85
	hyperpronation	25.89 (2.05)				
Symmetry of metatarsal loading	Healthy	-114.07 (3.11)	-2.44	-0.56	30.00	0.58
	hyperpronation	-54.63 (2.07)				
Symmetry of medial forefoot balance performance	Healthy	34.25 (3.58)	-2.72	-0.75	30.00	0.46
	hyperpronation	131.97 (3.86)				

**significant difference at P≤0.05*

Table 4. Results of the independent T-test of symmetry comparison of pressure distribution between healthy and hyper pronation girls in standing position

Variables	Group	Mean (SD)	Mean difference	T	Df	*P*-value
Symmetry of rear foot surface(cm2)	Healthy	1.75 (1.81)	1.76	0.59	31.00	0.56
	Hyperpronation	-1.01 (1.32)				
Symmetry of mid foot surface(cm2)	Healthy	-9.39 (2.44)	-1.88	-1.55	31.00	0.13
	Hyperpronation	3.49 (2.30)				
Symmetry of fore foot surface(cm2	Healthy	1.46 (1.51)	1.98	1.72	30.00	0.09
	Hyperpronation	-2.52 (1.52)				
Symmetry of rear foot impulse(Kpa))	Healthy	-4.60 (1.15)	1.47	0.83	31.00	0.04*
	Hyperpronation	-10.08 (2.34)				
Symmetry of mid foot impulse(Kpa)	Healthy	-0.38 (3.20)	-1.45	-0.41	30.00	0.60
	Hyperpronation	4.06 (2.02)				
Symmetry of fore foot impulse(Kpa)	Healthy	2.42 (3.49)	-0.42	-0.012	32.00	0.91
	Hyperpronation	2.58 (1.67)				
Symmetry of tars 1(Kpa)	Healthy	5.34 (2.76)	0.54	2.14	31.00	0.04*
	Hyperpronation	-43.20 (3.19)				
Symmetry of tars 2-5(Kpa)	Healthy	17.29 (1.14)	0.19	1.34	32.00	0.19
	Hyperpronation	-20.90 (3.53)				
Symmetry of metatarsal 1(Kpa)	Healthy	9.42 (2.88)	1.82	0.90	32.00	0.38
	Hyperpronation	-9.40 (1.62)				
Symmetry y of metatarsal 2(Kpa)	Healthy	-15.94 (4.14)	-2.03	-1.12	32.00	0.27
	hyperpronation	4.08 (2.84)				
Symmetry of metatarsal 3(Kpa)	Healthy	0.72 (4.94)	-2.93	-1.17	32.00	0.10
	Hyperpronation	26.65 (4.55)				
Symmetry of metatarsal 4(Kpa)	Healthy	1.17 (5.11)	-1.23	-0.77	32.00	0.45
	Hyperpronation	16.40 (5.09)				
Symmetry of metatarsal 5(Kpa)	Healthy	10.26 (5.46)	-3.45	-1.67	32.00	0.11
	Hyperpronation	13.71 (1.45)				
Symmetry of medial forefoot (MF)(K	Healthy	-14.45 (2.51)	-3.23	-1.67	32.00	0.92
	Hyperpronation	17.78 (5.45)				
Symmetry of medial heel(HM)	Healthy	-12.34 (2.01)	-1.23	-2.01	32.00	0.04*
	Hyperpronation	6.89 (2.70)				
Symmetry of lateral heel(HL)	Healthy	3.99 (2.54)	3.2	0.23	32.00	0.82
	Hyperpronation	-0.75 (5.79)				

**significant differenceat P≤0.05*

Results

According to demographic specifications, girls with hyper pronation significantly had more body mass index than healthy individuals, but the average height of both groups was approximately the same ($P>0.05$). Findings obtained by comparing the symmetry of balance function and the distribution of plantar pressure in healthy and hyperpronation adolescents are presented in Tables 2, 3, 4, and 5.

Based on findings in Table 2, a significant difference was observed only in variable of symmetry of rear foot pressure distribution is static position between two groups ($P=0.04$), but there was no significant difference in other variables ($P\leq0.05$).

Based on findings in Table 3, a significant difference was seen only in variable of symmetry of ankle rotation between two groups ($P=0.03$), but there was no significant differences in other variables.

The descriptive statistics with significance level of pressure distribution are presented in Table 4. Results indicated a significant difference between in the two groups in impulse symmetry of medial heel ($P=0.04$), so that this variable was significantly reduced in pronated foot girls than healthy girls. Also, the findings indicated significant a difference in symmetry of tars 1 ($P=0.04$) and symmetry of medial rear foot between in two groups, so that the healthy girls had more symmetry in both variables than pronated girls.

Discussion

The purpose of the current study was to compare the symmetry of plantar balance function and pressure distribution between healthy active adolescent girls and those with ankle hyperpronation when standing and at the stance phase of walking. The comparison of results between two groups showed that a significant difference in symmetry of rearfoot pressure distribution, symmetry of rearfoot impulse, symmetry of medial heel, symmetry of tars 1 and symmetry of ankle rotation, indicating more symmetry in healthy girls than those ankle hyperpronation. Moreover, according to achieved findings, the symmetry of dynamic balance of the heel around the ankle axis and the heel impulse was more in the healthy group compared to the pronation group, which is probably due to appropriate absorption, distribution, and transmission of reaction force from the ground to the ankle in the healthy group [5, 15, 16]. On the other hand, considering that in people with hyperpronation, the head of the talus and navicular bones rotate inwards-downwards and the direction of gravity center rotates inwards too, the medial edge of the foot of people girls with hyper pronation have more contact with the ground, which causes increased pressure distribution to the medial surface of the sole and decreased symmetry of lateral heel surface compared to the healthy group [3, 12, 16].

The current study's findings are not in line with Tasojian (12), Esmi (27), Seifipour (28), and Dehghani (29) studies which reported the maximum pressure distribution in the forefoot, toes, and heel, withless force on the tarsus 2 to 5 and the midfoot area. Since the heel has an important role in transmitting the body weight from the middle to the forefoot, increased contact level of the middle plantar area with the ground due to the navicular bone's drop and the affinity of the direction of the gravity center towards inside can lead to increased pressure distribution in the foot's medial surface and inappropriate distribution and absorption of the forces on the sole, therebyinducing compensative mechanisms in people's walking and standing patterns. At the same time, the current study's findings are compatible with the Anbarian (30), Dizaji (31), and Safaeipour (32) studies, which found more plantar pressure distribution in the tarsus and heel bones than other areas of the sole.

According to accomplished studies, people with ankle hyperpronation when walking are not able to rapidly maintain their ankle joint in its normal direction at the toe-off phase and they tend to change the direction of the pressure center towards the medial surface foot, which can lead to changes in the wave length and amplitude of pressure center's fluctuations and disturbance in transmission and absorption of forces from the ground to the sole. These results are is compatible with the results of previous studies [2, 19, 30]. However, Jafarnejad *et al.* (15) and Esmaeili*et al.* (9) reported a small difference between the two groups after studying the forces on the foot sole in people with hyperpronation and healthy people, which is not compatible with the current study. The reason is probably due to the specificity of the pattern of pressure distribution based on the type and the model of the ankle's anatomical structure, and its exclusive features. It also seems that in the static position and while taking short steps, variables related to plantar pressure distribution in people with hyperpronation have less disruption and mechanical changes due to the lack of muscles' fatigue and maintain of posture control. However, when taking long-term steps, they may suffer from early fatigue, more stress to other body parts, and disturbance in the balance function and posture control due to inappropriate absorption and distribution of forces from the ground to the foot sole [13, 15, 18]. An investigation by Jahani *et al.* (19) reported a more ankle plantar flexion in the stance phase in people with plantar abnormalities such as flat feet than in healthy ones, which can be a compensative mechanism to maintain the balance and stability while walking, which is compatible with a part of the current study's results. On the other hand, a review of studies done by some researchers in the field of plantar pressure distribution symmetry reveals that the body has a systematic tendency towards the dominant limb in special conditions like the occurrence of abnormalities, muscle weakness, neuromuscular disorders, and the length discrepancy between two limb, and this may result in asymmetry and the occurrence of secondary problems in the other parts of the body [2, 15,16]. Pezeshk*et al* (10) and Memar *et al.* (16) after examining the symmetry, plantar pressure distribution, and the ground reaction force in the dominant and non-dominant limbs of athletes found out that there is no significant difference in the pressure distribution pattern between their dominant and non-dominant limbs, and the index of symmetry in the 1st and 2nd metatarsus and 3rd to 5th toes of the rear foot was more than the forefoot, which is not compatible with our study. This discrepancy among results can be due to the difference in age, measuring tools, and the amount of physical activity of the subjects [4, 7, 13]. However, there is a need for more accurate and comprehensive studies on the relationship between the ankle's structure with the type of abnormality and plantar pressure distribution, and studying the symmetry and balance function of people in different age groups to achieve more practical and generalized results based on the scientific evidence and documentation.

Conclusion

The current study's findings showed that the girls with the hyperpronation had less asymmetry on the medial heel and increased pressure distribution on the 1st tarsus. Also, the symmetry of balance function of heel rotation around the ankle's axis and the impulse of rear foot in the healthy group were more than in the hyperpronation group. Furthermore, because of more contact of the lateral surface of the soles with the ground in the people with hyperpronation, the pressure level on the lateral surface and 1st metatarsus was increased and the medial heel symmetry in the pronation group was decreased compared to the healthy group. Hence, more scientific evidence is needed to generalize the results.

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All authors made substantial contributions to the conception, design, analysis, and interpretation of data.

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