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Original Article

Investigating the dynamic loading pattern of the foot in sedentary healthy adolescent

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Abstract

Aim: The aims of this study were to define the dynamic loading pattern of the foot in healthy adolescents and to investigate the differences between boys and girls.
Material and Methods: n = 89 adolescents (n = 42 girls, n = 47 males) using right hand-preferred and have normal body mass index (18.5- 24.9 kg/m2) were included in the study. Dynamic foot pressure analysis was used to determine the foot dynamical load patterns of the participants. The results were compared by considering be male or female factor and right-left foot dynamic loading pattern.
Results: In the comparison between the groups, it was seen that the contact percentages and active contact areas of the different regions of the feet were different in boys and girls ($p < 0.05$). When the right-left foot load patterns were compared, it was seen that the load transfer in the right foot progressed to the anterior medial and the left foot showed a delay in the load transfer processes ($p < 0.05$).
Conclusion: Boys walked with a wider contact percentage in the left foot and wider metatarsal and heel active contact areas in both feet than in girls. Furthermore, on the preferred side (right) the load transfer is positioned on the anterior medial of the foot, while the main difference in the other foot is due to the delay in reaching the maximum pressure.

Keywords: Adolescents; feet; plantar pressure distribution; timing; gait

INTRODUCTION

Feet are important organs that affect biomechanical arrangement in the body. Although the structure of the feet varies from person to person, there are many common points in the basic human anatomy (1). Recognizing the structure of the foot is important to determine the reference characteristics that are considered natural (2). Foot characteristics in different groups such as; elderly individuals, children, young people, soldiers, and disease conditions; were tried to be defined (3-8). However, it is seen that the foot structure in adolescents is not examined sufficiently. Several studies have been conducted on adolescent health and basic biomechanical properties such as; sitting height, subischial leg length, thigh segment length, shank segment length, inter-ASIS breadth, bicristal breadth, static knee frontal plane angle were described (9, 10). Adolescent age is the period in which rapid growth occurs and the body's final shape is reached. The rapid growth process may not be 100% synchronized in bones and soft tissue (11-13). At the same time, the changing hormonal structure changes the quality of collagen tissue. When the rate of change in tissue elasticity does not match the rate of bone growth, findings such as an increase in Q and spine deformations may be revealed (14-18). Also, previous studies showed that girls more tendency to experience the patellofemoral syndrome (14-18). Therefore, it is important to define the basic physical characteristics of healthy adolescents. Thus, reference information can be provided for clinicians and researchers. In previous studies, foot health or/ and pressure distribution characteristics of the foot in different age groups and diseases were examined (19-22). However, research on foot structures of healthy sedentary adolescents is limited (23,24). The anthropometric structures of the foot, as well as the basic load-bearing skills, play an important role in the smoothness of

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body biomechanics. Considering the different growth physiology of girls and boys, the rapid growth of the body and the importance of the foot biomechanics for body alignment in adolescents, it is seen that there is a need for more detailed information about foot characteristics in adolescents. The aim of this study was to define the dynamic loading pattern of the foot in healthy adolescents and to investigate the differences between boys and girls.

MATERIAL and METHODS

The study was utilized according to Helsinki Declaration and was approved by the local ethical committee of the university (TÜTF-BAEK 2019/292). Potential participants were invited to the study by communicating information and invitation letters to parents of students in secondary schools. N = 102 students aged 12-18 (mean age was 15±2,3 years) years who agreed to participate in the study and whose consent was sent by their parents were evaluated for compliance with the inclusion criteria of the study: First of all; they were asked by their physicians to submit documents indicating that they did not have any health problems (orthopedic, neurological, systemic, psychiatric). N = 89 adolescents (n = 42 females, n = 47 males) were included in the study. Dynamic foot pressure analysis was used to determine the foot dynamical load patterns of the participants. The dimensions of the pedobarogram used were 578 mm x 418 mm x 12 mm, data acquisition frequency was 300 Hz, active sensor area was 488 mm x 325 mm. Number of sensors were 4096 (arranged in a 64 x 64 matrix); sensor technology was resistive; pressure range was 1 – 127 N/cm²; data cquisition frequency was 300 Hz; resolution was 8 bits. In this study, pressure analysis was performed according to midgait protocol (25). To ensure validation of the data, participants were asked to walk on the platform for 7 repetitions. Participants were asked to walk barefoot, facing the normal walking rhythms. Dynamic pressure analysis was performed using at least 4 outcomes from the dynamic pedobarogram. Data were collected from the heel medial, heel lateral, mid-foot, 1st and 5th metatarsal heads. Parameters were determined as the time of maximum pressure (ms), maximum pressure (N / cm2), active contact area (cm2), contact percentage (%), and impulse (force-time integral in N s) was determined. Dynamic pedobarographic measurements were performed by the same researcher at the GERÇEK Prosthetics-Orthotics Center, at 2019 Aug.

Statistical Analyses

SPSS version 17.0 software was used for statistics. Descriptive statistics were given using mean and standard deviation. The suitability of the variables to normal distribution was examined by visual (histogram) and analytical methods (Shapiro-Wilk tests). Mann Whitney U test was used to test the significance of the difference between the two arithmetic means since the data were not normally distributed and the parametric conditions were not fulfilled. For statistical significance, total type-1 error level was taken as 5%. Using the GPower 3.0.1 software, the sample size was calculated by post-hoc methods. The standard deviation of the population was calculated as 9,604 using data from girls and boys from the active contact area of the left midfoot. The effect size was determined as 0,66 and the power of the study was calculated as 87%. The flowchart of the research is summarized in Figure 1.

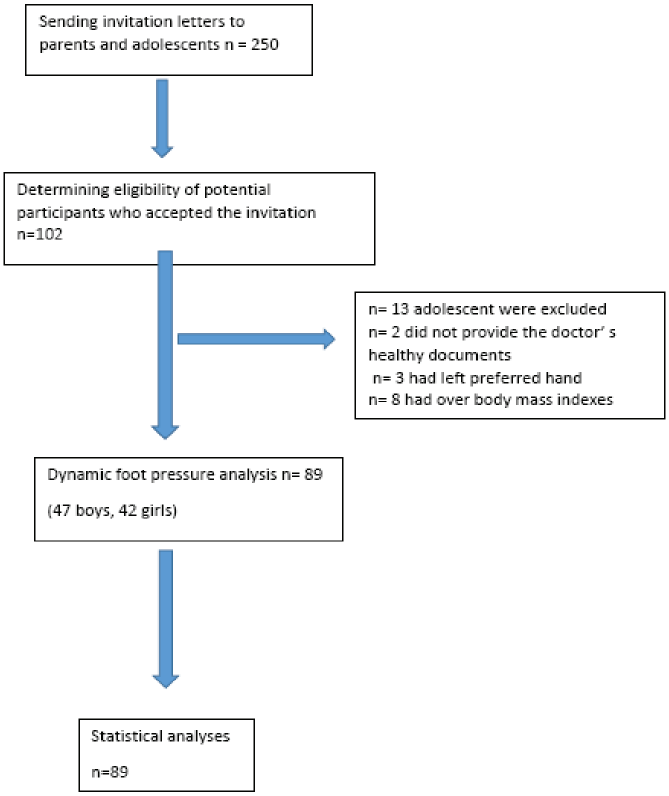

Figure 1. Flow chart

RESULTS

In the comparison results according to gender among the groups; there were differences in the parameters of active contact areas in the right foot; 2nd metatarsal ($p < 0.001$), 3rd metatarsal ($p = 0.01$), 4th metatarsal ($p = 0.01$), heel-medial ($p < 0.001$), heel-lateral ($p < 0.001$). Also, there were differences in the parameters of the active contact areas in the left foot; metatarsal 1 ($p = 0.001$), metatarsal 2 ($p < 0.001$), metatarsal 3 ($p < 0.001$), metatarsal 4 ($p = 0.004$), metatarsal 5 ($p = 0.038$), heel-medial ($p < 0.001$), heel-lateral ($p < 0.001$) and mid-foot ($p = 0.002$).

Contact percentages were compared between groups; There were differences in left foot metatarsal 1 ($p = 0.044$), metatarsal 2 ($p = 0.046$), metatarsal 3 ($p = 0.016$), metatarsal 4 ($p = 0.007$), metatarsal 5 ($p = 0.029$) regions.

In other words; male adolescents had a bigger active load in both feet on the metatarsal and heel areas ($p < 0.05$). Also in men, they had a more active load in the left middle foot region ($p < 0.05$). In addition, men had a greater percentage of metatarsal contact on their left feet during gait ($p < 0.05$). It was observed that both groups applied similar maximal pressure to the defined regions of

Table 1. Comparative Results of the Groups

Parameters	**Groups**		**p**
	Male N=47 X±SD	**Female N=42 X±SD**	
R MT1 Contact Percentil	81.74±7.97	82.38±8.14	.392
R MT2 Contact Percentil	83.34±8.73	85.54±6.04	.263
R MT3 Contact Percentil	85.53±7.75	87.19±5.30	.288
R MT4 Contact Percentil	84.25±7.64	86.47±4.92	.141
R MT5 Contact Percentil	10.45±2.64	9.73±2.56	.056
R Midfoot Contact Percentil	65.06±10.09	65.52±10.30	.702
R Heel Medial Contact Percentil	57.44±13.70	57.54±14.21	.805
R Heel Lateral Contact Percentil	57.06±13.98	56.19±14.50	.548
R MT1 Active Contact Area	17.71±4.18	16.22±3.61	.052
R MT2 Active Contact Area	13.72±2.22	12.03±2.67	**<.001**
R MT3 Active Contact Area	10.91±1.51	9.74±2.39	**.010**
R MT4 Active Contact Area	10.93±1.43	9.87±2.06	**.010**
R MT5 Active Contact Area	10.45±2.64	9.73±2.56	.056
R Midfoot Active Contact Area	10.45±2.64	9.73±2.56	.056
R Heel Medial Active Contact Area	21.00±3.01	18.83±6.96	**<.001**
R Heel Lateral Active Contact Area	18.07±2.88	15.69±2.92	**<.001**
L MT1 Active Contact Area	13.44±2.65	11.49±2.30	**.001**
L MT2 Active Contact Area	11.23±1.50	10.08±1.36	**<.001**
L MT3 Active Contact Area	9.12±1.22	8.15±1.17	**<.001**
L MT4 Active Contact Area	9.54±1.59	8.78±1.12	**.004**
L MT5 Active Contact Area	13.29±3.09	12.39±2.43	**.038**
L MT1 Contact Percentil	79.97±14.15	77.19±10.30	**.044**
L MT2 Contact Percentil	84.00±13.21	83.26±5.89	**.046**
L MT3 Contact Percentil	85.72±13.08	85.38±4.26	**.016**
L MT4 Contact Percentil	85.34±13.24	85.33±3.40	**.007**
L MT5 Contact Percentil	80.12±12.94	80.07±4.61	**.029**
L Midfoot Contact Percentil	68.00±12.63	66.80±6.26	.087
L Heel Medial Active Contact Area	19.57±3.36	16.62±2.62	**<.001**
L Heel Lateral Active Contact Area	16.46±2.43	14.14±2.21	**<.001**
L Midfoot Active Contact Area	52.51±10.30	46.19±8.84	**.002**
L Heel Lateral Contact Percentil	54.70±14.17	56.71±10.17	.773
L Heel Medial Contact Percentil	56.19±14279	58.42±9.99	.736
R MT1 Maximum pressure	5.66±5.69	4.93±3452	.745
R MT2 Maximum pressure	11.07±12.42	9.82±10.20	.282
R MT3 Maximum pressure	12.62±14.14	10.23±8.32	.349
R MT4 Maximum pressure	10.48±13.27	7.27±6.03	.543
R MT5 Maximum pressure	5.23±6.02	3.86±6.02	.060
R Midfoot Maximum pressure	3.78±4.46	2.55±2.48	.334
R Heel Medial Maximum pressure	9.07±8.14	7.49±5.68	.310
R Heel Lateral Maximum pressure	7.65±7.62	7.37±9.07	.749
L MT1 Maximum pressure	4.38±3.65	4.46±5.56	.767
L MT2 Maximum pressure	9.04±8.09	9.30±8.85	.330
L MT3 Maximum pressure	13.40±12.61	11.97±10.72	.808
L MT4 Maximum pressure	11.77±12.73	9.48±9.49	.905
L MT5 Maximum pressure	6.11±6.93	3.84±2.80	.204
L Midfoot Maximum pressure	3.86±4.21	3.25±3.13	.905

L Heel Medial Maximum pressure	11.23±11.70	9.80±10.20	.863
L Heel Latral Maximum pressure	8.98±8.51	7.82±6.41	.895
R MT1 Time of Maximum pressure	506.81±183.75	526.66±183.94	.579
R MT2 Time of Maximum pressure	561.91±167854	579.43±172.67	.582
R MT3 Time of Maximum pressure	555.88±172.62	587.85±170.67	.322
R MT4 Time of Maximum pressure	512.76±182.85	548.32±173.32	.406
R MT5 Time of Maximum pressure	472.12±189.25	474.60±200.47	.941
L MT1 Time of Maximum pressure	484.67±195.07	519.68±163.69	.318
L MT2 Time of Maximum pressure	545.10±190.42	587.46±142.91	.125
LMT3MaksPSüre	569.99±183.89	594.36±142.93	.302
L MT4 Time of Maximum pressure	550.77±181.73	569.60±149.95	.366
L MT5 Time of Maximum pressure	506.52±185.33	530.15±163.97	.342
R Midfoot Time of Maximum pressure	340.36±159.90	297.61±143.99	.142
L Midfoot Time of Maximum pressure	328.36±180.71	288.41±147.68	.347
R Heel Medial Time of Maximum pressure	151.12±109.63	150.79±120.15	.827
R Heel Lateral Time of Maximum pressure	149.00±122.09	153.89±96.56	.669
L Heel Medial Time of Maximum pressure	177.80±141.75	181.02±130.53	.773
L Heel Lateral Time of Maximum pressure	171.41±137.00	170.55±113.24	.593
R MT1 impuls	19543±2.06	17690±1.29	.449
R MT2 impuls	36362±4147	36585±3.61	.050
R MT3 impuls	42511±5.11	38512±3.21	.066
R MT4 mpuls	3.64±4.92	3.00±3.01	.805
R MT5 impuls	1.55±1.94	1.48±2.85	.226
L MT1 impuls	1.47±1.26	1.50±2.10	.696
L MT2 impuls	3.15±2.76	3.34±3.44	.526
L MT3 impuls	4.47±4.23	4.10±3.70	.770
L MT4 mpuls	3.99±4.26	3.31±3.01	.915
L MT5 impuls	1.96±2.28	1.30±1.05	.315
R Midfoot impuls	1.19±1.56	0.93±1.18	.452
L Midfoot impuls	1.35±1.65	1.17±1.37	.647
R Heel Medial impuls	2.64±3.30	2.15±2.15	.663
R Heel Lateral İmpuls	2.12±2.67	2.36±4.67	.834
L Heel Medial İmpuls	3.11±3.85	2.87±3.51	.850
L Heel Lateral İmpuls	2.35±2.72	2.17±2.05	.967

the foot (p> 0.05). Time of maximal pressure and impulse skills were also similar (p> 0.05). The results are shown in Table 1.

The 1st metatarsal contact percentage (p = 0.008), 1st - 4th metatarsal active contact areas (p <0.001), 1st metatarsal maximal pressure value (p = 0.009), 1st metatarsal impulse value (p = 0.03), heel medial impulse value (p = 0.013) was higher in the right foot. The 5th metatarsal contact percentage (p <0.001), the mid-foot contact percentage (p = 0.035), the 5th metatarsal active contact area (p <0.001), middle foot active contact area (p <0.001), heel medial and lateral active contact areas (p <0.001), 3rd metatarsal impulse value (0.011), 4. metatarsal impulse value (p = 0.007) 5th metatarsal impulse value (p00.006), mid-foot impulse value (p = 0.0099, the 3rd metatarsal maximal pressure value (p = 0.001), the 4th metatarsal maximal pressure value (p <0.001), the heel medial (p = 0.001) and lateral (p = 0.018) maximal pressure values, the time of maximal pressure of the 4th metatarsal (p = 0.029), the time of maximal pressure of the 5th metatarsal (p = 0.018) were higher in the left foot.

In this case, individuals transferred the load to the anterior medial region of their right foot while transferring load takes place on a more lateral line in the left foot. it was observed that the time of maximal pressure was shorter in the right foot. The pushing force was located in the medial area of the right foot, whereas it was located more laterally and midfoot areas of the left foot.

DISCUSSION

The results of this study provided basic information about the dynamic loading pattern of the foot in sedentary adolescents and showed that there were differences between the loading style of the foot between boys and girls. It was observed that boys walked with wider metatarsal and heel active contact areas of the left foot. And males had a wider contact percentage in both feet. On the preferred side, it was also found that the load transfer was positioned on the anterior-medial of the foot.

McWilliams et al. investigated the kinetics and kinematics of the feet during gait. They reported that hind foot had an important role in foot biomechanics and when it lost its function, the loading on the forefoot increased and the foot dynamics were disrupted. However, their study conducted on a wide age range and did not provide any information about the dynamic pressure distribution in the foot (23). Lee et al. investigated the distribution of static foot pressure in adolescents with idiopathic scoliosis and compared the results with the healthy age group (19). They found that the center of pressure line deviated from neutral more in individuals with idiopathic scoliosis. However, in the Lee et al.'s study, individuals were aged between 17-20 years and no gender-related comparisons were made (19). According to the results of the present study, active contact areas of the left foot were wider in boys. Although the dynamic load on the forefoot of both groups was similar, male used larger active load-bearing zones, especially on the left foot, the forefoot and heel. There could be two reasons for this. Firstly; simply, the expansion of the active contact area may be due to the structural properties of the foot. In other words, since men have larger feet, they can exhibit a wider contact surface and the active contact areas may be observed wider. However, males have more active contact areas in the left middle foot region. This suggests that pes planus tendency may be higher in boys than in girls, although they have not been identified. The reason for this difference on the left may be resulted from the less preferred foot core system is weaker in males. In this respect, the results of our study are similar to those of Tenenbaum et al.'s study (26). According to the Tenenbaum et al. the tendency of pes planus is higher in boys than in girls.

Zifchock et al reported that the dominant side arc height was higher than other side in adults aged 18-65 years (27). Present study's results are similar to literature in this respect. On the preferred side, individuals are able to provide load transfer from the heel to the medial anterior area faster and more strongly, whereas on the less preferred side, the load transfer continues more on the middle and lateral path. Therefore, it is thought that the arc structure could not be preserved during the pushing motion and the time to reach the maximal pressure on the forefoot was extended on the left side.

It may be important for clinicians and researchers to consider differences in foot biomechanics of girls and boys, both in interpreting clinical pathologies and in identifying participant groups in research. According to the results of this study, while carrying out a study on adolescent's biomechanics it is thought that for the homogenization of a group, it is necessary to include a certain number of individuals of both sexes in order to eliminate the difference.

There are some limitations of this study. First of all, no information was collected about the other physical characteristics of the individuals. This situation prevented the investigation of other features (such as foot core muscle strength, etc.) that might affect the results of the research. Furthermore, since the study was conducted only in sedentary adolescents, the population in which the results can be generalized is limited.

CONCLUSION

As a result; the dynamic loading pattern of the foot was different between boys and girls. Boys walked with a wider contact percentage in both left feet and wider metatarsal and heel active contact areas than girls.

Furthermore, on the preferred side (right) the load transfer is positioned on the anterior medial of the foot. The main difference in the non-preferred foot is due to the delay in reaching the maximum pressure. In future studies, it is recommended to investigate the factors that may affect the foot pressure distribution in adolescents.

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