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Static and dynamic plantar pressure measurements in adolescents

Ergenlik dönemindeki çocuklarda statik ve dinamik ayak basınç değerleri

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Amaç: Türk toplumunda ergenlik dönemi yaş grubunun statik ve dinamik pedobarografik normal verilerinin belirlenmesi ve bu değerler ile demografik veriler arasındaki ilişkilerin araştırılması amaçlandı.

Çalışma planı: Çalışmaya, AOFAS'nin (American Orthopaedic Foot and Ankle Society) ayak bileği ve ayak klinik değerlendirme sistemiyle sağlıklı ayağa sahip oldukları belirlenen 50 gönüllü (25 kız, 25 erkek, ort. yaş 14; dağılım 13-15) alındı. Tüm olguların statik ve dinamik ayak basınçları Mini-Emed pedobarografi cihazı kullanılarak ölçüldü.

Sonuçlar: Statik ölçümlerde kızlarda sağ ayağın ön-orta ve parmak kısımlarının, erkeklerde ise sol ayağın orta kısmının pedobarografik değerleri belirgin olarak diğer cinsten yüksekti ($p<0.05$). Tüm olgular birlikte değerlendirildiğinde sağ ve sol ayak statik basınç ölçümleri arasında anlamlı farklılık bulunmadı. Kızlarda sağ ayağın orta basınç değerleri sol ayağa göre yüksek bulundu. Erkeklerde ise sağ ve sol ayaklar arasında basınç değerleri açısından anlamlı fark gözlenmedi. Dinamik ölçümlerde erkeklerde sağ ayakta ayak temas alanı, kızlarda ise sol ayağın ön iç kısmında maksimum basınç değerleri diğer bölgelerden anlamlı derecede yüksek bulundu ($p<0.05$). Statik ölçümlerde kilo ve vücut kütle indeksi ile ayak maksimum basınçları arasında kuvvetli ($r=0.87$ ve $r=0.83$), temas alanı ile orta düzeyde ($r=0.63$ ve $r=0.59$) ilişki saptandı. Dinamik ölçümlerde kilo ve vücut kütle indeksi ile ayak temas alanı arasında orta düzeyde ($r=0.64$ ve $r=0.54$) ilişki bulundu.

Çıkarımlar: Ergenlik dönemindeki çocukların normal ayak basınç değerlerinin bilinmesi, ayağın gelişim evrelerinin izlenmesinde, ayak hastalıklarının değerlendirilmesinde ve yaş ile uyumlu ayakkabı değişikliklerinin yapılmasında önemlidir.

Anahtar sözcükler: Ergenlik dönemi; vücut ağırlığı; ayak/anatomi ve histoloji/fizyoloji; yürüyüş; topuk/fizyoloji; podiatri/enstrümantasyon/yöntem; pedobarografi; basınç; cinsiyet faktörü.

Objectives: This study was designed to determine normal values of pedobarography during standing and walking in adolescents in our country and to investigate correlations between demographic data and pedobarographic values.

Methods: Fifty volunteers (25 girls, 25 boys; mean age 14 years; range 13 to 15 years) who were found to have healthy foot according to the AOFAS (American Orthopaedic Foot and Ankle Society) clinical rating system for the ankle and foot were enrolled into the study. Plantar pressures were measured during standing and walking tasks with the use of the Mini-Emed pedobarographic device.

Results: Static measurements showed significantly higher pedobarographic values for right medial forefoot and toes in girls, and for left midfoot in boys ($p<0.05$). Overall, no significant differences existed between static pressure values for the right and left feet. The mean right medial foot pressure was higher than that of the contralateral foot in girls. There were no significant differences between the right and left feet in boys. Dynamic measurements showed a significantly larger contact area of the right foot in boys, and a significantly higher maximum plantar pressure of the left medial forefoot in girls ($p<0.05$). The strength of the correlation of body weight and body mass index was high with maximum plantar pressures ($r=0.87$ and $r=0.83$), and moderate with contact area of the foot ($r=0.63$ and $r=0.59$) in static measurements. Body weight ($r=0.64$) and body mass index ($r=0.54$) were moderately correlated with contact area of the foot in dynamic measurements.

Conclusion: Appreciation of normal plantar pressure values in adolescents is important in monitoring the development stages of foot, in the assessment of foot disorders, and in making proper footwear modifications in compliance with age.

Key words: Adolescent; body weight; foot/anatomy & histology/physiology; gait; heel/physiology; podiatry/instrumentation/ methods; pedobarography; pressure; sex factors.

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The clinical usage of of foot pressure assessment systems have been the issue of many studies[1,2]. Measurement of foot pressure by pedobarography have started in the early 1980's. The interest growing day by day inclined towards the studies about biomechanic, diabetics foot, ortopedic surgery and orthesis-shoe modification.

The distribution of the studies about the foot pressure of children is limited[3-5]. Exact information is obtained about the functions of foot by the pressure analysis[6]. When the foot of a child is compared with the foot of an adult, typical differences can be seen, particularly the shape and the walking manner of a baby change instantly. Moreover, the appearance of the foot associated with age and the phases of growing up[7]. Hence, some parents may feel anxious about whether their child have a normal walking manner or foot morphology.

Walking defect and foot deformities are the major reasons for the frequent application of the parents to the orthopaedic clinics[8,9]. The physicians come up against some difficulties while assessing these patients. These difficulties stem from being unable to understand the mechanisms and growing phases completely[10]. We believe that it is suitable and practical to make use of pedobarography in the prosecution of treatment and in the understanding of the changes in the shape of foot during the growing process. In order to achieve this goal, normal foot pressure values of the relevant age groups should be identified. We were unable to find a study aiming to examine this fact. The purpose of our study and the reason why we had planned to deal with this issue was to fix the normal pedographic measurement values of the adolescent individuals and put forth the relation between these values and the demographic data.

Methods

62 adolescents were called to the study from the age groups 13 to 15 to Trace University Hospital, Department of Physical Medicine and Rehabilitation. Initially/At first, demographic data was cross-examined. The body mass index (BMI)(kg/m2) was calculated in all cases. Radiographic examination was not used/taken into account. For the purpose of forming healthy foot group, the clinic assessment system was developed by AOFAS was used for ankle and foot (11). The clinical situation of the cases was assessed under 3 titles (total score:100). As a consequence of these assessments, 50 children whose AOFAS score had been 100, were admitted to the study (25 girls,25 boys, 14 middle-aged;distribution 13-15).

The measurement of the pressure of sole of foot was carried out by Mini Emed Pedobarographic device. This system carries out the measurement of the static and dynamic sole pressure.

These systems handle the task of measuring the foot sole of static (standing upright position) and dynamic (walking) pressures. The system includes Canon colour printer, screen, pressure perceptive platform, remote control, power unit, links between screen and platform. The pressure measurement (=assessment) platform of the device have a general frame having the dimensions of 650*290*25 mm and a perceptive area having the dimensions of 360*180 mm and there are three perceptive gauges on each cm2. The exemplification speed of the device is 14 squares in one second, deposit interval is 20 squares, pressure interval is 2-127 N/cm2, solubility is 1 N/cm2, accuracy rate depending on foot is %5,heat gap is 15C to 40 C, connection power was 220/110 volt.[12]. During the static measurements, in order not to direct the body weight on a particular side, the participants were asked some questions to attract their attention to other issues. In order to provide a balanced assessment, they were asked to look at a stable point on the wall which is 3 meters away from them. While standing up on the platform, step width interval was fixed as 8 cm.[13]. When the pressure on one foot becomes the %50 of the total pressure, the measurements were fixed and the data was recorded. The assessment was carried out for both feet separately. In the static assessment of the various parts, the following measurements were carried out: maximum pressure measurements of six regions using the N/cm2(heel, middle and forefoot medial, middle and lateral and phalanx), maximum pressure measurements, maximum pressure values of forefoot and rearfoot, total pressure applied to foot, the percentages of pressure applied on the fore and rear part of foot and the total contact area and the apportion of the pressure on front and back part of foot were assessed

For the dynamic assessment, the participant was requested to walk around an area of 30 m and then through a board having 5 length and carrying out walking while stepping on the board and passing by it. Depending on the fact that the impact of the walking speed over pressure values was not over %7,the normal walking speed of the participant was accepted as standard [5].The participants were requested to walk again provided that they stand motionless on the platform or have a faulty step on the platform. The measurements were carried out for /over both feet. In the dynamic measurement, maximum pressure data was collected from six regions of which were identified in the statistic measurement. Sole contact area was evaluated during walking. In addition to this, maximum pressure values were calculated by dividing the heel of a foot in to two separated parts as lateral and medial. The comparison of the demographic data between girls and boys was carried out via t-test. The relationship between pedobarographic values and demographic values was studying on carefully using correlation test. $p<0.05$ interval was accepted as statistically significant.

Table 1. The characteristics of study population

	Girls (n=25)	Boys (n=25)	P
Age (year)	14.2±0.8	13.9±0.6	>0.05
Height (m)	1.6±0.16	1.6±0.09	>0.05
Weight (kg)	50.4±8.9	52.9±13.5	>0.05
BMI (kg/m2)	19.6±3.2	20.2±4.1	>0.05

Results

No statistically significant difference detected among sex, age, height, weight and VKI averages (Table 1). Remarkable differences were observed in the average values of some parts during the right and left foot statistic pressure measurements as regards to the sex of the participants. No statistically significant difference between right foot and left food static pedobarographic measurements was found(Table 2)The pressure on the middle part of the right foot of the girls was found out to be higher in comparison to the left foot. As for boys, no statistically significant difference was observed in terms of pressure values. When the maximum area obtained from the right and left foot static pedobarographic values and the

Table 2. Comprasion of static pedobarographic values between two groups(N/cm2, mean ± SD

	Right feet			Left feet			All cases		
	Girls	Boys	*p*	Girls	Boys	*p*	Right	Left	*p*
Heel	8.6±4.4	8.3±2.8	>0.05	9.3±7.4	8.9±3.4	>0.05	8.5±5.67	9.1±5.7	>0.05
Middle foot	2.0±1.1	2.4±1.2	>0.05	1.5±7	2.4±1.5	**<0.05**	2.2 ±1.20	1.9±1.2	>0.05
Medial forefoot	4.0±2.5	4.7±1.7	>0.05	4.5±2.3	4.4±2.5	>0.05	4.1±2.37	4.4±2.4	>0.05
Middle forefoot	6.4±3.6	4.4±1.8	**<0.05**	5.6±2.1	4.6±1.9	>0.05	5.4±2.03	5.1±2.0	>0.05
Lateral forefoot	4.9±3.7	4.6±2.9	>0.05	4.1±1.7	4.6±3.2	>0.05	4.7±2.55	4.3±2.6	>0.05
Phalanx	4.5±2.7	3.2±2.5	**<0.05**	5.7±4.8	4.3±4.1	>0.05	3.9±4.49	5.0±4.5	>0.05

Table 3. Comprasion of static pedobarographic values (total contact area, the percentages of pressure applied on the front and back part of foot and the total contact area) between two groups

	Right Mean ± SD			Left Mean ± SD			Totaly Mean ± SD		
	Girls	Boys	*p*	Girls	Boys	*p*	Right	Left	*p*
MFP	7.9±3.7	6.9±2.5	>0.05	8.6±4.1	7.6±4.3	>0.05	7.4±3.2	8.1±4.2	>0.05
MRP	9.2±5.0	9.1±2.9	>0.05	9.5±7.2	9.2±3.4	>0.05	9.2±4.0	9.3±5.6	>0.05
FPFP	51.4±16.1	43.2±10.8	>0.05	53.0±19.9	43.6±12.8	**<0.05**	47.3±14.2	48.3±17.3	>0.05
RPFP	48.6±16.1	56.8±10.8	>0.05	44.9±17.5	56.4±12.8	**<0.05**	52.7±14.2	50.7±16.3	>0.05
MF	466.5±91.8	481.6±152.2	>0.05	447.8±109.1	484.4±113.2	>0.05	473.9±124.7	466.1±111.6	>0.05
CA	77.6±16.7	83.0±18.6	>0.05	76.0±13.4	84.5±18.4	>0.05	80.3±17.7	80.3±16.6	>0.05
FPCAP	57.8±10.0	51.4±8.3	**<0.05**	58.2±13.6	51.7±9.2	**<0.05**	54.6±9.7	54.9±11.9	>0.05
RPCAP	42.3±10.0	48.6±8.3	**<0.05**	40.1 ± 9.7	48.3 ± 9.2	**<0.05**	45.6 ± 9.6	44.2±10.2	>0.05

MFP: Maximal forefoot pressure, MRP: Maximal rarefoot pressure, FPFP: Forefoot plantar force percentage (%) , RPFP: Rearfoot plantar force percentage (%), MF: Maximal forcet, CA: Contact area, FPCAP: Forefoot plantar contact area percentage (%), RPCAP: Rearfoot plantar contact area percentage (%)

Table 4. Comparison of dynamic pedobarographic values (pressure on the six regions and contact area) between two groups

	Right feet			Left feet			All cases		
	Girls	Boys	*p*	Girls	Boys	*p*	Right	Left	*p*
Phalanx	39.2±19.3	32.1±17.3	>0.05	38.4±18.2	36.6±16.9	>0.05	35.7±18.5	37.5±17.4	>0.05
Medial forefoot	18.5±7.8	19.6±8.7	>0.05	22.7±12.5	16.9±10.5	**<0.05**	19.0±8.2	19.8±11.8	>0.05
Middle forefoot	21.3±6.3	21.7±7.3	>0.05	21.6±6.7	23.1±8.4	>0.05	21.2±6.7	22.37.6	>0.05
Lateral forefoot	18.7±13.8	17.6±7.3	>0.05	20.5±13.7	20.9±8.6	>0.05	18.2±10.9	20.7±11.3	>0.05
Middle foot	8.2±5.0	6.8±2.9	>0.05	6.4±3.1	6.8±3.7	>0.05	7.5±4.1	6.6±3.3	>0.05
Rear foot	23.1±6.7	20.7±6.1	>0.05	26.0±13.5	20.4±5.2	>0.05	21.9±6.4	23.2±10.5	>0.05
Contact area	114.2±13.5	125.4±19.3	**<0.05**	115.7±14.2	120.6±17.8	>0.05	119.8±17.4	118.1±16.1	>0.05

pressure on this area are and the distribution of percentages were examined, the percentage of the back area of both feet of the boys were higher than the girls' percentage significantly and percentage of the front area of both feet of girls were higher than the boy's percentage.(Table 3). No significant difference was detected when a comparison carried out in both sexes in terms of right and left pressure values. In the dynamic pedobarography measurements of foot, when the values of pressure on the six regions which had been determined anatomically and the foot contact area averages of both feet were examined, contact area of right foot among boys and the pressure values of front lateral part of foot were found out to be statistically significant (Table 4). It was seen that right foot contact area of the boys was seen statistically high. In the statistic measurements, it was detected that there had been a strong(r=0.87 and r=0.83) relationship between weight and BMI with foot maximum pressures and there had been a moderate(r=0.63 and r=0.59) relationship between weight and BMI with the contact area.

In the dynamic measurements, a moderate relation(r=0.654 and r=0.54) was found between weight, BMI and foot contact area. The static and dynamic value averages on six parts of foot which were mentioned formerly in this study, were shown in Figure-1. When all cases were assessed, it was seen that the highest pressure possessing areas were heel (%62 in right foot,%56 in left food) in the statistic measurement; toes (%62 on the right foot,%66 on the left foot) in the dynamic assessment. When the toes contact areas were examined, right and left foot average area values were 83.04±18.64cm2 and 84.48±18.53cm^2;125.36±19.34cm^2 and 120.56±17.75cm^2 respectively. The highest statistic and dynamic value averages obtained from the lateral and medial regions were illustrated in Table-5.

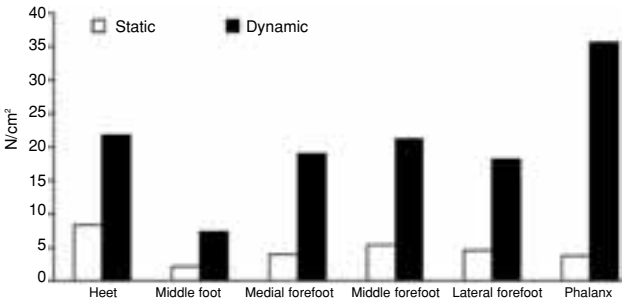

Figure 1. The relation of static and dynamic values in six points of foot in all cases is shown.

Discussion

Plantar pressure measurements display a change with the growing up depending on age. Foot growth is influenced considerably when the child learn how to stand up and walk. Static loading and muscle activity enables the perpendicular arc to grow until the age of six. The feet of children demonstrate typical differences compared to the feet of adults [6,14]. Hennig and et al.[5] compared their children's foot plantar pressure values with adults; they stated that 6-10 age group pressure values were nearly 1/3 of adult values. For the sake of getting normal pressure distributions, the first step is to detect that the subjects have healthy foot. For the purpose of keeping

Table 5. Mean static and dynamic highest values on lateral and medial of the heel (mean± SD)

Heel	Static		Dinamik	
	Right	Left	Right	Left
Medial area	32.4±15.4	33.3±19.2	82.7±25.5	87.3±29.2
Lateral area	27.9±12.0	27.2±14.6	72.5±22.7	76.0±29.2

the clinic condition of normal foot and foot ankle as standard, we used the form developed by AOFAS. The same form was used by Davitt and et al. [15] with pedobarography for the purpose of assessing the clinic results after distal calceneal lengthening during adolescence. During standing up right, the body weight is dispersed onto three parts in the plantar surface formed by calceneus, lateral column and medial column over talus.[10]The highest values were detected in the heel region during the statistic measurement of our study. The pressure distribution on the front part of foot (lateral-middle-medial) were measured as 4.16,4.40,4.56 N/cm2 respectively. These values didn't fit/weren't the right size and shape for the principle of Kapandji's [16]three points(heel,1. and 5 metetarsal head) contact. Having used a similar device in their study, Kanatlı and et.al [17] alleged that Kapandji's principle is not valid. Femery and et al.[18]stated that pressure values belonging to lateral and medial column in the front foot are not disintegrated. We could not understand whether these results arise from the method we used or from the foot structure of adolescence. Another factor causing this difference is the fact that obtaining statistically significant high pressure values in the middle and toe part of the front part of foot which makes us think that weight has a tendency to widen towards the front foot. While walking, body weight is conveyed to calceneus first, then to the lateral part of front foot and finally to the inner part of foot and to big toe.[10,19]It was shown that the highest pressure is on toes and the lowest is on the middle part of foot [4,5]. The same result was obtained in our study. The fact that the highest values were obtained on heel part during the static measurements and the lowest values were obtained on toes during the dynamic measurements in our study indicates that different parts of foot have priority during different activities.

In our study, the front-middle part values of foot in dynamic measurement were found out to be nearly four times bigger than the static values. These results are parallel to the study which was carried out by Rozema et.al [20] on adults. Moreover, the fact that a similar relationship was detected in other five parts in terms of static and dynamic values indicate that foot is exposed much heavier pressure force in comparison to standing up right while walking. Hennig and et.al [5] found out the heel lateral and inner parts' values while walking as 119+-61 and 99+-39 kPa respectively. Harmonious results with these values were obtained during our study. A similar relationship between the lateral and inner parts of heel was obtained during our static measurements. Plantar pressure values are influenced by a lot of factors such as the anatomical structure of foot, VKI, joint movement separation and sex [6,7]. There was no significant difference between the weight, height and VKI values of girls and boys who were in the same age in our study. Owing to the fact that AOFAS assessment was carried out in the beginning, the ones who had had limited joint separation, weren't taken to the study. We ascertained evident differences in the distribution of foot pressure among the girls and boys who had normal foot structure. When above factors influencing the foot structure is taken into consideration, we think that sex is a basic factor in the differences which are observed. Nevertheless, not being able to evaluate the anatomical differences between the girls and boys exactly is the deficiency of our study. What attracts attention about our study that there is a strong relationship between BMI, weight and foot pressure values and foot pressure values and foot contact areas of girls and boys who are in their adolescence. That's why; we think that it is necessary to adjust the material used according to weight. It was understood in our study that the static-dynamic condition relationship of foot is an important factor while choosing shoes. Such studies emphasizing the importance of wearing suitable/appropriate shoes, will assist in bringing up healthy generations.

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