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Pressure distribution patterns under the metatarsal heads in healthy individuals

Sağlıklı kişilerde metatars başlarında dinamik basınç dağılım şekilleri

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Amaç: Sağlıklı bireylerde ayak tabanında oluşan normal yük dağılım biçimlerinin bilinmesi metatarsaljinin tanı ve tedavisinde yararlı olacaktır. Bu çalışmada sağlıklı kişilerde metatars başlarına düşen yük dağılımı EMED-SF ayak tabanı basınç sistemi kullanılarak araştırıldı.

Çalışma planı: Çalışmada, gönüllü ve sağlıklı 106 üniversite öğrencisinde (45 kadın, 61 erkek; ort. yaş 24; dağılım 20-35), EMED-SF sistemi kullanılarak yürüme sırasında ayak tabanı basınçları ölçüldü. Ayak izleri tarsometatarsal eklemin fonksiyonel kolonları ile eşleşecek şekilde, birinci metatars başı, ikinci ve üçüncü metatars başları, dördüncü ve beşinci metatars başları olmak üzere üç bölgeye ayrıldı. Her bir bölgede ölçülen en yüksek ve ortalama basınç değerleri kaydedildi.

Sonuçlar: Yük dağılım biçimleri açısından iki cinsiyet arasında ve sağ ve sol ayak tabanları arasında anlamlı fark bulunmadı ($p>0.05$). Orta kolonda orta duruş fazında kaydedilen ortalama ve en yüksek basınç değerleri, medial ve lateral kolonlarda kaydedilen değerlere göre daha yüksek bulundu ($p=0.000$). Medial ve lateral kolonda ölçülen basınç değerleri arasında belirgin fark gözlenmedi. Salınım öncesi fazda ise medial kolonda elde edilen basınç değerleri lateral kolon değerlerine göre anlamlı derecede yüksek idi. Kolonlara göre yüklenme ağırlığı açısından ön ayakta dört farklı yüklenme biçimi belirlendi. Tüm katılımcılarda vücut kütle indeksi (VKİ) şişmanlık sınırının altında idi (<30 kg/m^2). Salınım öncesi fazda her bir bölgede elde edilen en yüksek basınç değerleri ile VKİ arasında anlamlı bağıntı olmasına karşın ($p<0.05$), orta duruş fazında ayak tabanı basınçları ile VKİ arasında anlamlı bağıntı yoktu ($p>0.05$).

Çıkarımlar: Bulgularımız, sağlıklı bireylerde yürümenin orta duruş fazında ayak tabanı basıncının çoğunlukla orta kolonda oluştuğunu, ancak belirgin derecede birbirinden farklı dört yük dağılım biçiminin var olduğunu göstermektedir.

Anahtar sözcükler: Ön ayak/fizyoloji; yürüme/fizyoloji; metatars kemikleri; basınç; stres, mekanik.

Objectives: Recognition of plantar pressure distribution patterns of healthy individuals would be helpful in the management of metatarsalgia. We investigated plantar pressure distribution patterns under metatarsal heads in healthy individuals using the EMED-SF plantar pressure analysis system.

Methods: Plantar pressure measurements were performed in 106 healthy volunteers (45 females, 61 males; mean age 24 years; range 20 to 35 years) during walking on the EMED-SF platform. Footprints were divided into three areas based on the three functional columns of the tarsometatarsal joint, that is, the first metatarsal head, the second and third metatarsal heads, and the fourth and fifth metatarsal heads. The mean and peak pressures obtained in these areas were recorded.

Results: Pressure distribution patterns did not differ significantly between the two sexes and the right and left soles ($p>0.05$). The mean and peak pressures of the middle column during the mid-stance phase of the gait cycle were significantly higher than those recorded for the medial and lateral columns ($p=0.000$). There were no significant differences between the medial and lateral columns in this respect. At the pre-swing phase, pressures were significantly greater in the medial column compared to the lateral column. Four different patterns were noted with respect to the distribution of pressures among the three columns. Body mass index (BMI) was below the limit for obesity (<30 kg/m^2) in all the participants. Peak pressure values obtained from each column at the pre-swing phase were significantly correlated with BMI ($p<0.05$); however, no correlation existed between the plantar pressures and BMI at the mid-stance phase ($p>0.05$).

Conclusion: Our data show that there are four distinct pressure distribution patterns, but the greatest plantar pressure occurs in the middle column of the foot in the majority of healthy individuals.

Key words: Forefoot/physiology; gait/physiology; metatarsal bones; pressure; stress, mechanical.

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Metatarsalgia may occur as a result repeated loadings of metatarsal heads, and is a common health problem. Pes cavus, pes planus, hallux valgus, capsulitis, synovitis, periostitis, stres fractures, plantar plate ruptures, neurinomas, callosities, Freiberg disease, fat pad athrophy, flexor tendinitis are among the conditions which lead to metatarsalgia.[1-4] Unbalanced distribution of weigth may be a cause of pain and stres fractures may also lead to high pressure on metatarsal heads.

Proper understanding of pattern of load distribution under metatarsal heads will be beneficial during management of metatarsalgia. And recognition of different patterns of gait and factors involved in their existance will be beneficial during planning of management strategies of various foot problems.

With recent advancement in technology, assessment of plantar pressure and load distribution become widely available.[5-7] These modern systems enable the authors to investigate metatarsal pressure distribution more accurately and quantitatively, however pressure patterns under metatarsal heads are still under discussion.[6, 8, 9]

In this study, we had have investigated the weight distribution pattern under the metatarsal heads by using EMED-SF (Novel GmbH, Munich, Germany) plantar pressure distribution measurement system.

Subjects and methods

Both feet of 106 healthy young volunteer university students were examined. There were 45 female and 61 male, with mean age of 23.6 years (SD 2.4, range 20-35). The mean weight of the subjects was 66.1 kg (SD 13.2, range 42-115), and a mean height of 171 cm (SD 9.4, range 148-196). Physical examinations were carried out on subjects to ensure that none of them had evidence of foot deformity or diseases affecting the foot.

Pressure measurement

On all subjects the distribution of plantar pressure under the bare feet was measured dynamically. For this purpose the EMED-SF system (Novel GmbH, Munich, Germany. 44.4 x 22.5 cm effective area, two sensors/cm2 with a sampling rate at 71Hz.) The platform is embedded in a 7 x 1m wooden walkway which is, covered by a thin layer of leather to conceal and protect the platform. Subjects were asked to walk at their normal walking speed. All subjects took at least three successful gait cycles before touching the platform. Three stance phases of each foot were recorded. Two identical steps selected for further analysis and the mean of these records were used for statistical analysis.

By using Novel Ortho software, the footprint was divided into seven areas called 'masks' (Figure 1). The tarsometatarsal articulation consists of three functional units or columns. For the evaluation of the pressure distribution of the forefoot, the footprint obtained from EMED system was divided into three areas as functional columns of the tarsometatarsal joint. These were the first metatarsal head, second and third metatarsal heads, fourth and fifth metatarsal heads. The other areas of interest were the heel, the midfoot, first toe and the lesser toes. Mean and peak pressures for each area were calculated at midstance and push-off phase of the gait cycle, which demonstrates the transverse arch of the foot more accurately (figure 2). Mean pressure is the sum of forces, of all sensors in an area, divided by the contact area. Peak pressure shows the value of a sensor with the maximum pressure, in the selected area.

For each subject, body mass index was calculated by dividing the weight (kg) by the square of the height (m).

Statistical analysis

The mean and standard deviations were obtained for all measures. To investigate the difference between right and the left foot, paired sample t-test was used. Pearson correlation coefficient was used to compare the body mass index and pressure distribution of the functional units of the forefoot. The difference between the pressure distributions of the functional units

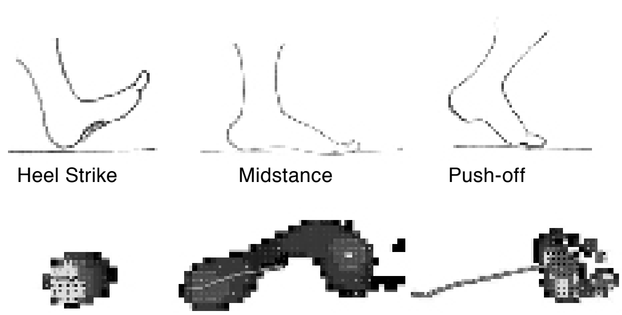

Figure 1. Parts of the stance phase of the gait cycles are illustrated. Data collected at the midstance phase of the gait cycle was used for the analyses of the metatarsal pressure distrubition.

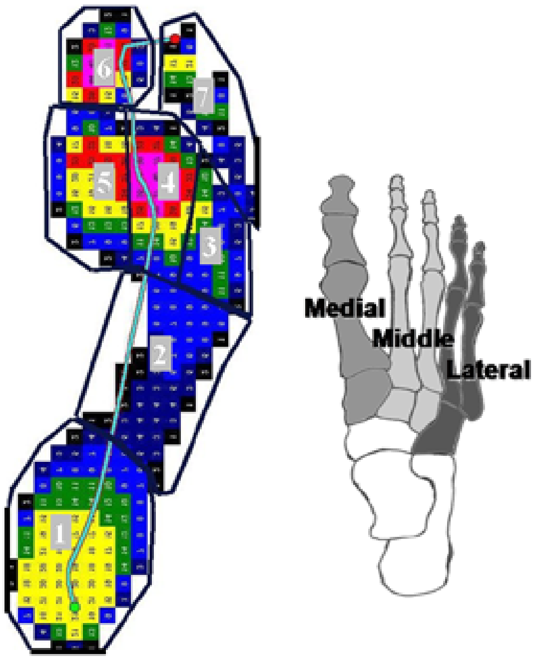

Figure 2. Pressure map of the data recorded from a stance phase of the gait cycle, divided into seven areas called 'masks'. The metatarsal region was divided into three masks as functional columns of the foot.

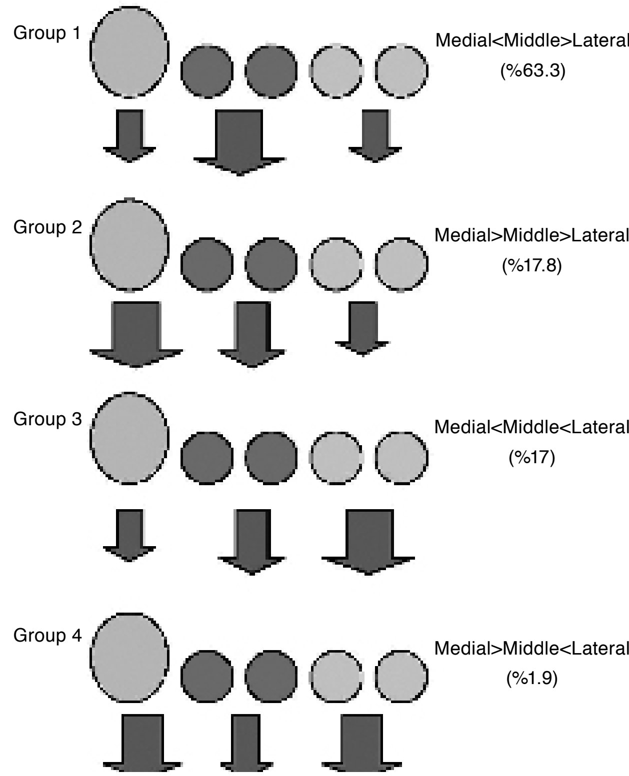

Figure 3. Four different pressure distribution patterns and their percentage can be seen in this illustration.

was illustrated by using two-sided t-test. Correlation of the peak pressures of the forefoot and body mass index was also investigated. Statistical calculations were performed with SPSS 13.0 (SPSS Inc., Chicago, Illionis, USA).

Results

There were no significant differences between female and male subjects or between right and left feet ($p>0.5$). Therefore, to simplify the analysis, only the results of the left feet have been used. The results of mean and standard deviations of forefoot's peak and mean pressures at midstance and push-off phases of the gait cycle were shown on table 1.

The mean and peak pressures of middle column (second and third metatarsal heads) were higher than the medial and lateral columns ($p=0.000$) at mid stance and push-off phases.

At midstance phase there was no significant difference between medial and lateral column, however the difference was significant at push-off phase of the gait cycle. This results show us that middle column carries higher pressures at midstance, and during the push-off phase the most of the load was carried by medial and middle columns, where middle column still carries the highest pressures.

There was no single pressure distribution sequence for all feet of the subjects. Although many feet

Table 1. The mean and peak pressures under the metatarsal heads of the left foot as determined using EMED-SF system at midstance and push-off phases of the gait cycle:

	Stance Phase		Push-off	
	Mean Pressure	Peak Pressure	Mean Pressure	Peak Pressure
Medial column	5.69± 2.82	11.66± 11.05	12.23± 4.49	25.49± 13.04
Middle Column	7.75±2.57	13.24±6.52	17.65±4.39	31.81±11.10
Lateral Column	6.18±1.88	11.44±4.27	8.75±2.99	22.74±8.51

Table 2. The correlation between body mass index and forefoot peak pressure distribution of the left foot. The significant positive correlation was found only at push-off phase of the gait cycle.

Midstance (*p*)	Push-off (*p*)
0.594	0.008
0.668	0.003
0.607	0.040

showed high middle column loading, in a proportion of subjects, the highest pressures were detected under the medial or lateral columns. In order to identify, the different patterns of metatarsal weight distribution mean pressures of each area were compared. Mean pressure gives the real pressure sustained in a selected period of the gait cycle of a selected area. There were four different pressure distribution patterns of loading in the forefoot that could be divided into four recognizable groups (Figure 3).

All of the subjects involved in this study were non-obese individuals (BMI < 30). Correlation analysis between BMI and plantar pressure distribution revealed that BMI was correlated with peak pressure values of each segment during push-off phase ($p<0.05$), however there were no correlation during midstance phase of gait cycle ($p>0.5$). (Table 3)

Discussion

Understanding of normal patterns of plantar pressure distributions under metatarsals heads would be beneficial during assessment of metatarsalgia and various other foot conditions.[2, 3, 10, 11] It may also yield to development of new treatment strategies.

Plantar pressure under metatarsal heads is among the most controversial topics of orthopaedics.[5, 9, 12, 13] Bankart proposed that an ideal foot collapses under weight bearing conditions, and Morton believed that all metatarsals are carrying equal load but first metatarsal was carrying twice the load the others carry.[12] Dickson and Diveley believed that first and second metatarsals were carrying all the load, and transverse metatarsal arch appears only during weight bearing.[8, 13, 14]

Although it has been accepted for many years that; there was an anatomic and functional transverse metatarsal arch,[13, 14] with the advent of modern pressure distribution measurement systems, the pressure distribution of the transverse arch investigated quantitatively.[5, 7-9]

Studies conducted with EMED-SF system demonstrated the peak pressures during stance phase appears on centralportion of foot, and forefoot.[5-8]

Additionaly these studies have also demonstrated different loading patterns on forefoot. [7, 10, 11] Huges et al[7] defined four different pattern as; medial (16%), medio-central (14%), central (53%) and lateral (4%). On the other hand, Yamamato et al described three types of pressure pattern of the forefoot, type A, type B and type C, where high peak pressures found to be at first, second and/or third, first-second and/or third metatarsal heads respectively.[11]

The forefoot can be divided into functional columns, which are clinically significant.[15] In this study, the pressure distribution of the metatarsal heads and the existence of the transverse metatarsal arch were all investigated according to the functional columns. For this purpose the data collected just at the mid-stance and push-off phases of the gait cycle were analyzed. In our opinion, the transverse arch of the foot can be demonstrated more accurately at mid-stance phase of the gait cycle (Figure 2).

Due to complex structure of the foot, it is difficult to draw the line between normal and abnormal. The basic task of clinical pressure distribution measurement is to describe the normal patterns and then help to diagnose the abnormal cases. The highest mean pressure was found at middle metatarsal heads ($p=0.000$) which indicates that there is no functional transverse metatarsal arch. Also, there was no single pressure distribution among the subjects. There were four recognizable pressure distribution patterns according to the columns of the foot (figure 3). The frequent group seen was the first one (%63) where middle metatarsals show the highest loading. The existence of the transverse arch found only in two patients (1.9%).

There is a growing interest in pressure measurement systems, but their clinical application is widely not available today.[6-8, 16] For clinical application of pressure analysis of the forefoot one should consider the existence of different pressure distribution patterns of the metatarsals. In order to investigate the pathology, the contra lateral foot can be used for comparison.

Also this study revealed that the pressure distribution of the metatarsal heads changes with the phases of the stance phase of the gait cycle (i.e., midstance and push off). When studying metatarsal loading patterns we should analyze midstance and push off phases separately, where the peak pressures of the push off phase is found to be correlated with body mass index. Increased knowledge about pressure distribution of the foot will lead us for the management of some problematic feet, which are due to mechanical problems, such as metatarsalgia. During midstance phase foot acts as a flexible unit and could absorb most of the loads, however during push-off phase foot foot acts as a lever arm and transferes the most of load to ground. This may explain the correlation between BMI and peak pressures observed during midstance phase.

We think, future antropometic and biomechanic studies on lower extremity will reveal more clues for understanding rationale of pressure distrubition under metatarsal heads, and their correlations with different disease conditions.

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