Original Article / Özgün Araştırma

Plantar Sole Characteristics are Associated with Postural Stability

Plantar Taban Özellikleri Postüral Stabilite ile İlişkilidir

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Abstract

Objective: The foot is the endpoint of the lower extremity kinetic chain and the role of the anthropometric measurements of the plantar sole in postural steadiness has not been established well. This study aimed to assess the association between plantar sole dimensions and body sway.

Materials and Methods: One hundred ten young healthy volunteers were recruited for the study. The postural stability was measured using the modified Clinical Test of Sensory Interaction on Balance and the Tandem Stance test on a force platform. Anthropometric assessments were performed on a digital footprint image that was recorded by the same force platform. Maximum foot length, maximum foot width, heel width, medial longitudinal arch width, total contact area, foot index, Clarke's angle (CA) and Staheli Arch index (SAI) were recorded.

Results: Foot length and foot width had the reverse relationship with body sway when visual and somato-sensory inputs were limited. Postural stability was better with increasing foot contact area in cushioned and eyes closed conditions. Postural stability worsened with increasing values of SAI and CA when somato-sensory and visual inputs limited.

Conclusion: This study revealed that plantar sole dimensions and foot postural influence balance, especially when the somato-sensorial and visual systems are challenged together.

Öz

Amaç: Alt ekstremite kinetik zincirinin son noktası ayaktır. Ayak tabanının antropometrik parametrelerinin postüral stabilite üzerindeki etkisi iyi belirlenmemiştir. Bu çalışmada ayak tabanının antropometrik değerleri ile vücut salınımı arasındaki ilişkiyi değerlendirmeyi amaçladık.

Gereç ve Yöntemler: Araştırmaya toplam 110 gönüllü katıldı. Postüral stabilite Tandem Stance testi ve Denge Üzerindeki Duyusal Etkileşim Klinik testi kullanılarak kuvvet platformunda ölçüldü. Antropometrik ölçümler platform tarafından kaydedilen dijital ayak izi görüntüsü üzerinde gerçekleştirildi. Maksimum ayak uzunluğu, topuk genişliği, maksimum ayak genişliği, ayak indeksi, toplam temas alanı, Clarke açısı (CA) ve Staheli Ark indeks (SAİ) değerleri kaydedildi. Verilerin istatiksel analizi %95 güven aralığında, SPSS versiyon 22.0 kullanılarak gerçekleştirildi, tanımlayıcı istatistikler ortalama ± standart sapma olarak ifade edildi, p<0,05 değeri istatiksel olarak anlamlı kabul edildi. Veriler arasındaki ilişkiler Pearson korelasyon analizi ile değerlendirildi.

Bulgular: Görsel ve somato-duyusal girdiler sınırlandırıldığında ayak genişliği ve ayak uzunluğu, vücut salınımı ile ters orantılı olarak bulundu. Postüral stabilitenin

Keywords
Anthropometric characteristics, foot, footprint analysis, postural control

Anahtar Kelimeler
Antropometrik özellikler, ayak, ayak izi analizi, postüral kontrol

Received/Geliş Tarihi : 12.02.2021
Accepted/Kabul Tarihi : 26.04.2021

doi:10.4274/meandros.galenos.2021.94546

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gözler kapalı iken yumuşak zeminde ayak temas alanı arttıkça daha iyi olduğu tespit edildi. Görsel ve somato-duyusal girdiler sınırlı olduğunda CA ve SAİ'nin artan değerleri ile postüral stabilite kötüleşti.
Sonuç: Bu çalışma, ayak duruşu ve plantar taban boyutlarının özellikle görsel ve somato-duyusal sistemler sınırlandırıldığında dengeyi etkilediğini ortaya koymuştur.

Introduction

Postural stability represents the act of maintaining the body in a state of balance and requires constant integrations of vestibular, visual, musculoskeletal, and environmental factors. Postural steadiness and balance is fundamental to activities of daily living and sports. Aging, neurodegenerative diseases, musculoskeletal impairments such as contractures, muscle weakness, and limited range of motion interfere with postural control. Understanding factors that contribute to postural stability can help to improve motor strategies in sports and rehabilitation.

The foot is the endpoint of the lower extremity kinetic chain and contact surface of our body to the environment. The plantar sole bears and conducts all the forces of the body to the surface. Vice versa, the plantar sole carries tactile information from the supporting surface to the central nervous system in order to maintain balance. The foot has a relatively small base for maintaining postural control and small alterations of its structure may give cause for load changes during posture correction. Therefore, the maintenance of postural stability when performing functional tasks can be influenced by foot characteristics.

The association between foot and postural control has been investigated in many studies. Studies have shown foot posture, strength, range of motion, and foot angle are contributing factors on postural stability (1-5). However, there is little published data on the possible relation between plantar sole dimensions and postural stability. A previous study by Molikova et al. (6) established that postural stability was related to foot width and length. Another study conducted by Angın et al. (1) focused on the relation between standardized foot size (calculated as foot width divided by foot length) and postural sway on unilateral stance. The authors observed decreased sway velocity with increasing standardized foot size. However, the foot is a complex structure and every single part plays fundamental roles in functional activities. The size and settlement of every bone and joint can differ in all individuals and this is independent from body proportions, height, and weight. Accordingly, if we intend to understand the foot's contribution to balance, it is not sufficient to limit foot dimensions only to length and width.

Although some research has studied the influence of foot length and width on postural sway, there is still very little scientific understanding of the relation between postural stability and detailed anthropometric measurements of the foot sole. Therefore, the aim of this present study was to find and discuss any association between plantar sole dimensions and body sway.

Materials and Methods

Participants

In this study a cross-sectional design was used. One hundred ten young healthy volunteers from the student population of a medical faculty were recruited for the study. Exclusion criteria were a history of neurologic, visual or vestibular disorder and orthopedic disorders. The study was approved by the local ethics committee (protocol no: 2017/1192, date: 06.07.2017) and each participants signed informed consent form.

Postural Stability Assessment

Measurement of postural stability was performed using the modified Clinical Test of Sensory Interaction on Balance (mCTSIB) and the Tandem Stance test (TS) on a force platform (RScan International, Olen, Belgium) according to procedures described by Cohen et al. (7) This platform consisted of 4096 sensors with a data acquisition frequency of 300 Hz. The active sensor area was 325 mm x 488 mm, which was synchronized to a personal computer.

The mCTSIB consists of four conditions for balance assessment: eyes closed on a firm surface (EC), eyes open on a firm surface (EO), eyes closed on a foam-cushioned surface (CEC) and eyes open on a foam-cushioned surface (CEO). Each condition of the mCTSIB and TS were repeated 3 times for 10 seconds. Each mean value of three measurements was taken as a final score and included into the statistical analysis.

Anthropometric Measurements

Anthropometric assessments were performed on a digital footprint image that was recorded by the force platform (Figure 1). All measurements were made using RSscan® software.

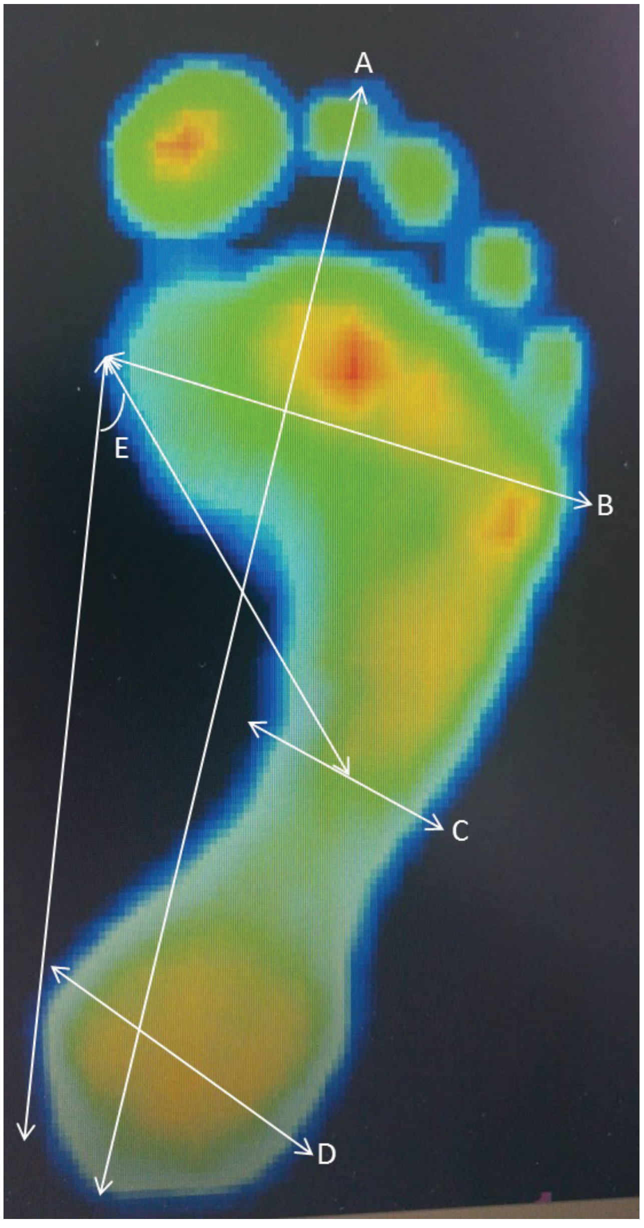

Figure 1. Representation of anthropometric measurements on digital footprint image. A line: maximum foot length; B line; maximum foot width; C line; medial longitudinal arch width; D line; heel width; Clarke's angle: E, Staheli Arch index: C/D

Maximum foot length and width were measured from the longest and widest points of the foot. Heel width and medial longitudinal arch width were recorded as well. Total plantar contact area was calculated using specific software. Also, foot index (FI) was calculated by dividing foot width (cm) by foot length (cm).

Clarke's angle (CA) is an objective, reliable and sensitive method for measuring the height of the internal longitudinal arch (8,9). It is defined as an angle between a line that joins the more internal point of the forefoot and the more internal point of the rear foot with another line that joins the more internal point of the forefoot with the deeper part of the footprint. While CA under 31 °C refers tendency to flat feet and/or pronation, above 41 °C refers to cavus foot.

The Staheli Arch index (SAI) is the midfoot width to hindfoot width ratio, which is calculated to illustrate foot arch development (10). A lower index value means a higher arch.

Statistical Analysis

Statistical analysis of the data was performed using SPSS version 22.0 at 95% confidence interval, descriptive statistics were expressed as mean ± standard deviation, $p<0.05$ was considered significant. Relationships between variables were evaluated with Pearson's correlation test.

Results

In total, 110 subjects 44 females (height 165.4±7.2 cm, and weight 59.2±11.3 kg) and 66 males (height 178.1±6.6 cm, and weight 75.2±12.7 kg) participated in the study. The mean age of the subjects was 20.3±1.6 years.

Table 1 shows the results of the correlation analyses between mCTSIB and plantar sole anthropometric measurements. Foot length had reverse relationship with body sway when visual input was eliminated. This relation was more significant when both visual and somato-sensory input were limited. The same relationship was observed for foot width; postural sway decreased significantly with increasing foot width in cushioned EC measurements. CA was significantly related to body sway in the CEC position. The body became more stable with increasing CA. Postural stability was better with increasing foot contact area in cushioned EC conditions. The SAI was significantly

Table 1. Associations between the modified anthropometric measurements of the plantar sole and Clinical Test of Sensory Interaction scores

	AP-EO	ML-EO	TSW-EO	AP-EC	ML-EC	TSW-EC	AP-CEO	ML-CEO	TSW-CEO	AP-CEC	ML-CEC	TSW-CEC
Foot length	0.072	0.050	0.061	-0.169	-0.177	0.192*	-0.159	-0.156	-0.176	-0.215*	-0.206*	-0.229*
Foot width	-0.161	-0.023	-0.078	-0.066	-0.166	-0.133	-0.023	-0.025	0.033	-0.113	-0.098	-0.112
Heel width	0.100	0.132	0.049	0.124	0.092	0.005	-0.001	0.036	-0.052	0.045	-0.007	-0.008
MLA width	-0.042	-0.016	-0.056	-0.013	-0.043	-0.019	0.140	0.091	0.302**	0.075	0.025	-0.007
PCA	0.004	0.020	-0.095	-0.057	-0.133	-0.160	-0.081	-0.086	-0.107	-0.166	-0.146	-0.190*
FI	-0.211*	-0.069	-0.120	-0.072	-0.021	0.021	0.110	0.100	0.173	0.048	0.062	0.058
SAI	-0.053	-0.030	-0.053	-0.024	-0.050	-0.021	0.144	0.092	0.308**	0.073	0.027	0.025
CA	0.055	0.000	0.015	0.016	-0.033	-0.002	-0.019	0.019	-0.091	-0.204*	-0.061	0.027

AP: Antero-posterior, ML: Medio-lateral, EO: Eyes open, EC: Eyes closed, CEO: Cushioned eyes open, CEC: Cushioned eyes closed, TSW: Total sway, MLA: Medial longitudinal arch, FI: Foot index, PCA: Plantar contact area, SAI: Staheli Arch index, CA: Clarke's angle, *p<0.05, **p<0.01

related to total sway when somato-sensory input was limited. Postural stability worsened with increasing values of SAI. Wider heel width was significantly associated with greater antero-posterior body sway in TS when visual input was eliminated.

The associations between postural sway in a TS and anthropometric measurements of the plantar sole are represented in Table 2. There was no relationship between body sway in the TS position and plantar sole measurements.

The correlation analysis between foot width, FI, and body sway revealed no significant influence of these variables on postural stability.

Table 2. Associations between anthropometric measurements of the plantar sole and postural sway in tandem stance

	AP-EO	ML-EO	TSW-EO
Foot length	-0.079	0.067	-018
Foot width	0.031	-0.036	-0.170
Heel width	0.021	0.134	-0.003
MLA width	0.059	0.133	0.095
PCA	-0.134	0.011	-0.091
FI	-0.042	-0.080	-0.088
SAI	0.059	0.124	0.103
CA	-0.158	-0.097	-0.060

AP: Antero-posterior, ML: Medio-lateral, EO: Eyes open, TSW: Total sway, FI: Foot index, PCA: Plantar contact area, SAI: Staheli Arch index, CA: Clarke's angle, *p<0.05, **p<0.01

Discussion

The present study investigated the impact of the structural properties of the foot to postural stability. The most significant body sway alterations observed were foot dimensions and foot posture when somato-sensory and visual inputs were limited. This result highlights the importance of foot structure on maintaining posture when other components of balance control are deprived.

In the present study, healthy individuals with smaller foot dimensions according to foot length, foot width and FI, demonstrated a significant increase in total body sway during bipedal stance on foam when their eyes were closed. This finding indicated that increasing foot dimensions are associated with better postural stability, especially on uneven surfaces and with limitation of visual input. This finding is reasonable because the foot neutralizes the forces produced by the body in order to provide postural correction. When somato-sensory and visual systems are challenged, people who have larger foot dimensions will have the advantage of a relatively wider base of support. In addition, people need more tactile stimulation from the surface when visual input is limited. A relatively larger contact surface area would provide more cutaneous sensation.

Parallel to our results, previous literature demonstrated diminished body sway in individuals with larger plantar contact area (1). Authors revealed that foot size was inversely related with postural sway velocity. They explained this entity by the larger support surface. Different from these previous studies, we found that foot dimensions were not important until the surface became rough. This result is important for the performance of people doing outdoor recreational and sporting activities.

Footprint analysis is one of the clinical approaches for identifying flatfoot. The Staheli plantar arch index and CA were proposed as indicators of plantar arch development. Our findings revealed that participants exhibiting more pronated feet had poorer performance in postural control when their eyes were closed. We confirmed this result both with the SAI and CA.

Previous literature has presented contradictory findings about the effect of foot posture on postural stability. Angın et al.'s (1) findings revealed that people with prone foot posture had increased sway velocity of center of gravity in a unilateral stance when their eyes were closed. Similarly, in another survey conducted by Spink et al. (4) older volunteers with prone foot posture demonstrated worse performance in postural sway control on foam. In the same vein, Cobb et al. (11) demonstrated higher antero-posterior postural sway in younger people with forefoot varus. Contrary to these results, there are findings that support increased postural sway in individuals with less plantar contact surface. Lin et al. (12) found higher sway area with eyes closed on foam in children aged 4-5 years. On the other hand, their results were not significant in children aged between 8 and 9 years when the foot arch development had been occurred. Another study conducted by Hertel et al. (2) demonstrated higher postural sway area in young individuals with pes cavus. We found increased body sway scores among volunteers with more pronated feet. The findings of our study were confirmed with two common quantitative assessment systems that were designed for the analysis of flatfoot.

These results suggest that prone foot posture could be a contributing factor in impaired postural stability. There are a number of possible explanations for this: 1) with increasing arch index values, increased stress is placed on the osseous, muscular, and ligamentous supports of the foot arch, which may disturb proper weight bearing and provide higher postural sway; 2) it is reasonable to assume that increased pronation of the foot influences lower extremity kinematics, which could also influence postural control strategies.

Our results imply that the influence of the heel width to body sway is very subtle. A possible explanation for this is that forefoot joints are fundamental in giving elasticity to the foot during stance and they allow it to adapt better to unreliable surfaces. So, forefoot dimensions have an impact on balance. On the other hand, the rear foot comprises the ankle joint and the talocalcaneonavicular joint. The rear foot joints secure movement in at least one direction and the inclination angle of the ankle joint contributes to stability during stance. Hence, a foot with larger forefoot dimensions could be able to react and neutralize forces that contribute to body sway more sufficiently.

This study has several limitations. As our study did not include three-dimensional measurements of the foot structure, it is not clear whether our findings represent the real impact of foot structure on postural sway. In addition, postural control of the whole body requires the participation of the postural muscles of the trunk and lower extremities. Thus, the results of this study could be limited to the postural correction strategies of the foot but not whole-body postural control. Other anthropometric measurements of the body could influence balance but they were not the subject of this present study. These limitations could be the target of future studies.

Conclusion

There is very little scientific understanding of the relation between postural stability and detailed anthropometric measurements of the foot sole. Therefore, we were assess the association between plantar sole dimensions and body sway.

This study revealed that plantar sole dimensions and foot posture influence balance, especially when the somato-sensorial and visual systems are challenged together. It seems more reasonable to analyze foot characteristics that influence balance for guiding training facilities in sports and recreational activities in order to achieve a more stable balance and to prevent injuries.

Ethics

Ethics Committee Approval: The present cohort study was designed as a survey and was approved by the Clinical Research Ethics Committee of Adnan Menderes University (protocol no: 2017/1192, date: 06.07.2017)

Informed Consent: Written consents from participants had taken and kept in files separated for each one.

Peer-review: Externally peer-reviewed.

Authorship Contributions

Concept: A.M.T., E.A., E.D.İ., Design: A.M.T., E.A., Data Collection or Processing: E.D.İ., İ.C., Analysis or Interpretation: A.M.T., E.A., E.D.İ., İ.C., Literature Search: A.M.T., E.A., Writing: A.M.T., E.A.

Conflict of Interest: No conflict of interest was declared by the authors.

Financial Disclosure: The authors declared that this study received no financial support.

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