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The Relationship between Plantar Sensation and Functional Parameters in Individuals with Hallux Valgus: A Pilot Study

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ABSTRACT

Objective: Hallux valgus (HV), one of the most common forefoot deformities, may increase mechanical loading on the lateral side of the foot, leading to hyperkeratosis in these areas and deterioration of plantar sensation. Thus, the objective of this study was to investigate the relationship between plantar sensation and clinical and functional parameters, such as HV severity, foot posture, gait, and balance in individuals with HV.

Materials and Methods: A total of 29 participants were recruited for the study. The following measurements were taken: the HV angle with a universal goniometer, hallux pain with the Visual Analog Scale, plantar cutaneous sensation with Semmes-Weinstein monofilaments, clinical status of the forefoot with the American Orthopaedic Foot and Ankle Society (AOFAS) Hallux-Metatarsophalangeal (MTP)-Interphalangeal (IP) Scale, foot posture with the Foot Posture Index (FPI), postural sway with a force platform, and temporospatial gait parameters with an electronic walkway. Spearman correlation analysis was applied to investigate the relationship between the parameters.

Results: Although age and plantar forefoot sensation were moderately correlated (p=001; r=0.63), the HV angle and pain intensity were not associated with any of the sensory parameters (p>0.05).

Conclusion: The present study showed that plantar forefoot sensation worsened as the patients' age increased. It is believed that pressure neuropathy may be the reason why HV patients' forefoot sensitivity deteriorates with age in particular.

Keywords: Hallux valgus, foot, pain, plantar sensation, sensory dysfunction

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INTRODUCTION

The human foot plays a crucial role in maintaining bipedal activities due to its various essential functions. It offers adequate base support for a well-balanced standing position. The foot's unique architecture allows it to be both stable and mobile while walking. During the heel strike and push-off phases, the foot remains stable and rigid to propel the human body forward, whereas, in the mid-stance phase, it adapts to the ground surface. To perform these functions, the passive, active, and neural subsystems work in harmony and cooperation. This paradigm, proposed by McKeon et al. (1), helps us understand the function of the intrinsic foot muscles. The active subsystem includes intrinsic and extrinsic muscles, while the passive subsystem covers the bones, plantar fascia, and ligaments, which support the foot arches. The neural subsystem includes sensory receptors in the muscles, plantar fascia, joint capsules, ligaments, and tendons, all of which are involved in the passive and active subsystems. Plantar sensation, provided by plantar cutaneous receptors, is critical since the foot is the only source of direct contact with the ground during weight-bearing tasks such as gait and balance (2). Foot-related issues such as plantar fasciitis, pes planus, posterior tibial tendon dysfunction, and hallux valgus (HV) can develop when the foot core system is not operating properly (1).

One of the most common foot abnormalities is HV, which is indicated by lateral deviation of the big toe at the metatarsophalangeal joint. Individuals with HV may experience pain, cosmetic problems, and gait disturbances (3). HV also affects the plantar pressure distribution during gait. Hida et al. (4) stated that the big toe becomes dysfunctional due to HV deformity when walking, which may also result in increased mechanical strain on the lateral side of the foot. The weight shift to the lateral area of the plantar surface may cause hyperkeratosis. It has been shown that hyperkeratosis is related to female sex, HV, toe deformity, and increased ankle flexibility (5). The most common hyperkeratotic lesion pattern is on the medial aspect of the first metatarsophalangeal joint, and it is associated with the severity of HV (5). Thickening of the skin may alter the sensitivity of the plantar surface of the foot.

Sensory dysfunction due to pressure neuropathy in individuals with HV has been demonstrated previously. However, this particular study only investigated the dorsal and medial aspect of the big toe (6) and the sensorial status of the weight-bearing plantar surface was not considered. Therefore, the objective of this study was to explore the relationship between plantar sensation and clinical and functional parameters, such as HV severity, foot posture, gait, and balance, in individuals with HV. Thus, the hypothesis was that plantar sensation could be associated with HV severity, pain, foot posture, gait, and balance parameters.

MATERIALS and METHODS

Study Design

This study was designed as a cross-sectional and descriptive study and was conducted between March 2020 and June 2022. Ethical approval was obtained from the Hacettepe University Clinical Research Ethics Boards on February 20, 2020 (number KA-20014). This study was conducted in accordance with the Declaration of Helsinki, and all participants provided written informed consent.

Sample Size Calculation

The required sample size was calculated using G*power (v3.1.9.2, Heinrich-Heine- University, Dusseldorf, Germany). The t-test was chosen as the test family, and a correlation bivariate normal model a priori test was performed. The sample size was calculated based on a large effect size=0.50 with an α value of 0.05 and a power of 0.80 (7). Based on this calculation, a total of 29 participants with HV were needed for the present study.

Subjects

The inclusion criteria for the study were as follows: a) being between 18 and 65 years of age, b) being female, and c) having been diagnosed with mild or moderate HV. The exclusion criteria included having pathologies that may cause sensory problems, such as diabetes, multiple sclerosis, myelomeningocele, severe disc herniation, or having an orthopedic, rheumatological, or neurological disease other than HV.

Outcome Measures

Measurement of the HV Angle

The angle between the line from the center of the metatarsal base to the metatarsal head of the first metatarsal bone and the line connecting the midpoint of the interphalangeal joint of the proximal phalanx was measured using a universal goniometer (8). Goniometric measurement of the Hallux Valgus Angle (HVA) was reported as reliable (9).

Hallux Pain

Pain was evaluated with a 10-cm Visual Analog Scale. The participants were asked to mark their perceived level of pain intensity within the previous week on the line according to the scale between 0 and 10 (score 0: no pain, score 10: the most severe pain) (10).

Plantar Cutaneous Sensation

The Semmes-Weinstein Monofilament test was used to evaluate light touch sensation of the sole of the foot. Positive responses to touch were recorded starting from the thinnest monofilament and the most distal (11) (Fig. 1).

Clinical Rating of the Forefoot

The American Orthopaedic Foot and Ankle Society (AOFAS) Hallux-Metatarsophalangeal (MTP)-Interphalangeal (IP) Scale was used to assess the forefoot clinical state. This is a 100-point rating system that assesses pain, function, and alignment, where 90–100 points are excellent, 75–89 are acceptable, 50–74 points are fair, and less than 50 points denote poor condition (12, 13).

Foot Posture Index

The foot postures of the participants were assessed using the Foot Posture Index, which is a frequently used tool. Foot posture was defined as neutral, pronation, or supination according to the scores obtained in this six-item evaluation (14).

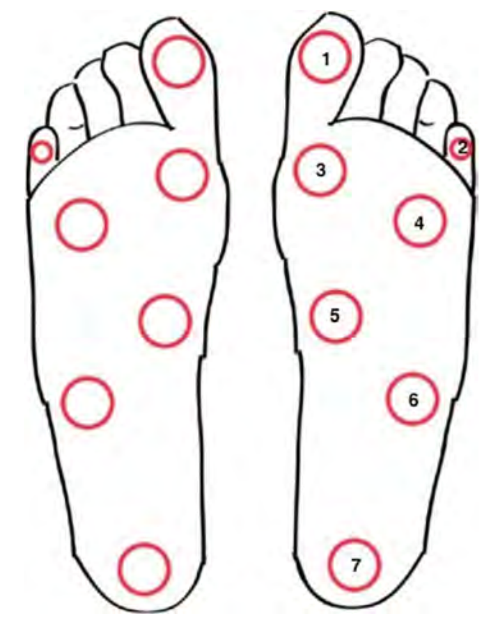

Figure 1. Assessment points for plantar cutaneous sensation on the foot sole

Postural Sway

Postural sway of the participants was evaluated with the Bertec Balance Check Trainer (Force plate AM, Bertec, Columbus, OH, USA). The participants were asked to stand upright for 10 seconds under different conditions, and their postural oscillations were recorded in centimeters in the anteroposterior and mediolateral directions (15).

Temporospatial Gait Parameters

The individuals' gait was evaluated using the GAITRite computerized walking pathway (GAITRite, CIR Systems, Clifton, NJ, USA). The participants were required to walk at their self-selected speed, and after a familiarization trial, the mean of three trials was recorded.

Statistical Analysis

Statistical analyses were performed using the IBM SPSS Statistics for Windows 23.0 (IBM Corp., Armonk, NY, USA). Before statistical analysis, light touch sensation data were processed and organized as regional light touch sensation to interpret easily. Data obtained from plantar sensory regions were processed as follows: medial forefoot: (region 1 + region 3)/2; lateral forefoot: (region 2 + region 4)/2; medial midfoot: region 5; lateral midfoot: region 6; and rearfoot: region 7. The Kolmogorov-Smirnov test and histogram were used to analyze the normality of variables. Since the data were not normally distributed, nonparametric tests were used for data analysis. Median and interquartile ranges are given as descriptive statistics. Spearman correlation analysis was used to interpret the relationship between the variables. The significance level was set at an alpha of 0.05. The magnitudes of the correlations were categorized as follows: a) 0.10 to 0.30: negligible, b) 0.30 to 0.50: low, c) 0.50 to 0.70: moderate, d) 0.70 to 0.90: high, and e) 0.90 to 1.00: very high correlation (16).

RESULTS

The present study included 29 women (46 feet in total) with symptomatic HV. The demographic and clinical characteristics of the participants are given in Table 1. It was shown that the light touch sensation of the lateral midfoot was diminished. The foot posture of the participants was in the neutral range according to the foot posture index. All correlation analyses between plantar sensations and other variables are given in Table 2.

Regarding the correlation analysis between the regional plantar sense and demographic parameters, there was a moderate correlation between age and medial and lateral forefoot sense (p=0.01, r=0.64; p=0.01, r=0.63). There was also a low correlation between age and lateral midfoot sense (p=0.04, r=0.43).

Associations Between Plantar Sense and Clinical Parameters

In terms of the clinical parameters and regional plantar sense, there were negative moderate correlations between the lateral forefoot and the FPI (p=0.001, r=–0.63), and positive low correlation between the AOFAS total score and lateral forefoot sense (p=0.038, r=0.44).

Associations Between Plantar Sense, Balance, and Gait Parameters

There was no statistically significant correlation between plantar sense and balance; however, gait velocity and medial midfoot plantar sense had negative low correlations (p=0.031, r=–0.451).

DISCUSSION

The results of the present study revealed that age has a destructive effect on the plantar sensation of the forefoot in individuals with HV. Interestingly, there were no correlations of plantar sense and pain severity with HV angle in individuals with HV.

According to previous research, patients with HV can exhibit pressure neuropathy. The sensory impairment, however, has been exclusively seen in regions that are innervated by the dorsomedial cutaneous nerve. Particularly in the region of the deformity, it concentrates on the proximal phalanx and bunion (17). According to Herron et al. (6), around 44% of their HV patients experienced sensory problems, and there was no association between sensory impairment and the HV angle. Their study focused mainly on the dorsal sense of the foot and did not assess the connection between sensory loss and other factors that might be related to HV. Additionally, Jastifer et al. (18) showed that there was no correlation between the clinical parameters and sensory deficit. They also reported that the sensory deficit in HV patients healed within up to two years following surgery. Unlike prior studies focusing on the HV angle and sensory impairments, the current study investigated the plantar surface of the foot and showed comparable results in this regard.

According to the current study, there is an association between forefoot plantar sensation and age. HV is a forefoot deformity that worsens over time and becomes more common as people age. The pressure of the forefoot in the shoe generated by the bunion brought on by HV may impair the sense of forefoot (19). Herron et al. (6) observed that their patients had medially located paresthesia in the big toe as a symptom of HV before surgery and interpreted that one of the possible causes of this condition could be nerve traction. However, they did not report any relationship between HV angle and sensory dysfunction. The association between sensory loss and increased age has been well-demonstrated in previous research (2, 20–22). Jalali et al. (20) stated that heel sensory loss was the most common type in older people with foot problems such as HV, edema, sensory loss, and callus. The difference between these conflicting results could be due the participant groups included in the research.

Table 1. Demographic variables of the participants

Parameters	Median (25th/75th Quartile) (n=29)
Age (years)	50.5 (24/57)
BMI (kg/m^2)	24.2 (21.5/26.7)
HV angle (0)	21 (17/25)
Pain severity (VAS-cm)	4.05 (2/7)
SWMT	
Medial forefoot	3.61 (3.61/4.31)
Lateral forefoot	3.61 (3.6/4.2)
Medial midfoot	3.61 (3.61/4)
Lateral midfoot	3.61 (3.61/4.31)
Rearfoot	4.31 (3.61/4.31)
FPI 4 (3/5)	
AOFAS score	62 (53/72)
LOS forward	9.2 (7.7/10.3)
LOS backward	6 (4.3/6.9)
LOS-affected side	10.01 (9.6/11.6)
Anteroposterior sway range	0.37 (0.3/0.5)
Mediolateral sway range	0.15 (0.11/0.21)
Gait velocity (cm/s)	107 (102/121.3)
Step length (cm)	58.47 (56.8/62.8)
Support base (cm)	9.73 (9.4/10.8)
Swing percentage (%)	37.4 (36.1/38.5)
Stance percentage (%)	62.62 (61.4/63.8)

IQR: Interquartile range; BMI: Body mass index; HV: Hallux valgus; VAS: Visual analog scale; SWMT: Semmes Weinstein monofilament Test; FPI: Foot posture index; AOFAS: American Orthopaedic Foot and Ankle Society Scale; LOS: Limits of stability

Foot posture and lateral forefoot sense were negatively correlated, indicating that a more pronated foot indicates better lateral forefoot sense. Evidence suggests that ground reaction forces during gait are displaced medially by excessive pronation. Research has shown that a pronated foot causes decreased pressure in the medial and lateral forefoot and increased pressure under the big toe, central forefoot, and medial midfoot when compared to feet with neutral alignment (23–25). The findings in the current study are similar to those in previous research, and the present study associated forefoot sense with higher scores in the FPI.

Table 2. Correlation analysis between all parameters

	Regional plantar sensory				
	Medial forefoot	Lateral forefoot	Lateral midfoot	Medial midfoot	Rearfoot
Age (years)	**0.636* (0.001)**	**0.626* (0.001)**	**0.426* (0.043)**	0.321 (0.135)	0.351 (0.1)
BMI (kg/m²)	0.118 (0.593)	0.223 (0.307)	0.342 (0.111)	-0.034 (0.878)	0.24 (0.269)
HV angle (0)	-0.263 (0.225)	-0.304 (0.159)	0.11 (0.619)	-0.051 (0.816)	0.066 (0.765)
Pain severity (cm)	0.088(0.689)	-0.124 (0.572)	-0.149 (0.498)	0.3 (0.164)	-0.014 (0.949)
FPI	-0.299 (0.165)	**-0.625* (0.001)**	-0.048 (0.828)	-0.082 (0.708)	-0.03 (0.891)
AOFAS score	0.377 (0.076)	**0.436* (0.038)**	0.295 (0.172)	0.136 (0.535)	0.412 (0.051)
LOS forward	0.132 (0.549)	0.05 (0.819)	-0.042 (0.848)	0.013 (0.953)	0.201 (0.359)
LOS backward	-0.119 (0.59)	-0.241 (0.267)	0.033 (0.883)	-0.137 (0.534)	-0.363 (0.089)
LOS-affected side	-0.081 (0.713)	-0.166 (0.45)	-0.255 (0.241)	-0.003 (0.988)	-0.201 (0.357)
Anteroposterior sway range	-0.009 (0.967)	0.19 (0.385)	0.066 (0.764)	0.158 (0.471)	-0.253 (0.243)
Mediolateral sway range	-0.039 (0.861)	0.103 (0.641)	0.149 (0.499)	0.012 (0.955)	-0.008 (0.973)
Gait velocity (cm/s)	-0.277 (0.201)	-0.279 (0.197)	-0.372 (0.08)	**-0.451* (0.031)**	-0.239 (0.273)
Step length (cm)	-0.385 (0.07)	-0.288 (0.182)	-0.26 (0.23)	-0.309 (0.151)	-0.119 (0.588)
Support base (cm)	-0.197 (0.367)	-0.169 (0.44)	0.236 (0.277)	0.159 (0.469)	-0.068 (0.759)
Swing percentage (%)	-0.387 (0.068)	-0.371 (0.081)	-0.256 (0.238)	-0.074 (0.736)	-0.247 (0.256)
Stance percentage (%)	0.387 (0.068)	0.371 (0.081)	0.256 (0.238)	0.074 (0.736)	0.247 (0.256)

*: P<0.05, all values were given as r(p). BMI: Body mass index; HV: Hallux valgus; FPI: Foot posture index; AOFAS: American Orthopaedic Foot and Ankle Society Scale; LOS: Limits of stability

Higher AOFAS forefoot scores indicate better clinical status and are associated with poorer sensation. It is thought that this might be due to the hypersensitivity of individuals with poor clinical status who scored low on the AOFAS. Upon examining foot problems and quality of life in the elderly, Jalali et al. discovered that HV was the most prevalent deformity. They also noted that discomfort, edema, and sensory loss were related to quality of life, even though their participants had mild HV deformity (20, 26).

There was a negative correlation between gait speed and the medial midfoot when the gait and plantar sensory data were analyzed. As the medial midfoot sensation worsens, walking speed decreases. The push-off phase of gait is correlated with gait speed (27), and the pushing phase involves the supination of the foot. Walking at a slower pace could result from the foot continuing to pronate because it will exert less force. The medial midfoot may be loaded by pronation, which can lead to callus formation and subsequent desensitization.

The present study had several limitations. The sample size was relatively small, and the participants had mild to moderate HV. Since there were no participants with severe HV, the results of the present study could not be generalized. Despite these limitations, to the best of our knowledge, this is the first study investigating the association between plantar sense and clinical parameters in individuals with HV.

CONCLUSION

Based on the study findings, it is believed that pressure neuropathy may be the cause of deteriorating forefoot sensitivity in HV patients as they age. The study also found that gait speed was related to medial midfoot sensation, but the HV angle and pain severity were not associates with sensory dysfunction. Additionally, the study established the significance of the pronation posture, which increases stress on the medial midfoot in patients with HV.

Ethics Committee Approval: The Hacettepe University Clinical Research Ethics Committee granted approval for this study (date: 12.03.2020, number: KA-20014).

Informed Consent: Written informed consent was obtained from patients who participated in this study.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept – EK, PK, GY; Design – EK, PK, GY; Supervision – EK, GY; Resource – EK, PK, GY; Materials – EK, PK, GY; Data Collection and/or Processing – EK, PK, GY; Analysis and/or Interpretation – EK, PK, GY; Literature Search – EK, PK, GY; Writing – EK, PK, GY; Critical Reviews – EK, PK, GY.

Conflict of Interest: The authors have no conflict of interest to declare.

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