Do Plantar Pressure and Loading Patterns Vary with Joint Hypermobility in Young Females?

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Background: Joint hypermobility is a connective tissue disorder that increases joint range of motion. Plantar pressure and foot loading patterns may change with joint hypermobility. We aimed to analyze static plantar pressure in young females with and without joint hypermobility.

Methods: Joint laxity in 27 young females was assessed cross sectionally using the Beighton and Horan Joint Mobility Index. Participants were divided into the hypermobility (score, 4–9) and no hypermobility (score, 0–3) groups according to their scores. Static plantar pressure and forces were recorded using a pedobarographic mat system.

Results: Higher peak pressures ($P = .01$) and peak pressure gradients ($P = .025$) were observed in the nondominant foot in the hypermobility group. According to the comparison of dominant and nondominant feet in each group, the hypermobility group showed significantly higher peak pressures ($P = .046$), peak pressure gradients ($P = .041$), and total force values ($P = .028$) in the nondominant foot.

Conclusions: The plantar pressure and loading patterns vary in young females with joint hypermobility. Evaluation of plantar loading as an injury prevention tool in individuals with joint hypermobility syndrome can be suggested. (J Am Podiatr Med Assoc 111(1): 1-6, 2021)

Joint hypermobility (JH) is a connective tissue disorder in which the joint motion increases farther than the normal range.[1] Although joint laxity is a part of heritable connective tissue disorders such as Marfan syndrome and Ehlers-Danlos syndrome, besides JH, additional clinical signs and symptoms are seen in these diseases.[2] Although JH is seen from 10% to 15%, its prevalence varies with age, sex, and ethnicity: it is most prominent in childhood,[3] three times more common in women than in men,[4] and more established in Asian and African individuals.[5] Hypermobility syndrome was first described by Kirk et al[6] in 1967, and since then the syndrome has been defined by various names, such as *joint hypermobility syndrome*, *generalized joint laxity*, or *joint hypermobility*. The Beighton and Horan Joint Mobility Index (BHJMI), which was first identified in 1969 and modified in 1973, is the most widely used scoring system to describe JH.[5,7]

Joint hypermobility and hypermobility syndrome are common in musculoskeletal disease clinics but have received slight consideration in sports medicine, orthopedics, and physical therapy literature.[8,9] Patients cannot be evaluated and treated appropriately due to missed diagnosis, and it has been reported that many patients presenting with chronic, idiopathic, and nontraumatic musculoskeletal

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complaints may have unrecognized JH.[10,11] Although most patients with JH have no symptoms, studies have shown that JH is clinically relevant, with musculoskeletal problems such as pain, increased fatigue, tendency for soft-tissue injury, joint dislocation or subluxation, and scoliosis.[9,11-13]

Musculoskeletal problems related to JH are commonly seen in weightbearing joints such as knees and ankles.[9] Joint hypermobility is an underlying risk factor that leads to lower-extremity injuries by influencing postural balance and alignment.[14] Therefore, foot and ankle injuries are higher in people with JH, and arthralgia, joint subluxations or dislocations, sprains, and impaired proprioception are seen with increased incidence.[15]

Pedobarography is a leading assessment tool that provides data on the interaction between the foot and the supporting surface. It gives information about the plantar pressure and force distribution for the biomechanical analysis of standing.[16] According to a study that evaluated pedobarographic plantar pressure in individuals with JH, it was found that athletes with high BHJMI scores have increased midfoot peak pressure and maximum force.[17]

Lack of awareness about the relationship between JH and plantar loading pattern may lead to complaints and injuries such as arthralgia, sprains, and impaired proprioception, which can be preventable.[17-19] Assessing the differences between individuals with JH can help us identify the possible risk factors of pain and injury, as well as act as a guide for physicians and rehabilitation therapists to better understand this issue. Therefore, we planned this study to determine whether plantar pressure and loading patterns of young females with and without JH would differ while standing. The aim was to compare the static distribution of foot pressure and loading patterns in young females with and without JH using a pedobarographic system.

Methods

We designed a cross-sectional study of young females who applied to a sports medicine outpatient clinic for a regular preparticipation sports evaluation. This study was conducted in agreement with the principles of the Helsinki Declaration. The study protocol was approved by the local ethics committee on research with human subjects. Written informed consent was obtained from all of the participants.

Participants with a history of sustained lower-extremity injury within the year, foot deformity, alignment problems, and previous lower-extremity surgery were excluded from the study because the pressure analysis results would be affected. The sample size was found to be at least 12 participants for each group with 80% power and 5% error. Of 40 surveyed candidates, 27 female participants older than 18 years (mean ± SD age, 26.4 ± 8.2 years) were included in the study.

Age and body mass index (BMI [calculated as weight in kilograms divided by height in meters squared]) were recorded; participants' height and weight were measured using a digital scale (Seca 769; Seca, Hamburg, Germany). According to the literature, a question such as "If you would shoot a ball on a target, which leg would you use to shoot the ball?" was asked to determine leg dominance of the participants.[20]

Joint laxity assessment, as a part of the regular sporting examination, was performed according to the BHJMI[5,21] and included five subevaluations: 1) thumb opposition test—passive opposition of the thumb to the flexor side of the forearm, 2) fifth finger hyperextension test—passive dorsiflexion and hyperextension of the fifth metacarpal joint beyond 90°, 3) elbow hyperextension test—passive hyperextension of the elbow beyond 10°, 4) knee hyperextension test—passive hyperextension of the knee beyond 10°, and 5) palms to floor test—active forward flexion of the trunk with the knees fully extended so that the palms of the hands rest flat on the floor. All of these maneuvers, except the palms to floor test, were performed for the right and left sides of each patient, and if the conditions were met, a score of 1 was given. According to their BHJMI scores, the participants were divided into two groups: the no hypermobility (NH) group (score, 0–3) and the hypermobility (HM) group (score, 4–9).[22] The reliability of the BHJMI was found to be good to excellent in previous studies.[21] The joint laxity assessments of all of the patients were measured by the same physician, who demonstrated an intraclass correlation coefficient of 0.93 for intrarater reliability.

Plantar pressures and forces were recorded using the MatScan system (TekScan Inc, Boston, Massachusetts). The system consists of a 5-mm-thick floor mat (432 × 368 mm) comprising 2,288 resistive sensors (1.4 sensors/cm^2) and a data sampling frequency of 40 Hz. For static measurement, participants were requested to stand barefoot on a pressure distribution platform in an appropriate position with the arms at the side. The pressure plate was calibrated to minimize errors before each measurement, according to the manufacturer's instructions, using the body weights recorded before each test session. The tests were repeated

two times, and the mean values were reported in each condition. Peak pressures and maximum forces were recorded by using FootMat 7.0 software (TekScan Inc). All of the force data were normalized to body weight. The pedobarographic assessments of all of the patients were assessed by the same experienced investigator (S.Y.).

The variables were investigated using visual (histograms, probability plots) and analytical (Kolmogorov-Smirnov test) methods to determine normal or nonnormal distribution. Descriptive analyses are presented using means, standard deviations, medians, and interquartile ranges. The Mann-Whitney *U* test was used to compare the plantar pressure and force distributions between the NH and HM groups. Comparison of the plantar pressure and force distributions between the right and left feet in each group was performed by Wilcoxon test. Statistical analyses were performed using IBM SPSS Statistics for Windows, Version 21.0 (IBM Corp, Armonk, New York). A $P < .05$ was considered statistically significant.

Results

The mean ± SD age and BMI in the NH group (n = 15) were 28.4 ± 9.1 years and 25.2 ± 5.6 kg/m^2, respectively, and in the HM group (n = 12) were 23.8 ± 6.4 years and 24.7 ± 4.6 kg/m^2, respectively. There were no statistically significant differences in age and BMI in the groups ($P = .07$ and $P = .81$, respectively).

When the plantar pressure and force distributions in the static pedobarographic analysis were examined, the differences in peak pressures and peak pressure gradients on the nondominant side were found to be significantly higher in the HM group than in the NH group, and there was no difference in the analyses on the dominant side (Table 1). Statistically significantly higher peak pressures and peak pressure gradients in the HM group than in the NH group were observed in the analysis of the nondominant foot (mean ± SD peak pressure: 1.69 ± 0.41 kg/cm^2 and 1.23 ± 0.39 kg/cm^2, respectively, $P = .01$; and mean ± SD peak pressure gradient: 2.21 ± 0.38 kg/cm^2 and 1.73 ± 0.56 kg/cm^2, respectively, $P = .025$). There were no statistically significant differences in total, heel, and metatarsal force values between the HM and NH groups.

According to the comparison of the plantar pressure and force distributions between dominant and nondominant feet in each group, the HM group showed significantly higher peak pressure (nondominant: 1.69 ± 0.41 kg/cm^2, dominant: 1.42 ± 0.31 kg/cm^2, $P = .046$), peak pressure gradient (nondominant: 2.21 ± 0.38 kg/cm^2, dominant: 1.84 ± 0.33 kg/cm^2, $P = .041$), and total force (nondominant: 5.8 ± 1.2 N/kg, dominant: 5.4 ± 1.04 N/kg, $P = .028$) on the nondominant side (Table 2). Although higher heel (nondominant: 2.9 ± 0.9 N/kg, dominant: 2.5 ± 0.7 N/kg) and metatarsal force (nondominant: 1.8 ± 0.5 N/kg, dominant: 1.7 ± 0.6 N/kg) were recorded on the nondominant side of the HM group, no significant differences were found ($P = .06$ and P

Table 1. Intergroup Comparison of Plantar Pressure and Force Distribution in Static Measurements

	Dominant Feet			Nondominant Feet		
Measurement	NH Group	HM Group	*P* Value	NH Group	HM Group	*P* Value
Peak pressure (kg/cm^2)			.61			.01[a]
Mean ± SD	1.37 ± 0.38	1.42 ± 0.31		1.23 ± 0.39	1.69 ± 0.41	
Median (IQR)	1.37 (0.5)	1.39 (0.4)		1.15 (0.8)	1.74 (0.4)	
Peak pressure gradient (kg/cm^2)			.65			.025[a]
Mean ± SD	1.8 ± 0.39	1.84 ± 0.33		1.73 ± 0.56	2.21 ± 0.38	
Median (IQR)	1.86 (0.5)	1.86 (0.4)		1.69 (0.9)	2.34 (0.6)	
Force total (N/kg)[b]			.43			.57
Mean ± SD	5.8 ± 0.7	5.4 ± 1.04		5.7 ± 0.7	5.9 ± 1.2	
Median (IQR)	5.6 (1.01)	5.6 (1.2)		5.6 (0.9)	5.9 (1.4)	
Force heel (N/kg)[b]			.94			.24
Mean ± SD	2.5 ± 0.6	2.5 ± 0.7		2.5 ± 0.7	2.9 ± 0.9	
Median (IQR)	2.4 (0.9)	2.8 (1.3)		2.6 (1.2)	2.8 (1.9)	
Force metatarsal (N/kg)[b]			.11			.26
Mean ± SD	2.06 ± 0.5	1.7 ± 0.5		2.01 ± 0.5	1.8 ± 0.5	
Median (IQR)	2.2 (0.9)	1.7 (0.9)		2.04 (0.8)	1.7 (0.6)	

Abbreviations: HM, hypermobility; IQR, interquartile range; NH, no hypermobility.
[a]Statistically significant.
[b]All force data were normalized to body weight.

Table 2. Intragroup Comparison of Right and Left Plantar Pressure and Force Distribution in Static Measurements

	NH Group (n = 15)			HM Group (n = 12)		
Measurement	Dominant Feet	Nondominant Feet	*P* Value	Dominant Feet	Nondominant Feet	*P* Value
Peak pressure (kg/cm^2)			.59			.046[a]
Mean ± SD	1.37 ± 0.38	1.23 ± 0.39		1.42 ± 0.31	1.69 ± 0.41	
Median (IQR)	1.37 (0.5)	1.15 (0.8)		1.38 (0.4)	1.74 (0.3)	
Peak pressure gradient (kg/cm^2)			.61			.041[a]
Mean ± SD	1.79 ± 0.39	1.73 ± 0.56		1.84 ± 0.33	2.21 ± 0.38	
Median (IQR)	1.86 (0.5)	1.69 (0.9)		1.86 (0.4)	2.34 (0.6)	
Force total (N/kg)[b]			.58			.028[a]
Mean ± SD	5.8 ± 0.7	5.7 ± 0.7		5.4 ± 1.04	5.8 ± 1.2	
Median (IQR)	5.6 (1.01)	5.6 (0.9)		5.6 (1.2)	5.9 (1.4)	
Force heel (N/kg)[b]			.32			.06
Mean ± SD	2.5 ± 0.6	2.5 ± 0.7		2.5 ± 0.7	2.9 ± 0.9	
Median (IQR)	2.4 (0.9)	2.6 (1.2)		2.8 (1.3)	2.8 (1.9)	
Force metatarsal (N/kg)[b]			.75			.73
Mean ± SD	2.06 ± 0.5	2.02 ± 0.5		1.7 ± 0.6	1.8 ± 0.5	
Median (IQR)	2.2 (0.9)	2.04 (0.9)		1.7 (0.9)	1.7 (0.6)	

Abbreviations: HM, hypermobility; IQR, interquartile range; NH, no hypermobility.
[a]Statistically significant.
[b]All force data were normalized to body weight.

= .73, respectively). In the NH group there were no statistically significant differences between dominant and nondominant feet in terms of the plantar pressure and force distributions (Table 2).

Discussion

The foot is the main part of static or dynamic conditions of the load weight.[23] Individuals with JH often have clinical demonstrations such as recurrent joint dislocations and chronic joint and limb pain, with a higher rate of occurrence on the lower extremity.[24] These people seem to be more prone to foot anomalies, some of which are pes planus, hallux valgus, and claw toe.[25] Along with these changes in the foot, pain in the lower extremity accompanies JH, and this may lead to difficulties in the spread of muscle strength that alters the work of the foot and ankle.[24,26] Therefore, the present study intended to analyze the differences in static plantar pressure in participants with or without JH.

According to the present results, the peak pressures and peak pressure gradients on the nondominant foot were higher in participants in the HM group ($P = .01$ and $P = .025$, respectively). Similar to the present study, Pau and colleagues[27] found that patients with Ehlers-Danlos syndrome had smaller forefoot areas and larger static peak pressures compared with a control group of unaffected women ($P < .001$). The authors concluded that patients with Ehlers-Danlos syndrome have a morphological and functional adaptation of the lower limb that is characterized by specific forms of pressure on the foot, possibly associated with this syndrome.[27] In contrast to the present findings, Aydin et al[28] stated significantly higher relative static pressure loads underneath the right forefoot in participants with BHJMI scores of 0 to 2 compared with 3 to 4.

Although pedobarographic analysis in the present study measured static plantar pressure, it had several similarities with the findings of Foss and colleagues[17] in which dynamic plantar pressure was measured. In the group with high generalized joint laxity, peak pressure and maximum force were greater than in the low generalized joint laxity group.[17] These results were correlated with the present study, where peak pressure on the nondominant side was greater in the group with high BHJMI scores ($P = .01$).

Recent studies declared that athletes have different loading patterns between both feet. In the study by Dag et al,[29] which investigated the plantar pressure differences between preferred and nonpreferred feet in 11 elite taekwondo athletes, higher peak pressure was found in the nonpreferred feet. In the present study, we also found significantly higher peak pressure ($P = .046$) and total force ($P = .028$) on the nondominant side of the HM group. In the NH group there was no difference between right and left feet in terms of the plantar pressure and force distributions.

Risk of overuse injuries caused by repetitive loading is high in athletes. According to the

literature, a statistical correlation was found between JH syndrome and injury ($P < .01$).[30] Young dancers with a benign JH syndrome have widespread presence of arthralgia, with subsequent implications for training.[31] Aside from the impact of JH syndrome on athletes, individuals with a normal arch compared with those with a high or low arch may be at increased risk for certain overuse injuries involving stress fractures.[32] In the study by Carson and colleagues,[32] American football players with high arches had greater maximum force in the lateral hindfoot ($P = .008$). Unfortunately, we were unable to investigate the relationships of contact area percentages thereafter to obtain information regarding the arch between the groups because the present study was limited to investigating plantar loading only. Moreover, the study by Cimolin et al,[33] which was performed in this area, during pedobarographic evaluation found pes cavus in hypermobile participants. Consequently, further data collection is required to determine exactly how JH affects plantar loading and arch.

A further limitation of the present study was that male individuals were not included, which created a lack of data for the male sex. Besides, subsequent researches should focus on a larger sample of participants. In addition to the aforementioned, we were unable to evaluate for the existence of hallux valgus and other foot deformities that will enhance a better understanding of correlation between plantar loading and JH in this area. This study was limited to use of static loading pressure evaluation; however, dynamic measurements also should be obtained while participants wear shoes to establish the dynamic contribution of biomechanics properties of the foot during sports activities.

In conclusion, the present study revealed that peak pressures and peak pressure gradients in nondominant feet of the HM group were significantly higher than in those of the NH group. Moreover, according to the comparison of dominant and nondominant feet in each group, the HM group showed significantly higher peak pressure, peak pressure gradient, and total force in the nondominant foot. The present study suggests that patients with JH are characterized by specific plantar loading patterns that are probably caused by the morphological and functional foot modification associated with this syndrome. From a clinical point of view, it can be hypothesized that individuals with JH would be more prone to foot pathology such as arthralgia and patellofemoral pain according to higher pressure compared with individuals without JH and asymmetry between dominant and nondominant feet. Peak pressure and load asymmetry between dominant and nondominant feet in individuals with JH indicates that each foot should be assessed and trained separately to reduce the bilateral differences and prevent injuries. The BHJMI may be used clinically to assess JH in patients, and the use of pedobarography may provide useful information to physicians and rehabilitation therapists regarding plantar loading as an injury prevention tool in individuals with JH. In line with the results of pedobarographic analysis, appropriate treatment modalities, such as patient education, self-management, exercises, splints, insoles, or adaptive devices, may be used in patients with JH.

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