ORIGINAL ARTICLES

Hallux Interphalangeal Joint Range of Motion in Feet with and Without Limited First Metatarsophalangeal Joint Dorsiflexion

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Background: This work was designed to assess the degree of correlation between hallux interphalangeal joint and first metatarsophalangeal joint dorsiflexion and to compare the mobility of the hallux interphalangeal joint between participants with and without limited first metatarsophalangeal joint dorsiflexion (hallux limitus).

Methods: Dorsiflexion of the hallux interphalangeal joint was measured in 60 normal feet and in 60 feet with hallux limitus to find correlations with first metatarsophalangeal joint dorsiflexion with the Spearman correlation coefficient and a simple linear regression equation. In addition, movement of the hallux interphalangeal joint was compared between normal and hallux limitus feet with the Mann-Whitney *U* test.

Results: Significant differences were found between the groups in mean ± SD interphalangeal joint dorsiflexion (control group: 1.17° ± 2.50°; hallux limitus group: 10.65° ± 8.24°; $P < .001$). A significant inverse correlation was found between first metatarsophalangeal joint dorsiflexion and hallux interphalangeal joint dorsiflexion ($\rho = -0.766$, $P < .001$), and the regression equation from which predictions could be made is the following: hallux interphalangeal joint dorsiflexion = 27.17 – 0.381 × first metatarsophalangeal joint dorsiflexion.

Conclusions: Hallux interphalangeal joint dorsiflexion was greater in feet with hallux limitus than in normal feet. There was a strong inverse correlation between first metatarsophalangeal joint dorsiflexion and hallux interphalangeal joint dorsiflexion. (J Am Podiatr Med Assoc 102(1): 47-53, 2012)

Hyperextended hallux interphalangeal joint (IPJ) is observed frequently in clinical practice associated with limited first metatarsophalangeal joint (MPJ) dorsiflexion, although, to our knowledge, data regarding the prevalence of this alteration has not been reported. In a normal foot, the first ray should be able to become plantarflexed so that the transverse axis of the first MPJ alters its position during the propulsive phase of gait, enabling supination of the rearfoot and external rotation of the leg.[1,2] When hypermobility of the first ray exists, the head of the first metatarsal is displaced dorsally in response to ground reaction force in this phase of gait, and there is a deficit in support that the subtalar joint has to compensate by pronating so that the first metatarsal bears part of the weight of the body. However, once the first ray is dorsiflexed, and the subtalar joint is pronated as a compensatory mechanism, the peroneus longus muscle does not stabilize the first ray, having lost its mechanical advantage.[3-5] This incomplete support of the first ray is made up for by the proximal phalanx of the hallux, which adopts a plantarflexed position, translating the point of support from the head of the first metatarsal to the plantar region of the hallux IPJ and, thus, elongating the lever of the deficient first metatarsal. With this position of the proximal phalanx, the hallux IPJ is hyperextended to prevent the distal phalanx from being traumatized against the ground. However, this compensatory position gives rise to other signs and symptoms often present in participants with hallux limitus, such as subungual exostoses,[6] overload on the heads of the external metatarsals and under the

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hallux,[7-10] and ungual dystrophies by chronic trauma of the distal end of the distal phalanx against the toe box of the shoe.[9,11] Therefore, these alterations should be treated bearing in mind the state of mobility of the first MPJ.

Although there are studies[12] assessing the mobility of the hallux IPJ, to our knowledge, there are few works[13-16] that contribute specific data on the relationship between the mobility of this joint and the mobility of the first MPJ. Understanding this relationship would enable us to know to what extent hallux IPJ mobility is affected when first MPJ dorsiflexion is reduced. Thus, the aims of this work were to assess the degree of correlation between hallux IPJ and first MPJ dorsiflexion and to compare the mobility of the hallux IPJ between participants with and without hallux limitus. The null hypotheses of this study were that 1) there is no correlation between first MPJ dorsiflexion and hallux IPJ mobility and 2) there is no difference in hallux IPJ dorsiflexion between individuals with normal feet and participants with hallux limitus.

Materials and Methods

This cross-sectional correlational study was conducted in a private podiatric medical center in Marbella (Málaga, Spain) during 2008 and 2009. The software G*Power version 3.0.10 (Franz Faul, Universität Kiel, Kiel, Germany) was used to calculate a priori the sample size required for the estimation of two independent means (one-tailed test) to be able to detect a medium effect size (0.5), with a type I error rate of 5% ($\alpha = 0.05$) and a power of 80% ($1 - b = 0.80$). The required sample size was 51 individuals per group ($N = 102$). The final sample comprised 60 volunteer participants (30 participants [60 feet] with normal feet and 30 participants [60 feet] with hallux limitus). Note that references are always to feet, rather than to persons, because the clinical signs of the two first MPJ joints (right and left) could have been different in the same participant, and in clinical practice the need to make a separate evaluation for each foot is frequent. As Menz and Munteanu explain,[17] the main conceptual and statistical problems generated by this type of design arise when the inferences derived from such studies are made with reference to persons when the feet or extremities have been used as the unit of analysis. Given that the aim of this study was to analyze and relate the characteristics of a segment of the foot, and not of the person, we used the feet, and not the individuals, as the unit of the sample. Thus, we considered the final sample to comprise 120 feet: 60 in the control group and 60 in the hallux limitus group. All of the participants gave their written consent once they had been informed of the nature of the study. The study was approved by the Experimentation Ethical Committee of the University of Seville.

Participants were recruited as they attended the podiatric medical center in Marbella (Málaga, Spain) and were matched on the following selection criteria. All of the participants had to be 20 years or older (so that the growth physes were closed). For the control group, the specific inclusion criterion was to have a normal hallux dorsiflexion, ie, 65° or more of first MPJ dorsiflexion. For participants with hallux limitus, the specific inclusion criterion was to have a bilateral hallux dorsiflexion not exceeding 55°. This range (55°–65°) was established to avoid confusion in cases in which hallux dorsiflexion showed values close to the limit between normal dorsiflexion and restricted dorsiflexion. Also, Dananberg et al[18] consider hallux limitus to be mild when a first MPJ range of dorsiflexion of 35° to 55° is present. The exclusion criteria from the study, common to both groups, were osteoarticular surgery of the lower extremity, severe trauma to the lower extremity in the past 12 months, neuromuscular imbalance, pain in the first MPJ, and other diseases or conditions affecting hallux or first ray range of motion, such as hallux abducto valgus, rheumatic alterations, and surgical interventions.

The main variables recorded were maximum dorsiflexion of the first MPJ and maximum dorsiflexion of the hallux IPJ; other variables studied were maximum flexion of the first MPJ and maximum flexion of the hallux IPJ. The protocol for data collection was as follows. Once a participant fulfilled the inclusion criteria and had given consent to take part in the study, hallux dorsiflexion was measured, and the participant was assigned to the control group or the study group. During the measurement of joint mobility, the participant remained in the supine position on the exploration table, with the backrest inclined approximately 30° and the feet overhanging the table. Dorsiflexion and plantarflexion of the hallux were measured following the method proposed by Buell et al[19] but having taken as neutral position the relaxed position of the hallux with respect to the first metatarsal (Figs. 1 and 2). This method has been used previously in other studies.[20] Dorsiflexion and plantarflexion of the hallux IPJ were measured using the same method, adapted to this joint. The measuring instrument used in both joints was a two-arm 2° scaled goniometer. All of the quantitative variables

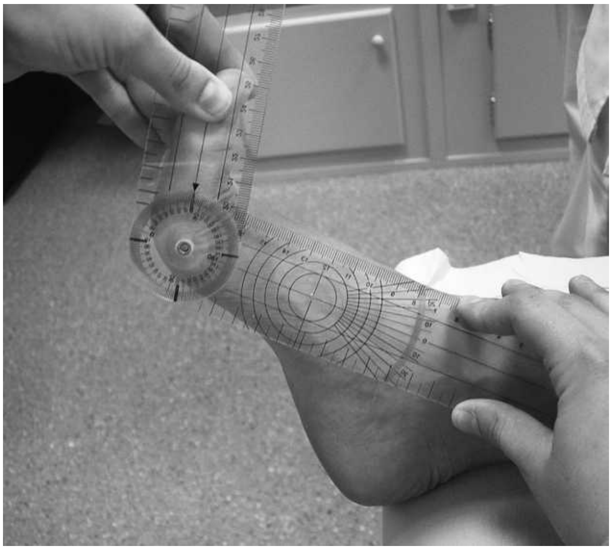

Figure 1. Method of measurement of first metatarsophalangeal joint range of motion.

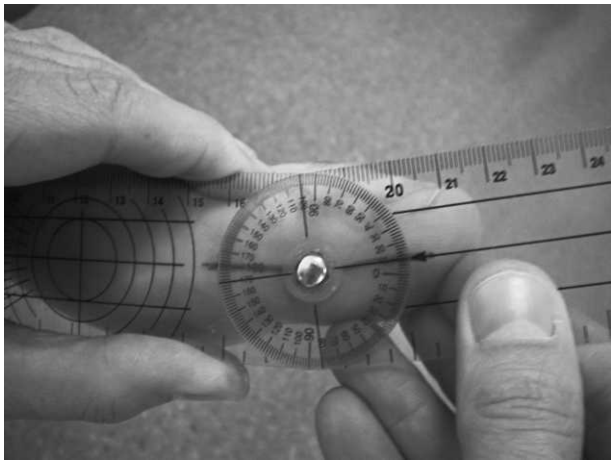

Figure 2. Method of measurement of hallux interphalangeal joint range of motion.

were measured three times, and the resulting mean was used for the statistical analysis. These variables were always measured by the same examiner (P.T.).

The data were analyzed with a statistical software package (SPSS 15.0 for Windows; SPSS Science, Chicago, Illinois). To assess the reproducibility of the measurement procedures, six participants were chosen at random from each group, and the measurements were made on three occasions, with 1 week between measurements. The data obtained from this group of measurements were used to calculate the intraclass correlation coefficient (3,1). It was also checked whether the data followed a Gaussian distribution; using a Kolmogorov-Smirnov test, it was found that the only quantitative variable distributed normally in the two groups was plantarflexion of the hallux IPJ. The descriptive analysis supplied the means, standard deviations, and 95% confidence intervals of the main quantitative variables. The values for plantarflexion of the hallux IPJ were compared between the two study groups using a Student t test for independent samples (with a Levene test to check the equality of variances), as well as weight, height, and body mass index (the weight in kilograms divided by the square of the height in meters). The other quantitative variables, including age, were compared between the two groups using a nonparametric Mann-Whitney U test. All of the comparisons were considered significant at $P < .05$. The Cohen d value was calculated for comparisons, using means and standard deviations, considering that it is small when $d = 0.20$, medium when $d = 0.50$, and large when $d \geq 0.80$.[21] Correlations between the quantitative variables were also studied using the Spearman correlation coefficient (ρ) and a two-sided test of significance. This also gave values for the effect size for the correlations, considering that it is small when $\rho = 0.10$, medium when $\rho = 0.30$, and large when $\rho \geq 0.50$.[21] The analysis of simple linear regression was used to construct a statistical model to reveal whether hallux IPJ dorsiflexion could be predicted from the values for first MPJ dorsiflexion. This also gave values for the size effect for the regression, considering that it is small when $R^2 = 0.01$, medium when $R^2 = 0.06$, and large when $R^2 \geq 0.14$.[21]

Results

Reliability of Measurements

The intraclass correlation coefficients for all of the variables measured on the first MPJ and hallux IPJ are shown in Table 1. All of these coefficients can be considered very high so that the reproducibility of the measurements is acceptable with the methods used.

Participant Demographics

The control group comprised 30 participants: 9 men and 21 women (mean ± SD values: age, 43.03 ± 14.33 years; weight, 69.90 ± 10.24 kg; height, 1.69 ± 0.09 m; and body mass index, 24.39 ± 2.51), yielding 60 feet. The hallux limitus group comprised 30 participants: 11 men and 19 women (mean ± SD values: age, 51.50 ± 17.10 years; weight, 69.63 ±

Table 1. ICCs and 95% CIs of the Main Quantitative Variables

Variable	ICC	95% CI
First MPJ dorsiflexion	0.995	0.997–0.999
First MPJ plantarflexion	0.997	0.986–0.999
Hallux IPJ dorsiflexion	0.974	0.894–0.996
Hallux IPJ plantarflexion	0.968	0.874–0.995

Abbreviations: CI, confidence interval; ICC, intraclass correlation coefficient; IPJ, interphalangeal joint; MPJ, metatarsophalangeal joint.

8.62 kg; height, 1.67 ± 0.07 m; and body mass index, 24.73 ± 1.95), yielding 60 feet. There were no significant differences in weight, height, and body mass index between patients and controls ($P = .913$, $P = .474$, and $P = .558$, respectively). However, there was a significant difference in age between groups ($P = .005$).

Differences in First MPJ and IPJ Ranges of Motion

Means, standard deviations, and 95% confidence intervals of the main quantitative variables are shown in Table 2, as well as the *P* values for comparisons of these variables between the two groups. Statistically significant differences were found between the two groups in hallux dorsiflexion, hallux plantarflexion, hallux IPJ dorsiflexion, and hallux IPJ plantarflexion. Participants with hallux limitus had a greater capacity of hallux IPJ dorsiflexion than did the control group.

Correlations

The study of the correlations showed a strong, significant inverse correlation between first MPJ dorsiflexion and hallux IPJ dorsiflexion; that is, the smaller the range of first MPJ dorsiflexion the greater the range of IPJ dorsiflexion, and vice versa. The other correlations were weak or very weak, not exceeding 0.5 in absolute value, although some of them were significant. The value of ρ and the significance are shown in Table 3.

The coefficient of simple regression for hallux IPJ dorsiflexion over first MPJ dorsiflexion was significantly different from 0, and with a large effect size ($F_{1,118} = 156.96$, $P < .001$, R^2 [proportion of variation explained] = 0.571).[21] As first MPJ dorsiflexion decreased, hallux IPJ dorsiflexion increased (R = 0.766). The regression equation from which predictions could be made is as follows: $y = 27.17 - 0.381x$, where y indicates hallux IPJ dorsiflexion; and x, first MPJ dorsiflexion) (Fig. 3).

Discussion

The present work was conducted to assess the degree of correlation between dorsiflexion of the hallux IPJ and that of the first MPJ and to compare dorsiflexion of the hallux IPJ between participants with and without hallux limitus. From the results obtained in the studied sample, the first null hypothesis was rejected because there was a strong, significant inverse correlation between first MPJ dorsiflexion and hallux IPJ dorsiflexion ($\rho = -0.766$). The second null hypothesis was also rejected because there was a significant difference in hallux

Table 2. Statistics for the Main Quantitative Variables in the Control and Hallux Limitus Groups

Variable and Group	Mean ± SD	95% CI	*P* Value	Cohen *d*
First MPJ dorsiflexion (°)			<.001	4.156
Control	69.63 ± 3.48	68.73–70.53		
Hallux limitus	42.12 ± 8.69	39.87–44.36		
First MPJ plantarflexion (°)			.001	0.611
Control	50.07 ± 11.85	47.00–53.13		
Hallux limitus	43.60 ± 9.14	41.24–45.96		
Hallux IPJ dorsiflexion (°)			<.001	1.556
Control	1.17 ± 2.50	0.52–1.80		
Hallux limitus	10.65 ± 8.24	8.52–12.78		
Hallux IPJ plantarflexion (°)			.034	0.393
Control	63.02 ± 10.69	60.26–65.78		
Hallux limitus	58.05 ± 14.35	54.34–61.76		

Abbreviations: CI, confidence interval; IPJ, interphalangeal joint; MPJ, metatarsophalangeal joint.

Table 3. Spearman Rho and Significance for the Correlations Between the Main Quantitative Variables

Variable	Spearman ρ	*P* Value
First MPJ dorsiflexion and hallux IPJ dorsiflexion	−0.766[a]	<.001
First MPJ dorsiflexion and hallux IPJ plantarflexion	0.107	.246
First MPJ plantarflexion and hallux IPJ dorsiflexion	−0.093	.310
First MPJ plantarflexion and hallux IPJ plantarflexion	0.390[b]	<.001
First MPJ dorsiflexion and first MPJ plantarflexion	0.324[b]	<.001
Hallux IPJ dorsiflexion and hallux IPJ plantarflexion	−0.024	.791

Abbreviations: IPJ, interphalangeal joint; MPJ, metatarsophalangeal joint.
[a]Strong significant correlation.
[b]Weak but significant correlation.

IPJ mobility between participants with normal feet and those with hallux limitus.

Joseph,[12] in 1954, published values for normality of movement of the hallux IPJ and observed that dorsiflexion of the first MPJ was less in older participants than in younger participants and that, however, hallux IPJ extension was greater in the older group. The present results coincide with those of Joseph[12] because participants with hallux limitus in the present study were older than those of the control group and had a greater range of dorsiflexion in the hallux IPJ.

Basically, this study has corroborated something that is widely known and accepted: the fact that in hallux limitus deformity, the distal phalanx of the hallux adopts a hyperextended position, which is related to the equine position of the proximal phalanx and to the raised position of the first metatarsal (Fig. 4). Phillips et al[13] compared hallux IPJ dorsiflexion with first MPJ dorsiflexion during the last 20% of propulsion to see whether hallux IPJ extension was associated with the lack of first MPJ extension and found a Pearson correlation coefficient of –0.62, which is similar to that obtained in the present study using the Spearman correlation (–0.766). The study by Phillips et al[13] demonstrated that the lack of first MPJ extension was associated with hyperextension of the distal phalanx. However, those authors believed that the hallux IPJ was extended to some degree in almost all of the participants because the first MPJ was extended late in the propulsive phase because they did not obtain a perfect linear regression between the amount of first MPJ movement and that of hallux IPJ movement. Something similar occurred in the present study, as the coefficient *B* obtained was –0.381. This indicates that hallux IPJ extension may play a role in lifting the heel from the ground during propulsion, even in participants with adequate movement of the first MPJ.

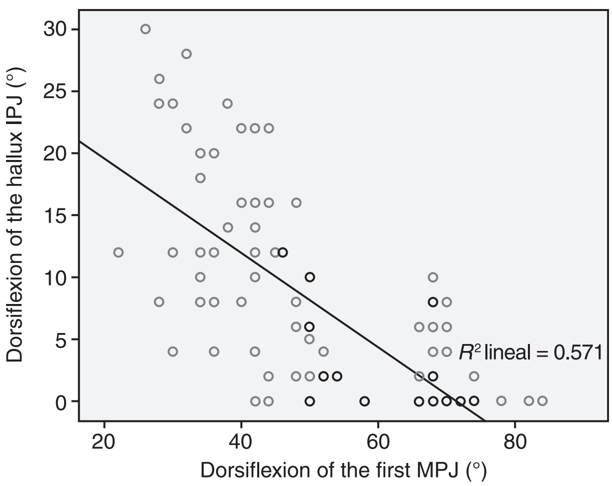

Figure 3. Dispersion graph with a straight slope showing the correlation between dorsiflexion of the first metatarsophalangeal joint (MPJ) and the interphalangeal joint (IPJ) of the hallux.

Figure 4. Foot with limited first metatarsophalangeal joint dorsiflexion showing hyperextension of the distal phalanx of the hallux.

Hallux IPJ hypermobility is often associated with arthrodesis of the first MPJ.[14-16] Mann and Oates[14] maintained that with first MPJ arthrodesis or extreme hallux limitus, there was hyperextension of the hallux IPJ. Suckel and Wülker[16] observed that approximately 15% of the participants studied who had been subjected to first MPJ arthrodesis developed asymptomatic degeneration of the hallux IPJ due to hyperextension and overuse. Bingold and Collins[22] reported that they found a hypermobile hallux IPJ in adolescents with hallux rigidus and that up to 60° or 70° of passive dorsiflexion could develop in such cases of blockage of first MPJ movement. Galois et al[15] performed a study in participants who had been subjected to arthrodesis of the first MPJ. They observed that there was a significant reduction in the force of propulsion in the vertical and anteroposterior planes, with a significant delay in lifting the heel and a systematic displacement of the ground reaction forces anterior to the first MPJ on the side of the arthrodesis. Reflectors placed at the distal end of the hallux showed that the essential part of the compensation occurred at the IPJ level, and it was concluded that the first MPJ arthrodesis did not alter either the general parameters of gait or the kinetic and kinematic values, as the compensation was achieved via the hallux IPJ. All of these studies show that when a severe lack of first MPJ dorsiflexion exists, a hyperextended hallux IPJ develops.

A common theoretical compensation in hallux limitus is hyperextension of the distal phalanx at the hallux IPJ due to the raised position of the first metatarsal and the flexed position of the proximal phalanx. The terms that have been used to define the positions of these last two bony segments of the foot are *metatarsus primus elevatus*[23] and *hallux equinus*,[24] respectively. Although they are usually described as different, isolated entities, they are codependent and mutually associated, as is hyperextension of the distal phalanx of the hallux. If the first metatarsal is raised, it would be necessary for the proximal phalanx of the hallux to assume a flexed position or equine attitude to provide stability to the medial column.[11,25,26] The distal phalanx adopts a hyperextended position so as not to be traumatized against the ground. In such cases, as the weight of the body is transferred forward, the first MPJ becomes loaded, and the hallux is unable to extend completely; the distal phalanx is hyperextended as the foot seeks to advance the movement in the sagittal plane of the body weight. This hyperextension takes place by the bony adaptation that occurs after many years of excessive pressure on the hallux IPJ during gait. In fact, it has been asserted that in some cases, the bony adaptation is so extreme that a lateral radiograph reveals that the distal phalanx is not straight but curved upward in the sagittal plane under the ungual bed.[27]

This structural and compensatory scheme is so characteristic of hallux limitus that some authors compared it with the flexor stabilization that takes place in the smaller toes and gives rise to claw toe, denominated *flexor stabilization syndrome of the hallux*.[11] The excessive pronation of the rearfoot destabilizes the plantarflexor action of the peroneus longus muscle on the first ray so that this is placed in dorsiflexion during the propulsive phase (similar to the extended proximal phalanx in a hammer toe, due to destabilization of the interossei and lumbricals). The intrinsic musculature attempts to stabilize the medial column by flexing the proximal phalanx of the hallux to move the point of support of the first metatarsal forward (similar to the flexed middle phalanx of a hammer toe, by contraction of the flexor digitorum brevis, which is inserted in the middle phalanges of the smaller toes). Last, the distal phalanx is hyperextended so as not to "dig into" the ground, which is what would happen if it remained aligned with the flexed proximal phalanx (similar to the extended distal phalanx of a hammer toe, to prevent overloading on the soft parts).

This study has several limitations. The study was cross-sectional (not prospective); therefore, the findings are associations, and future prospective study is the only way to determine cause and effect between the measures. Another limitation could be that the examiner who made the measurements was not blinded to the range of first MPJ dorsiflexion, so it is possible that this may have affected measures of hallux IPJ dorsiflexion. Also, we think that one aspect that could have improved its design would have been to divide the hallux limitus group into various subgroups depending on the degree of the condition (mild, moderate, or severe) and comparisons made between them; this would have required a minimum of 50 feet in each subgroup, as specified by the calculation of the sample size. The fact that the two groups were different regarding age could also be considered a limitation because, as has previously been demonstrated, the range of movement of the first MPJ decreases with age.[18]

Conclusions

The findings of this study indicate that the range of hallux IPJ dorsiflexion was greater in participants with limited first MPJ dorsiflexion than in those without this condition. In addition, this study shows that there is a strong inverse correlation between first MPJ dorsiflexion and hallux IPJ dorsiflexion, although there was not a perfect linear regression between the amount of first MPJ dorsiflexion and hallux IPJ dorsiflexion. These findings are consistent with theoretical models of foot function and could explain the development of secondary alterations and symptoms associated with hallux limitus, such as subungual exostoses, overload under the hallux, and ungual dystrophies by chronic trauma of the distal phalanx against the toe box of the shoe. Future studies could assess whether creating subgroups of participants with limited first MPJ dorsiflexion (mild, moderate, and severe hallux limitus) may provide additional information about the changes occurring at the hallux IPJ.

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Conflict of Interest: None reported.

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