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First ray mobility in hallux limitus patients vs. normal patients

Movimiento del primer radio en sujetos con hallux limitus vs. *sujetos con pies normales*

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Keywords:

Hallux limitus, hallux rigidus, first ray, dorsiflexion, plantarflexion, measurement device.

Abstract

Objectives: The objective of this study was to determine the first ray range of motion (ROM) in the sagittal plane in *hallux limitus* patients and to compare it with those patients with normal feet by using a new measuring device of first ray mobility. In addition, to assess the relationship between metatarsophalangeal dorsiflexion and first ray mobility.

Patients and methods: The dorsiflexion for the first metatarsophalangeal joint and the mobility of the first ray in the sagittal plane were assessed in two study groups: *hallux limitus* patients and a control group. A new valid and reliable measuring device of the first ray mobility was used.

Results: ROM of the first ray for the *hallux limitus* group in the sagittal plane was 7.04 ± 0.22 mm for dorsiflexion, 3.51 ± 0.29 mm for plantarflexion, and 10.55 ± 0.33 mm of total range. And for the control group it was 5.82 ± 0.21 mm of dorsiflexion, 5.33 ± 0.21 mm of plantarflexion and 11.15 ± 0.39 mm of total range. The total movement of metatarsophalangeal dorsiflexion showed a moderate and direct correlation with the plantarflexion of the first ray (*r = 0.63*), and weak and inverse with the dorsiflexion of the first ray (*r = - 0.36*).

Conclusion: In the participants of this study, it was observed that the subjects with *hallux limitus* had more dorsiflexion and less plantarflexion than normal subjects. However the total range of motion was similar in both study groups.

Palabras clave:

Hallux limitus, hallux rigidus, primer radio, dorsiflexión, plantarflexión, instrumento de medida.

Resumen

Objetivos: El objetivo de este trabajo fue determinar el movimiento del primer radio en el plano sagital en sujetos con *hallux limitus* y compararlo con el de los sujetos con pies normales mediante el uso de un nuevo instrumento de medida del primer radio. Además, valorar la relación entre la extensión metatarsofalángica y los movimientos del primer radio.

Pacientes y métodos: Se valoró la extensión de la primera articulación metatarsofalángica y la movilidad del primer radio en el plano sagital en dos grupos de estudio: sujetos con *hallux limitus* y un grupo control. Para ello se utilizó un nuevo instrumento de medida del primer radio válido y fiable.

Resultados: El movimiento del primer radio para el grupo de *hallux limitus* en el plano sagital fue de 7.04 ± 0.22 mm de dorsalflexión, 3.51 ± 0.29 mm de plantarflexión y de 10.55 ± 0.33 mm de rango total. Y para el grupo control fue de 5.82 ± 0.21 mm de dorsalflexión, 5.33 ± 0.21 mm de plantarflexión y de 11.15 ± 0.39 mm de rango total. El movimiento total de extensión metatarsofalángica mostró una correlación moderada y directa con la plantarflexión del primer radio (*r = 0.63*), y débil e inversa con la dorsalflexión del primer radio (*r = - 0.36*).

Conclusión: En los participantes de este estudio se observó que los sujetos con *hallux limitus* presentaron más movimiento en dorsalflexión y menos movimiento en plantarflexión que los sujetos normales. Sin embargo, el rango de movimiento total fue similar para ambos grupos de estudio.

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INTRODUCTION

First ray mobility is an important component in the normal function of the foot, this is why it has been related with different disorders both of the feet and the locomotor apparatus. Furthermore, many surgical interventions are based on the first ray to correct structural and functional deformities of the first metatarsophalangeal joint, such as *hallux abductus valgus* (HAV) and *hallux rigidus* (HR)[1-4].

The terms *hallux limitus* (HL) and HR make reference to the mobility limitation of the first metatarsophalangeal joint (1st MPJ) in the sagittal plane, especially in the dorsiflexion. The deformity of HL has been defined as the one in which the base of the proximal phalanx of the hallux is subluxed in a plantar way over the head of the first metatarsal, thus the 1st MPJ is not able to develop the whole dorsiflexion range[5-8]. It has also been defined as an alteration which goes along with the limitation of the metatarsophalangeal dorsiflexion of less than 20° without the plantarflexion of the first metatarsal[5]. In general, it is accepted that for HL to exist, it needs a range a range of mobility of less than 60-65° in the 1st MPJ[5,6].

There are several pathomechanical and morphological factors that have a negative influence in the normal function of the 1st MPJ and diminish the dorsiflexion range, contributing to the development of HL/HR. The biomechanical cause and dynamic dysfunction are the most probable causes in the development of this deformity, although they are not the only one[1].

For a normal stance phase of gait to be produced, the first ray has to be able to plantarflex during the push off. If there is any pathological condition that prevents this to happen, the head of the metatarsal will move dorsally in response to the ground reaction forces. This displacement in craneal direction prevents the change in the axis of mobility of the 1st MPJ, and therefore the slipping of the base of the phalange over the head of the metatarsal is impeded. This makes the compressive forces in the dorsal half of the cartilage to increase, triggering degenerative changes and subchondral injuries in the dorsal part of the head of the first metatarsal, because of continued microtrauma of the base of the phalange over that area[1,9].

On this basis, there are authors that mention that the main cause of HL/HR is the *metatarsus primus elevatus* (MPE)[7,9-12] this being a deformity that goes together with an *hallux equinus*, and that both of them contribute to the decrease of the 1st MPJ range of motion. Nevertheless, the presence that a metatarsal elevation higher than 5mm appears in two thirds of normal feet, and therefore, it is not a pathological entity and it is not correlated with the articular affectation[13].

Because there is controversy as to whether there is a direct relationship in presenting a dorsiflexed first metatarsal when HL or HR or present, and because there are very few studies on the quantification of first ray mobility in the sagittal plane in patients with HL or HR, this study aims to determine first ray mobility in the sagittal plane in patients with HL and to compare it with patients with normal feet by the use of a new measurement device for the first ray. Moreover, to appreciate the relationship between the metatarsophalangeal dorsiflexion and first ray mobility.

PATIENTS AND METHODS

Study design

This is an analytic descriptive study that compared the mobility of the 1st MPJ and the first ray in a group of feet with HL and a group of normal feet.

Participants

Patients who participated in this study were adults that attended to a private clinic, provided that they met the selection criteria, and voluntarily accepting the participation in the study. This study was conducted from December 2020 to May 2021. The sample was divided into two groups. The HL group was formed by patients with this pathology. For that purpose, a correct diagnosis was performed based on the measurement of the extension of the 1st MPJ with the use of a two arm goniometer. The exclusion criteria was: to have experienced any traumatism or surgical intervention on the first ray; to present HAV; to have suffered inflammatory or metabolic processes, degenerative or neuromuscular illnesses that affect the foot. The control group was constituted by individuals with normal feet[14], with a first ray without any morphologic or functional alterations. The inclusion criteria was a normal first ray mobility[15], and an extension of the 1st MPJ bigger than 60 degrees. The exclusion criteria was the same as the ones for the sample group.

Clinical exploration

The clinical examination of every patient was conducted by the main researcher (P.T.V.), a podiatrist with 8 years of experience. For this purpose, the volunteer was placed on an examination table in supine position with a relaxed ankle and the subtalar joint in neutral position. The evaluation of the mobility of the 1st MPJ was conducted with the two branches goniometer and the one of the first ray by using a new validated measurement device.

Measurements

- *Determination of the metatarsophalangeal dorsiflexions:* The centre of the goniometer was placed on the head of the first metatarsal. The proximal arm was placed in parallel to the bisection of the metatarsal diaphysis, and fixed to the foot with one hand. The distal arm was placed in parallel to the bisection of the proximal pha-

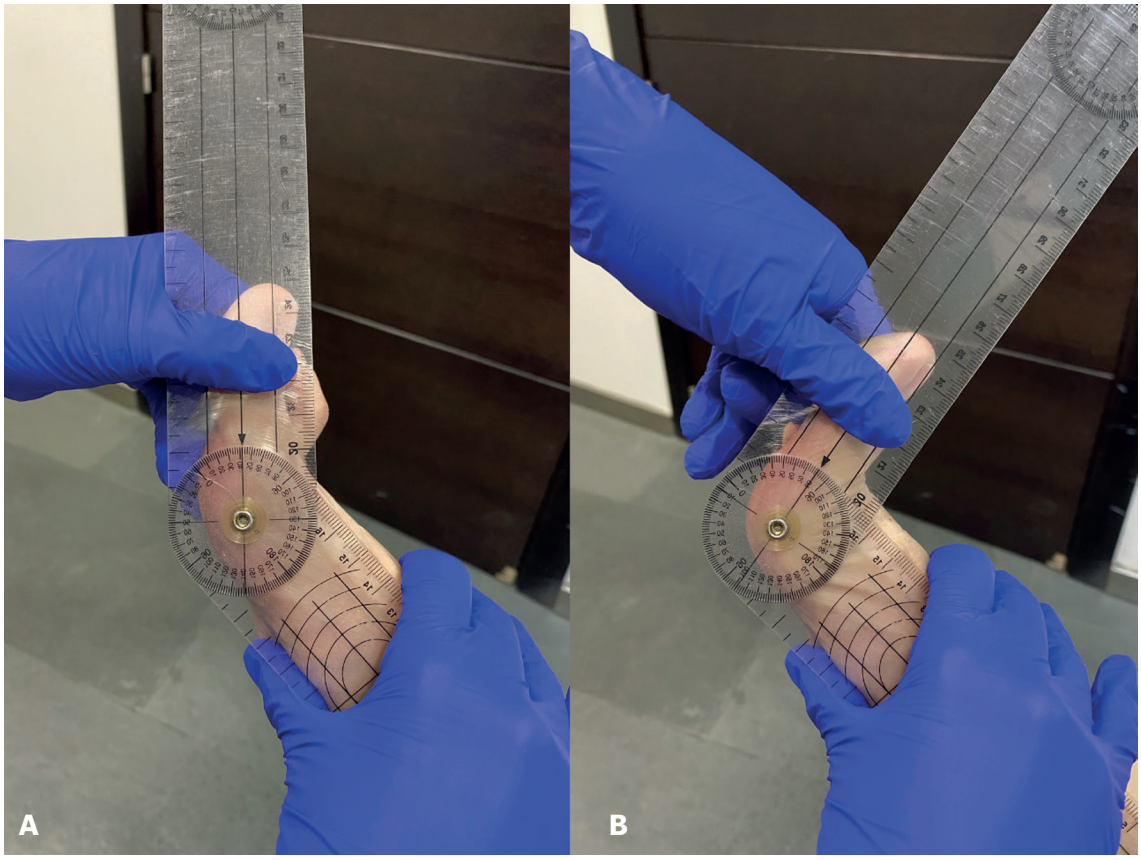

Figure 1. Determination of the metatarsophalangeal dorsiflexion. A: neutral position. B: maximun dorsiflexion position.

lanx, and it was fixed to the hallux with the other hand. From the neutral position (Figure 1A) the hallux was taken along with the distal arm of the goniometer up to the higher dorsiflexion, allowing the first ray to plantarflex so that the dorsiflexion was produced[16] (Figure 1B).

– *Determination of the first ray maximum dorsiflexion/plantarflexion:* The measurement of the first ray mobility was performed with the new measurement device *(national patent 201500721)*[17] in order to find the range of motion in millimeters both in maximum dorsiflexion and maximum plantarflexion (Figure 2). This device consists of two parts that are joined together in its central part by a rail that allows both parts to slide. Each part presents two branches one of them is horizontal in order to be placed in the dorsal surface of the metatarsal heads and the other one is vertical, presenting a ruler measured in millimeters. The explorer held the long branch over the heads of the second to the fifth metatarsal with one hand and held the short branch over the head of the first with the other one. In this position, the head of the first metatarsal was moved upwards up to its maximum dorsiflexion (Figure 3A) and subsequently it was moved downwards up until its maximum plantarflexion (Figure 3B). The range of motion was determined after observing in the ruler of the tool how many millimeters it slided in both positions. The examiner performed the measuring 3 times in the same patient in order to use the mean of the three of them in the statistical analysis.

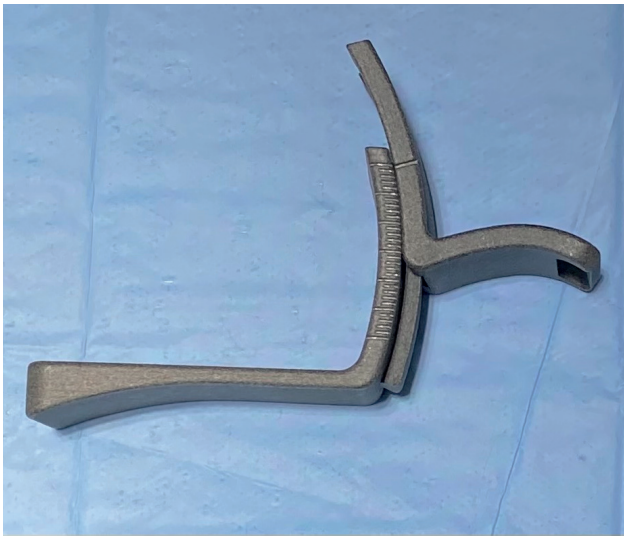

Figure 2. New measurement device of first ray mobility.

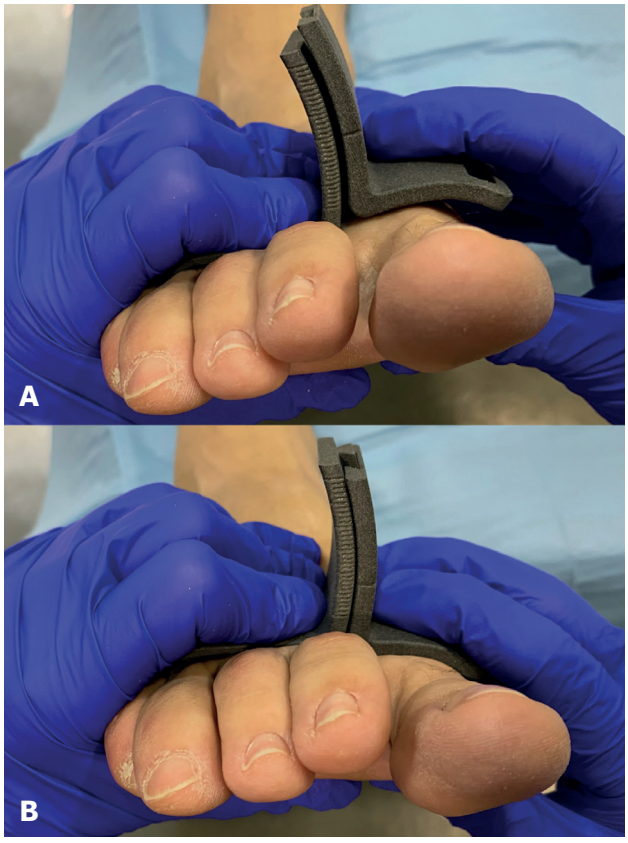

Figure 3. Determination of first ray mobility. A: maximun dorsiflexion. B: maximun plantarflexion.

Data analysis

The statistical analysis of the data was carried out by the SPSS Statistics® software, version 25 (IBM, Corp, Armonk, USA) for Windows®. In order to check the intra-observer reliability of the measuring procedure, the measurements were performed 3 times in the same patient by using the new measuring device of the first ray. For this, the intraclass correlation coefficient was used.

It was checked if the extension of the 1st MPJ and the motion of the first ray was different between the HL group and the control group. The Shapiro-Wilk test was used to determine if the data followed a normal distribution. In the cases where the distribution was normal the Student t test was used for independent samples to perform comparisons. When it was not normal, the Mann-Whitney U test was used. The Chi-squared test was used to compare the distribution by sex and laterality between the two groups, with the aim of verifying if they were homogenuous according to those variables. With the same aim, age and BMI between both groups was compared by the Student t test for independent samples. Pearson's correlation coefficient was used in order to determine the relation between the metatarsophalangeal dorsiflexion, the dorsiflexion and the plantatflexion of the first ray in both groups. Every difference with a value of $p < 0.05$ was considered statistically significant.

RESULTS

The sample for the study consisted of 30 patients, 15 were part of the study group and 15 were part of the control group. Eleven left feet and 19 right feet were included. The distribution by laterality between the two groups was not significantly different ($p = 0.705$). There were 10 men and 5 women in the HL group. There were 7 men and 8 women in the control group. The sex distribution was not significantly different between the two groups ($p = 0.269$). The age of the HL group was 53.13 ± 3.85 (29-76 range) and the age of the control group was 45.53 ± 5.55 (range 19-81). The BMI in the HL group was 23.9 ± 0.55 (normal weight) and in the control group it was 23.01 ± 0.55 (normal weight). Age and BMI between the two groups were compared using the Student t test and the difference was not significantly different ($p = 0.270$ y $p = 0.269$ respectively). Intraobserver reliability was determined in a previous study[18] in which the main researcher measured the dorsiflexion and the plantarflexion twice in 24 patients with normal feet using this instrument with a period of separation between 10 and 30 days each, and the intraclass correlation coefficient was calculated (mixed two factors model). The results were the following: ICC = 0.885 in the dorsiflexion motion; ICC = 0.884 in the plantarflexion movement. This suggests that the reproducibility of the measuring procedure was good[19].

The initial and final metatarsophalangeal position, the total metatarsophalangeal dorsiflexion, the dorsiflexion, plantarflexion and the total motion of the first ray in both groups are shown in Table I. Statistically significant differences were obtained in every variable (initial metatarsophalangeal position $p = 0.001$; final metatarsophalangeal position $p < 0.001$; total metatarsophalangeal dorsiflexion $p < 0.001$; dorsiflexion of the first ray $p = 0.003$; plantarflexion of the first ray $p < 0.001$), but not in the total range of motion of the first ray ($p = 0.254$).

Regarding the correlations between the variables: total metatarsophalangeal dorsiflexion and the dorsiflexion and plantarflexion of the first ray in both groups, the results were the following: total metatarsophalangeal dorsiflexion showed a moderated and direct correlation ($r = 0.63$; $p < 0.001$) with the plantarflexion of the first ray, in other words, the greater the plantarflexion of the first ray, the greater the metatarsophalangeal dorsiflexion, and vice versa. The total metatarsophalangeal dorsiflexion showed a weak and inverse correlation ($r = -0.36$; $p = 0.45$), meaning, the greater the dorsiflexion of the first ray, the smaller the metatarsophalangeal dorsiflexion and vice versa. Lastly, the plantarflexion showed a weak and inverse correlation ($r = -0.37$; $p = 0.44$) with the

Table I. Positions and mobility of metatarsophalangeal dorsiflexion and first ray range of motion in the sagittal plane in both study groups.

Variable	HL group	Control group
Metatarsophalangeal initial position (mm)	22.67 ± 1.53	32.00 ± 1.53
Metatarsophalangeal final position (mm)	53.67 ± 3.53	98.67 ± 2.90
Total movement of metatarsophalangeal dorsiflexion (mm)	31.00 ± 2.49	66.67 ± 2.56
First ray dorsiflexion (mm)	7.04 ± 0.22	5.82 ± 0.21
First ray plantarflexion (mm)	3.51 ± 0.29	5.33 ± 0.21
First ray total range of motion (mm)	10.55 ± 0.33	11.15 ± 0.39

mm = millimeters.

dorsiflexion of the first ray, that is, the greater the dorsiflexion of the first ray, the lower the plantarflexion of the first ray and vice versa.

DISCUSSION

The main aim of this research was to determine the first ray range of motion in the sagittal plane in HL patients and normal patients by using a new measuring device of the first ray. The obtained results reveal that for the participants of this study, the dorsiflexion of the first ray in the feet with HL was increased, with a result of 7.04 ± 0.22 mm, unlike the control group, who had a motion of 5.82 ± 0.28 mm. On the contrary, the HL group's plantarflexion diminished, with 3.51 mm ± 0.29 as results, unlike the control group, in which 5.33 ± 0.21 was obtained. However, the total motion of the first ray was very similar in both groups, being 10.55 ± 0.33 mm in the HL group and 11.15 ± 0.39 mm in the control group.

As discussed earlier, the controversy around the role of the MPE in the development of the HL, exists. In the literature review that has been done, it has been found that some authors mention that it can be an etiologic factor in the pathogenesis of the HL[10,11,20,21] and some believe it cannot[13,22].

Meyer et al.[13] , in their research of 1987, after evaluating the position of MPE in 120 radiographies, concluded that the metatarsal elevation in HR was occasioned by the increase of the diameter of the metatarsal head, the retraction of the plantar soft tissues and the sesamoids bones, finding that a metatarsal elevation greater than 5 mm appears in two thirds of normal feet and, therefore, it is not a pathological entity, and it was not correlated with the articulation disorder. In the same way, Horton et al.[22] in 1999 carried out a research with the aim of defining the role of the elevation of the first ray in the pathogenesis of the HR comparing a group of patients with HR and a control group. They analyzed 264 radiographies in weightbearing conditions, comparing the elevation of the first metatarsal with regard to the second and the results showed that the values of elevation of the first ray in patients with mild or moderate HR were almost identical to the ones of the control group. The patients with advanced HR had a slightly higher average value. These authors indicate that an average MPE of 8 mm was a normal finding in patients with HR, as well as in normal subjects.

On the contrary, Grady et al.[10], who in 2002 carried out a retrospective research in 772 patients with symptomatic HL, observed that 45 % of the patients presented as etiological factor some biomechanical cause, from which 9.6 % were because of an excessive pronation of the foot and a 35.4 % because of a MPE. Roukis[11] in 2005 revealed in his research that there was more presence of the MPE in the HR than the one found in other groups of research. For that, he studied 275 lateral radiographs in patients without traumatism or surgical antecedents and divided them in 4 groups of research (HR, HAV, patients with plantar fasciitis and patients with Morton's neuroma). The results proved that significant differences in the HR group existed, which presented elevation in the first metatarsal with regard to the second (HR 5.8 mm, HAV 4.2 mm, plantar fasciitis 4.6 mm and Morton neuroma 4.1 mm $p < 0.05$). Further on, in 2010 Bouaicha et al.[20] carried on a research of cases and controls, in which they made 295 lateral radiographs, 99 with HR, 99 with HAV and 97 normal feet. They analyzed the elevation in the first metatarsal with regard to the second, and they found as results 5.2 mm in the HR group, 2.8 mm in the HAV and 2.6 mm ($p < 0.001$) in the control group. These authors disagree in the conclusions of the research of Horton et al.[22], since they mention a lack of standardisation and validation and believe that this explains the great variability of the obtained values. Thus, they suggest that having a MPE greater than 5 mm can be a predictive factor in the presence of HL. Further on, in 2014 Usuelli et al.[21] carried out a research in which they measured the same parameters that were mentioned before in 394 feet and found 6.4 mm in the HR group, 4.0 mm in the HAV and 3.4 mm in the control group ($p < 0.05$). These

authors concluded that these results were insufficient for defining the dorsiflexion of the first ray as an etiological factor of the HR, but on the basis of this data, they consider that the dorsiflexion of the first ray was an important consequence of the HR.

As it can be observed, when the authors study the dorsiflexion of the first ray, they do it by a radiographic evaluation of the patient standing in his position regarding the second. Unlike our study, in which we carry out a clinical examination with a new, valid and reliable measuring device for the first ray. This is why it is very hard to compare our results with the ones we have found. It should be noted that in the aforementioned studies, in the patients with HL in the first ray there is a more dorsiflexed position than in the normal patients or with another type of pathologies, being this one a fixed position registered by a radiographic image. In our study, in which what was valued was not a fixed position but the first ray mobility after clinical examination, the patients with HL presented more motion in dorsiflexion than normal patients, being the total range of motion very similar and having no significant differences.

Regarding the mobility of the first ray in patients with normal feet, we can make a comparison of the mobility with two of our studies that were published recently in 2020[17] and 2021[23] in which the results obtained were 6.49 y 5.91 mm for the dorsiflexion mobility, 5.26 and 4.92 mm in plantarflexion and the total path was 11.75 and 10.84 mm respectively. As we can observe, in dorsiflexion as in plantarflexion and in the total range of motion are very similar in these studies and in the current one.

Lastly, another one of the objectives was to value the relation between the metatarsophalangeal dorsiflexion and the first ray mobility. We have not found studies that relate the plantarflexion of the first ray with the etiology of the HL. The results we obtained present more relationship between the decrease of the 1st MPJ dorsiflexion (as occurs in the case of patients with HL) and the decrease of the plantarflexion of the first ray (r = 0.63), than with the increase of the dorsiflexion of the first ray (r = -0.36). These findings support the theory that some authors claim in terms of to obtain the metatarsophalangeal dorsiflexion degrees needed in the propulsive phase of walking, an adequate plantarflexion of the first ray[1] is required.

We can consider as research limitations the following: The sample size was small compared to similar researches[17], and there have only been included patients with normal first ray and with HR, therefore the results may vary with other pathologies (for instance: HAV, plantarfelexionated first ray, etc.).

In future research it would be appropriate to include patients with other pathologies, such as HAV or plantarflexed first ray, in order to study the movement of the first ray in these conditions. Also, studying along with the extension of the sample the relationship that exists in the decrease of the plantarflexion of the first ray and the limitation of the metatarsophalangeal dorsiflexion.

In conclusion, in the participants of this research it was observed that the patients with HL presented an increase of motion in dorsiflexion and a decrease of motion in plantarflexion (7.05 mm; 3.51 mm respectively), in the first ray in comparison with the patients with normal feet (5.82 mm, 5.83 mm respectively). However, the total range of motion of the first ray was similar in both research groups (10.55 mm *vs.* 11.15 mm). Furthermore, the correlation between the motion of the plantarflexion of the first ray and the metatarsophalangeal dorsiflexion was moderated (r = 0.63).

CONFLICTS OF INTEREST

The authors declare that there are no conflicts of interests in this study.

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