Association between degenerative changes of the first metatarsophalangeal joint with goniometric variables of the internal longitudinal arch: observational study

Abstract

Introduction: Radiographically, an association has been shown between hallux rigidus and Metatarsus Primus Elevatus. The objective of this article is to assess the association between degenerative changes of the first metatarsophalangeal joint with goniometric values of the internal longitudinal arch.

Patients and methods: Observational study on patients of the University Podiatry Clinic (UCM) from September 2022 to March 2023 who presented reduced mobility of first metatarsophalangeal joint of less than 60° in nonweightbearing. From a weight bearing lateral x-ray it was analyzed: joint space alteration, dorsal osteophytesis in proximal phalanx and in first metatarsal. inclination angle of first metatarsal, inclination angle of calcaneus, Meary-Tomeno line and internal Costa Bartani angle.

Results: 37 feet (37 patients) were analyzed with a mean age of 52 years (64.9 % women, 35.1 % men). Decreased joint space was associated with more plantar Meary-Tomeno line (8.4° ± 5.6 vs. 1.1° ± 5.4; p < 0.001), less calcaneal inclination (21.4° ± 4.8 vs. 25.5° ± 6.4; p = 0.032) and less inclination of first metatarsal (21.5° ± 2.5 vs. 23.8° ± 3.3; p = 0.018). Patients who presented dorsal osteophytesis of proximal phalanx had a lower calcaneal inclination (19.8° ± 4.4 vs. 24.5° ± 1.3; p = 0.021). Patients with any signs of hallux rigidus showed a Meary-Tomeno line with more plantar apex (7.0° ± 7.0 vs. 2.7° ± 5.1; p = 0.041).

Conclusions: Goniometric measurements representing values compatible with flattening of the internal longitudinal arch are associated with signs of joint degeneration of the first metatarsophalangeal joint.

Palabras clave:
Hallux rigidus, arco longitudinal interno, radiografía.
Introduction

The term hallux rigidus (HR) refers to degenerative arthritis, or osteoarthritis, of the first metatarsophalangeal joint (1MTPJ). It presents with painful limitation to dorsiflexion of this joint, which is crucial dynamically as it bears approximately 119% of body weight during the gait cycle. HR is the second most common pathology of the 1MTPJ, surpassed only by Hallux Abductus Valgus. It is estimated that HR affects 2.5% of the population over 50 years old and is less common in adolescence, in this latter case as an evolution of an osteochondral injury. Additionally, it has been observed that females are twice as likely as males to develop HR.

A weak association has been found in the literature between HR and some risk factors based on clinical findings, such as a history of trauma, or deformities like Hallux Abductus Valgus, Hallux Abductus Interphalangeus, alteration in the length of the first metatarsal or the proximal phalanx of the hallux. Radiographically, a significant association has been demonstrated between HR and the presence of Metatarsus Primus Elevatus (MPE).

On the other hand, the diagnosis of HR disease is based on clinical and radiological findings. The most common clinical findings in the diagnosis of HR are pain and limited joint mobility of the 1MTPJ, surpassed only by Hallux Abductus Valgus. It is estimated that HR affects 2.5% of the population over 50 years old and is less common in adolescence, in this latter case as an evolution of an osteochondral injury. Additionally, it has been observed that females are twice as likely as males to develop HR.

A weak association has been found in the literature between HR and some risk factors based on clinical findings, such as a history of trauma, or deformities like Hallux Abductus Valgus, Hallux Abductus Interphalangeus, alteration in the length of the first metatarsal or the proximal phalanx of the hallux. Radiographically, a significant association has been demonstrated between HR and the presence of Metatarsus Primus Elevatus (MPE).

In this study, we assessed the association between degenerative processes in the 1MTPJ, the main objective of this study was to assess the association between degenerative changes of the 1MTPJ and the goniometric values of the internal longitudinal arch in the sagittal plane.

Table I. Coughlin and Shurnas classification.

<table>
<thead>
<tr>
<th>Grade</th>
<th>Dorsiflexion</th>
<th>Radiological findings</th>
<th>Clinical findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade 0</td>
<td>40-60°</td>
<td>Within normal limits</td>
<td>– No pain&lt;br&gt;– Only moderate stiffness</td>
</tr>
<tr>
<td>Grade 1</td>
<td>30-40°</td>
<td>– Dorsal osteophytes&lt;br&gt;– Minimal joint space narrowing&lt;br&gt;– Minimal subchondral sclerosis&lt;br&gt;– Minimal flattening of the metatarsal head</td>
<td>– Intermittent pain at end ranges of dorsiflexion&lt;br&gt;– Mild stiffness</td>
</tr>
<tr>
<td>Grade 2</td>
<td>10-30°</td>
<td>– Dorsal, lateral, and medial osteophytes giving a flattened appearance to the metatarsal head&lt;br&gt;– Mild/moderate joint space narrowing&lt;br&gt;– Moderate subchondral sclerosis&lt;br&gt;– No sesamoid involvement</td>
<td>– Moderate to severe pain and stiffness&lt;br&gt;– Pain before maximal dorsiflexion and plantarflexion during examination</td>
</tr>
<tr>
<td>Grade 3</td>
<td>&lt;10°</td>
<td>Same as Grade 2, plus:&lt;br&gt;– Periarticular cystic changes&lt;br&gt;– Significant joint space narrowing&lt;br&gt;– Sesamoid hypertrophy</td>
<td>– Almost constant pain&lt;br&gt;– Stiffness at the extreme range of motion</td>
</tr>
<tr>
<td>Grade 4</td>
<td>&lt;10°</td>
<td>Same as Grade 3</td>
<td>– Constant pain and stiffness&lt;br&gt;– Pain in the mid-range during passive dorsiflexion</td>
</tr>
</tbody>
</table>

[Rev Esp Podol. 2024;35(1):36-41]
Patients and methods

Study type and sample size

We conducted an observational study on a sample of 37 feet corresponding to 37 patients who visited the Pathology and Orthopedics service of the University Podiatry Clinic of Universidad Complutense de Madrid, Madrid, Spain during the period from September 2022 through March 2023. In individuals who showed bilateral HR symptoms, only the foot with the most severe symptoms was included in the study.

Inclusion criteria

The inclusion criteria for the study population were established as the presence of a maximum dorsiflexion (DF) mobility of the 1MTPJ of < 60° in non-weight-bearing conditions or a loss of ≥ 10% of the degree of motion of the 1MTPJ vs the contralateral limb, and the patient’s ability to walk distances > 50 meters without the aid of walking support devices such as crutches or walkers.

Pregnant patients, those with a history of surgery localized to the 1MTPJ or other osteoarticular structures of the internal column, a history of diabetes mellitus, rheumatic diseases such as psoriatic arthritis, rheumatoid arthritis, and gouty arthritis, and/or having received a corticosteroid or hyaluronic acid injection in the 12 weeks prior to data collection were excluded.

Data mining

All patients included in the study underwent a weight-bearing lateral X-ray of the included foot. The following radiographic variables related to the presence of hallux rigidus according to the Coughlin and Shurnas classification were analyzed: alteration of the joint space (decrease or absence), dorsal osteophytosis in the proximal phalanx, and in the head of the first metatarsal. Additionally, the following clinical variables were recorded: joint stiffness (mild/moderate/severe), pain (with movement/intermittent/almost constant/constant), and the maximum DF range of the 1MTPJ, following the protocol developed by López del Amo et al.10 in which joint examination of the 1MTPJ in non-weight-bearing conditions is described. This involves placing the patient in a supine position on the examination table in a relaxed state, placing the goniometer fulcrum at the center of the head of the first metatarsal, the proximal arm parallel to the shaft of the first metatarsal, and the distal or movable arm parallel to the shaft of the proximal phalanx, moving the toe to its maximum extension.

Regarding the goniometric variables in the lateral X-ray, the following angles were obtained: first metatarsal inclination angle, calcaneal inclination angle, Meary-Tomeno line, and internal Costa Bartani angle. The metatarsal inclination angle or Fick angle involves the inclination of the 5 metatarsals; however, for this study, only the inclination angle of the first metatarsal was considered (Figure 1), which was defined by the diaphyseal axis of the first metatarsal with the horizontal plane of the ground support11. The calcaneal inclination angle (Figure 2) is defined by the axis of the calcaneus, a line connecting the calcaneal tuberosity to the plantar margin of the anterior extension of the calcaneus near the calcaneocuboid joint, and the support plane (line formed by the proximal plantar tuberosity of the calcaneus and the head of the 5th metatarsal). A value of 20° is considered normal12. The Meary-Tomeno line (Figure 3) is defined as the line passing through the axis of the talus (bisector of the angle formed by the tangent to the superior and inferior borders of the talus) and the axis of the diaphysis of the first metatarsal13. The internal Costa Bartani angle (Figure 4) is defined as the union of 3 points: the lowest point of the medial sesamoid, the lowest point of the posterior tuberosity of the calcaneus, and the lowest point of the talonavicular joint14.

These angles were chosen because they best represent the alignment of the internal longitudinal arch, in which the decrease...
or inclination towards the plantar side is associated with flattening of the arch. An initial training session was conducted among the research group for the evaluation of goniometric measurements. Subsequently, the signs and radiographic angles were evaluated by two podiatrists blinded to each other’s results using the Kodak POC 360 quality control software for measurements; both researchers performed 3 measurements of the radiographic angles to minimize bias, with the mean of the measurements being taken as the valid measurement.

**Main study variable**

The main variable of the study was the presence of HR defined as the existence of grade 0 or higher in the Coughlin and Shurnas classification. Additionally, to determine the study’s objective, each of the degenerative changes of the 1MTPJ in the classification was individually evaluated.

**Statistical analysis**

Statistical analysis was performed using SPSS for MacOS version 25.0 (SPSS, Inc. Chicago, IL, United States). Qualitative variables were expressed as frequency and percentage, and quantitative variables as mean and standard deviation. The Kolmogorov-Smirnov test was used to determine the normality of the sample. To determine the goniometric variables that best related to clinical signs and degenerative changes of the 1MTPJ a contrast hypothesis test was carried out by means of the t-test that was used for parametric samples and the Wilcoxon-Mann-Whitney U test for non-parametric samples. A p value < 0.05 was considered statistically significant.

**Results**

A total of 37 feet out of 37 patients (n = 37) with a mean age of 52 (± 17.1) years were included, 64.9 % of whom were women (n = 24) and 35.1 % men (n = 13), with a mean BMI of 26 (± 4.8) kg/m², 38 % of which (n = 14) experienced pain. A total of 40.5 % (n = 15) of the entire sample belonged to stage 0 according to the classification described by Coughlin and Shurnas, 32.4 % (n = 12) to stage 1, 18.9 % (n = 7) to stage 2, and 8.1 % (n = 3) to stage 3. No patient met the clinical and radiological criteria consistent with stage 4.

Patients with dorsal osteophytosis of the proximal phalanx (n = 11; 30 %) had a smaller calcaneal inclination angle than those without osteophytosis (19.8° ± 4.4 vs. 24.5° ± 1.3; p = 0.021; CI [0.753 to 8.747]) (Table II). The presence of joint space narrowing was associated with patients with a more plantar-vertex Meary-Tomeno angle (8.4° ± 5.6 vs. 1.1° ± 5.4), a smaller calcaneal inclination (21.4° ± 4.8 vs. 25.5° ± 6.4), and a smaller first metatarsal inclination (21.5° ± 2.5 vs. 23.8° ± 3.3) (p < 0.05) (Table III). No significant associations were found between the goniometric variables and patients with dorsal osteophytosis of the first metatarsal head (Table IV).

Finally, based on the Coughlin and Shurnas classification, patients with any sign of hallux rigidus (n = 22; 60 %) showed a more plantar-vertex Meary-Tomeno line than those without signs of hallux rigidus (7.0° ± 7.0 vs. 2.7° ± 5.1 respectively; p = 0.041; CI [-8.301 to -0.183]) (Table V).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Presence (+) Mean ± SD</th>
<th>Absence (-) Mean ± SD</th>
<th>p-value</th>
<th>95 % CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meary-Tomeno (degrees)</td>
<td>8.13 ± 6.5</td>
<td>4.05 ± 6.4</td>
<td>0.079</td>
<td></td>
</tr>
<tr>
<td>Internal Costa Bartani (degrees)</td>
<td>128 ± 7.2</td>
<td>123 ± 6.9</td>
<td>0.082</td>
<td>[-10.129, 0.667]</td>
</tr>
<tr>
<td>Calcaneal Inclination (degrees)</td>
<td>19.8 ± 4.4</td>
<td>24.5 ± 5.8</td>
<td>0.012*</td>
<td>[-1.124, 8.377]</td>
</tr>
<tr>
<td>First Metatarsal Inclination (degrees)</td>
<td>22.0 ± 2.6</td>
<td>22.7 ± 3.2</td>
<td>0.470</td>
<td>[-1.359, 2.854]</td>
</tr>
</tbody>
</table>

[Rev Esp Podol. 2024;35(1):36-41]
### Table III. Association between the absence of joint space and the different study variables. The + sign indicates a radiographic sign of HR. Statistically significant values (p-value < 0.05). The 95 % CI values are shown for quantitative variables that present a normal distribution.

<table>
<thead>
<tr>
<th>Joint space</th>
<th>Variable</th>
<th>Present (-) Mean ± SD</th>
<th>Absent (+) Mean ± SD</th>
<th>p-value</th>
<th>95 % CI</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Meary-Tomeno (degrees)</td>
<td>1.10 ± 5.4</td>
<td>8.42 ± 5.6</td>
<td>&lt; 0.001*</td>
<td>[-9.042, 0.684]</td>
</tr>
<tr>
<td></td>
<td>Internal Costa Bartani (degrees)</td>
<td>122 ± 7.6</td>
<td>126 ± 6.5</td>
<td>0.089</td>
<td>[-9.042, 0.684]</td>
</tr>
<tr>
<td></td>
<td>Calcaneal Inclination (degrees)</td>
<td>25.5 ± 6.4</td>
<td>21.4 ± 4.8</td>
<td>0.041*</td>
<td>[0.183, 8.016]</td>
</tr>
<tr>
<td></td>
<td>First Metatarsal Inclination (degrees)</td>
<td>23.8 ± 3.3</td>
<td>21.5 ± 2.5</td>
<td>0.024*</td>
<td>[0.341, 4.366]</td>
</tr>
</tbody>
</table>

### Table IV. Association between the presence of osteophytosis of the head of the first metatarsal and the different study variables. The + sign indicates a radiographic sign of HR. Statistically significant values (p-value < 0.05). The 95 % CI values are shown for quantitative variables that present a normal distribution.

<table>
<thead>
<tr>
<th>Presence of dorsal osteophytosis of the head of the first metatarsal</th>
<th>Variable</th>
<th>Presence (+) Mean ± SD</th>
<th>Absence (-) Mean ± SD</th>
<th>p-value</th>
<th>95 % CI</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Meary-Tomeno (degrees)</td>
<td>4.66 ± 7.2</td>
<td>6.50 ± 5.2</td>
<td>0.452</td>
<td>[-0.322, 8.713]</td>
</tr>
<tr>
<td></td>
<td>Internal Costa Bartani (degrees)</td>
<td>123 ± 7.7</td>
<td>128 ± 5.5</td>
<td>0.067</td>
<td>[-0.322, 8.713]</td>
</tr>
<tr>
<td></td>
<td>Calcaneal Inclination (degrees)</td>
<td>24.0 ± 5.79</td>
<td>21.3 ± 5.7</td>
<td>0.191</td>
<td>[-6.898, 1.462]</td>
</tr>
<tr>
<td></td>
<td>First Metatarsal Inclination (degrees)</td>
<td>22.9 ± 2.47</td>
<td>21.7 ± 4.0</td>
<td>0.387</td>
<td>[-3.807, 1.560]</td>
</tr>
</tbody>
</table>

### Table V. Association between the presence of clinical signs of HR according to the Coughlin and Shurnas classification and the different study variables. The + sign indicates a radiographic sign of HR. Statistically significant values (p-value < 0.05). The 95 % CI values are shown for quantitative variables that present a normal distribution.

<table>
<thead>
<tr>
<th>Hallux rigidus</th>
<th>Variable</th>
<th>Presence (+) Mean ± SD</th>
<th>Absence (-) Mean ± SD</th>
<th>p-value</th>
<th>95 % CI</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Meary-Tomeno (degrees)</td>
<td>6.98 ± 7.0</td>
<td>2.74 ± 5.1</td>
<td>0.044*</td>
<td>[-7.806, 1.803]</td>
</tr>
<tr>
<td></td>
<td>Internal Costa Bartani (degrees)</td>
<td>126 ± 7.4</td>
<td>123 ± 6.8</td>
<td>0.212</td>
<td>[-7.806, 1.803]</td>
</tr>
<tr>
<td></td>
<td>Calcaneal Inclination (degrees)</td>
<td>22.1 ± 5.3</td>
<td>22.6 ± 2.9</td>
<td>0.221</td>
<td>[-1.605, 6.636]</td>
</tr>
<tr>
<td></td>
<td>First Metatarsal Inclination (degrees)</td>
<td>22.9 ± 2.47</td>
<td>22.3 ± 3.3</td>
<td>0.800</td>
<td>[-2.363, 1.835]</td>
</tr>
</tbody>
</table>

### Discussion

The results of this study show that goniometric measures that represent values consistent with flattening of the medial longitudinal arch are associated with signs of joint degeneration of the 1MTPJ, with the Meary-Tomeno angle showing the best association with the clinical-radiographic diagnosis of HR.

We have not found studies comparing the radiological morphometry in the midfoot or rearfoot with the presence of HR, so we cannot make direct comparisons with our results. However, some authors have...
have previously demonstrated that certain structural changes in the forefoot, such as HAV, are related to the presence of HR, suggesting that other deformities in the midfoot or rearfoot might be related to this pathology, which seems to be suggested by our findings.

Coughlin and Shurnas did not find an association between HR and abnormal foot position. However, they analyzed rearfoot deformities based on clinical evaluation of calcaneal position and considered pathological values >6° of valgus and arch height by the width of the arch measured in the plantar footprint. Radiographic goniometric values are more precise for detecting subtler changes in foot morphology, so we recommend further studies using this methodology to confirm our findings.

On the other hand, Anwander et al. found a direct relationship with MPE. One reason could be the impact of pronation or flattening of the midfoot and/or rearfoot, which could favor deformation in a dorsiflexion position of the first metatarsal, thus contributing to the initial stages of HR.

Our results suggest that it is important to evaluate the position of the foot in a weight-bearing lateral X-ray to determine foot position, recommending the measurement of the Meary-Tomeno angle since the presence of a plantar vertex was associated with a higher presence of HR.

The results of this study should be interpreted with caution. First, because a sample size calculation was not carried out, and therefore we consider the study sample to be small. Secondly, because the sample does not proportionally represent all HR stages, with milder stages of this disease being predominant. However, this could suggest that variations in goniometric angles are associated with the presence of HR in the early stages, although future studies are needed to prove this. The main strength of the study is that it is the first to prove this. The results of this study should be interpreted with caution. First, because a sample size calculation was not carried out, and therefore we consider the study sample to be small. Secondly, because the sample does not proportionally represent all HR stages, with milder stages of this disease being predominant. However, this could suggest that variations in goniometric angles are associated with the presence of HR in the early stages, although future studies are needed to prove this. The main strength of the study is that it is the first to prove this.

In conclusion, the results of the present study have shown that goniometric measures that represent values consistent with flattening of the MLA are associated with signs of joint degeneration of the 1MTPJ, with the Meary-Tomeno angle showing the best association with the clinical-radiographic diagnosis of HR, suggesting a possible association between HR and tarsal pronation or flatfoot.

Ethics declaration

The study was conducted and completed in full compliance with the ethical standards of the responsible committee, and ethical approval was obtained (Ethics Committee of Hospital Clínico San Carlos [IdISSC], with internal code: 22/355-E). Informed consent was obtained from all patients included in the study. The authors declare that the study complied with the ethical code of the Declaration of Helsinki.

Conflicts of interest

None declared.

Funding

None declared.

Authors’ contributions

Study idea and design: RSS, MNC, RCM, and OMA. Data collection: RSS, MNC, and OMA.

Analysis and interpretation of results: RSS, MNC, RMB, AMOG, and OMA. Drafting, writing, and preparation of the initial manuscript: RSS, MNC, RCM, RMB, AMOG, and OMA.

Review and approval of the final version prior to publication: RSS, MNC, RMB, AMOG, and OMA.

References