Proximal Epiphysis of the Second Metatarsal: Normal Trait, Possible Contribution to Growth, and Clinical Implications

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abstract

Analysis of 998 dorsoplantar foot radiographs of 231 patients was performed. Age ranged between 0.21 and 19.94 years. The authors proved the existence of a previously undescribed additional proximal ossification center in the second metatarsal. This additional proximal center was seen in 78 of 998 radiographs, which corresponds with 7 of the 231 patients. If only 111 patients within the age range in which the additional proximal center appears are considered, the true prevalence of the additional proximal center was found in 7 (6.3%) patients. This additional proximal center was found to be bilateral in 4 (57.1%) of these 7 patients. The presence of the proximal center was more common in girls and was associated with index plus metatarsal type \((P = .000)\) and foot pathology, especially flatfoot \((P = .000)\). Age of appearance was 2.3 ± 0.24 years and age of fusion was 5.5 ± 2.2 years. Using a descriptive maturation scale, the authors classified the ossification stages of the additional proximal center in 4 stages: rudimentary, fully formed, partially fused, and fully fused. After creating a mathematical ratio, the authors could not prove that the presence of this additional proximal center increased the length of the second metatarsal or the complete second ray.

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Drs Pizones, Gomez-Rice, Pareja, and Fernandez-Camacho have no relevant financial relationships to disclose.

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To the authors’ knowledge, this is the first study concerning the presence of an additional proximal ossification center of the second metatarsal. Knowing it exists can help in the diagnostic process of daily practice.

The existence of the distal additional epiphysis of the first metatarsal was previously described, but few articles referring to the proximal additional epiphyses of the lateral metatarsals have been published, except for articles about the proximal center of the fifth metatarsal. In published literature, no description exclusively discussing the existence of an epiphyseal center located at the proximal end of the second metatarsal has been found. Anderson searched through medieval bone fossils looking for accessory epiphyses of hands and feet and did not find any belonging to the second metatarsal.

Other authors recognize the possibility of finding additional proximal centers at the proximal ends of lateral metatarsals behaving as histological or radiographic pseudoeipiphyses or as definable radiographic proximal centers. Some authors report that these additional proximal centers have no clinical significance and that they are common among children with no pathology.

The authors are not aware of any detailed study regarding the additional center of the second metatarsal. Knowing its existence, distribution, and characteristics may have clinical importance to properly evaluate traumatic injuries, congenital anomalies, and metabolic diseases because additional centers can be a potential confusion factor in the clinical diagnostic process.

**MATERIALS AND METHODS**

A prospective analysis of 998 dorso-plantar foot radiographs of 231 patients was performed. Patients’ age range was between 0.21 and 19.94 years. Radiographs were obtained from clinical charts between 1984 and 2005 and were first taken as a necessary examination in their orthopedic diagnosis processes, which were not initially related to the current study. No radiographs were taken for this study only. The research was performed following the Declaration of Helsinki principles. Some patients only contributed 1 radiograph to the study (if no more radiographs were needed during the diagnostic and therapeutic process), and others contributed a wide series of films during the follow-up years of their specific pathologies. These different pathologies were recorded under the variable “orthopedic diagnosis,” which was later used for statistical analysis.

Each radiograph was analyzed and searched for the existence of the additional proximal center of the second metatarsal. When one was seen, the age of appearance and fusion of the center were recorded, as well as its maturation stage using a maturation classification similar to the one published by Risser for the iliac crest, but adapted to long bone’s epiphyseal centers (Figure 1). The radiographic morphology of the centers was examined to study a possible standard image pattern.

The association between the presence or absence of the nucleus and different variables was statistically studied. For dichotomorphic variables, Fisher’s exact test was used. For nondichotomorphic variables, the likelihood ratio was applied. Foot type (digital and metatarsal shape) was established according to the method described by Hardy and Clapham, which was recommended by the Research Committee of the American Orthopaedic Foot and Ankle Society (Figure 2). Digital foot types were described as follows: the most common shape is the Egyptian foot, in which the first toe is larger than the second, Greek foot when the second toe is larger than the first toe, square foot when both are equally long (A). Metatarsal foot types: Index plus when the first metatarsal is longer than the second, index minus when the second metatarsal is longer than the first metatarsal, index plüssminus when both are equally long (B).
metatarsal compared with the second; the index plus-minus shape has equal length between the first and the second metatarsals; and the index plus shape has a longer first metatarsal. The association between the age of appearance and fusion of the additional proximal center and the referred variables was also evaluated by means of Student’s t test, analysis of variance, and Tukey’s posthoc test. A ratio was obtained by using the longitudinal measures of the second metatarsal and the second ray of the foot (resulting from its equation) (Figure 3). This ratio enabled the assessment of center contribution to longitudinal growth.

**RESULTS**

The global sample mean age was 8.7 years (range, 0.21-19.94 years). Sixty percent were boys and 40% were girls. Laterality was homogeneous (51% left feet and 49% right feet). Thirty-two orthopedic diagnoses were gathered, but only the 4 principal diagnoses (70.6% of all diagnoses) were used for the statistical analysis: flatfoot, valgus deformation of the hallux, congenital clubfoot, and traumatic injuries (considered control healthy cases).

**Prevalence**

The additional proximal ossification center of the second metatarsal was seen in 78 of the 998 radiological images (Figure 4), which corresponds with 7 of the 231 patients in this study. The age range in which this proximal center was identified was 2.16 to 9.1 years, and the authors stratified the sample to estimate the prevalence of the proximal center. If only 111 patients within the age range in which the proximal center appears are considered, the true prevalence of the additional proximal center was 6.3% (7 of 111). This additional proximal center was bilateral in 4 (57.1%) of these 7 patients. All 7 patients presented with an additional distal epiphysis at the end of the first metatarsal.

**Specific Characteristics**

The authors confirmed that the proximal second metatarsal epiphysis was more common in girls (3.2% of the girls’ sample) than in boys (2.9% of the boys’ sample) with statistical evidence. They did not find predominance regarding foot laterality. An association between the presence of the additional proximal center and the index plus type (64.1% of global sample) exists that has been stati-

| Table 1 | Association Between the Presence of the Additional Ossification Center of the Second Metatarsal and Metatarsal Formulaa |
|-----------------|-------------------------------------------------|-----------------|-----------------|-----------------|
| Proximal Center 2nd MTT | Index Minus | Index Plus | Index Plus Minus | Total |
| Presence (N) | 27 | 50 | 1 | 78 |
| Center, % | 34.6 | 64.1 | 1.3 | 100 |
| MFT, % | 6.8 | 10.2 | 0.9 | 7.8 |
| Total, % | 2.7 | 5 | 0.1 | 7.8 |
| Absence (N) | 368 | 442 | 110 | 920 |
| Center, % | 40 | 48 | 12 | 100 |
| MFT, % | 92.9 | 89.8 | 97.3 | 91.9 |
| Total, % | 36.8 | 44.2 | 11 | 91.9 |
| Total (N) | 395 | 492 | 111 | 998 |

*Abbreviations: [AQ 6]; MFT, metatarsal foot type; MTT, metatarsal; N, number.*
cally proven $P=.000$ (Table 1). Nine of the 10 feet presenting the additional nucleus had an index plus type. There was a tendency towards Egyptian foot ($75.6\%$) when the additional proximal center was present (Table 2). Eight of the 10 feet presenting the additional nucleus had an Egyptian foot. This double relationship with a longer first foot ray (Figure 5) is contrary to the theory of a supplementary growth of the second metatarsal due to the additional spurt of the proximal epiphysis.

**Association with Pathology**

A strong association between the presence of the proximal nucleus and patients with flatfoot has been statistically demonstrated ($P=.000$). Five of the 10 feet presenting with the additional proximal center were initially diagnosed as flatfoot (Figure 5). The additional proximal center of the second metatarsal has also been seen in patients with arthrogryposis, clubfoot, and traumatic injuries. The latter represent the healthy feet sample, which was the group with lower prevalence of the additional proximal center.

### Ages of Appearance and Fusion

Using a descriptive maturation scale (Figure 1), the authors classified the ossification stages of the additional proximal centers in 7 patients, which allowed them to know the age of appearance of the additional proximal centers and the age of fusion of their physis (Table 3). Two of the images showed a rudimentary stage (taken at the age of appearance), with a mean age of $2.3\pm0.24$ years. In 7 radiographs, the additional proximal centers were fully formed and completely separated from the adjacent metaphysis (stage 2); patients presenting this had a mean age of $3.2\pm0.99$ years. Nine radiographics showed where the proximal epiphysis began its fusion with the second metatarsal metaphysis (stage 3); patients presenting this had a mean age of $3.9\pm1.07$ years. This partial fusion was statistically proved to happen later in the Egyptian foot and index plus combination forefoot shape ($P=.02$). Examples of stages 2 and 3 are shown in Figure 6. Complete physis closure was reached at the mean age of $5.5\pm2.22$ years. This stage occurred earlier in patients with clubfoot, Greek foot, and index plus shape. It was delayed in flatfoot, Egyptian foot, and index minus shape ($P=.01$).

### Does the Additional Center Contribute to the Growth of the Second Ray?

A mathematical ratio was created to calculate the relationship between the additional proximal center presence and the definitive length of the second metatarsal and the second ray (Figure 3). It was used in 2 groups; patients still growing through the second metatarsal (showing partial fusion of the distal physis) and patients who had ended with the second metatarsal growing process (complete fusion of the distal physis). The

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**Table 2**

<table>
<thead>
<tr>
<th>Proximal Center 2nd MTT</th>
<th>Greek Foot</th>
<th>Egyptian Foot</th>
<th>Square Foot</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Presence (N)</td>
<td>13</td>
<td>59</td>
<td>6</td>
<td>78</td>
</tr>
<tr>
<td>Center, %</td>
<td>16.7</td>
<td>75.6</td>
<td>7.7</td>
<td>100</td>
</tr>
<tr>
<td>Digital F, %</td>
<td>4.9</td>
<td>9</td>
<td>8.3</td>
<td>7.8</td>
</tr>
<tr>
<td>Total, %</td>
<td>1.3</td>
<td>5.9</td>
<td>0.6</td>
<td>7.8</td>
</tr>
<tr>
<td>Absence (N)</td>
<td>254</td>
<td>600</td>
<td>66</td>
<td>920</td>
</tr>
<tr>
<td>Center, %</td>
<td>27.6</td>
<td>65.2</td>
<td>7.2</td>
<td>100</td>
</tr>
<tr>
<td>Digital F, %</td>
<td>95.1</td>
<td>91</td>
<td>91.7</td>
<td>92.2</td>
</tr>
<tr>
<td>Total, %</td>
<td>25.5</td>
<td>60.1</td>
<td>6.6</td>
<td>92.2</td>
</tr>
<tr>
<td>Total (N)</td>
<td>267</td>
<td>659</td>
<td>72</td>
<td>998</td>
</tr>
</tbody>
</table>

*Likelihood ratio test $P=.109$. 

Abbreviations: Digital F, digital formula; MTT, metatarsal; N, number.

**Table 3**

<table>
<thead>
<tr>
<th>Maturation Stage</th>
<th>Total Sample</th>
<th>Boys</th>
<th>Girls</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appearance (rudimentary center), y</td>
<td>2.33±0.24</td>
<td>2.51</td>
<td>2.16</td>
</tr>
<tr>
<td>Partial fusion, y</td>
<td>3.94±1.07</td>
<td>4.46±0.54</td>
<td>3.77-4.9</td>
</tr>
<tr>
<td>Complete fusion, y</td>
<td>5.54±2.22</td>
<td>6.81±2.64</td>
<td>4.53-9.1</td>
</tr>
</tbody>
</table>

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**Figure 5:** Radiograph of the feet of a 4.7-year-old boy showing the bilateral presence of the proximal additional center of the second metatarsal, with an Egyptian digital formula and an index plus metatarsal formula. Both feet were diagnosed as flatfoot. Additional centers were found in every metatarsal.

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presence of the additional proximal center was evaluated in these 2 groups. However, the authors could not prove that the presence of the additional proximal center increased the length of the second metatarsal or the second complete ray (Table 4). This finding makes them doubt the true growth potential of the proximal additional physis.

**DISCUSSION**

To the authors’ knowledge, this is the first study concerning the presence, prevalence, and characteristics of the additional proximal center of the second metatarsal. This center has rarely been found among the authors’ sample (6.3% of patients within the age range) and was bilateral in 57% of these patients. This prevalence is low when compared with the frequency observed by other authors regarding the distal additional nucleus of the first metatarsal (24%-75%).15,22 These results agree with Ogden et al,12 who determined that the pseudoepiphysis of the first metatarsal was seen more often than in the rest of metatarsals. The authors found a limiting factor in determining its prevalence. The fusion of the additional proximal center to its adjacent metaphysis occurs between the ages of 4 and 9, and the authors cannot be sure that patients entering the study after that age have had this epiphysis in early development stages.

This additional epiphysis is more frequently observed in pathologic feet compared with healthy feet (although the number of cases was limited). A statistically significant association with flatfoot and with a longer first metatarsal was found. However, patients were included in this study after seeking clinical advice; the prevalence of flatfoot was higher in the authors’ sample than among the general population, and foot shape was found not to be a fixed parameter in children over time. Although a statistically significant association was found, its clinical significance remains unknown.

As it has been histologically proved, pseudoepiphyses are usually well formed at the age of 4 or 5.11,12 In the authors’ sample, the additional proximal centers were completely formed at a mean age of 3.2 years. However, they verified that fusion with the adjacent metaphysis occurs months or years before it does on the opposite (distal) epiphysis, as Ogden et al11,12 stated happens with pseudoepiphyses.

The authors of this study observed that complete proximal fusion is achieved at a mean age of 5.5 years, whereas distal second metatarsal closure in these same patients was reached at age 14.4 years. This additional proximal center fusion age is delayed in patients with flatfoot, Egyptian forefoot, and index minus and occurs earlier than the age that has been published for the fusion of the distal physis of the first metatarsal.15 Anderson9 studied medieval hand bone fossils and found a similar pattern in the additional epiphysis of the first and second metatar-
pals. This could be explained by an earlier fusion of the additional proximal centers of second rays compared with first rays (in both hands and feet).

Two radiologic patterns have been described in the literature for the recognition of additional epiphysis: the presence of a radiolucent line observed in 2 different radiographic views,15 and the appearance of a secondary center connected by a bone bridge to the metaphysis.11,12 We propose a similar descriptive classification that can be applied for the proximal epiphysis of the second metatarsal. It is divided into 4 development stages. Type 1 is a rudimentary nucleus with a half moon shape, separated from the metaphysis. In type 2, the additional proximal center has a round morphology and is completely formed with no connection to the metaphysis. In type 3, the proximal end of the metatarsal shows a cleft that extends to half its width, whereas the other half is fused to the adjacent metaphysis. Type 4 has a complete fusion showing the final morphology of the proximal end of the metatarsal (Figure 7). The final appearance of the proximal epiphysis of the second metatarsal in patients who developed the additional proximal center did not differ from those that did not develop one.

Once the authors accepted the possible existence of the additional nucleus, they debated about its real growth potential. Different authors consider the additional proximal center of the first metatarsal to be a pseudoepiphysis (not a true epiphysis).18-25 The importance of this subject lies in the fact that a real epiphysis would have a true growing cartilage affected by Delpech-Hueter-Völkmann’s law and, therefore, different applied loads can modify growth development (important in prosthetic treatment).

It has been histologically accepted that tubular metatarsal bones have 2 different and opposed potentially growing ends. However, only 1 stays as a true condroepiphysis for the longitudinal enlargement of the bone during growth; the other phys- 

end,18 in this case forming the metatarsal proximal end. This end can appear as a variation of the additional proximal center is known as pseudoepiphysis and has a radiological and anatomical entity but lacks growth potential.12,18 These pseudoepiphyses have been considered a hereditary variation of normality or a result of skeletal anomalies during growth.26 Rochera and Rabat15 considered that the short life of these additional physis is the reason for their poor fertility and their little contribution to longitudinal bone growth.

The authors have not been able to demonstrate that the presence of the additional proximal center increases the length of the second metatarsal. Therefore, they cannot assure its function as a true epiphysis, increasing the second ray length, which happens with the first ray, where a longer ray has been associated with hallux valgus or hallux rigidus.35-37 Moreover, the presence of this additional proximal center does not vary the morphology of the second metatarsal when comparing the images with those of patients without this specific nucleus. Therefore, they acknowledge that the proximal additional epiphysis of the second metatarsal may be a pseudoepiphysis because they were not able to demonstrate that its cartilage tissue contributes to the longitudinal growth of the second metatarsal.

There were several limitations to this study, including a small sample size (given the low prevalence of the proximal epiphysis of the second metatarsal) and potential selection bias because patients were included in this study after seeking clinical diagnosis and a radiographic study. Because of the low prevalence of the additional proximal center in the second metatarsal, only bivariate analysis was undertaken to seek associations with the presence of foot pathologies. Despite these limitations, this is the first study describing this additional proximal center.

The authors demonstrated the presence of an additional ossification center in the proximal end of the second metatarsal that has a low prevalence in the population and does not seem to influence metatarsal growth. Knowing its existence can help in the diagnostic process of daily practice.

REFERENCES

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