Morphofunctional Study of Brachymetatarsia of the Fourth Metatarsal

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Brachymetatarsia is abnormal anatomical shortness of the metatarsals. We describe a new diagnostic test that enables quantification of the shortening of the fourth metatarsal in brachymetatarsia. The metatarsodigital alterations most frequently related to this deformity are presented. (J Am Podiatr Med Assoc 94(4): 347-352, 2004)

Brachymetatarsia is abnormal shortness of the metatarsals.[1] When this causes the clinical appearance of short toes, the term *brachymetapody* is used. This deformity can affect any of the five metatarsals, but the fourth metatarsal is most frequently involved,[2-5] although this is disputed by authors such as Choudhury et al,[6] Tachdjian,[7] and Hutchinson.[8] The deformity is not common: its overall prevalence has been determined to be 1 in 1,820 to 1 in 4,586.[9, 10] In the present study, there were 12 cases among 7,508 podiatric clinical histories (0.16%, or approximately 1 in 625 individuals). The brachymetatarsia can be unilateral or bilateral, and it has a clear preponderance in females, with a female-to-male ratio of 4:1 according to our data, although authors such as Urano and Kobayashi[10] report a ratio of 25:1. In most cases the deformity is congenital but does not manifest clinically until the age of 4 to 15 years.[5, 11] Brachymetatarsia is readily visible, but other alterations exist that may be mistaken for metatarsal shortening, eg, surgical removal of the middle phalanx of a toe or an excessively short proximal phalanx (Fig. 1).

The etiology of brachymetatarsia is not known, although there are various theories. It is known that metatarsal physeal growth closes prematurely, but the reason is unknown. The etiology can be classified into three groups: acquired, associated congenital, and idiopathic congenital. The acquired etiology refers to premature closure of physeal growth after trauma, a neurotrophic disorder, or even, as claimed by Yale[12] in 1978, an accumulation of radiation from excessive exposure to x-rays. Other causes of a short metatarsal are surgery, such as poor surgical technique or resection of a metatarsal head; infections, such as osteomyelitis that completely destroys the metatarsal head; or osteochondrosis, such as Freiberg's infraction.[6]

The associated congenital etiology refers to the association of this deformity with other general pathologic conditions such as Down's, Turner's, Larsen's, and Albright's syndromes, parathyroid alterations (pseudohypoparathyroidism and pseudo-pseudohypoparathyroidism), and diseases such as poliomyelitis, dystrophic dwarfism, enchondromatosis, and ossifying myositis.

The idiopathic congenital etiology is the most frequent of the three. It produces very early closure of the epiphyseal plate, but the cause is not known. However, in some cases there is a hereditary factor, as we found up to three members of the same family with the disorder despite its rareness.

The aim of the present article is to describe a new quantitative diagnostic test that determines whether

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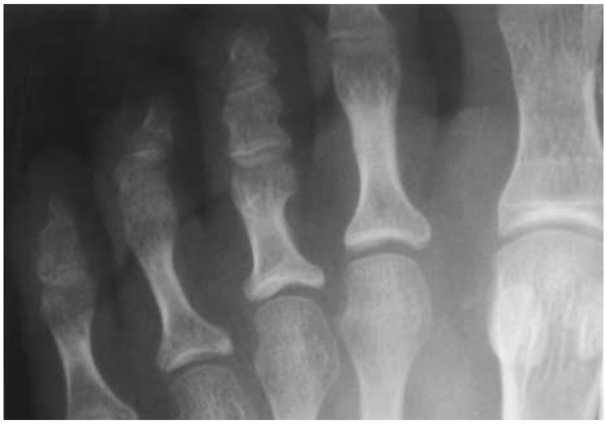

Figure 1. Radiograph showing that the proximal phalanx of the third toe is shorter than that of the other toes.

or not the fourth metatarsal is abnormally short (brachymetatarsia). We also describe the metatarsodigital alterations most frequently associated with brachymetatarsia of the fourth metatarsal.

Materials and Methods

Using radiographic measurements, we determined the approximate length of the fourth metatarsal in a control sample of individuals not affected by the deformity and in a second sample of patients with short fourth metatarsals. On the basis of the differences observed between the two groups, we established the most frequent metatarsodigital alterations associated with shortening of the fourth metatarsal.

The control sample comprised 117 patients (100 females [85.5%] and 17 males [14.5%]) with 221 foot radiographs. The selection criteria for the control sample were as follows: the radiography had to be dorsoplantar and performed with the foot weightbearing, the subjects had to have closed growth plates, and there could be no visible alterations of the metatarsal arc that could distort the results.

The second group comprised 20 patients (28 feet) affected by brachymetatarsia of the fourth metatarsal (15 females [75%] and 5 males [25%]) aged 8 to 79 years (mean, 37.6 years). For each patient, we filled out a record including personal data (full name, age, sex, and telephone number), anamnesis (localization of the brachymetatarsia, family history of the disorder, personal medical history, and whether or not the affected foot had sustained trauma), data on articular exploration (alterations in mobility of the tibiofibular-astragalar, infra-astragalar, and mediotarsal articulations; first and fifth rays; central rays; and toes), and data on digital alterations and stress-loading symptoms of any metatarsal. Subsequently, each patient had a dorsoplantar radiograph taken with the foot weightbearing.

On each radiograph in the two groups, we used pencils, rules, set squares, compasses, protractors, and tracing paper to make the following measurements:

1) Angle of fourth metatarsal shortening or second–fourth angle: This is a novel angle defined by us to quantify the shortening of the fourth metatarsal in brachymetatarsia. The tracing paper was fixed to the radiograph for the drawing. The two lines forming the angle are the longitudinal bisection of the second metatarsal and a tangent to the most distal points of the second and fourth metatarsal heads (Fig. 2).

2) Metatarsal protrusion between the second and fourth metatarsals: In 1951, Hardy and Clapham[13] described a method to measure metatarsal protrusion between the first and second metatarsals; we adapted this method for the purposes of this study. The transverse axis of the tarsus (the line joining the most proximal point of the scaphoid tuberosity with the most proximal lateral point of the proximal articular face of the cuboid) and the longitudinal axis of the second metatarsal were traced. From the point of intersection of these two lines, two curved lines were drawn to round the most distal points of the second and fourth metatarsal heads. The distance between

Figure 2. Angle of fourth metatarsal shortening or second–fourth angle.

the curved lines was then measured on the second metatarsal axis (Fig. 3).

3) Second–fifth angle: This angle, described by Oller Asensio[14] in 1995, is formed by the longitudinal axis of the second metatarsal and a tangent to the most distal points of the second and fifth metatarsal heads. This angle and the second–fourth angle are similar, so it was included in the radiographic measurements, and the difference between the two angles was compared in the control group and the brachymetatarsia group.

Statistical Analysis

The statistical analysis of the data was performed using SPSS, version 10.0 for Windows (SPSS Science, Chicago, Illinois). The normality of the sex distributions of the different variables (second–fourth angle, second–fourth protrusion, and difference between the second–fourth and second–fifth angles) was tested using the Shapiro-Wilkes test. Both sexes had a normal distribution for these variables. Subsequently, males and females were compared using the Student *t*-test, after comparison of the variances using the Lévene test. The values of the second–fourth angle obtained from the measurements made on the radiographs of the control group were tested using the receiver operating characteristic curve to obtain the section with the best sensitivity-to-specificity ratio.

Figure 3. Metatarsal protrusion between the second and fourth metatarsals, using the method of Hardy and Clapham.[13]

Results

The measurements of the radiographic parameters in the two samples are given in Table 1. The second–fourth angle was a mean of 22.78° (males, 22.17°; females, 23.39°) smaller in the brachymetatarsia group than in the control group—a significant difference ($P < .001$). The values of this angle in both groups are ranked in Table 2.

The results also show that in the brachymetatarsia group, the difference between the protrusion of the fourth and second metatarsals is 1.27 cm greater than in the control group. In the control group, the mean difference between the second–fourth and second–fifth angles was 6.40°, whereas in the brachymetatarsia group the mean difference was 13.34°. The second–fourth angle was greater than the second–fifth angle in all cases in the control group and smaller in all cases in the group with shortening of the fourth metatarsal; the difference between these two parameters in the two groups was 19.74°.

A significant difference was also observed between males and females in the mean values of the second–fourth angle in the control group. Thus the angle determining whether or not the fourth metatarsal is short will be different for males and females.

Additional data were obtained specifically relating to the sample of feet with brachymetatarsia. Of the 20 patients studied, 12 (60%) had this deformity unilaterally and 8 (40%) bilaterally. We observed that 18 patients (90%) would be classified in the idiopathic congenital etiology group, 1 (5%) in the associated congenital etiology group (the patient had Down's syndrome), and 1 (5%) in the acquired etiology group (the patient sustained a fracture of the fourth metatarsal during childhood, which may have caused the deformity). Findings regarding metatarsodigital alterations related to the short fourth metatarsal were as follows: 16 feet with brachymetatarsia (57%) had partial syndactyly of the second and third toes, 21 (75%) had lateral deviation of one of the toes adjacent to the shortened toe, 16 (57%) displayed the fourth metatarsophalangeal articulation in the process of luxation, 27 (96%) had the floating toe syndrome, and 27 (96%) had an overload on one of the adjacent metatarsals (a thick keratotic buildup under those metatarsals was noted as an indication of overload).

Discussion

It is logical to assume that the shortening of a metatarsal can distort the normal functioning of the foot. Brachymetatarsia of the fourth metatarsal leads to alterations that cause disruption of the normal biome-

Table 1. Comparison of Radiographic Measurements in Controls and Patients with Brachymetatarsia

	Control Group			Brachymetatarsia Group		
	Second–Fourth Angle (°)	Second–Fourth Protrusion (mm)	Difference Between Second–Fourth and Second–Fifth Angles (°)	Second–Fourth Angle (°)	Second–Fourth Protrusion (mm)	Difference Between Second–Fourth and Second–Fifth Angles (°)
Men						
Mean ± SD	59.10 ± 5.28	13.74 ± 2.35	5.27 ± 2.25	36.93 ± 8.22	25.40 ± 1.78	12.69 ± 5.79
No. of cases	44	21	44	8	5	8
Women						
Mean ± SD	62.36 ± 5.49	10.24 ± 3.18	6.68 ± 2.65	38.97 ± 7.18	22.88 ± 5.43	13.60 ± 4.60
No. of cases	177	128	177	20	17	20
P value	< .001	< .001	.001	.551	.118	.698

Table 2. Ranked Values of the Second–Fourth Angle Measured in Controls and Patients with Brachymetatarsia

Group	Angle (°)	No. (%) of Feet
Control (n = 221)	44–50	7 (3.17)
	51–57	35 (15.84)
	58–64	121 (54.75)
	65–71	49 (22.17)
	72–78	8 (3.62)
	79–85	1 (0.45)
Brachymetatarsia (n = 28)	29–35	12 (42.86)
	36–42	10 (35.71)
	43–49	4 (14.29)
	50–56	1 (3.57)
	57–63	1 (3.57)

chanical process of the forefoot in the weightbearing phase of locomotion. One of these alterations is the floating toe syndrome, produced because as the rest of the metatarsals grow and the affected one does not, the toe is "left behind" or retracted.[8, 15] The toe remains in a shortened position and dorsiflexed with respect to the others. It is also typical to find the adjacent toes deviated as a result of the excessive shortening of the fourth metatarsal. The adjacent toes, especially the fifth toe, undergo rotation and medial displacement, tending to occupy the space left by the retarded fourth toe and increasing its instability and elevation. The weakening of the insertion of the plantar fascia and the articular capsule contributes to the instability of the toe,[16] and this, together with the retraction of the skin at this level, causes the toe to lose its function so that it does not make contact with the ground at any point of the weightbearing phase. This leads to a tendency for the fourth metatarsophalangeal articulation to undergo luxation.

The overload on the adjacent metatarsals is produced by a well-known mechanism widely discussed in the literature: the transfer of load to the other metatarsals. When a metatarsal is deficient (in this case because of its short length), it loses its load function, which is transferred to the adjacent metatarsals.

An alteration that we often found to be associated with brachymetatarsia was an incomplete syndactyly of the second and third toes, in which the membrane joining the two toes does not extend to their distal part.[11] The frequency with which we found this association (57%) and the fact that normally the membrane between the second and third toes is the last to appear during fetal development and the fourth and fifth metatarsals are the last to begin development suggest that the mechanisms producing the two anomalies could be related.

We will now explain the design of a new diagnostic test enabling quantification of the shortening of the fourth metatarsal, as well as the normal value. In 1990, Bartolomei[5] described a method for the quantitative diagnosis of shortening of the fourth metatarsal consisting of tracing the metatarsal arc using two lines: one connecting the most distal point of the second metatarsal head with the most distal point of the first metatarsal head, and another connecting the most distal point of the second metatarsal head with the most distal point of the fifth metatarsal head. If a metatarsal terminates 5 mm or more proximal to the parabolic arc, it is considered abnormally short. This is a good method in that it relates the length of the affected metatarsal to the rest of the metatarsal arc, but it has one drawback: the dependence on the length of the fifth metatarsal in determining that of the fourth metatarsal, which in certain cases may lead to error. Figure 4 shows a case in which use of the Bartolomei method would not result in the fourth metatarsal's being considered excessively short, even though its shortness with respect to the adjacent toes is evident on the radiograph. The index proposed in our study—the angle of fourth metatar-

Figure 4. Dorsoplantar radiograph of a brachymetatarsia of the fourth metatarsal in the left foot. The distance between the fourth metatarsal head and the angle drawn is less than 5 mm.

sal shortening—has the advantage of directly involving the metatarsal concerned.

This angle enables quantitative evaluation of the shortness of the fourth metatarsal. Moreover, the angle establishes a value that can help determine whether or not a fourth metatarsal can be considered abnormally short, which is of greater interest in metatarsals found at the limit of normality, as very short fourth metatarsals are obvious from radiographic examination. It can be seen that for the male subjects of the control group, the value 52.25° represents a sensitivity of 100% and a specificity of 86%; for the female control subjects, the value representing the best ratio of sensitivity to specificity is 50.5°. Therefore, the value of the angle at which the fourth metatarsal is considered abnormally short is 52.25° for males and 50.5° for females. An interesting result that has a sensitivity and specificity of 100% for the diagnosis of brachymetatarsia of the fourth metatarsal is that in all of the control subjects, the second–fourth angle is greater than the second–fifth angle, whereas in all of the patients with shortening of the fourth metatarsal, the second–fourth angle is smaller than the second–fifth angle. This could be of great use in diagnosing brachymetatarsia of the fourth metatarsal, especially in situations where the length of the metatarsal is close to the boundary between normal and pathologic.

Conclusion

The fourth metatarsal is abnormally short if its angle of shortening is smaller than 52.25° in males or 50.5° in females and if this angle is also smaller than the second–fifth angle.

Brachymetatarsia of the fourth metatarsal results in various metatarsodigital alterations; some of these alterations can become serious problems in certain circumstances, for example, metatarsal overloads in patients with loss of sensitivity in the sole of the foot. Further research should be aimed at confirming current hypotheses about the etiology of this deformity. We believe that there is a hereditary component in some cases, that the mechanism producing this alteration may be directly related to the one responsible for syndactyly, and that the primary cause could be stresses on the metatarsal in the first few years of life combined with a hereditary predisposition.

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References

1. *Stedman's Medical Dictionary*, 26th Ed, sv "brachymetatarsia," Williams & Wilkins, Baltimore, 1995.
2. Handelman RB, Perlman MD, Coleman WB: Brachymetatarsia: a review of the literature and case report. JAPMA **76:** 413, 1986.
3. Ferrandez L, Yubero J, Usabiaga J, et al: Congenital brachymetatarsia: three cases. Foot Ankle **14:** 529, 1993.
4. Levine SE, Davidson MD, Dormans JP, et al: Distraction osteogenesis for congenitally short lesser metatarsals. Foot Ankle Int **16:** 196, 1995.
5. Bartolomei FJ: Surgical correction of brachymetatarsia. JAPMA **80:** 76, 1990.
6. Choudhury SN, Kitaoka HB, Peterson HA: Metatarsal lengthening: case report and review of the literature. Foot Ankle Int **18:** 739, 1997.
7. Tachdjian MO: "Congenital Deformities," in *The Child's Foot*, ed by MO Tachdjian, p 131, WB Saunders, Philadelphia, 1985.
8. Hutchinson BL: "Cirugía de los Metatarsals Menores," in *Atlas a Color y Texto de Cirugía del Antepié*, ed by R Butterworth, GL Dockery, p 111, Ortocen Editores, Madrid, 1992.
9. Mah KK, Beegle TR, Falknor DW: A correction for short fourth metatarsal. JAPMA **73:** 196, 1983.
10. Urano Y, Kobayashi A: Bone lengthening for shortness of the fourth toe. J Bone Joint Surg Am **60:** 91, 1978.
11. Bouchard JL: "Congenital Deformities of the Forefoot," in *Comprehensive Textbook of Foot Surgery*, 2nd Ed, Vol 2, ed by ED McGlamry, AS Banks, MS Downey, p 1191, Williams & Wilkins, Baltimore, 1992.
12. Yale I: "Inflamaciones Primarias de las Estructuras del Pie," in *Podología Médica*, ed by I Yale, p 233, Jims,

Barcelona, 1978.
13. Hardy RH, Clapham JCR: Observations on hallux valgus: based on a controlled series. J Bone Joint Surg Br **33:** 376, 1951.
14. Oller Asensio A: Influencia del pie en el sistema rotacional del eje femoro-tibial. Rev Esp Podol **6:** 418, 1995.
15. Viladot A: "Malformaciones Congénitas," in *Patología del Antepié*, 3rd Ed, ed by A Viladot, p 75, Masson, Barcelona, 1984.
16. Berges Manfredi MJ, Suarez Méndez JM, Gallar Ortega J, et al: Braquimetatarsia y braquimetapodia: a propósito de un caso. Rev Esp Podol **11:** 59, 2000.

Additional References

Alonso Montero C, Garcia Carmona FJ, Jiménez Leal R, et al: Valoraciones longitudinales y angulares en el primer radio en radiografía dorsoplantar. Rev Esp Podol **8:** 71, 1997.

Back GH, Chung MS: The treatment of congenital brachymetatarsia by one-stage lengthening. J Bone Joint Surg Br **80:** 1040, 1998.

Bryant JA: A comparison of radiographic foot measurements taken in two different positions. JAPMA **91:** 234, 2001.

Goforth WP, Overbeek TD: Brachymetatarsia of the third and fourth metatarsals. JAPMA **91:** 373, 2001.

Hughes J, Clark P, Klenerman L: The importance of the toes in walking. J Bone Joint Surg Br **78:** 245, 1990.

Leliévre J, Leliévre JF: "Introdución," in *Patología del Pie*, 4th Ed, ed by J Leliévre and JF Leliévre, p 1, Masson, Barcelona, 1987.

Mann RA, Hagy JL: The function of the toes in walking, jogging and running. Clin Orthop **142:** 24, 1979.

Montagne J, Chevrot A, Galmiche JM: "Anomalias osteoarticulares en la forma o tamãno," in *Atlas de Radiología del Pie*, ed by J Montagne, p 109, Masson, Barcelona, 1984.

Robinson JF, Ouzounian TJ: Brachymetatarsia: congenitally short third and fourth metatarsals treated by distraction lengthening: a case report and literature summary. Foot Ankle Int **19:** 713, 1998.

Rueda Sanchez A, Rueda Sanchez M, Alonso Guillamon J: "Conceptos de Biomecánica Metatarso-digital," in *Patología Metatarsodigital*, p 65, Federación Española de Podólogos, Madrid, 1991.

Upton J, Khouri R, Ramos D, et al: Distraction lengthening for the congenitally short metatarsal: a case report. Foot Ankle **10:** 184, 1989.