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ORIGINAL RESEARCH

The Zero-Plus First Metatarsal and Its Relationship to Bunion Deformity

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The relationship between first metatarsal length and hallux valgus (HV) deformity was examined. Retrospectively, 210 randomly selected radiographic files were reviewed between 1988 and 1993. The morbid population consisted of 110 feet with HV deformities. The control population consisted of 100 healthy feet (no deformity). Seventy-seven percent of the patients with HV deformity had a first metatarsal length that was equal to or longer than the second metatarsal. This was defined as a zero-plus first metatarsal. Only 28% of the control population had this same proportion in length. Thus, prevalence of zero-plus first metatarsal was significantly associated with HV formation (χ^2_1 = 51.15, P < .001). The mean first metatarsal protrusion distance was significantly higher in the bunion population (+1.58 mm) than in the control patients (−2.05 mm) (P < .001). The distribution of head shape differed significantly between the patients with HV and control patients; patients with HV had predominantly round heads (91%) and the control patients had predominantly square and square with a ridge heads (80%) (χ^2_2 = 107.7, P < .001). All zero-plus first metatarsals in the HV population had a round first metatarsal head. Only 7.1% of the control patients had a round head with a zero-plus metatarsal. There was a positive relationship between the protrusion distance of the first metatarsal and the severity of the intermetatarsal angle, particularly in those patients with intermetatarsal angles ranging from 13° to 20° (P < .01). It was concluded that a zero-plus first metatarsal is a significant etiologic factor in the development of bunion deformity and should be part of the preoperative evaluation. (The Journal of Foot & Ankle Surgery 42(6):319–326, 2003)

Key words: long first metatarsal, metatarsal protrusion, hallux valgus, bunion, zero-plus metatarsal

Although there are many theories regarding the formation of hallux valgus (HV), the literature is inconsistent about the significance of first metatarsal length in this regard. Mann and Duvries (1) related that there was no direct relationship between metatarsal-length pattern and HV formation. Morton (2) maintained that a short first metatarsal will lead to pronation and hypermobility of the first ray with consequent HV development, but it was later disputed in a large radiographic series by Harris and Beath (3) in their Canadian Army Foot Survey. Plaster (4) and Duke et al (5) independently stated that, when HV presents itself with a long first metatarsal, short shoe gear might be the causative factor. Hardy and Clapham (6) concluded that a long first metatarsal could cause HV; however, this relationship would be consistent with a low intermetatarsal (IM) angle. Heden and Sorto (7) asserted that a long first metatarsal would result in HV deformity with a high IM angle, which was related to the buckle point. Root et al (8) stated that hypermobility of the first ray, immobilization of the first

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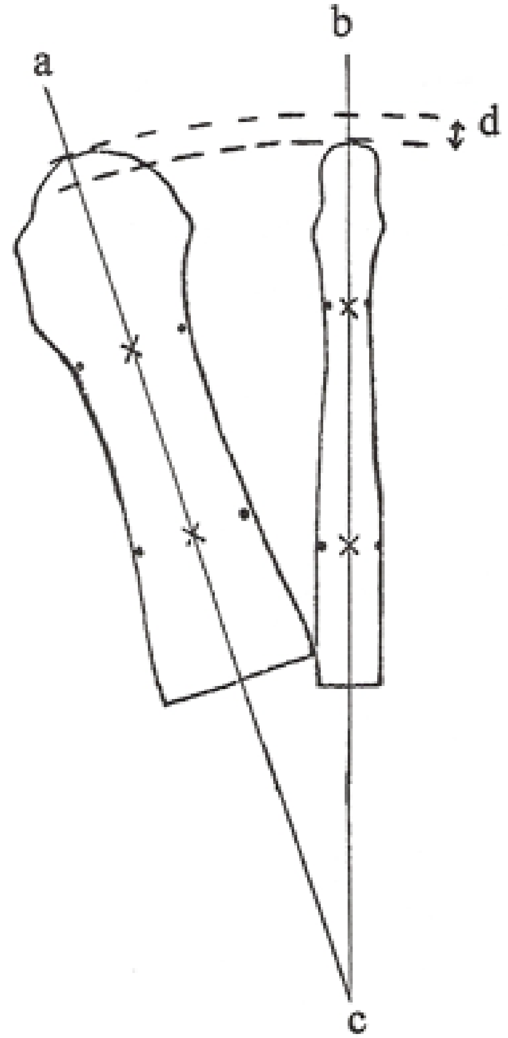

FIGURE 1 Currently accepted measurement of first metatarsal protrusion distance (9). a, Bisection of first metatarsal. b, Bisection of second metatarsal. c, Common intersection of a and b. From point c, arcs are drawn to distal first and second metatarsals. d, Distance measured in millimeters; represents difference between arcs of first and second metatarsals.

FIGURE 2 HV caused by a zero-plus metatarsal. Note round first metatarsal head.

TABLE 1 Patient data for HV and normal populations

	HV Population	Control Population
No. patients	110	100
Age (yrs)	Mean, 44.0; range, 17–70	Mean, 40.0; range, 15–85
Sex	Male = 10 (10%)	Male = 27 (27%)
	Female = 100 (91%)	Female = 73 (73%)

ray, an excessively long first metatarsal, and a dorsiflexed first ray are conditions that would interfere with normal dorsiflexory mechanism of the first metatarsophalangeal joint and lead to joint subluxation.

The length of the first metatarsal as it relates to the pathogenesis of HV is not an absolute measurement but rather a relative length of the first metatarsal length to that of the second metatarsal. This metatarsal protrusion distance is a measurement between the 2 arcs that represent the first and second metatarsal lengths (Fig 1). Healthy first metatarsal protrusion has been determined to be between ± 2 mm (9). Characterization of this relationship as normal in this context is confusing in that it does not distinguish frequency of occurrence from an absence of pathology. In fact, there is no correlation between an abnormal metatarsal protrusion distance and the presence of pathology.

The purpose of this study was to examine the relationship between first metatarsal length and the presence of HV (Fig 2). Specifically, we wanted to determine the significance of the long first metatarsal (zero-plus first metatarsal) in the formation of HV deformity. Second, we sought to determine the frequency of such a long first metatarsal in both the HV population and the healthy population. The third objective was to redefine and to clarify the definition of first metatar-

TABLE 2 Results: IM angle and first metatarsal protrusion distance

	HV population	Control Population
IM Angle	9° or greater	0 to 8°
Metatarsal Protrusion Distance	<−2 mm, 10 of 110 (9.1%)	<−2 mm, 50 of 100 (50%)
	<0 to −2 mm 15 of 110 (13.6%)	<0 to −2 mm, 22 of 100 (22%)
Zero = Plus First Metatarsal		
	0 to +2 mm, 39 of 110 (35.5%)	0 to +2 mm, 20 of 100 (20%)
	>+2 mm = 46 of 110 (41.8%)	>+2 mm, 8 of 100 (8%)
Total	77.3%	28%

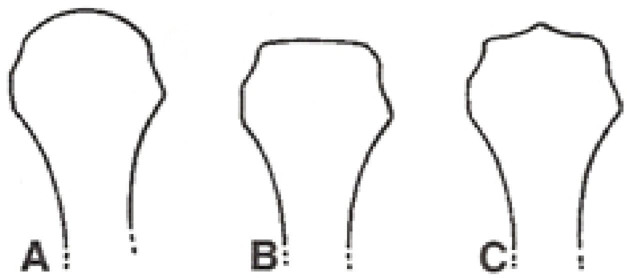

FIGURE 3 Shapes of the first metatarsal head. (*A*) round, (*B*) square (oblique), (*C*) square with a ridge.

TABLE 3 Distribution of zero-plus metatarsals

	HV	Control	
Zero-Plus (N)	85	28	113
Control (N)	25	72	97
Total	110	100	210

TABLE 4 First metatarsal protrusion distance in HV and control populations

Population	Average Metatarsal Protrusion (SD)
HV (n = 110)	+1.58mm (2.4)
Control (n = 102)	−2.05mm (2.4)

sal protrusion distance and to introduce the concept of zero-plus first metatarsal.

Materials and Methods

A retrospective chart review of patient records from 4 of the authors' private offices was conducted. Data was collected from those patients who had visited 1 of these 4 authors from 1988 to 1993 (Table 1). From the authors' offices, 210 patient files were randomly selected from more than 14,000 patient files. These 210 patients were divided into an HV (morbid) group and a healthy (control) population. The HV population was defined as patients that presented with HV deformity with an IM angle of ≥9° (N = 110). The control population consisted of patients who presented with problems confined to areas other than the first metatarsophalangeal joint and had an IM angle of ≤8°(N = 100). Only 1 foot per patient was analyzed. Excluded from the study were patients with previous first metatarsophalangeal joint surgery.

Radiographic parameters were determined from a standard anteroposterior radiograph for each patient. Foot radiographs were weightbearing, in the angle and base of gait, with the central ray angulated 15° from vertical. The IM angle was defined as the angle formed between lines representing the bisection of the first and second metatarsal measured on a standard anteroposterior radiograph. The metatarsal protrusion distance was determined by establishing the common point of intersection between lines formed by the bisection of the first and second metatarsal. At this common point, a compass was used to draw 1 arc at the distal portion of the first metatarsal and another arc at the distal portion of the second metatarsal. The difference between these arcs was the metatarsal protrusion distance (Fig 1). A positive millimeter distance portrays a first metatarsal that is longer than the second, whereas a negative millimeter distance portrays a first metatarsal that is shorter than the second (Table 2). These measurements were all obtained by the senior author (J.E.M.). Additionally, a subjective analysis of the AP foot radiographs was performed to determine the shape of the metatarsal head. They were classified as round, square (oblique), or square with a ridge by a consensus of all of the authors (Fig 3).

The radiographic measurements were used to determine the relationship between relative first metatarsal length and HV development. Differences in metatarsal protrusion distance were arranged into 4 groups from short to long in the HV and the control populations: 1) first metatarsal ≥2-mm shorter than the second metatarsal, 2) first metatarsal between 2-mm shorter and less than equal to the second metatarsal, 3) first metatarsal between equal and 2-mm longer than the second metatarsal, and 4) first metatarsal >2-mm longer than the second metatarsal. The number of patients with zero-plus first metatarsals in the HV and control populations was used to calculate the incidence of

TABLE 5 Distribution of various metatarsal head shapes in the study populations

Shape of Metatarsal Head	HV, N (%)	Control, N (%)	Total
Round	100 (91)	20 (20)	120
Square (oblique)	7 (6.3)	46 (46)	53
Square with ridge	3 (2.7)	34 (34)	37
Total	110	100	210

TABLE 6 Shape of first metatarsal head in zero-plus group by population

HV Population	Control Population
Round, 85 of 85 (100%)	Round, 2 of 28 (7.1%) Square, 17 of 28 (60.7%) Square with ridge, 9 of 28 (32.2%)

TABLE 7 Relationship between IM angle and metatarsal protrusion distance

IM Angle (°)	Average Metatarsal Protrusion (mm)
0 to 8	−2.05
9° to 15	+1.32
>15	+3.50

TABLE 8 Prevalence of round first metatarsal head zero-plus first metatarsal, and mean metatarsal protrusion distance by IM angle size among HV patients

IM Angle (°)	% Round Head	% Zero-Plus	Mean Metatarsal Protrusion Distance (mm)
0 to 8°	20.0	28.0	−2.05
9° to 12°	86.6	75.0	+1.0
13° to 20°	96.0	80.0	+2.3

n = 100.

the zero-plus first metatarsal and the average metatarsal protrusion distance in both populations (Tables 2–4).

Additionally, correlations were developed among the first metatarsal length, the shape of the metatarsal head, and the presence of HV. The shape of the metatarsal heads in those patients with zero-plus metatarsals was determined within comparable age groups. The incidence of each type of shape could be determined in both populations (Tables 5 and 6). Finally, average metatarsal protrusion distance for both HV and control populations was also determined and correlated with the IM angles to determine the relationship between IM angle and metatarsal protrusion (Tables 7 and 8). Statistical analysis was used to determine the significance of the zero-plus first metatarsal in the HV population.

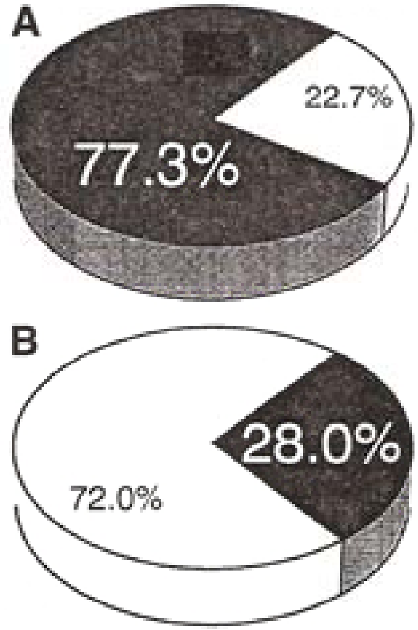

FIGURE 4 Pie chart depicting the percentage of patients with zero-plus metatarsals in the (*A*) HV population and (*B*) the healthy population.

Results

In the 110 patients with HV deformity, 77.3% had a zero-plus first metatarsal versus 28% in the control group (Tables 2 and 3, Fig 4). Seventy-two percent of patients in the control group demonstrated first metatarsal length to be shorter than the second metatarsal (Tables 2 and 3, Fig 4). The prevalence of zero-plus first metatarsal shows a statistically significant association with the presence of HV ($\chi^2_1 = 51.15$, $P < .001$).

When the first metatarsal protrusion distance data from Table 2 was plotted on a bar graph, an inverse relationship was noted between the HV and control populations (Fig 5). The trend in the HV population was toward the first metatarsal protrusion distance being 0 or greater as compared with it being less than 0 in the normal (control) population. The first metatarsal tended to be the same length or longer than the second metatarsal in the HV population, whereas the first metatarsal tended to be shorter than the second metatarsal in the normal (control) population. As shown in Table 4, the mean average first metatarsal protrusion distance was significantly higher in the HV population (+1.58 mm) than in the control group (−2.05 mm) (2-tailed *t* test, $P < .001$).

The first metatarsal head shape in the bunion population was round in 91% of the subjects, square (oblique) in 6.3%, and square with a ridge in 2.7% (Table 5). In the control population 20% of metatarsal heads were round, 46% were square (oblique), and 34% were square with a ridge (Table

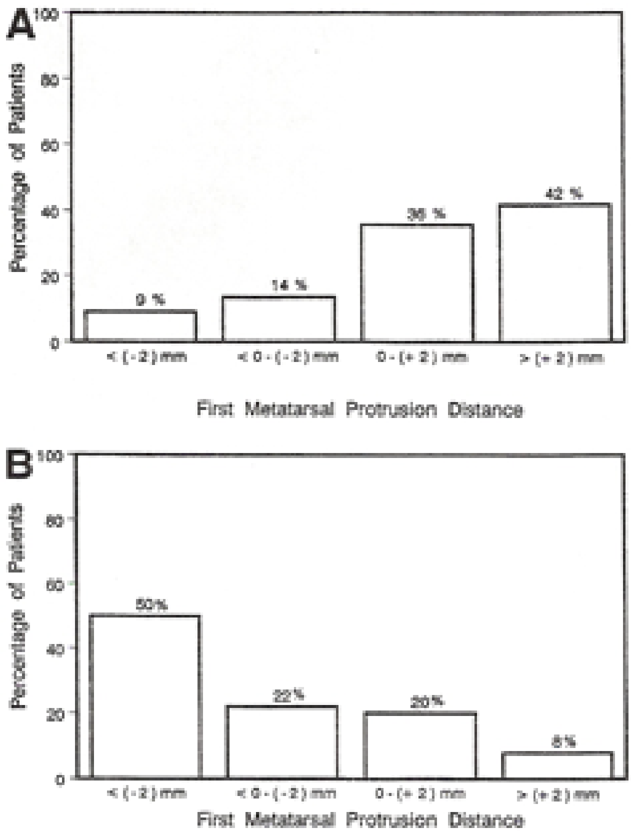

FIGURE 5 Percentage of patients, grouped by first metatarsal protrusion distance in the (*A*) HV population and (*B*) the control population.

5). All 85 (100%) patients in the HV population who had a zero-plus first metatarsal also had a round head (Table 6). In the control population, only 2 of 28 patients with a zero-plus first metatarsal head (7.1%) had a round first metatarsal head. The distribution of head shape differed significantly between the HV patients and the control patients, with predominantly round heads (91%) in the HV cases and predominantly square (oblique) and square with ridge heads (80%) in the control patients (Table 5) ($\chi^2_2 = 107.7$, $P <$ .001).

First metatarsal protrusion (distance) was then compared with the IM angle (Table 7). An IM angle between 0° and 8° correlated with an average relative first metatarsal protrusion of −2.05 mm. An IM angle between 9° and 15° correlated with average first metatarsal protrusion of +1.32 mm. IM angles <15° correlated with an average first metatarsal protrusion of +3.50 mm. The average first metatarsal protrusion in the bunion population was +1.65 mm, whereas in the control population, it was −2.05 mm.

Table 8 shows the prevalence of round metatarsal head, zero-plus first metatarsal, and mean metatarsal protrusion distance within each IM angle range among HV patients (n = 110). The percentage of round first metatarsal heads and zero-plus first metatarsals was greater in patients with IM angles of 13° to 20° than in those with IM angles of 9° to 12°, but this did not attain statistical significance (χ^2_1 = 2.83 and 0.41, respectively). Mean metatarsal protrusion distance was significantly higher in patients with IM angle size of 13° to 20° (2-tailed *t* test, $P < .01$).

Discussion

In a normally functioning first ray, the head of the first metatarsal moves equally above and below the transverse plane of the lesser metatarsals. During normal locomotion, first ray dorsiflexion is not required as long as the midtarsal joint is functioning properly, whereas first ray plantarflexion is necessary to maintain ground contact and to allow propulsion (10). Plantarflexion of the first ray will be affected by relative lengths of the first and second metatarsals. A long second metatarsal allows plantarflexion of the first ray that facilitates hallux dorsiflexion, which is essential for normal locomotion.

A long first metatarsal hinders the dorsiflexory capability of the first metatarsophalangeal joint because it is prevented from dropping below the second metatarsal. In effect, the first ray functions in an elevated position. Over time, this functional metatarsus primus elevatus can lead to subluxation of the first metatarsophalangeal joint (10).

The type of compensatory joint deformity that may subsequently occur is related to the shape of the first metatarsal head (11). A metatarsal head that is square (oblique) or square with a ridge (Fig 3) will result in saggital-plane compensatory deformity. The presence of a met-primus elevatus, whether it is structural or functional from a zero-plus first metatarsal, will lead to a hallux limitus rigidus (10, 11) (Fig 6). A round metatarsal head will lead to HV because of joint instability on the transverse plane (8, 10, 11) (Fig 2).

Data have been presented to support a causative relationship between first metatarsal length and bunion formation. This correlation was previously discussed by Hardy and Clapham (6) in 1951 by and Heden and Sorto (7). The data also suggest the direct relationship between first metatarsal protrusion and the IM angle. Those with an average first metatarsal length of −2.05 mm (shorter than the second metatarsal) had an IM angle between 0° and 8°. Those with a first metatarsal protrusion averaging +1.32 mm had an IM angle between 9° and 15°, whereas those with a first metatarsal protrusion of +3.50 mm had IM angles >15° (Table 4). Likewise, Duke et al (5) correlated increased first metatarsal protrusion with an increased hallux abductus and greater deformities at the first metatarsophalangeal joint. As the deformity progresses in severity, the retrograde effect of the hallux on the rounded first metatarsal head causes an increase in the IM angle. Haden and Sorto (7) coined the

FIGURE 6 Hallux limitus/rigidus caused by a zero-plus metatarsal. Note the square (oblique)-type first metatarsal head.

term "Buckle Point" to describe this phenomenon. The findings in the current study corroborate the concept that increased first metatarsal length, increased IM angle, and HV severity are related.

In addition to introducing the concept of the zero-plus first metatarsal, the authors also suggest abandoning the word "normal" to describe any metatarsal protrusion distance value. Not only does this data show that 58% of the control population has a metatarsal protrusion distance outside the "normal" range (Fig 5*B*), it also provides that 50% of the population with "normal metatarsal protrusion distance" (Fig 5*A*) developed HV deformity. The term "normal metatarsal protrusion distance" is thus inaccurate as it relates to frequency of occurrence and misleading as it relates to absence of pathology. The term "zero-plus" first metatarsal simply associates a long first metatarsal with an increased incidence of bunion formation and avoids the inaccuracy and ambiguity associated with "normal metatarsal protrusion distance."

The specific reference to how this "normal range" came to be or the method used for its determination is uncertain (9). Morton (2), in 1935, from which we get the concept of the short first metatarsal (Morton's foot), used an extraordinary measurement technique for the determination of first metatarsal protrusion (Fig 7). Using this technique, it is soon realized that as the IM angle increases there is an apparent shortening of the first metatarsal. This explains Morton's concept of the short first metatarsal as a cause of HV. The notion that a short first metatarsal is an etiologic factor in HV development may be flawed by the method used. It is the authors' belief that the short first metatarsal is not as common as has been accepted. In fact, the data from this article would show that a short metatarsal is an uncommon finding. If the length of the first metatarsal is measured by the presently accepted technique (9), one may conclude that a zero-plus first metatarsal is a recurrent factor in HV.

Harris and Beath (3), in their 1949 Canadian Army Foot Survey entitled "The Short First Metatarsal," challenged Morton's thesis on the incidence and clinical significance of the short first metatarsal. They described an alternative technique for the determination of first metatarsal protrusion distance, which may serve as the basis of the so-called "normal metatarsal protrusion" (3). When their data on metatarsal protrusion were plotted, they determined the majority of their population fell between +2 mm and −2 mm. It should be understood that, in addition to using a flawed measurement technique, the population in this survey was limited to 3600 young adult male recruits only. Most importantly, Harris and Beath (3) determined metatarsal protrusion distances from this select population irrespective of any pathology that may have existed. Therefore, the normal range of metatarsal protrusion distance in use today is based solely on its occurrence in the population and has little correlation with normal foot function.

Hardy and Clapham (6) questioned the accuracy of the works of Morton (2) and Harris and Beath (3) and devised an alternative technique for measuring relative metatarsal protrusion. They determined that Morton's technique was most inaccurate because the higher the IM angle, the further the first metatarsal head would move from the distal refer-

FIGURE 7 Morton's method for measuring metatarsal protrusion. From a bisection of the second metatarsal, a perpendicular line is drawn from the distal second metatarsal toward the first metatarsal. The distance from this perpendicular line to the distal first metatarsal is the metatarsal protrusion. Note that, as the IM angle increases, the distance between the distal first metatarsal and the perpendicular to the distal second metatarsal increases, giving the impression of a relatively shorter first metatarsal.

ence line, thereby allowing a false measurement of first metatarsal shortening. Even though Hardy and Clapham's method was slightly different from the presently accepted technique of measuring metatarsal protrusion (9), they did bisect the first and second metatarsals and draw arcs to their distal points. The radial distance between these 2 arcs was the metatarsal length protrusion. Hardy and Clapham (6) were the first to determine, "... that in cases of hallux valgus the first metatarsal is longer than in the controls."

The authors believe that an understanding of metatarsal length is vital in the selection of procedures to correct HV. First metatarsal osteotomy can produce varying amounts of absolute first metatarsal shortening. In addition, the orientation and morphology of the osteotomy will also affect length. This shortening effect may be useful in the maintenance of correction of HV. There is little mention of the effect of first metatarsal length when considering soft-tissue corrective procedures (12–19). The presence of a zero-plus first metatarsal may contribute to failure because the deforming force will not have been addressed. Of equal significance, the potential for overcorrection or hallux varus exists with a soft-tissue procedure. If a true McBride procedure (ie, fibular sesamoidectomy) is performed on a zero-plus first metatarsal, reverse buckling (20) may dominate, and the retrograde force of the hallux will induce the IM angle closure and hallux varus. Therefore, first metatarsal length should be an integral criterion in the selection of procedures for the correction of HV.

Conclusion

The authors have presented data supporting the relationship between the zero-plus first metatarsal and the formation of HV. Seventy-seven percent of our HV population had a zero-plus first metatarsal, whereas 28% of our control population had a zero-plus first metatarsal. Greater significance should be placed on first metatarsal length in HV surgical criteria.

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