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Radiographic Analysis of Feet With and Without Morton's Neuroma

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Abstract

Background: The aim of this research was to investigate the association of various structural measurements of the forefoot with Morton's neuroma (MN).

Methods: Weightbearing anteroposterior and lateral foot radiographs of subjects attending the University of Western Australia (UWA) Podiatry Clinic and the first author's private practice were included in this study. A single assessor measured the following angles: lateral intermetatarsal angle (LIMA), intermetatarsal angle (IMA), hallux valgus angle (HVA), digital divergence between the second and third digits (DD23), digital divergence between the third and fourth digits (DD34) and relative metatarsal lengths of the first to fifth metatarsals (Met1-5), and the effect of MN size as measured by ultrasonograph on digital divergence. Intratester reliability of all radiographic measurements was assessed on all radiographic measurements. The study included 101 subjects, of whom 69 were diagnosed with MN and 32 were control subjects without MN. The mean (± standard deviation) age of MN subjects was 52 (±15) years and for control subjects, 48 (±12) years.

Results: When comparing all feet, there were no significant differences in the LIMA, HVA, IMA, digital divergence angles and the relative metatarsal distances between subjects with MN and control subjects. No relationship between MN size and digital divergence was found in either foot, or in either neuroma location.

Conclusion: We were unable to demonstrate any relationship in this study between radiographic metatarsal length and angular measurements in a symptomatic MN group compared to a control group. In addition, we did not find any correlation between the size of MN as measured from ultrasonographic images and radiographic evidence of digital divergence.

Level of Evidence: Level III, case control study.

Keywords: Morton's neuroma, metatarsal length, radiographic measurements, digital divergence

Introduction

Morton's neuroma (MN) is a painful condition in the forefoot caused by swelling of the common digital plantar nerve to the affected interspaces.[36] Most literature indicates the nerve enlarges and becomes fibrosed as a result of repetitive trauma.[1,21,32,45] The diagnosis of MN has traditionally been based on clinical signs and symptoms. Pastides et al in a prospective study of 36 patients with histopathology-confirmed diagnosis of MN found Mulder's click to be the most sensitive clinical sign (98%).[31] In recent years, physicians often use the imaging modalities of MRI and ultrasonography to confirm the diagnosis. According to a recent systematic review, ultrasonography was more accurate than MRI in diagnosing MN with 90% sensitivity and 88% specificity.[46]

Injury to the nerve has been attributed to foot morphology,[2] ankle equinus,[3] and possibly the relative metatarsal lengths.[30] Recently, metatarsal shortening osteotomies have been recommended to decompress MN.[4,30] Morton believed the symptoms associated with the condition were probably the result of having a short first metatarsal that caused an overload of the lesser metatarsals, thus traumatizing the common digital nerve.[27] Patients with short and hypermobile first rays are observed to have higher plantar pressures beneath the second metatarsal, leading to transfer metatarsalgia.[17,34] Other factors are also discussed in the literature, such as the presence of

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Table 1. The Interspaces Affected With Morton's Neuroma for Right, Left, and Both Feet.

	2/3 Interspace	3/4 Interspace	Both Interspaces	Total
Right foot only	13	12	0	25
Left foot only	12	13	8	33
Both feet	4	1	6	11
Total	29	26	14	69
Right foot total	17	13	6	36
Left foot total	16	14	14	44

hallux valgus deformity and dorsiflexed first ray.[19,42,44] These potentially increase the pressure under the lesser metatarsal heads, which may lead to MN formation.

One phenomenon that can be seen radiographically in the assessment of patients with MN is digital divergence. This can conceivably occur as a result of enlargement of the bursa-neuroma complex, which may place pressure at the base of the affected proximal phalanges.[18,25,39] Digital divergence can also be seen in other pathologies such as digital contractures and plantar plate ruptures, which are normally ruled out as differential diagnoses when assessing MN. Grace et al did not find any relationship between MN and digital divergence.[18] However, their study did not include data on the size of the neuromas or on the interspaces that were affected by the divergences.

There are no published studies that compare MN patients with control subjects in terms of the metatarsal parabola and radiographic measurement. The aim of this research was to evaluate various structural measures in the forefoot of patients with MN.

Methods

Weightbearing anteroposterior (AP) and lateral foot radiographs of subjects attending the University of Western Australia (UWA) Podiatry Clinic as well as R.N.'s private practice were used in this study. One hundred and one subjects (69 with MN diagnoses and 32 controls) were recruited to the study, which was part of a larger research project investigating the etiology of MN. This research project was approved by the Human Research Ethics Committee of UWA (File reference no. RA/4/1/2543). All participants consented to the use of their radiographs for this study. The mean (± standard deviation) age of MN subjects was 52 (±15) years and for control subjects, 48 (±12) years. The 69 MN subjects had 80 affected feet; the right foot was affected in 36 subjects and the left foot in 44 subjects. The number of interspaces affected for both right and left feet of MN subjects is shown in Table 1.

Inclusion criteria for MN subjects were a minimum of 6-month history of neuroma symptoms, a clinically demonstrated painful Mulder's click with ultrasonographic confirmation of MN. Ultrasonographic diagnosis of MN was made by an experienced musculoskeletal radiologist and assessed on both transverse and longitudinal axes as an abnormal ovoid hypoechoic thickening corresponding to the location of maximum tenderness.[11] Each MN subject was clinically examined by the corresponding author and by an experienced musculoskeletal radiologist to rule out any other source of pain such as capsulitis and lesser metatarsal phalangeal joint instability such as plantar plate pathology. The inclusion criterion for control subjects was a negative history of MN or neuroma-like pain in the forefoot. Exclusion criteria for both neuroma and control groups were any previous history of surgery to the lower extremity, any proximal nerve entrapment at the level of the ankle, knee, hip, or back; any history of significant trauma to the forefoot area (including plantar plate pathology); metatarsus adductus greater than 15°; any difficulty in walking or standing; diabetes; or a history of systemic arthritis.

A single assessor performed the radiographic measurements for each patient using standard weightbearing AP and lateral radiographs. The following angles were measured: lateral intermetatarsal angle (LIMA), intermetatarsal angle (IMA), hallux valgus angle (HVA), digital divergence between the second and third digits (DD23), digital divergence between the third and fourth digits (DD34), and relative metatarsal lengths of the first to fifth metatarsals (Met1-5). All radiographic measurements were performed via an InteleViewer System computer program (http://www.intelerad.com/en/products/inteleviewer/). Intratester reliability of all radiographic measurements was assessed on radiographs from 5 randomly selected subjects. These were reassessed 1 week after the initial measurements had been made and established the test-retest reliability of the radiographic measurements used in the study.

The LIMA was determined from the weightbearing lateral radiograph by placing a tangential line over the central portion of the dorsal cortex of the first and second metatarsal shafts. The angle between the 2 tangential lines was measured as described by Bryant et al (Figure 1).[7] If the lines diverged distally the value was positive, and if the lines converged it was given a negative value.

The HVA angle was formed by bisecting the proximal phalanx and the first metatarsal, and measured as described by Gerbert (Figure 2).[16] The IMA was formed by the bisection of the first and second metatarsal (Figure 2).

The digital divergence angles (DD23 and DD34) were formed by bisecting the proximal phalanges of the second, third, and fourth digits. The angles between these bisection lines were measured to assess the relative divergence of the digits on the affected interspaces (Figure 3).

The relative metatarsal distances were measured by using the Maestro technique (Figure 4).[24] The reliability of this measurement technique has been favorably reported in the

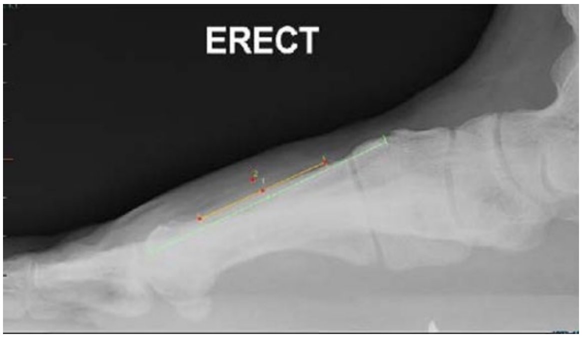

Figure 1. Radiograph demonstrating Lateral intermetatarsal angle (LIMA).

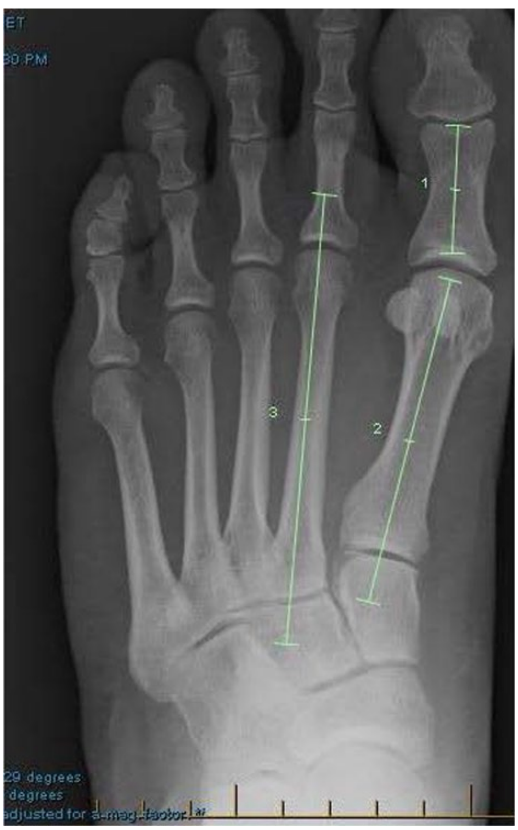

Figure 2. Hallux valgus and intermetatarsal angles.

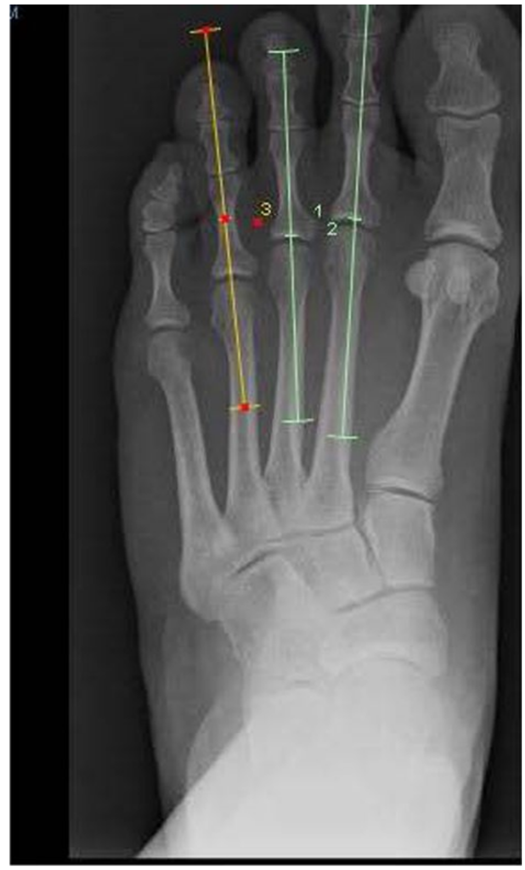

Figure 3. DD23 and DD34 measurements. DD23, digital divergence between the second and third digits; DD34, digital divergence between the third and fourth digits.

literature.[12] First, the M1 axis, defined as the "axis of the foot," was drawn from the midpoint of the medial talar head to the distal lateral aspect of the calcaneocuboid joint. Next the SM1 line was drawn perpendicular to the M1 axis such that it bisected the fibular sesamoid. A line was then drawn parallel to the SM1 line tangentially to the apex of the head of the second metatarsal called the SM2 line. The purpose of having SM2 was to measure the distance of all metatarsals relative to the second metatarsal. The relative length of each metatarsal was the measurement of the perpendicular line drawn from the apex of each metatarsal to the SM2. If the perpendicular line was above SM2, the value was assigned as negative, whereas if below, a positive value was given.

The intraclass correlation coefficient (ICC) for the LIMA, IMA, DD23, and DD34 angles and the metatarsal distance measurements ranged between 0.95 and 0.99, values that are considered to be excellent.[33]

The size of MN was based on measurements from the transverse ultrasonographic image as reported by radiology reports. Only participants with a transverse view measurement were included in this study.

Data were entered into Microsoft Excel and exported to IBM SPSS Statistics v23 for analyses. Independent sample t tests were used to compare the angle and distance measurements between the MN and control groups. Right and left feet were analyzed separately to ensure data were independent. In addition, metatarsal length measurements of subjects with single neuromas were compared to those of control subjects. For these analyses,

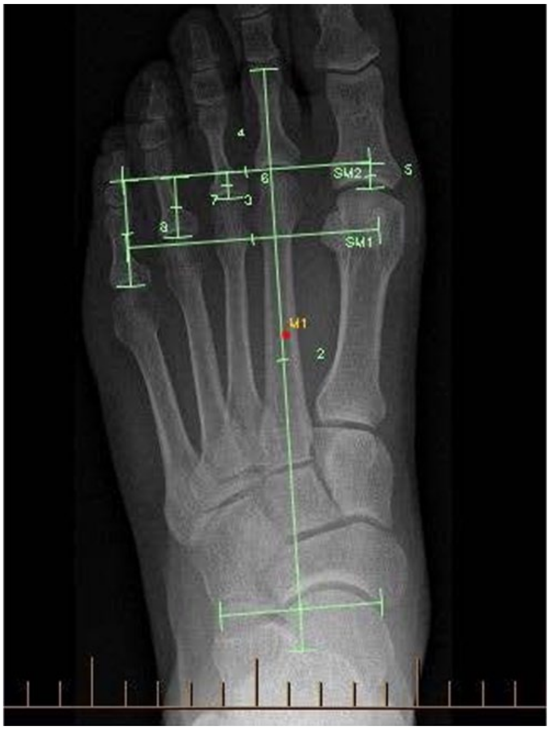

Figure 4. Maestro technique to assess relative metatarsal lengths.

as well as distinguishing between right and left feet, the second and third interspaces were evaluated separately. Mann-Whitney *U* tests (MWU) were performed to take into account the reduced sample sizes and the non-normality of the distributions of some of the measurements. Spearman rank correlation coefficients were used to assess relationships between neuroma size and digital divergence. Feet with both the 2/3 and 3/4 interspaces affected were not included as increased divergence in one interspace may have affected the divergence in the adjacent interspace.

As insufficient data were available before this study to allow sample size calculations, retrospective power calculations were conducted using PS: Power and Sample Size Calculation.[15] No mathematical correction was made for testing multiple associations. Instead, all results including 95% confidence intervals and *P* values <.05 are reported.

Results

When comparing all feet, there were no significant differences in the LIMA, HVA, IMA, digital divergence angles, and the relative metatarsal distances between subjects with MN and control subjects (Table 2).

Second Interspace Measurement Comparison

In the left foot there was a significant difference in the IMAs of the MN subjects compared to the control subjects (mean 10.7 vs 8.2, MWU *P* = .02; Table 3). In the right foot there was a significant difference in the mean of the fifth metatarsal length of the MN subjects compared to control subjects (mean 3.1 vs 2.7, MWU *P* = .01). In the left foot the DD34 angles of the MN and control subjects differed significantly (mean 2.0 vs 4.1, MWU *P* = .02), and in the right foot similar differences were seen (mean 0.9 vs 4.4, MWU *P* < .001).

Third Interspace Measurement Comparison

In the left foot there was a significant difference in the Met4 of the MN subjects compared with the control subjects (mean 1.3 vs 1.5, MWU *P* = .02; Table 3). Similarly, in the right foot the Met3 and Met4 lengths of the MN and control subjects differed significantly (mean 0.4 vs 0.5, MWU *P* = .03, and mean 1.1 vs 1.3, MWU *P* = .02, respectively).

The average MN size was 7.5 mm (range 3-12 mm) in transverse section as measured on ultrasonograph. No relationship between MN size and digital divergence was found in either foot, or in either neuroma location (Table 4).

Discussion

Metatarsal shortening osteotomy for "decompression" of MN was introduced by Park et al in 2013.[30] They retrospectively compared the outcomes for deep transverse metatarsal ligament (DTML) release in 46 MN patients with those of 40 MN patients who underwent both DTML release and shortening of a lesser metatarsal using a Weil osteotomy. In their preoperative evaluation of patients, metatarsal lengths were measured according to the technique described by Maestro et al. A Weil shortening osteotomy was performed on the longer metatarsal adjacent to the affected interspace. Outcomes were measured using the Foot Function Index and the American Orthopaedic Foot & Ankle Society Forefoot Score. The outcomes for the group that received DTML release with Weil osteotomy were significantly better than those of the group that received DTML release only. There are no published case-control studies that evaluated the relative metatarsal lengths of patients with MN compared to a control group. We therefore undertook this study using the radiographic measurements described by Maestro et al in order to explore the validity of performing a lesser metatarsal osteotomy for MN. We found no significant differences in the relative lengths of metatarsals between the feet of MN and control subjects. However, some unusual findings were made for the single interspace comparisons with controls. These may be due to chance, however, and due to the relatively small sample size.

Table 2. Comparison of Radiographic Measurements Between MN and Control Groups by Foot Affected.

	MN (L) (n = 43)	Control (L) (n = 32)	*P* Value[a] (95% CI)	MN (R) (n = 37)	Control (R) (n = 32)	*P* Value[a] (95% CI)
LIMA	0.3 ± 3.0	−0.2 ± 2.1	0.45 (−0.77, 1.72)	0.6 ± 1.9	0.1 ± 2.2	0.26 (0.44, 1.57)
HVA	13.4 ± 7.2	11.3 ± 7.2	0.28 (−1.78, 5.94)	13.0 ± 9.1	10.6 ± 7.1	0.22 (−1.50, 6.41)
IMA	9.6 ± 3.3	8.2 ± 2.5	0.05 (−0.02, 2.76)	8.6 ± 3.1	8.0 ± 2.8	0.40 (−0.82, 2.00)
DD23	7.7 ± 6.0	5.6 ± 4.5	0.07 (−0.33, 4.68)	7.0 ± 5.1	5.1 ± 4.7	0.11 (−0.45, 4.26)
DD34	3.6 ± 3.9	4.1 ± 3.7	0.60 (−2.25, 1.32)	3.0 ± 3.7	4.4 ± 4.0	0.15 (−3.18, 0.52)
Met1	0.3 ± 0.2	0.2 ± 0.6	0.66 (−0.14, 0.23)	0.2 ± 0.4	0.3 ± 0.3	0.59 (−0.20, 0.11)
Met3	0.5 ± 0.2	0.6 ± 0.2	0.64 (−0.11, 0.07)	0.5 ± 0.2	0.5 ± 0.2	0.49 (−0.06, 0.13)
Met4	1.4 ± 0.4	1.5 ± 0.2	0.45 (−0.18, 0.08)	1.4 ± 0.4	1.3 ± 0.3	0.45 (−0.09, 0.21)
Met5	2.9 ± 0.5	2.9 ± 0.3	0.88 (−0.19, 0.17)	2.9 ± 0.5	2.7 ± 0.3	0.16 (−0.05, 0.33)

Abbreviations: MN, Morton's neuroma; L, left; R, right; CI, confidence interval; LIMA, lateral intermetatarsal angle (degrees); HVA, hallux valgus angle (degrees); IMA, first and second intermetatarsal angle (degrees); DD23, digital divergence between second and third toes (degrees); DD34, digital divergence between third and fourth toes (degrees); Met1, relative first metatarsal length (cm); Met3, relative third metatarsal length (cm); Met4, relative fourth metatarsal length (cm); Met5, relative fifth metatarsal length (cm);
[a]*P* value reported by independent sample *t* tests.

Table 3. Comparison of Radiographic Measurements in Subjects With MN in the Second and Third Interspaces, Right and Left Foot (see Table 2 for Control Values).

	2/3L (n = 16)	*P* Value MWU (95% CI)	2/3R (n = 17)	*P* Value (95% CI)	3/4L (n = 14)	*P* Value (95% CI)	3/4R (n = 12)	*P* Value (95% CI)
LIMA	−0.3 ± 4.3	0.24 (−1.94, 1.72)	1.0 ± 1.9	0.17 (−2.22, 0.36)	0.3 ± 1.6	0.30 (−0.82, 1.71)	−0.1 ± 2.3	0.59 (−1.31, 1.69)
HVA	15.2 ± 9.7	0.12 (−1.12, 8.83)	15.0 ± 8.5	0.09 (−9.01, 0.13)	11.7 ± 5.5	0.77 (−3.92, 4.78)	12.4 ± 10.2	0.90 (−7.30, 3.65)
IMA	10.7 ± 3.5	0.02 (0.70, 4.25)	8.7 ± 2.4	0.42 (−2.31, 0.90)	8.8 ± 2.3	0.70 (−1.05, 2.12)	9.1 ± 4.1	0.63 (−3.28, 1.05)
DD23	9.0 ± 7.2	0.05 (−0.67, 7.46)	7.6 ± 4.7	0.11 (−5.33, 0.32)	4.9 ± 4.6	0.62 (−3.54, 2.30)	4.9 ± 4.2	0.74 (−2.90, 3.32)
DD34	2.0 ± 2.7	0.02 (−4.1, 0.05)	0.9 ± 2.9	0.001 (1.29, 5.70)	4.7 ± 4.7	0.85 (−1.99, 3.23)	6.4 ± 3.0	0.07 (−4.60, 0.51)
Met1	0.3 ± 0.2	0.61 (−1.9, 0.39)	0.1 ± 0.3	0.10 (−0.41, 0.35)	0.3 ± 0.1	0.90 (−0.24, 0.37)	0.3 ± 0.3	0.57 (−0.26, 0.15)
Met3	0.5 ± 0.2	0.45 (−0.12, 0.10)	0.6 ± 0.2	0.10 (−0.20, 0.01)	0.4 ± 0.2	0.07 (−0.23, 0)	0.4 ± 0.2	0.03 (−0.02, 0.21)
Met4	1.5 ± 0.3	0.98 (−0.11, 0.21)	1.5 ± 0.3	0.05 (−0.36, −0.02)	1.3 ± 0.3	0.02 (−0.35, 0)	1.1 ± 0.3	0.02 (0.02, 0.38)
Met5	3.0 ± 0.5	0.40 (−0.11, 0.35)	3.1 ± 0.4	0.01 (−0.53, −0.13)	2.7 ± 0.5	0.17 (−0.38, 0.08)	2.5 ± 0.4	0.08 (0.05, 0.47)

Abbreviations: 2/3L, second interspace mean and standard deviation left foot; 2/3R, second interspace mean and standard deviation right foot; 3/4L, third interspace mean and standard deviation, left foot; 3/4R, third interspace mean and standard deviation right foot); CI, confidence interval; MWU, Mann-Whitney *U* test.

Table 4. Correlation Between MN Size and Digital Divergence.

Foot	Position	n	*r*	*P* Value
Right	2/3	13	0.370	0.21
	3/4	11	0.135	0.69
Left	2/3	12	0.184	0.57
	3/4	12	−0.047	0.88

Menz et al evaluated relative metatarsal lengths using the Maestro technique in older people with forefoot pain (n = 40) and in a control group of older patients with no forefoot complaint (n = 70).[26] They found no association between pain in the forefoot and relative metatarsal lengths. However, using a MatScan system they found the peak plantar pressure under metatarsals 3 to 5 was significantly higher compared to the control group. They also observed a weak negative correlation between pressure in the forefoot and metatarsal length. Patients with forefoot pain were selected on a subjective basis and none had a confirmed diagnosis of MN. The increase in pressure under the lesser metatarsals in this elderly group can perhaps be explained by fat pad atrophy and stiffness of the forefoot.[9,23]

Kaipel et al[22] did not find any relationship between increased metatarsal length and plantar pressure in 91 patients with and without forefoot pain. They prospectively followed 2 groups of patients (51 feet in each group) with and without metatarsalgia, measured the relative metatarsal lengths using the Maestro et al technique, and performed plantar pressure measurements on an EMED-SF1 platform. These workers reported that relative metatarsal length had no effect on peak pressure or peak force. Their findings question the rationale of performing shortening osteotomies such as Weil osteotomy for the management of metatarsalgia.

Morton was the first to propose that hypermobility of the first ray resulting from a short first metatarsal and/or dorsal extension of the first metatarsal can lead to the lateral transfer of load to metatarsals 2 to 5.[27,28] This phenomenon, known as "first ray insufficiency,"[8,42] can lead to increased pressure in the lesser metatarsal area, and Morton suggested this could predispose to MN formation.[10,42,43] Breusch et al reported MN development following Wilson osteotomy, which significantly shortens the first metatarsal.[6] Bauer et al also reported that short length of the first metatarsal is a risk factor for recurrence of MN after open neurectomies.[4] However, using a technique first described by Hardy and Clapham, Grebing and Coughlin measured the relative difference in lengths of the first and second metatarsals for 46 control, 53 hallux valgus, 54 hallux rigidus, and 49 MN patients. They found no correlation between shortness of the first metatarsal and hypermobility of the first ray in all groups investigated.[10] Similarly, our study found no significant difference between the MN and control groups with regard to the first metatarsal lengths or the relative lengths of the first and second metatarsals. Collectively, these findings question Morton's belief that short first metatarsals cause MN formation.

Measurement of the LIMA was used to evaluate the relationship between first ray dorsiflexion and MN formation. We used the LIMA to determine whether the dorsal cortex of the first metatarsal was more elevated in relation to the second metatarsal on weightbearing lateral view of subjects. In our study, even though the first metatarsal was more elevated in the MN group the differences were not statistically significant. Roukis reported LIMA measurements of MN patients (n = 50) and compared them to a group of patients with hallux rigidus, hallux valgus, and plantar fasciitis.[35] He found that LIMA in the hallux rigidus group was significantly greater than in other groups, including MN. Horton et al also measured first ray elevation using a different technique in 3 groups of patients with hallux rigidus (n = 146), asymptomatic controls (n = 50) and MN group (n = 64).[20] They reported no difference between the groups with respect to elevation of the first metatarsal head. Based on the review of the literature and on our present findings, a significant relationship between MN and first ray dorsiflexion cannot be demonstrated.

A limitation of measuring the LIMA is that the weightbearing lateral view depicts the foot during midstance.[20] The pathological forces in MN are most likely caused during propulsion when maximum force is applied to the forefoot. During initial and final propulsion, strong forces are applied to the metatarsal heads.[14] Future studies should investigate radiographically the change in first ray dorsiflexion from midstance through propulsion in order to assess the role of the first ray in transferring load to the forefoot.

Lateral shifting of the hallux and increases in the IMA have been described as possible causes of forefoot symptoms.[6,19,26,40,41,44] Dietze et al performed a radio-kinematic and pedobarographic study and found that in 8 patients with HVA and first ray instability, there was a significant increase in force transfer to metatarsals 2 to 4.[13] This transfer of force may cause overload to the forefoot and result in MN formation. Waldecker studied the plantar loading patterns in 50 patients with hallux valgus (HV) and metatarsalgia and in 50 patients with HV and no forefoot symptoms.[44] He found a significant increase in peak pressure from medial to lateral across the forefoot in patients with HV and forefoot pain. He explained this load transfer as a possible lack of the windlass mechanism which can occur as a result of increase in hallux valgus and increase in varus rotation of the first ray. In our study, we compared the HVAs and IMAs between the MN and control groups and found no significant differences.

To our knowledge, the only case control study on digital divergence was published in 1993 by Grace et al.[37] These workers did not find a significant increase in digital divergence in MN subjects (n = 48) compared to normal subjects (n = 100). Their study did not state the size of the neuromas, nor did they report the divergence angles of the second and third interspaces separately. We found no significant differences in the DD23 and DD34 angles between MN and control groups. Based on the data available, we found no correlation between size of the MN and digital divergence.

One limitation of our study relates to statistical power. Retrospective calculations indicate the study had a power between 0.54 and 0.78 to detect differences of 2 mm in Met measurements, and a minimum power of 0.83 to detect a difference of 5 degrees in angle measurements when all MN and control subjects were compared. However, for the single interspace and digital divergence analyses, the sample size and hence statistical power was reduced. Another limitation of our study may be that females were approximately twice as frequent in our MN group. However, this represents the normal demographic presentation of MN as indicated by the 3-fold higher rate of hospital admission for MN among females in Australia compared to males.[29] Another potential limitation is the use of 2-dimensional weightbearing AP radiographs when examining the metatarsal length. It would also be important to assess sagittal plane measurements of metatarsals when investigating increased pressure of the forefoot as an etiology of MN, as suggested by Bauer et al.[4] Future studies could conceivably measure coronal images of the transverse arch to assess the relative height of the metatarsals relative to the ground. As recommended by some statisticians,[5,38] no statistical correction was made for multiple testing and instead all results are reported. Thus, some of the significant associations observed here could be due to chance.

Conclusion

In conclusion, we were unable to demonstrate any relationship between metatarsal length and MN formation in symptomatic MN patients compared to a control group. Therefore, based on these results and in the absence of an irregular lesser metatarsal parabola, it is difficult to justify metatarsal shortening procedures as a routine surgical treatment of MN. Furthermore, we found no correlation between the sizes of MN estimated using ultrasound images and radiographic evidence of digital divergence. Lastly, we found no relationship between first ray dorsiflexion or shortness of the first metatarsal and presence of MN, which questions the validity of Morton's early thoughts on the etiology of MN.

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Declaration of Conflicting Interests

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