METATARSUS ADDUCTUS: Radiographic and Pathomechanical Analysis

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INTRODUCTION

Metatarsus adductus is deformity of the foot defined as a uniplanar transverse plane deformity where the metatarsals are adducted at Lisfranc joint (1-3). The measurement of the metatarsus adductus angle has classically been described as the angle between the longitudinal axis of the second metatarsal (representing the longitudinal axis of the metatarsus) and the longitudinal axis of the lesser tarsus. The measurement of the longitudinal axis of the lesser tarsus has been described three ways. Classically, the longitudinal axis of the lesser tarsus has been described as the line perpendicular to the transverse axis of the lesser tarsus. Two ways are described in the literature to measure the transverse axis of the lesser tarsus. Medially, both ways use the midpoint between the line connecting the talonavicular joint and the first metatarsal cuneiform joint. Laterally, one method uses the lateral joint of the fourth metatarsal with the cuboid as a reference (MAA4) (Figure 1A) (4,5). Others use the lateral joint of the fifth metatarsal with the cuboid as a reference (MAA5) (Figure 1B) (6-8). Engel described the longitudinal axis of the lesser tarsus as the longitudinal axis of the second cuneiform (Figure 1C) (9).

Prior to the advent of digital radiography, MAA4 and MAA5 measurement techniques were time consuming and cumbersome for clinical practice. Therefore, the simple technique described by Engel gained popularity. Engel's angle is much easier to draw and has also been shown by Thomas (10) to be reproducible by. The MAA4 and MAA5 have both been shown to have strong intra-observer and inter-observer reliability when measuring these angles radiographically (6,7,11-12). Although Engel concluded that his measurement correlated well to the MAA5 technique, closer examination of the data call into question the strength of the Pearson correlation coefficients(r); many of the r values, although statistically significant, are closer to 0 than 1 indicating poor correlation (9).

Like metatarsus adductus, digital deformity is a common foot deformity encountered by the foot and ankle surgeon. Multiple contributing factors to the development of digital deformity have been suggested including rheumatoid arthritis, plantar plate tear, second metatarsophalangeal joint (MPJ) stress syndrome, and imbalance between intrinsic or extrinsic musculature of the foot. An imbalance can occur between the intrinsic and extrinsic muscles of the foot secondary to a peripheral neuropathy such as diabetes or Charcot Marie Tooth. In addition, flexor stabilization, flexor substitution, and extensor substitution are all causes of imbalance between intrinsic and extrinsic musculature of the foot. Each cause of digital deformity mentioned above predominantly describe pathological force or imbalance in the sagittal plane. We are not aware of any research investigating a transverse plane deformity as a possible destabilizing force across the MPJ giving rise to digital deformity.

Multiple studies have suggested a larger MAA as a factor in contributing to multiple foot pathology: hallux abducto valgus (4,13,14), lateral metatarsal fractures (15,16), and hindfoot deformity (17). There have been no studies to investigate the relationship between the metatarsus adductus angle and hammertoe deformity. Adducted metatarsal heads would move the fulcrum of the

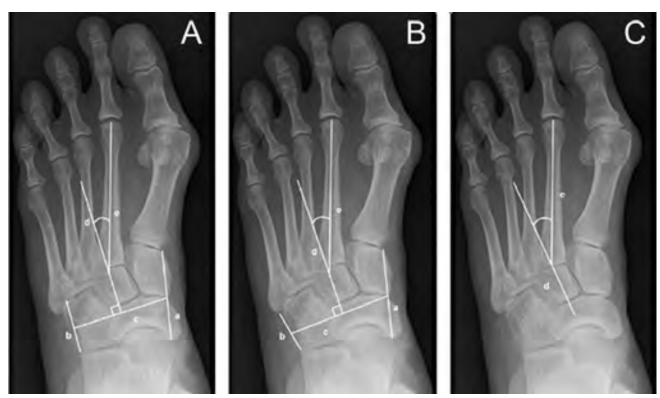


Figure 1A. Metatarsus Adductus Angle (MAA4) using the 4th metatarsocuboid joint as reference. Line (a) is between the most distal medial point of the talonavicular joint and the medial point of the 1st metatarsal cunieform joint. Line (b) is between the most lateral point of the calcaneo-cuboid joint and the most lateral point of the fourth metatarsocuboid joint. (B) Metatarsus Adductus Angle (MAA5) using the lateral fifth metatarsocuboid joint as reference instead of the most lateral point of the fourth metatarsocuboid joint . Line (a) is between the most distal medial point of the talonavicular joint and the medial point of the 1st metatarsal cunieform joint . Line (b) is between the most lateral point of the calcaneo-cuboid joint and the most lateral point of the fifth metatarsocuboid joint. (C) Engel's Angle. Line (d) bisects the middle cuneiform. Line (e) is the longitudinal axis of the second metatarsal.

pull of the tendons across the MPJ laterally; thus causing additional imbalance of intrinsic and extrinsic musculature across the MPJ.

The aim of this study was twofold. Primarily, we wanted to investigate the relationship between metatarsus adductus angle and the presence of digital deformity to lend support to the idea that transverse plane deformity can contribute to a primarily sagittal plane deformity of digital contracture. Secondly, we wanted to examine Engel's angle and MAA4 techniques using digital radiography for reliability, reproducibility, and correlation to the traditional measurement of MAA5. We hypothesized that patients with digital deformities would have significantly higher metatarsus adductus angle measurements compared to patients without digital deformity. In addition, we hypothesized that Engels angle would be reproducible but correlate poorly to the traditional measurement of MAA5.

MATERIALS AND METHODS

Patient Population

Anterior posterior weight-bearing radiographs from 99 consecutive patients with the diagnosis of hammertoe and 99 consecutive patients without hammertoe seen between January 1, 2009 and January 31, 2013 were collected retrospectively from the practice of the primary author. Exclusion criteria included any patient with one or more of the following diagnoses: rheumatoid arthritis, peripheral neuropathy, diabetes, neuromuscular disease, and Charcot-Marie-Tooth. Patients were included in the hammertoe group if they had a diagnosis of hammertoe as indicated by ICD9 code 735.4. Patients were included in the control group if they did not have any hammertoe and they did not meet any of the exclusion criteria.

Measurement of the Metatarsus Adductus Angle

The metatarsus adductus angle was measured on digital anterior posterior weight-bearing radiographs by the second author who was blinded to which group the radiographs belonged. Three different measurements were taken corresponding to the three major methods of measuring the metatarsus adductus angle described in the literature (Figure 1). The measurements were made using Tiger View imaging system angular drawing and calculation software.

Intra-Rater Reliability Study

Ten radiographs from each group were randomly selected using randomizer.org algorithm to generate 10 random numbers between 1 and 200. Those patients with corresponding subject identification numbers were selected to participate in the intra-rater reliability study. One evaluator, the second author, made all three measurements for each radiograph at three different times separated by 1 week. Before each measurement session, the order of the patients was randomized so that the radiographs viewed would not be in the same order as the previous weeks measurements.

Statistical Analysis

Data were analyzed using IBM SPSS professional software. The mean (95% confidence intervals) metatarsus adductus angle measured using the three methods for each group were calculated. The Kolmogorov-Smirnov test for normality indicated that the best test to compare the means between the hammertoe and control group would be the student t test for independent samples. We then examined the incidence of hammertoes in a small subset of the population with MAA4 greater than 21 degrees and MAA5 greater than 24 degrees. To measure the reliability of the measurement, the intra-class correlation coefficient was calculated by using the single-factor, random-effects model. To study the relationship between angles, we calculated the average difference and range of difference between each measurement type. In addition, we calculated Pearson's correlation coefficient to specifically examine how the MAA4 and Engel's angle correlated to MAA5.

RESULTS

Patient Demographics

The subject demographics are shown in Table 1. In the hammertoe group, the mean age of the subjects was 65 years ±16 (range 20-97 years). There were 99 controls (135 radiographs) made up of 69 females (81 radiographs) and 30 males (39 radiographs). In the control group, there were 99 patients (134 radiographs) the mean age of the subjects was 55 years ± 16.46 (range 21-90 years). There were 62 females (81 radiographs) and 37 males (54 radiographs).

Metatarsus Adductus Angle

The mean metatarsus adductus angle, standard deviations, and *P* values for the total group, control group, and hammertoe group for each measurement technique are shown in Table 2. The mean metatarsus adductus angle MAA4 in the hammertoe group was 13.38 (± 5.67) compared to the control group, which was 12.09 (± 5.13). There was statistical significance between the two groups ($P = 0.05$). The mean metatarsus adductus angle using MAA5 in the hammertoe group was 17.4 (± 8.44) compared to 15.09 (± 5.29) in the control group. The difference between the two groups was statistically significant ($P = 0.005$). The mean metatarsus adductus angle using Engel's angle was 23.20 (± 7.39) in the hammertoe

Table 1

STUDY SUBJECT DEMOGRAPHIC DATA

	n	Age (Mean, STD, Range)	Radiographs Bilateral	Unilateral	Total Films
Controls					
Females	62	54 ±16.23 (20-97)	19	43	81
Males	37	57 ±16.86 (21-90)	17	20	54
Totals	99	55 ±16.46 (20-97)	36	63	135
HT					
Females	69	68 ±13.90 (22-97)	26	43	95
Males	30	58 ±17.48 (20-83)	9	21	39
Totals	99	65 ±16 (20-97)	35	64	134
Study Totals	198	60 ±16.73 (20-97)	71	127	269

Table 2

DESCRIPTIVE STATISTICS OF THE METATARSUS ADDUCTUS ANGLE

Total Measurement Type	Angle, Mean ± SD (95% CI) Sample (n=269)	Hammertoe (n=135)	Controls (n=100)	*P* Value
MAA1	16 (±) 7.0 (4.20-49.10)	13.38 (±) 5.67 (1.9-32.9)	12.09 (±) 5.13 (1.7-28.6)	*0.05*
MAA2	13 (±) 5.44 (range)	17.14 (±) 6.44 (4.7-42.4)	15.09 (±) 5.29 (1.2-31.9)	*0.005*
MAA3	22 (±) 5.97 (1.20-42.40)	23.20 (±) 7.39 (4.2-49.1)	20.73 (±) 6.38 (9-41.9)	*0.005*

Abbreviations: SD, standard deviation; CI, confidence interval

group compared to 20.73 (±6.38) in the control group. The difference between the two groups was statistically significant ($P = 0.005$).

Incidence of Hammertoe Deformity

The number of subjects, incidence of hammertoe, and incidence of controls with abnormal metatarsus adductus angles are given in Table 3. There were 20 radiographs with MAA4 greater than 21 degrees, 15 of the subjects (75%) had a diagnosis of hammertoe while 5 (25%) did not. There were 25 radiographs with MAA5 greater than 24 degrees, 18 (72%) had a diagnosis of hammertoe while 7 (28%) did not (Table 3). There were 20 radiographs with a MAA4 greater than 21 degrees; 75% of them had hammertoes. There were 25 radiographs with a MAA5 greater than 24 degrees; 72% of these patients had hammertoes.

Intra-Observer Reliability

Intra-class reliability coefficients (ICC) were 0.969 (0.92-0.98), 0.963 (0.91-0.98), 0.971 (0.93-0.98) for MMA4, MAA5, and Engel's angle respectively (Table 4). The data gathered for between-session reliability, the results demonstrated high reliability for the MAA4, MAA5, and Engel's angle.

Differences and Correlation of Techniques

The average difference, standard deviations, and ranges between measurement techniques are summarized in Table 5. The MAA5 technique was on average 3.38 (± 2.52) degrees larger than the MAA4 technique with a range of -11 to +4. Engel's angle was on average 5.85 (± 5.23) degrees larger than MAA5 with a range of -8.9 to +22.8. Engel's angle was on average 9.23 (±5.29) degrees larger than MAA4 with a range of -3 to + 23.

Table 3

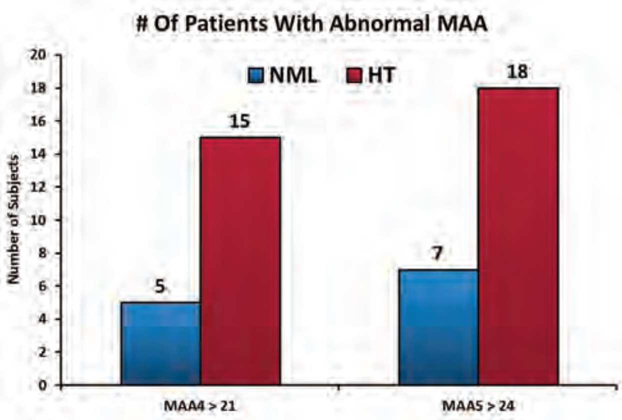


Table 4

INTRA-OBSERVER RELIABILITY

Measurement Type	ICC	CI 95%
MAA4	0.969	0.92-0.98
MAA5	0.963	0.91-0.98
Engel's	0.971	0.93-0.98

The Pearson's correlation coefficients comparing MAA4 to MAA5 and Engel's angle to MAA5 across a range of measurements are given in Table 6. From each 5 degree segment of the traditional metatarsus adductus angle, we calculated the correlation coefficient r with the Engel's angle and MAA4 and verified its statistical significance *P*. For MAA4, observing each range of the traditional method (MAA5) we found that 0 to 5.9 degrees yields r = 0.216 ($P = 0.364$); 6 thru 10 yields r = 0.529 ($P < 0.001$); 10.1 to 15 yields r = 0.57 ($P < 0.0001$); 15.1 thru 20 yields r = 0.468 ($P < 0.0001$); 20.1 thru 25 yields r = 0.461 ($P < 0.001$); >25 yields r = 0.83 ($P < 0.0001$). For Engel's angle, observing each range of the traditional method (MAA5) we found that 0 to 5.9 degrees yields r = 0.075 ($P = 0.452$); 6 thru 10 yields r = 0.118 ($P = 0.264$); 10.1 to 15 yields r = 0.087 ($P = 0.206$); 15.1 thru 20 yields r = 0.232 ($P < 0.05$); 20.1 thru 25 yields r = 0.043 ($P < 0.05$); >25 yields r = 0.642 ($P < 0.001$).

DISCUSSION

The typical contributing factors to digital deformity have been well documented, and typically involve a sagittal plane deforming force. Imbalance of intrinsic and extrinsic musculature of the foot and ankle has been the most common deforming force and can be caused by a multitude of pathology: peripheral neuropathy, neuromuscular disease, flexor substitution, flexor stabilization, extensor substitution, plantar plate pathology, second MPJ stress syndrome, and rheumatoid arthritis. Multiple studies have suggested a larger MA as a factor in contributing to multiple foot pathology: hallux abducto valgus (4,13,14), lateral metatarsal fractures (15,16), and hindfoot deformity (17). This is the first study to show the relationship between a larger metatarsus adductus angle and the presence of hammertoe deformity. Our data suggest that transverse plane deformity such as metatarsus adductus is a contributing factor in the development of hammertoe deformity. Primarily, the mean metatarsus adductus angle in patients with hammertoe deformity was larger and this reached statistical significance. In addition, in the subset of our patient population that had abnormal metatarsus adductus angles, the incidence of hammertoe deformity was approximately 75%. Ultimately, it is prudent to assess both sagittal plane deformity as well as transverse plane deformity when assessing the pathomechanics of hammertoe deformity. The transverse plane deformity, if present may need to be addressed in order to get long term correction.

MAA4 and MAA5 measurement techniques have been validated to be reliable and reproducible by many studies (6,7,11,12). Engel's angle has been said to also be reliable and reproducible. Engel's original study suggests Engel's angle correlates well to the traditional MAA5 technique (9). Closer examination of the results show correlation coefficients that are closer to 0 than to 1; suggesting poor correlation to MAA5. Our results show a poor correlation of Engel's angle compared to the MAA5 technique. In addition, the MAA4 technique shows much stronger correlation to the MAA5 technique. In addition, Engel's angle shows a much wider average difference with a significantly larger range of difference compared to MAA5 and MAA4. These results suggest that Engel's angle should be used with caution when attempting to estimate the metatarsus adductus angle as it has poor correlation and a wide range of difference compared to traditional techniques.

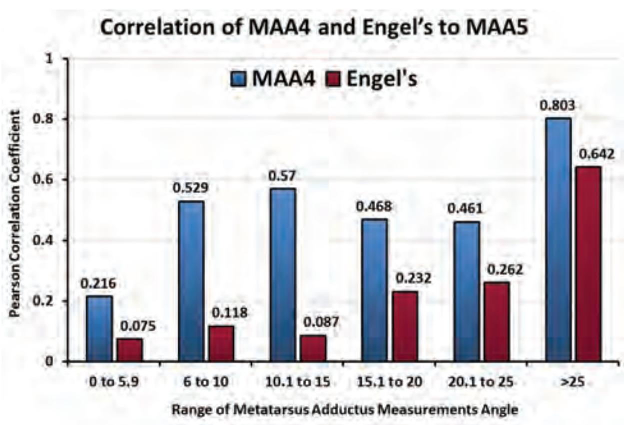
During this study, the lateral aspect of the fifth metatarsocuboid joint was cumbersome to identify and often arbitrary due to metatarsal overlap and shadow (Figure 2). However, identifying the lateral aspect of the fourth metatarsal cuboid joint was never cumbersome and easily identified on each radiographic study. Therefore, the authors recommend that the ideal measurement technique would be MAA4 as it is less cumbersome to identify across all radiographic studies, and shows a strong correlation to the traditional measurement of MAA5. It is important to remember that we found the average metatarsus adductus

Table 5

MEAN DIFFERENCE BETWEEN MEASUREMENT TECHNIQUES

Measurement	Average	Mean Difference ± STD (Range)		
		MAA4	MAA5	Engel's
MAA4	12.66	—	+3.38 (±)2.52 (-4 to +11)	+9.23 (±)5.29 (-3 to +23)
MAA5	16.12	-3.38 (±)2.52 (-11 to +4)	—	+5.85 (±)5.23 (-8.9 to +22.8)
Engel's	21.96	-9.23 (±)5.29 (-23 to +3)	-5.85 (±)5.23 (-22.8 to +8.9)	—

Table 6



angle using MAA4 was approximately 3.5 degrees smaller than the traditional measurement of MAA5.

The results of this study primarily support the idea that transverse plane deformity of the metatarsal heads contribute to a primarily sagittal plane deformity of digital contractures. In addition, when measuring the metatarsus adductus angle, Engel's angle should be used with caution as there is a wide range, large difference, and poor correlation compared to traditional measurement techniques. Lastly, the most ideal measurement technique to quickly and accurately assessing the metatarsus adductus angle would be using the four point technique with the lateral aspect of the fourth metatarsal cuboid joint as a reference.

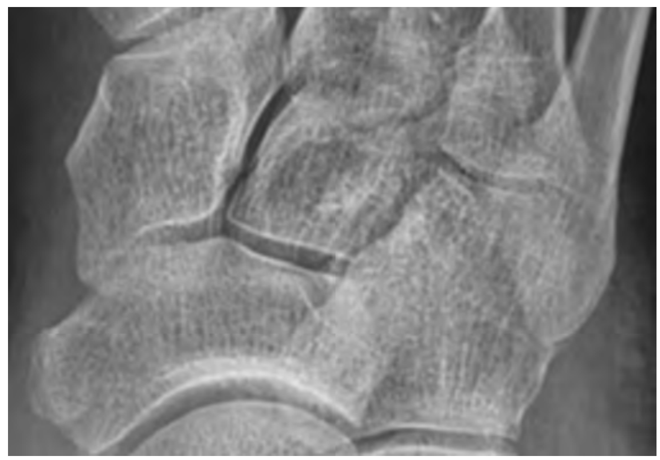


Figure 2. Landmarks of the fourth and fifth metatarsocuboid joints. The lateral aspect of the fifth metatarsal cuboid joint is very difficult to identify in this anterior-posterior weight bearing radiograph due to overlap of the cuboid and styloid process of the fifth metatarsal. However, the lateral aspect of the fourth metatarsal cuboid joint is easily identified in this subject.

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