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Assessment of Various Measurement Methods to Assess First Metatarsal Elevation in Hallux Rigidus

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Abstract

Background: While metatarsus primus elevatus (MPE) has been implicated in the development of hallux rigidus, previous studies have presented conflicting findings regarding the relationship between MPE and arthritis. This may be due to the variety of definitions for MPE and the radiographic measurement techniques that are used to assess it. Additionally, previous studies have only assessed elevation of the first metatarsal with respect to the floor or the second metatarsal, and not with respect to the proximal phalanx. The aim of this study was to examine the reliability of new radiographic measurements that consider the elevation of the first metatarsal in relation to the proximal phalanx, rather than in relation to the second metatarsal as previously described, to assess for MPE. In addition, we aimed to determine whether the elevation of the first metatarsal was significantly different in patients with hallux rigidus than in a control population.

Methods: A retrospective chart review was conducted from prospectively collected registry data at the investigators' institution to identify patients with hallux rigidus ($n = 65$). A size-matched control cohort of patients without evidence for first metatarsophalangeal (MTP) joint arthritis was identified ($n = 65$). Patients with a previous history of foot surgery, rheumatoid arthritis, or hallux valgus were excluded. Five blinded raters of varying levels of training, including 2 research assistants, 1 senior orthopedic resident, 1 foot and ankle fellowship-trained orthopedic surgeon, and 1 attending musculoskeletal fellowship-trained radiologist, evaluated 7 radiographic measurements for their reliability in assessing for MPE in hallux rigidus and control groups. Four of the 7 were newly designed measurements that include the relationship of the first MTP joint. Inter- and intrarater reliability were calculated using intraclass correlation coefficients (ICCs) and categorized by Landis and Koch reliability thresholds. The measurements between the hallux rigidus and control populations were compared using an independent *t* test.

Results: Six of the 7 radiographic measurements were found to have substantial to almost perfect interrater reliability (ICC, 0.800-0.953) between all levels of training, except for the proximal phalanx–first metatarsal angle, which showed moderate reliability (ICC, 0.527). Substantial to almost perfect intrarater reliability (ICC, 0.710-0.982) was demonstrated by the measurements performed by research assistants. All 7 of the measurements taken by the musculoskeletal fellowship-trained radiologist demonstrated significant differences in first metatarsal elevation between the hallux rigidus and control populations, with the hallux rigidus group showing increased elevation ($P < .001$-.019).

Conclusion: This study confirmed the reliability of 7 radiographic measurements used to assess for MPE, including 3 previously established and 4 newly described measurements. Observers across all levels of training were able to demonstrate reliable measurements. In addition, the measurements were used to show that patients with hallux rigidus were more

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likely to have MPE compared with patients without radiographic evidence for first MTP arthritis. These measurements could be used in future work to examine how the presence of MPE relates to the etiology and progression of hallux rigidus, and how it affects the results of operative treatment.

Level of Evidence: Level III, retrospective comparative study.

Keywords: hallux disorders, arthritis, hallux rigidus, first metatarsal elevation, metatarsus primus elevatus, first metatarsophalangeal arthritis, measurement

Introduction

"Hallux rigidus" is a term for degenerative arthritis in the first metatarsophalangeal (MTP) joint and is the most common arthritic condition of the foot.[10] Although it is recognized as a degenerative arthritic process, multiple causative factors[1,2,4,7,8,12-15] leading to the development of first MTP arthrosis have been proposed including trauma, osteochondritis dissecans, hereditary factors, poor shoewear, and anatomical differences such as forefoot pronation, hallux valgus deformity, a long first ray, and metatarsus primus elevatus (MPE).

MPE was first described by Lambrinudi in 1938, when he suggested it as an etiology of hallux rigidus.[9] Since then, many surgical procedures have been designed to treat hallux rigidus by lowering the elevation of the proximal end of the first metatarsal. While MPE has often been implicated in the development of hallux rigidus, previous studies have presented conflicting findings regarding the relationship between MPE and hallux rigidus.

Past studies have used several different measurements that assess the elevation of the first metatarsal above the second metatarsal to compare patients with hallux rigidus with controls.[3,6,17,18] Such measurements have also been used to assess the relationship between first ray elevation and the grade of hallux rigidus.[6] Some studies have suggested that MPE measurements can be used to predict the presence of hallux rigidus,[3] while others have concluded that measurements may be used to screen for the presence of elevation but not to define pathologic conditions.[19] In all of these previous studies, the measurements have been based on the elevation of the first metatarsal with respect to the second metatarsal or the plane of the floor, overlooking the importance of the relationship between the first metatarsal and the proximal phalanx at the joint. We hypothesize that elevation of the first metatarsal with respect to the first proximal phalanx may cause abnormal or increased loading at the MTP joint and lead to arthritis.

The current study therefore seeks to assess MPE by measuring the elevation of the first metatarsal to the proximal phalanx. The study aims to examine the inter- and intrarater reliability of new radiographic measurements that consider the elevation of the first metatarsal in relation to the proximal phalanx. It also seeks to determine whether the new measurements assess MPE differently from previous measurements. Furthermore, we aimed to determine whether the elevation of the first metatarsal was significantly different in patients with hallux rigidus than in a control population.

Methods

Study Design

This was a single-center, retrospective study conducted from prospectively collected registry data at the investigators' institution. Steering committee approval was obtained for the use of the foot and ankle registry approved by the institutional review board. All patients were diagnosed by either of the 2 senior authors (J.T.D., S.J. E.), both fellowship trained in orthopedic foot and ankle surgery. The study group included patients diagnosed with hallux rigidus, and the control group included patients diagnosed with Morton's neuroma. Consecutive patients seen from 2006 to 2015 were eligible for inclusion. Patients with hallux rigidus were identified using ICD-9 code 735.2 and ICD-10 code M20.20. Patients with Morton's neuroma were identified using ICD-9 code 355.6 and ICD-10 code G57.60. The diagnoses were all confirmed by reading patient charts and evaluating the initial presenting radiograph. Patients with hallux rigidus were identified first and then matched by age and gender with specific patients from the control group. A 1:1 match was created in each case. In the hallux rigidus group, inclusion criteria were a radiographic and clinical diagnosis of hallux rigidus in skeletally mature patients.[5] Exclusion criteria were a diagnosis of rheumatoid arthritis, prior surgeries of the first MTP joint, and a radiographic or clinical diagnosis of hallux valgus. In the control group, patients were included with a confirmed clinical diagnosis of Morton's neuroma. Patients were excluded from the control group with clinical or radiologic confirmation of pathology in the first MTP joint including hallux rigidus and hallux valgus.

Patient medical records were retrospectively reviewed for age, sex, laterality of condition, date of diagnosis, and radiographic assessment. Radiographs taken at the first diagnosis of hallux rigidus or Morton's neuroma were used. All radiographs were weightbearing and performed according to the standard of care at the investigators' institution. All measurements were taken on separate occasions with 2 weeks between measurements by 5 independent observers in a blinded, random fashion. The observers included 2 research assistants with bachelor degrees, 1 senior orthopedic surgery resident, 1 foot and ankle fellowship-trained orthopedic surgeon, and 1 musculoskeletal fellowship-trained attending radiologist specializing in foot and ankle conditions.

The study group consisted of 65 patients (mean age, 52.7 years; range, 25-76 years), and the control group

Table 1. Population Demographics.

		Hallux Rigidus	Control Group (Morton's Neuroma)	All Patients	*P* Value
Age, y	Mean (SD)	52.7 (9.7)	52.6 (9.9)	52.6 (9.8)	.972
	Range (min-max)	(25-76)	(22-77)	(22-77)	
Gender	No. of females (%)	49 (75)	49 (75)	98 (75)	>.999
	No. of males (%)	16 (25)	16 (25)	32 (25)	
Foot affected	No. of right feet (%)	40 (62)	32 (49)	72 (55)	.158
	No. of left feet (%)	25 (38)	33 (51)	58 (45)	

included 65 patients (mean age, 52.6 years; range, 22-77 years). The mean age for all patients was 52.6 $\pm$ 9.8 years, with 75% of the subjects being female. There were no considerable differences between the 2 groups (Table 1).

Radiographic Analysis

Radiographic analysis included 3 previously used and supported measurements in the assessment of MPE, as well as 4 newly proposed measurements by the authors. The 3 measurements previously described assess elevation of the first metatarsal relative to the floor or second metatarsal on the lateral view, including the first metatarsal declination angle,[6] Seiberg index,[18] and Bouaicha index.[3] The 4 measurements that have been newly proposed in this study assess elevation of the first metatarsal relative to the proximal phalanx on the lateral view. The newly proposed measurements include the first metatarsal uncoverage angle, first metatarsal midpoint uncoverage angle, first metatarsal longitudinal axis uncoverage angle, and proximal phalanx–first metatarsal angle. All observers were trained to measure all 7 radiographic parameters of interest. Each observer made measurements independently and was blinded to both patient identification and the measurements taken by others. All measurements were taken on separate occasions with 2 weeks between measurements and the order of images randomized. The 2 medically untrained research assistants took every measurement twice to confirm intrarater reliability. Since the measurements of the research assistants showed excellent intrarater reliability, it was decided that it would be unnecessary to further test intrarater reliability among the raters of higher training levels. The measurements taken by the musculoskeletal fellowship-trained radiologist were used for the analysis of correlations between the previously established and new measurements and the analysis on differences between controls and patients with hallux rigidus. To assess interrater reliability, the measurements taken by a research assistant, the fellowship-trained orthopedic surgeon, and the attending radiologist were compared.

Previously Used Measures of Metatarsus Primus Elevatus

All measurements were taken on the lateral view. The first metatarsal declination angle was defined as the angle between the longitudinal midline of the first metatarsal and the ground, with a smaller angle indicating increased elevation of the first metatarsal (Figure 1).[7] Prior studies have found patients with hallux rigidus to have an average first metatarsal declination angle of 20.6 $\pm$ 0.3 degrees and control patients to have an average first metatarsal declination angle of 20.2 $\pm$ 0.3 degrees.[6] The Seiberg index was defined as the difference between the perpendicular distance, in millimeters, from the dorsal aspect of the first metatarsal shaft to the dorsal aspect of the second metatarsal shaft at the neck of the first metatarsal and 15 mm from the base of the first metatarsal, with a larger distance indicating increased elevation (Figure 2).[18] If the distance between the dorsal aspects of the first and second metatarsal was larger proximally than distally, then the Seiberg index would be negative.[18] Prior studies have found patients with hallux rigidus to have an average Seiberg index of 1.8 $\pm$ 1.5 and patients with Morton's neuroma to have an average Seiberg index of 1.2 $\pm$ 1.6.[18] The Bouaicha index was measured by fitting a circle within the metatarsal head congruent with the joint surface, and then drawing a tangent line along the dorsal surface of the first metatarsal shaft and another vertical line perpendicular to the tangent line at the proximal point of intersection with the circle (Figure 3).[3] The Bouaicha index is defined as the distance between the points of intersection of the first and second metatarsal dorsal aspects and the vertical line.[3] A larger distance indicates increased elevation of the first metatarsal, and if the second metatarsal is elevated above the first metatarsal along this line, the measurement of the Bouaicha index would be negative.[3] A Bouaicha index greater than 5.0 mm has been found to be significantly correlated with hallux rigidus.[3] While the Bouaicha index only measures the elevation of the first metatarsal relative to the second metatarsal at the distal position of the head, the Seiberg index and first metatarsal declination angle both assess the angle at which the first metatarsal falls relative to the second metatarsal and the floor, respectively.

Newly Developed Measures of Metatarsus Primus Elevatus

The first metatarsal uncoverage angle was defined as the angle between a line drawn from the dorsal edge to the plantar edge of the first metatarsal joint surface and a line drawn from the plantar edge of the first metatarsal joint

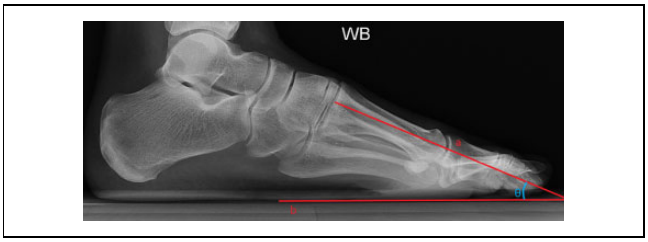

Figure 1. A weightbearing lateral radiograph shows the measurement of the first metatarsal declination angle. First, a line is drawn along the longitudinal midline of the first metatarsal (a), and then a line is drawn along the ground (b) and a measurement is taken of the angle formed by the intersection of those 2 lines (θ). A smaller angle indicates increased elevation of the first metatarsal as a smaller angle results when the distal head of the metatarsal is raised relative to the proximal base.

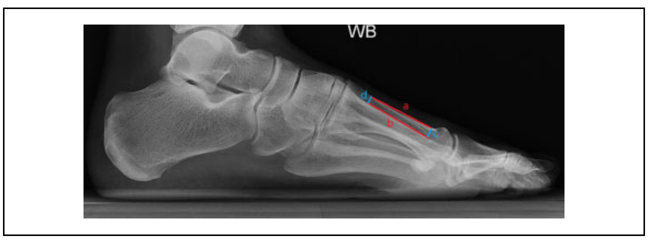

Figure 2. A weightbearing lateral radiograph demonstrates the Seiberg index. The first line is drawn along the dorsal aspect of the first metatarsal (a), and the second line is drawn along the dorsal aspect of the second metatarsal (b). Then the distance between the 2 lines is measured at the neck of the first metatarsal (c) and 15 mm from the base of the first metatarsal (d). The index is the difference between c and d (d subtracted from c), with a larger difference indicating increased elevation.

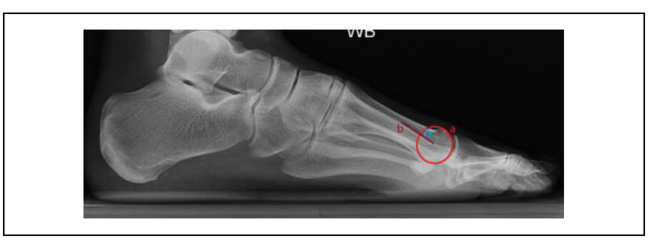

Figure 3. A weightbearing lateral radiograph demonstrates the Bouaicha index. First, a circle (a) is fit within the metatarsal head congruent with the joint surface. Then a line (b) is drawn along the dorsal surface of the second metatarsal until it intersects the circle. A perpendicular line (c) is drawn from the point where the circle intersects the dorsal aspect of the first metatarsal until it intersects with line b. The Bouaicha index is defined as the distance along that line (c). A larger distance indicates increased elevation of the first metatarsal.

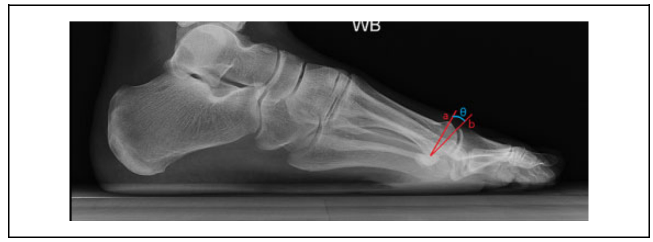

Figure 4. A lateral weightbearing radiograph shows the measurement of the first metatarsal uncoverage angle. First, a line is drawn from the dorsal edge to the plantar edge of the first metatarsal joint surface (a). Next, a line is drawn from the plantar edge of the first metatarsal joint surface to the dorsal edge of the proximal phalanx (b). The first metatarsal uncoverage angle is formed by the intersection of line a and line b (θ). An increased angle is indicative of increased metatarsal elevation.

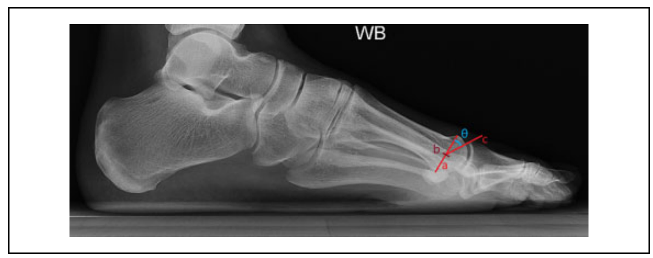

Figure 5. A lateral weightbearing radiograph shows the measurement of the first metatarsal midpoint uncoverage angle. First, a line (a) is drawn from the dorsal edge to the plantar edge of the first metatarsal joint surface. Next, the midpoint (b) of line a is identified. Then a line (c) is drawn from the midpoint (b) to the dorsal edge of the proximal phalanx. The first metatarsal midpoint uncoverage angle is the angle (θ) between line a at point b and line c. An increased uncoverage angle is indicative of increased metatarsal elevation.

surface to the dorsal edge of the proximal phalanx, with an increased angle indicating increased metatarsal elevation (Figure 4). The first metatarsal midpoint uncoverage angle was defined as the angle between a line drawn from the dorsal edge to the plantar edge of the first metatarsal joint surface and a line drawn from the midpoint of the first line to the dorsal edge of the proximal phalanx, with an increased uncoverage angle indicating increased metatarsal elevation (Figure 5). The first metatarsal longitudinal axis uncoverage angle was defined as the angle between a line drawn from the dorsal edge of the first metatarsal joint surface perpendicular to the first metatarsal longitudinal axis and a line from the point of intersection of the first line with the longitudinal axis and the dorsal aspect of the proximal phalanx (Figure 6). An increased first metatarsal longitudinal axis uncoverage angle indicates increased metatarsal elevation. The proximal phalanx–first metatarsal angle was defined as the angle between a line drawn along the dorsal aspect of the first metatarsal and a line drawn along the dorsal aspect of the proximal phalanx, with a smaller angle indicating increased metatarsal elevation (Figure 7). The line drawn along the proximal phalanx began at one-third and two-thirds the length of the proximal phalanx to account for variation in the shape of the proximal phalanx.

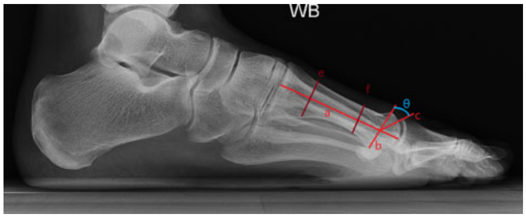

Figure 6. A lateral weightbearing radiograph demonstrates the measurement of the first metatarsal longitudinal axis uncoverage angle. First, 2 lines (e and f) are drawn from the dorsal to plantar edge of the first metatarsal. Another line (a) is drawn connecting the midpoints of lines e and f. Next, a line (b) is drawn that begins at the dorsal edge of the first metatarsal joint surface and is perpendicular to line a. Then a line (c) is drawn from the point where line a intersects line b to the dorsal aspect of the proximal phalanx. The first metatarsal longitudinal axis uncoverage angle is the angle (θ) between line b and line c. An increased uncoverage angle is indicative of increased metatarsal elevation.

Figure 7. A lateral weightbearing radiograph demonstrates the measurement of the proximal phalanx–first metatarsal angle. First, a line (a) is drawn along the dorsal aspect of the first metatarsal. Next, a line (b) is drawn to measure the length of the dorsal aspect of the proximal phalanx. That line is then trisected (at points c and d) and another line (e) is drawn between those 2 points. The proximal phalanx–first metatarsal angle is the angle (θ) between line a and line e. A smaller angle is indicative of increased metatarsal elevation.

Statistical Analysis

All analyses were performed using SPSS version 22.0 (IBM Corp, Armonk, NY). Descriptive statistics were reported as means and standard deviations for continuous variables, and discrete variables were reported as frequencies and percentages. Comparisons of continuous data including demographic, clinical, and radiographic data between study groups were analyzed using independent samples *t* tests. Chi-square tests were used to compare discrete variables between study groups. Two-way, random single measures intraclass correlation coefficients (ICCs) with 95% confidence intervals (CIs) were used to operationalize the intra- and interrater reliabilities. Interpretation of reliability values was based on the Landis and Koch classification (<0.00 = less than chance agreement; 0.01-0.20 = slight agreement; 0.21-0.40 = fair agreement; 0.41-0.60 = moderate agreement; 0.61-0.80 = substantial agreement; 0.81-0.99 = almost perfect agreement). Pearson correlation coefficients were used to evaluate the correlation between various radiographic measures. *P* values of .05 or less were considered statistically significant. Low correlations would suggest that the measures are not related, and thus measure different aspects of metatarsal elevation, while higher correlations would suggest an overlap between measures. Correlation coefficients from |0.90| to |1.00| represent a very high correlation, correlation coefficients from |0.70| to |0.90| represent a high correlation, correlation coefficients from |0.50| to |0.70| represent a moderate correlation, correlation coefficients from |0.50| to |0.70| represent a low correlation, and correlation coefficients from |0.00| to |0.30| represent a negligible correlation.[14]

Results

Intra- and Interrater Reliability

Intrarater reliabilities were determined based on measurements taken by 2 medically untrained research assistants. All measurements but one showed almost perfect agreement (Table 2). Interrater reliabilities were determined based on measurements taken by 2 medically untrained research assistants, 1 orthopedic foot and ankle fellow, 1 foot and ankle fellowship-trained orthopedic surgeon, and 1 musculoskeletal fellowship-trained attending radiologist specializing in the foot and ankle. All measurements showed substantial or almost perfect agreement (Table 3).

Correlation Between Previously Described Measurements and Newly Proposed Measurements

Correlation analyses were performed to determine whether the measurements were all assessing the same structural relationships, or if the new measurements were contributing new information. The proximal phalanx–first metatarsal angle was positively correlated with the first metatarsal declination angle (0.420; $P < .001$) and negatively correlated with the Seiberg index (–0.303; $P < .001$) and the Bouaicha index (–0.350; $P < .001$). The first metatarsal longitudinal axis uncoverage angle was negatively correlated with the first metatarsal declination angle (–0.383; $P < .001$) and positively correlated with the Bouaicha index (0.257; $P = .003$). All of the statistically significant correlations between measures demonstrated low correlation coefficients ($r = 0.257\text{-}0.420$). The remainder of the newly proposed measurements were not significantly correlated with the previously established measurements (Table 4).

Metatarsus Primus Elevatus in Controls Versus Hallux Rigidus

All 7 of the measurements taken by the attending radiologist demonstrated considerable differences in first metatarsal elevation between the hallux rigidus and control populations, with the hallux rigidus group showing increased elevation ($P < .001$ to $P = –.019$). A larger value indicates

Table 2. Intrarater Reliability of Radiographic Measurements Assessing for Metatarsus Primus Elevatus.

				95% CI			
		Radiographic Measurement	ICC	Lower Bound	Upper Bound	Agreement[b]	*P* Value
Rater 1[a]	Old	Seiberg index	0.959	0.942	0.971	Almost perfect	<.001
		Bouaicha index	0.970	0.958	0.979	Almost perfect	<.001
		First metatarsal declination angle	0.982	0.974	0.987	Almost perfect	<.001
	New	First metatarsal uncoverage angle	0.926	0.895	0.948	Almost perfect	<.001
		First metatarsal midpoint uncoverage angle	0.906	0.867	0.933	Almost perfect	<.001
		First metatarsal longitudinal axis uncoverage angle	0.948	0.927	0.963	Almost perfect	<.001
		Proximal phalanx–first metatarsal angle	0.959	0.942	0.971	Almost perfect	<.001
Rater 2[a]	Old	Seiberg index	0.881	0.831	0.916	Almost perfect	<.001
		Bouaicha index	0.957	0.940	0.970	Almost perfect	<.001
		First metatarsal declination angle	0.980	0.972	0.986	Almost perfect	<.001
	New	First metatarsal uncoverage angle	0.710	0.590	0.795	Substantial	<.001
		First metatarsal midpoint uncoverage angle	0.839	0.773	0.886	Almost perfect	<.001
		First metatarsal longitudinal axis uncoverage angle	0.902	0.861	0.931	Almost perfect	<.001
		Proximal phalanx–first metatarsal angle	0.932	0.904	0.952	Almost perfect	<.001

Abbreviations: CI, confidence interval; ICC, intraclass correlation coefficient.
[a]Raters 1 and 2 were medically untrained research assistants.
[b]Agreement based on the Landis and Koch classification.

Table 3. Interrater Reliability of Radiographic Measurements Assessing for Metatarsus Primus Elevatus Between Different Levels of Training.

			95% CI			
	Radiographic Measurement[a]	ICC	Lower Bound	Upper Bound	Agreement[b]	*P* Value
Old	Seiberg index	0.875	0.832	0.908	Almost perfect	<.001
	Bouaicha index	0.952	0.936	0.965	Almost perfect	<.001
	First metatarsal declination angle	0.949	0.932	0.963	Almost perfect	<.001
New	First metatarsal uncoverage angle	0.712	0.613	0.789	Substantial	<.001
	First metatarsal midpoint uncoverage angle	0.768	0.688	0.829	Substantial	<.001
	First metatarsal longitudinal axis uncoverage angle	0.845	0.792	0.886	Almost perfect	<.001
	Proximal phalanx–first metatarsal angle	0.889	0.851	0.919	Almost perfect	<.001

Abbreviations: ICC, intraclass correlation coefficient.
[a]Observers included 2 medically untrained research assistants, 1 foot and ankle fellow, 1 fellowship-trained foot and ankle orthopedic surgeon, and 1 fellowship-trained attending radiologist specializing in foot and ankle
[b]Agreement based on the Landis and Koch classification

increased elevation for all except 2 of the measurements; the first metatarsal declination angle and proximal phalanx–first metatarsal angle both indicate increased elevation with a smaller angle (Table 5).

Discussion

This study is proposing the use of new measurements to assess MPE. We believe the primary advantage of these novel measurements over traditionally used measurements is the utilization of angles between the proximal phalanx and first metatarsal instead of angles between the first and second metatarsal. While angles between the first and second metatarsal may be influenced by abnormal weight loading during standing foot radiographs, we believe the angles between the proximal phalanx and first metatarsal are more likely to reflect consistent elevation as well as the aspect of MPE that is most relevant to the pathology of hallux rigidus. Since these angles exist in the same sagittal plane, they could be used to assess MPE in weightbearing computed tomography scans, which is not possible using the previously established measurements since they must compare multiple sagittal planes. In this study, all of the radiographic measurements for MPE, including those newly proposed, were found to have considerable intra- and interrater reliability. Significant differences were found in first metatarsal elevation between the hallux rigidus and control populations, with the hallux rigidus group showing increased elevation.

A 1999 study originally used a measurement, the Horton index, assessing elevation of the first metatarsal above the second metatarsal to compare controls and patients with hallux rigidus, and also assessed the relationship between first ray elevation and the grade of hallux

Table 4. Correlations Between the Previously Established Measurements and the Newly Proposed Measurements.

	Radiographic Measurement[a]		Previously Established Measurements: Seiberg Index	Bouaicha Index	First Metatarsal Declination Angle
Newly proposed measurements	First metatarsal uncoverage angle	Pearson correlation	0.034	0.136	–0.147
		P value	.699	.124	.097
		N	129	129	129
	First metatarsal midpoint uncoverage angle	Pearson correlation	0.032	0.185	–0.168
		P value	.719	.036	.057
		N	129	129	129
	First metatarsal longitudinal axis uncoverage angle	Pearson correlation	0.161	**0.257**	**–0.383**
		P value	.068	**.003**	**<.001**
		N	129	**129**	**129**
	Proximal phalanx–first metatarsal angle	Pearson correlation	**–0.303**	**–0.350**	**0.420**
		P value	**<.001**	**<.001**	**<.001**
		N	**129**	**129**	**129**

[a]Measurements were taken by a fellowship-trained attending radiologist specializing in the foot and ankle. Bold type signifies statistical significance ($P < .01$)

Table 5. Comparison of Metatarsus Primus Elevatus in Patients With Hallux Rigidus Versus Controls.

	Radiographic Measurement[a]	Overall Mean	Overall SD	Control Group (Morton's Neuroma) Mean	Control Group (Morton's Neuroma) SD	Hallux Rigidus Mean	Hallux Rigidus SD	*P* Value	*d*
Old	Seiberg index	0.5	1.2	0.0	1.1	0.9	1.2	<.001	0.8
	Bouaicha index	4.7	1.8	4.0	1.6	5.5	1.6	<.001	0.9
	First metatarsal declination angle	20.6	4.2	22.2	3.9	19.0	3.8	<.001	0.8
New	First metatarsal uncoverage angle	25.8	5.2	24.7	5.5	26.8	4.6	.019	0.4
	First metatarsal midpoint uncoverage angle	44.0	7.8	41.6	7.5	46.5	7.5	<.001	0.7
	First metatarsal longitudinal axis uncoverage angle	46.7	8.1	44.2	7.6	49.2	7.8	<.001	0.7
	Proximal phalanx–first metatarsal angle	9.8	6.7	11.6	5.2	7.9	7.5	<.001	0.6

Abbreviation: SD, standard deviation.
[a]Measurements were taken by a fellowship-trained attending radiologist specializing in the foot and ankle.

rigidus.[6] On the basis of this measurement, they concluded elevation of the first ray to be a normal radiographic finding and found no direct linear relation between elevation and grade of hallux rigidus.[6] Results from our study, however, demonstrated that 7 measurements could be used to show that patients with hallux rigidus have a more elevated first metatarsal compared with patients without radiographic evidence for first MTP arthritis. We did not assess the relation between elevation and grade of hallux rigidus because it was determined that the grade of hallux rigidus may be an unreliable assessment.[16] In addition, we cannot prove whether the elevation of the first metatarsal leads to hallux rigidus or vice versa given the retrospective nature of this study.

In another study, several established measurements of MPE were used, including the index created by Seiberg for assessment of MPE, and found statistically significant differences between populations with hallux valgus, plantar fasciitis, and Morton's neuroma compared with a population with hallux rigidus.[17] In addition, the authors conducted a review of the literature to compare other control groups and demonstrated that MPE is greater in patients with hallux rigidus than other populations.[17] The results of our study agreed with these findings when comparing the Morton's neuroma and hallux rigidus populations, and further confirmed the reliability of the Seiberg index. In 2008, a study using yet another proposed measurement for MPE concluded that an MPE greater than 5 mm could be considered a predictive factor in the presence of hallux rigidus.[3] While our study confirmed the reliability of the Bouaicha index and found a significant difference in the measurement between a control and hallux rigidus population, we were unable to conclude whether the degree of MPE could be predictive of hallux rigidus.

A 2011 study analyzed the sensitivity and specificity of multiple measurements that assessed MPE. They concluded that 3 parameters, the Horton index, the Seiberg index, and the sagittal intermetatarsal angle, which is the angular divergence between dorsal shafts of the first and second metatarsal, had good sensitivity and could be used as screening tests for the presence of elevation, though not as a method of defining pathologic conditions.[19] The data from that study, like ours, were not sufficient to determine MPE to be an etiological factor of hallux rigidus, but did agree with our findings that MPE is significantly different in hallux rigidus and control populations.[19] The consistency of the data from Usuelli, Bouaicha, and Roukis and the present study does support MPE to be an important factor in the development of hallux rigidus. Whether it is involved as an etiological factor or a sequela, however, should be determined in future studies. Our newly proposed measurements were unique from those previously analyzed because they assess elevation of the first metatarsal compared with the proximal phalanx, while those previous studies only assessed elevation of the first metatarsal compared with the second metatarsal or the floor.

A 2008 study claimed that MPE is more common than past studies have suggested, and even advocates for a surgical intervention with the intent of correcting first ray elevation.[11] Considering the use of surgical interventions to treat hallux rigidus by decreasing the elevation of the first ray, and the proposal of surgical interventions to correct first ray elevation, it is important to identify reliable measurements that can be used to assess first ray elevation. The current study has confirmed the reliability of 7 such measurements. Our study has confirmed previous findings in the literature that the first metatarsal is considerably more elevated in hallux rigidus populations than in control populations.

Limitations of this study include the retrospective nature and our inability to determine whether MPE is a cause or effect of hallux rigidus. Future studies should seek to determine whether MPE is part of disease etiology or disease sequelae, and whether surgical intervention in the early stages of disease can prevent the progression and improve outcomes. In addition, we did not record the number of eligible patients first identified by diagnostic code before assessing patient charts or radiographs. We also did not record the number of total potential control patients eligible before matching. This could have created some selection bias. Finally, we did not correlate the new parameters with measures of hallux rigidus grade. We believe that the grading system itself is unreliable in terms of both clinical exam and radiographic analysis.[16] Strengths of our study include the establishment of novel parameters to assess MPE at the anatomical area of interest, the double-blind nature of the study, and the large patient population assessed in a case-control design. Furthermore, it establishes the reliability of the measurements taken by multiple readers at various levels of training. We also provide an estimate of normal values from our population of healthy controls for all new and old measurements.

The 4 newly proposed measurements, which were found to be just as reliable as the 3 original measurements, may be more relevant for hallux rigidus since they account for the angle between the first metatarsal and proximal phalanx, rather than a comparison between the first and second metatarsal. Though the ICCs for the old parameters were technically higher than those for the new parameters, all of the old and new measurements fell into the previously described substantial to near-perfect categories. We therefore believe that none are more reliable than the others and each could be used reliably in future studies. While the proximal phalanx–first metatarsal angle and the first metatarsal longitudinal axis uncoverage angle were both correlated with previously established measurements, the first metatarsal uncoverage angle and first metatarsal midpoint uncoverage angle were not. This suggests that the latter 2 measurements contribute new information to the assessment of first metatarsal elevation by incorporating the proximal phalanx's position at the joint. Future studies could assess the correlations between the 2 new parameters themselves to assess whether they are redundant.

Since the first metatarsal uncoverage angle and first metatarsal midpoint uncoverage angle are so similar and the first metatarsal midpoint uncoverage angle has higher inter- and intrarater reliability, we propose the use of the first metatarsal midpoint uncoverage angle for further studies on first metatarsal elevation with regard to the proximal phalanx. We believe that this angle will be more clinically relevant than the previously used measures because it assesses first metatarsal elevation in relation to the proximal phalanx, which is where corrective surgeries intervene.

Conclusion

This study demonstrated the reliability of 7 radiographic measurements used to assess for MPE, including 3 previously established and 4 newly described measurements. Observers across all levels of training were able to record reliable measurements. Two new measurements were found to assess the angle between the first metatarsal and proximal phalanx in a way that correlated with previous measurements, while the other 2 new measurements were found to assess the angle in a new way. In addition, the measurements were used to show that patients with hallux rigidus were more likely to have MPE compared with patients without radiographic evidence for first MTP arthritis. These measurements could be used in future work to examine how the presence of MPE relates to the etiology and progression of hallux rigidus, and how it affects the results of operative treatment.

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