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"Angle to Be Corrected" in Preoperative Evaluation for Hallux Valgus Surgery: Analysis of a New Angular Measurement

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Abstract

Background: The most common methods for assessing severity of hallux valgus deformity and the effects of an operative procedure are the angular measurements in weightbearing radiographs, specifically the hallux valgus angle and intermetatarsal angle (IMA). Our objective was to analyze the interobserver variability in hallux valgus patients of a new angle called the "angle to be corrected" (ATC), and to compare its capacity to differentiate between different deformities against IMA.

Methods: We included 28 symptomatic hallux valgus patients with 48 weightbearing foot x-rays. Three trained observers measured the 1 to 2 IMA and the ATC. We then identified retrospectively 45 hallux valgus patients, which were divided into 3 operative technique groups having used the ATC as reference, and analyzed the capacity of the IMA to differentiate between them.

Results: The IMA average value was 13.6 degrees, and there was a significant difference between observer 3 and observer 1 (P = .001). The average value for the ATC was 8.9 degrees, and there was no difference between observers. Both angles showed a high intraclass correlation. Regarding the capacity to differentiate between operative technique groups, the ATC was different between the 3 operative technique groups analyzed, but the IMA showed differences only between 2.

Conclusions: The ATC was at least as reliable as the intermetatarsal angle for hallux valgus angular measurements, showing a high intraclass correlation with no interobserver difference. It can be suggested that the ATC was better than the IMA to stratify hallux valgus patients when deciding between different operative treatments.

Level of Evidence: Level III, comparative study.

Keywords: hallux valgus, angle to be corrected, angular measurement, interobserver reliability

Introduction

Hallux valgus is defined by medial deviation of the first metatarsal, great toe lateral deviation and pronation, and sesamoid subluxation.[3] Symptomatic hallux valgus resistant to nonoperative management can be treated surgically. A variety of operative methods have been developed to correct the hallux valgus.[4,6] To choose the appropriate operative technique and assess the postoperative outcome, most authors consider radiographic evaluation an important tool.[8,9]

The most common method for assessing hallux valgus severity is the angular measurements in weightbearing radiographs, specifically the hallux valgus angle and intermetatarsal angle.[20] Both angles have been shown to have a very high correlation with the clinical appearance.[15,21] The physiological mean value of the metatarsophalangeal angle was reported as 15.7 degrees by Hardy and Clapham[5] and as 12.0 degrees by Steel et al.[17] The physiological mean value of the first intermetatarsal angle was reported by these same authors as 8.5 degrees and 7.0 degrees, respectively. These 2 angles are mentioned in most articles dealing with hallux valgus deformities with variable limits set to determine severity of deformity.

In hallux valgus deformities, the sesamoid complex stays in the same location, whereas the metatarsal deviates medially.[18] Therefore, it can be postulated that a line that goes from the base of the first metatarsal to the middle of the sesamoid complex could theoretically represent the original position of the first metatarsal. It would be ideal if we could determine the original position of the metatarsal bone for each case and propose a surgical technique specific for that patient, powerful

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enough to reposition the metatarsal to its nondeformed position. A protocol was already proposed in the literature.[22]

The first objective of this study was to compare the interobserver variability in hallux valgus patients of a new angle called the "angle to be corrected" (ATC) with the variability of the intermetatarsal angle (IMA). The ATC corresponds to the angle needed to move the first metatarsal bone laterally from its deformed position to a theoretical normal position lying centered over the sesamoid complex. Our second objective was to analyze the capacity of the IMA to differentiate groups of hallux valgus patients that were already different having used the ATC as a reference. Our hypothesis was that the ATC would show at least the same interobserver variability as the intermetatarsal angle, and that the IMA would not be able to differentiate as well between hallux valgus deformities compared to the ATC.

Methods

We analyzed 28 adult patients (25 female) that presented to our office with a chief complaint of symptomatic incongruent hallux valgus and having a metatarsophalangeal angle greater than 15 degrees. Forty-eight foot weightbearing x-rays were analyzed. Three different observers (3 orthopedic surgeons trained in digital imaging measurement) measured the IMA and the ATC in digital anteroposterior weight-bearing images of the foot, using a commercially available software (Xero®; Agfa HealthCare N.V., Mortsel, Belgium). The different measurements were always performed on weight-bearing x-rays, which has been shown to decrease the error in angular measurement in hallux valgus.[11] The IMA was measured using a line drawn from the first metatarsal head center to the center of the base of the first metatarsal, as described by Miller[13,14] and a line through the mid-diaphyseal points of the second metatarsal bone.[2] The ATC was measured between a line representing the first metatarsal axis, drawn as described above, and a line drawn from the first metatarsal base passing distally through the sesamoid complex midpoint (Figure 1). It represented the angular correction needed to theoretically properly place the metatarsal head over the sesamoid complex. To evaluate the interobserver variability for these 2 angular measurements, we used Analysis of variance for repeated measures by mixed models methodology. The significance value was set at $P < .05$. Then, we used intraclass correlation (ICC) estimates to determine which of the measurements had a smaller interobserver variability. (An ICC of 1 indicates a perfect correlation and 0 no correlation between observers. A high correlation is considered with an ICC >0.7).

To compare the capacity of the ATC and IMA angles to differentiate between different hallux valgus deformities, we performed a retrospective analysis on surgically treated hallux valgus patients. Forty-five consecutive hallux valgus patients operated in our center with 3 different operative techniques were retrospectively collected, considering 15 patients per operative technique and a minimum 1-year follow-up. This group consisted of 45 female patients, average age 51.6 years, average follow-up 32 months. The operative technique was chosen depending on the severity of the deformity as published previously,[22-24] using the ATC as reference. The treatment protocol considered using the chevron technique for hallux valgus deformities with ATC between 1 and 5 degrees, which constituted group 1; a modified scarf technique for hallux valgus deformities with ATC between 6 and 9 degrees, or group 2; and Poscow technique for deformities with ATC greater than 10 degrees, or group 3. No formal lateral release was performed on any patient included in these

Figure 1. Anteroposterior x-ray of a hallux valgus patient. Lines drawn represent the angle to be corrected (ATC). The black line represents the first metatarsal bone axis, passing through the midline of the base and of the head of the metatarsal. The white line starts at the same starting point as the metatarsal axis, but its distal end goes through the midpoint of the sesamoid complex, that is, the mid-distance between the medial and lateral sesamoid.

Table 1. Summary Statistics for IMA, as Measured by 3 Observers.

Observer	N	Min	P25	P50	P75	Max	Mean	SD
1	48	6.3	11.1	13.5	16.6	25.1	13.9	3.8
2	48	7.9	11.6	13.9	15.4	22.0	13.8	3.1
3	48	7.1	10.9	13.2	14.9	19.8	13.2	3.0
Total	144	6.3	11.1	13.7	15.6	25.1	13.6	3.3

Abbreviations: IMA, intermetatarsal angle; Max, maximum value; Min, minimum value; N, number of observations; P25, 25th percentile; P50, 50th percentile; P75, 75th percentile; SD, standard deviation.

Table 2. Analysis of Variance for Repeated Measures by Mixed Models Methodology, IMA Measurement.

i	Coeff.	SE	*Z*	*P* > z	95% CI
Observer 2	–0.210	0.265	–0.79	.428	–0.728, 0.309
Observer 3	–0.806	0.265	–3.04	.002	–1.324, –0.287
Constant	13.963	0.475	29.42	.000	13.033, 14.894

Abbreviations: CI, confidence interval; Coeff., coefficient; Constant, observer 1 (observer 2 and 3 compared against him); i, instrument; IMA, intermetatarsal angle; SE, standard error.

Table 3. ICC Estimates of the Intermetatarsal Angle.

	ICC	SE	95% CI
Intermetatarsal angle	0.845	0.028	0.789, 0.900

Abbreviations: CI, confidence interval; ICC, intraclass correlation; SE, standard error.

series. Although the ATC was meant to be used mainly for the preoperative evaluation, we included pre- and postoperative values of the ATC and IMA for comparison to analyze if both angles could differentiate between the 3 groups studied. All measurements were done in digital anteroposterior weight-bearing images of the foot, using Xero, by an independent orthopedic surgeon trained in digital imaging measurement. Finally, we performed analysis of variance among the 3 groups with Dunet's test for multiple comparison.

Results

Regarding the variability evaluation of IMA and ATC, the analysis on the 48 weight-bearing foot x-rays of hallux valgus patients showed an average value for the IMA of 13.6 degrees (SD = 3.31) (Table 1). There was a significant difference between observer 3 and observer 1 ($P = .002$) in that observer 3 measured repeatedly smaller angles (Table 2). The ICC estimate was high (0.844) (Table 3). Furthermore, the average value for the ATC was 8.9 degrees (SD = 3.74) (Table 4). There was no difference between observers (Table 5). The ICC estimate was high (0.82) (Table 6).

In the 45 surgically treated hallux valgus patients, the preoperative/postoperative average value of the IMA was 12.3/4.8 degrees (SD = 2.82/1.99) (Table 7). The preoperative/postoperative average value of the ATC was 7.1/1.6 degrees (SD = 2.79/1.26) (Table 8). Analyzing the preoperative values between the 3 groups, the IMA was different between group 3 and the other 2 groups ($P < .002$) but did not show any difference between groups 1 and 2 (Table 9). When analyzing the preoperative values for the ATC between the 3 groups, there were statistically significant differences between every group ($P < .0001$) (Table 10).

Discussion

Various radiographic measurements such as hallux valgus angle, intermetatarsal angle, interphalangeal angle, sesamoid rotation angle, and first metatarsal protrusion distance have been described and used to evaluate hallux valgus.[1,12] However, some may not be reliable, necessary, or useful.[7] Radiographic angles are measured to assess severity of deformity, help in operative procedure selection, assess postoperative correction, and compare results. The use of angular measurements is based on the belief that they are reliable, consistent, and provide a constant value for comparison with other studies.[16] It has been shown that inter- and intraobserver measurement reliability of various radiographic measurements in hallux valgus is poor, with ICC coefficients ranging from 0.38 to 0.92.[7]

In this study, we analyzed the interobserver variability of the IMA and compared it to a new angle called angle to be corrected (ATC). The rationale behind developing this angle considers that the sesamoid complex stays in the same location, whereas the metatarsal deviates medially in hallux valgus deformities.[18] The correct relationship between the metatarsal bone and the sesamoid complex cannot be overstated, as an incomplete reduction of the sesamoids is an important risk factor for hallux valgus recurrence.[10] It appears attractive to consider that a line that goes from the base of the first metatarsal to the middle of the sesamoid

Table 4. Summary Statistics for ATC, as Measured by 3 Observers.

Observer	N	Min	P25	P50	P75	Max	Mean	SD
1	48	1.2	6.1	9.1	11.5	16.3	8.8	3.6
2	48	2.1	5.3	9.1	11.5	22.0	8.8	4.1
3	48	1.3	5.7	9.8	11.8	17.3	9.1	3.6
Total	144	1.2	5.9	9.4	11.7	22.0	8.9	3.7

Abbreviations: ATC, angle to be corrected; IMA, intermetatarsal angle; Max, maximum value; Min, minimum value; N, number of observations; P25, 25th percentile; P50, 50th percentile; P75, 75th percentile; SD, standard deviation.

Table 5. Analysis of Variance for Repeated Measures by Mixed Models Methodology, ATC Measurement.

i	Coeff.	SE	Z	$P > z$	95% CI
Observer 2	0.033	0.319	0.10	.918	−0.592, 0.658
Observer 3	0.275	0.319	0.86	.388	−0.349, 0.900
Constant	8.809	0.539	16.36	.000	7.754, 9.865

Abbreviations: ATC, angle to be corrected; CI, confidence interval; Coeff., coefficient; Constant, observer 1 (observer 2 and 3 compared against him); i, instrument; IMA, intermetatarsal angle; SE, standard error.

Table 6. ICC Estimates, ATC.

	ICC	SE	95% CI
Angle to be corrected	0.825	0.032	0.763, 0.887

Abbreviations: ATC, angle to be corrected; CI, confidence interval; ICC, intraclass correlation; SE, standard error.

complex could theoretically represent the original, proper position of the first metatarsal.

When analyzing the variability between the IMA and ATC, the ICC estimates showed that both methods have a good and comparable variability, but the difference found between observers for the IMA and not for the ATC suggests that the former angle is probably harder to measure than the latter. Hence, it is a less reliable method than the newly described angle. Considering the way to measure the IMA and the ATC, the ATC is obtained by defining just 3 points on an x-ray, possibly being a faster and easier method to use in comparison with the one for IMA. In our experience, this method is very easy to teach orthopedic residents in a training institution. Another advantage of the ATC is that it can be easily measured on standard film x-rays using just a goniometer, given that both lines used have a common axis point (located at the metatarsal base). To measure the IMA, 2 lines have to be drawn that intersect most of the time outside the film x-ray. That is why another set of closer lines, parallel to the lines already drawn, have to be drawn to be able to measure the intersection angle.

Relative to the retrospective portion of this study, we analyzed the capacity of the IMA to differentiate groups of hallux valgus patients that were already different having used the ATC as a reference. We compared 3 previously operated hallux valgus groups following a predefined protocol, where depending on the ATC value, a certain operative procedure was indicated, for example, Chevron technique for ATC between 1 and 5 degrees, modified scarf for ATC between 6 and 9 degrees, and Poscow osteotomy for ATC greater than 10 degrees. As expected, the ATC was different ($P < .0001$) between each group. The IMA could not differentiate between the groups with ATC between 1 and 9 degrees (groups 1 and 2), showing a mean value of 10.4 degrees for group 1 and 11.86 degrees for group 2 ($P = .092$). These results suggest that the IMA was not useful in differentiating mild against moderate hallux valgus deformities. This fact is important for surgeons who use more than 1 operative technique for their hallux valgus patients as it may help them decide which mild to moderate case should be treated with a slightly more aggressive technique and which should be treated just with a distal chevron technique, for example. In our group, the ATC has allowed us to define a treatment protocol. Depending on the ATC, the most adequate operative technique is planned and proposed to the patient. This protocol has been mentioned before in the literature and considers at least 3 different osteotomy techniques depending on the correction capacity needed.[22-24]

Our study has a few limitations. It contains a retrospective portion where the IMA was compared to the ATC with respect to its capacity for differentiating hallux valgus deformities. The quality of the information could have been improved by performing a prospective study comparing the clinical usefulness of both angles. We could expect the postoperative ATC value to be zero, as it measures the ATC and, therefore, after surgery if we performed an adequate correction, we should have been able to move the first metatarsal to its original situation. The mean postoperative ATC value was 1.6 degrees, being slightly higher in severe cases and slightly lower in mild cases. We think this difference represents one of the limitations of this angle, which attempts to locate the original

Table 7. Summary of IMA Preoperative and Postoperative Values in Surgically Treated Group.

Group	N	Min preop/postop	P50 preop/postop	Max preop/postop	Mean preop/postop	SD preop/postop
1	15	6.8/1.1	10.2/4.1	13.9/8.3	10.4/4.2	2.11/1.8
2	15	7.1/1.2	11.7/2.8	17.5/9.3	11.9/3.5	2.1/2.2
3	15	12.5/1.9	14.0/4.6	19.3/9.8	14.6/4.8	1.8/1.9
Total	45	6.8/1.1	12.4/4.2	19.3/9.8	12.3/4.2	2.8/1.9

Abbreviations: IMA, intermetatarsal angle; Max, maximum value; Min, minimum value; N, number of observations; P50, 50th percentile; postop, postoperative; preop, preoperative; SD, standard deviation.

Table 8. Summary of ATC Preoperative and Postoperative Values in Surgically Treated Group.

Group	N	Min preop/postop	P50 preop/postop	Max preop/postop	Mean preop/postop	SD preop/postop
1	15	1.7/0.3	4.6/0.8	5.3/2.5	4.0/0.9	1.2/0.5
2	15	5.2/0.0	7.0/0.8	9.8/4.1	7.2/1.1	1.7/1.0
3	15	9.2/0.7	9.8/2.9	11.9/5.1	10.1/2.9	0.8/1.0
Total	45	1.7/0.0	7.0/1.1	11.9/5.1	7.1/1.6	2.8/1.3

Abbreviations: ATC, angle to be corrected; Max, maximum value; Min, minimum value; N, number of observations; P50, 50th percentile; postop, postoperative; preop, preoperative; SD, standard deviation.

Table 9. Analysis of Variance Among the 3 Groups With Dunet's Test for Multiple Comparison, for Preoperative IMA Values.

IMA	Coeff.	SE	*t*	*P*>*t*	95% CI
Group 1	−4.18	0.827	−5.05	.000	−5.849, −2.510
Group 2	−2.752	0.827	−3.33	.002	−4.422, −1.084
Constant (group 3)	14.62	0.584	25	.000	13.439, 15.8
Group 1	−1.426	0.827	−1.72	.092	−3.095, 0.242
Group 3	2.753	0.827	3.33	.002	1.084, 4.422
Constant (group 2)	11.866	0.584	20.29	.000	10.686, 13.047

Abbreviations: CI, confidence interval; Coeff., coefficient; IMA, intermetatarsal angle; SE, standard error.

Table 10. Analysis of Variance Among the 3 Groups With Dunet's Test for Multiple Comparison, for Preoperative ATC Values.

ATC	Coeff.	SE	*t*	*P*>*t*	95% CI
Group 1	−6.066	0.462	−13.11	.000	−7.000, −5.133
Group 2	−2.906	0.462	−6.28	.000	−3.84, −1.973
Constant (group 3)	10.1	0.327	30.87	.000	9.439, 10.76
Group 1	−3.16	0.462	−6.83	.000	−4.093, −2.226
Group 3	2.906	0.462	6.28	.000	1.973, 3.840
Constant (group 2)	7.193	0.327	21.99	.000	6.533, 7.853

Abbreviations: ATC, angle to be corrected; CI, confidence interval; Coeff., coefficient; SE, standard error.

position of the metatarsal head over the sesamoid complex, but does not consider metatarsal rotation, sesamoid rotation, metatarsophalangeal arthrosis, tarsometatarsal instability, or soft tissue imbalance, which may alter the type of correction needed. The fact that the ATC is not zero may show our inability to perfectly correct hallux valgus. No clinical correlation was performed with the final radiologic evaluation, which may be seen as a limitation, because it has been shown that the amount of correction does not influence the outcome on hallux valgus patients.[19] The ATC relies on the assumption that every patient before developing a hallux valgus deformity has its first metatarsal perfectly centered over the sesamoids. No associated foot deformities were measured nor identified in this study, such as metatarsus adductus, planus or cavus foot, or neurologic syndromes. The foot x-rays analyzed belonged mostly to women, indicating a lack of symmetric gender distribution; however, that reflects the typical clinical gender distribution of symptomatic hallux valgus. Lastly, no

patient under 20 years of age was included in this study, meaning that no extrapolation should be done for juvenile hallux valgus. Having said this, we consider that the ATC represents a better approximation to the preoperative hallux valgus deformity evaluation than the IMA, as it represents the final objective, that is, correct first metatarsal alignment.

In conclusion, the optimal operative treatment for hallux valgus remains a matter of debate. The correction power of some osteotomies determined through trigonometric models is a tool that provides reliable information on what surgery should be performed on a certain patient.[22-24]As every hallux valgus patient is unique, the authors believe that there should be an armamentarium of techniques to choose from, to be able to individually treat each deformity. Using just 1 technique would likely be insufficient, as we would not be able to address every type of deformity. We think that this new angle, the angle to be corrected, may allow us to better stratify patients according to the correction required to move the first metatarsal back to its original, proper position (center of the sesamoid complex) and to choose an operative technique according to its correction power. In our hands, the ATC angle was a fast and easy angle to measure and to teach, and it was superior to other methods to decide which surgical procedure to use.

Declaration of Conflicting Interests

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