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Digital Measurements With Hallux Valgus Before and After Modified Long Oblique Osteotomy

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ABSTRACT

Radiographic measurements of the hallux valgus (HV) angle (HVA) and the first intermetatarsal angle (IMA_{1-2}) are important for assessing the severity of HV. The purpose of the present study was to digitally investigate the intraobserver and interobserver reliability of various methods for measuring HVA and IMA_{1-2}, as well as each axis composing them, such as axes of the first proximal phalanx (PP1), the first metatarsal (MT1), and the second metatarsal (MT2) in patients with a metatarsal shaft osteotomy-modified long oblique osteotomy. Three orthopedic surgeons measured the HVA, IMA_{1-2}, and the angles between axes of PP1, MT1, and MT2, and the digitally-set reference line (α, β, and γ, respectively) using 6 different methods for 39 patients with a minimum of 1 year of follow-up after operative treatment. The intraobserver and interobserver intraclass correlation coefficients (ICC) and agreements were calculated. Significant differences were observed within the methods with regard to preoperative HVA, IMA_{1-2}, α, and β, and postoperative IMA_{1-2} and β. Intraobserver and interobserver ICC were high or very high in most methods. For HVA and IMA_{1-2}, the method connecting the center of the head through the center of the base showed the highest agreement. For α, β, and γ, this method showed the highest agreement, more than 80% intraobserver and interobserver agreement and a discrepancy of $<2°$. A digital method connecting the center of the head through the center of the base was regarded as the least variable for the HV evaluation and the assessment of the radiographic results in a metatarsal shaft osteotomy-modified long oblique osteotomy.

Radiographic measurements of the hallux valgus (HV) angle (HVA) and the first intermetatarsal angle (IMA_{1-2}) are essential for assessing the status of HV deformity (1). These have been used to select the appropriate procedure for operatively correcting HV deformity and to compare radiographic outcomes following operative procedures.

Because an average interobserver error of 6.4° for HVA and 5.4° for IMA_{1-2} was previously reported (2), the measurement error of such angular indexes is well documented. It is potentially the result of the observers' experience and abilities, including skill of placement of the reference points, creation of axis lines, and the result of measurement methods and imaging techniques (3–9).

Schneider et al. (10) evaluated the accuracy and reproducibility of various measurement methods in a study on patients managed with distal chevron osteotomy of the first metatarsal (MT1) and concluded that the method (7) in which the longitudinal axis corresponds to the line connecting the centers of the MT1 head and base was the most precise. For a proximal crescentic metatarsal osteotomy, Shima et al. (9) concluded that a line connecting the centers of MT1 head and the proximal articular surface of MT1 to define the longitudinal axis yields the best intraobserver and interobserver reliability for measurement of the HVA and IMA_{1-2}. These studies, however, were confined to the manual measurement error of MT1 using a goniometric device on conventional film-copied radiographs with the axes of the first proximal phalanx (PP1) and the second metatarsal (MT2) drawn and fixed. Considering that an angle is composed of two lines, the axes of PP1 and MT1 as well as MT2 should also be simultaneously evaluated to understand measurement error of HVA and IMA_{1-2}.

To our knowledge, no study has investigated the reliability of angular variation of longitudinal axes of PP1, MT1, and MT2, which are each components of HVA and IMA_{1-2}. Thus, the purpose of the present study

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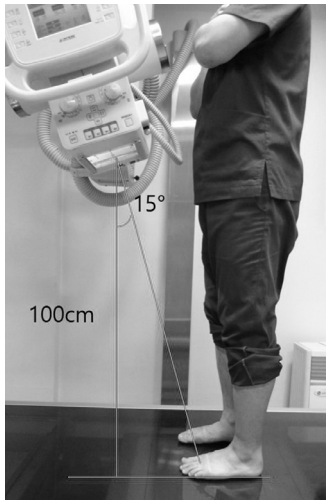

Fig. 1. Radiograph taken under standardized weightbearing status and with the radiograph beam inclined at 20° from anterosuperior to posteroinferior in the sagittal plane at a distance of 100 cm.

was to investigate the intraobserver and interobserver reliability of different methods for measuring each axis of HVA and IMA_{1-2} and their angles, using computer-assisted analysis before and after the modified long oblique osteotomy.

Materials and Methods

Our institutional review board approved the present study. We randomly selected 39 preoperative and postoperative plain anteroposterior radiographs with a minimum of 1 year of follow-up between March 2003 and April 2011. All radiographs were taken under standardized weightbearing status and were taken with the radiograph beam inclined at 20° from anterosuperior to posteroinferior in the sagittal plane at a distance of 100 cm, directed vertically to the cassette in the coronal plane, and centered in the middle of the third metatarsal (Fig. 1). All preoperative and postoperative radiographs were made following a modified long oblique osteotomy combined with medial eminence resection and a distal soft-tissue procedure for MT1. Twelve patients underwent the Akin procedure. All operative procedures were carried out by a single surgeon (I.H.S.).

Three orthopedic surgeons (K.C.K, C.H.S., J.H.L.) independently performed measurements twice with at least 1 week between the 2 measurements.

Methods of Radiographic Measurement

Six methods were used to set up the longitudinal axes of PP1, MT1, and MT2 on radiographs (Fig. 2).

In method 1, a line was drawn through the longitudinal axis (4). All reference points were located 1/2 to 1 cm proximal or distal to the articular surfaces and placed as close to the diaphysis as possible. In method 2, a line was drawn to bisect the shaft of the diaphysis at 2 levels, with the points of bisection joined and the line extended (11); method 3 used a line drawn to connect the center of the articular surface of the head and the center of the proximal articulation (12). In method 4, a line was drawn from the center of the head through the center of the base (7); in method 5, a line was drawn through the center of the head and the center of the proximal shaft (8); and in method 6, a line was drawn through the center of the head and the center of the proximal articular surface (9).

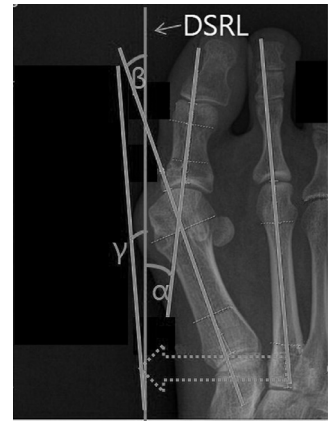

Fig. 3. Photoradiographs showing angles α, β, and γ using a digitally set reference line (DSRL). The axis of the second metatarsal was moved to the DSRL for convenience.

The authors who developed methods 3 and 4 did not describe a way to measure the PP1 axis. In those patients, we applied the MT1 measurement method to PP1. In the same way, the measurement method for MT1 was also applied to MT2 in methods 2 and 4. In method 5, the reference points for PP1 and MT1 described by the authors were different from MT2, and in method 6, the reference points for PP1 and MT2 described by the authors were different from MT1; however, in this study, we applied the same reference points for MT1 to PP1 and MT2.

The longitudinal axis of an irregular bone of the postoperative MT1 was determined by the definition of each method by each observer. The center of the PP1, MT1, and MT2 heads was established digitally on a point equidistant from the medial, distal, and lateral osseous surfaces using a geometric device (the Mose sphere) in methods 4, 5, and 6 (4).

The digital measurements were taken on a medical diagnostic monitor (model No. MDRC-2120, Barco®) with a picture archiving and communication system (PACS) to measure angles after 150% magnification. Before measurement, the medial border of the foot was put on the left side of the screen, the lateral border was placed on the right side, the forefoot was placed on the top, and the hindfoot was placed on the bottom with the mirror or rotation tools built into π-viewer® to eliminate confusion caused by foot position and standardize the circumstances used for measurement.

Angular measurements were performed pre- and postoperatively using the measurement tools built into the PACS software for radiology. To measure the reliability of the PP1, MT1, and MT2 axes, the line of axis of digital ruler, digitally generated by the software, was used as a vertical reference axis. The digitally set reference line (DSRL) generated by the software and developed for this study was a constant and reproducible line perpendicular in the plane of the floor of the screen as a reference. The longitudinal axes of PP1, MT1, and MT2 were determined using the 6 methods described previously. The angles between DSRL and PP1, MT1, and MT2 were called α, β, and γ (Fig. 3). HVA and IMA_{1-2} were calculated using α, β, and γ.

Statistical Analysis

A power analysis was performed to determine the appropriate sample size. The sample size was estimated for an 1-way analysis of variance (ANOVA). With mean

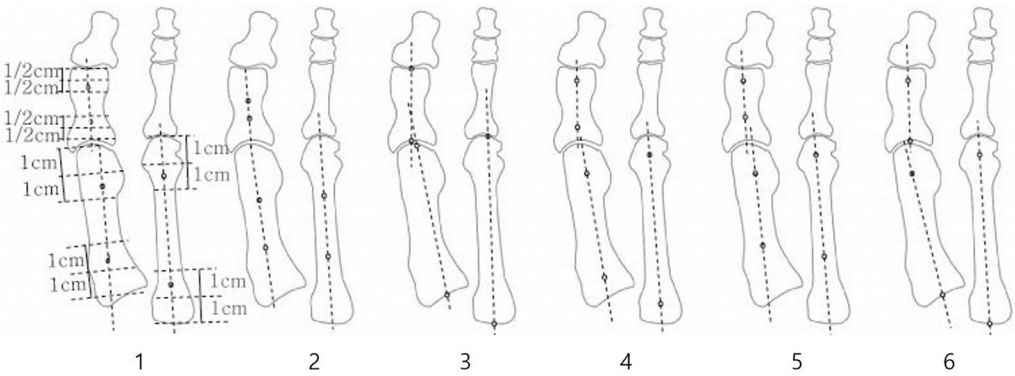

Fig. 2. Diagrams depicting the 6 methods for drawing the axes of the first proximal phalanx and the first and second metatarsals.

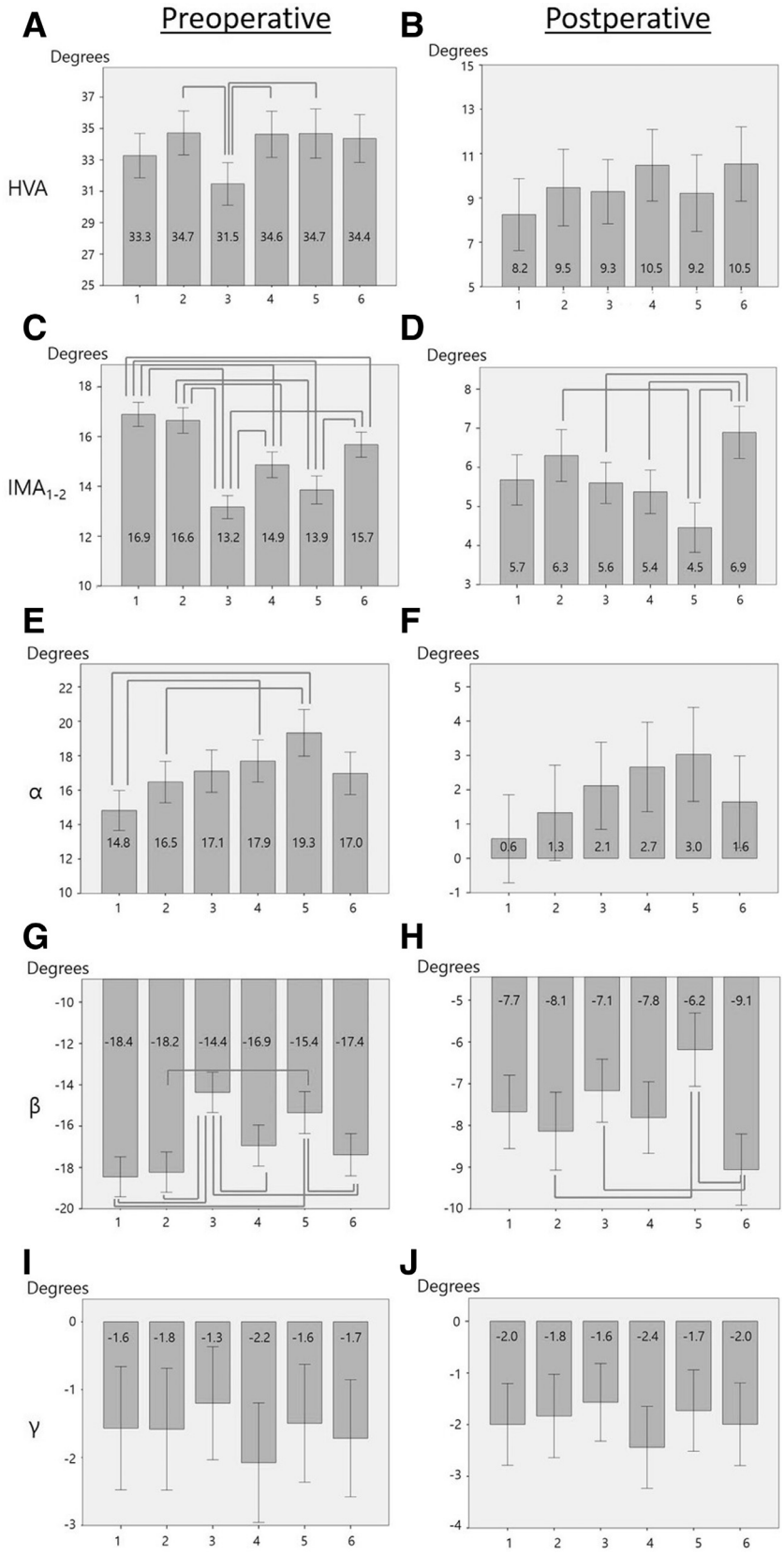

Fig. 4. Bar graphs illustrating the preoperative and follow-up values of (*A, B*) hallux valgus angle (HVA), (*C, D*) first intermetatarsal angle (IMA_{1-2}), (*E, F*) α, (*G, H*) β, and (*I, J*) γ determined by all 6 methods. The number underneath each bar indicates the corresponding method. *$p \leq .05$. Error bars indicate the standard deviation. N = 39 feet.

preoperative and postoperative measurements of HVA and IMA_{1-2} (setting alpha = 0.05, and 1 − beta = 0.8), the power was calculated using a sample-size calculation tool (G*Power, version 3.0.10; Franz Faul, University of Kiel, Kiel, Germany). The minimum number of subjects was found to be 37.

One-way ANOVA was used to compare the mean preoperative and postoperative α, β, and γ as well as HVA and IMA_{1-2} using the 6 methods described previously to evaluate the differences between methods. Post hoc analyses were conducted using the Tukey test, with the level of significance set at the 5% ($p \leq .05$) level.

Intraclass Correlation Coefficient

Intraobserver and interobserver reliability were calculated using intraclass correlation coefficients (ICCs) for all continuous variables. The mean value obtained by each observer was used for the analysis of interobserver reliability. Intraobserver and interobserver reliability were categorized as minimal (correlation coefficient, ≤0.25), low (0.26 to 0.49), moderate (0.50 to 0.69), high (0.70 to 0.89), or very high (≥0.90).

Intraobserver and Interobserver Agreement

The intraobserver and interobserver agreement of each method were evaluated by the percentage of the measurements with a discrepancy of 1° within and between observers in α, β, and γ as well as HVA and IMA_{1-2} (9,13). The approximate bounds were determined by the cumulative frequency distribution of the differences in measured values. All statistical analyses were performed size by 1 of the authors (K.C.K).

Results

ANOVA

The mean values for the preoperative and postoperative measurements of HVA, IMA_{1-2}, α, β, and γ are shown in Fig. 4. There were significant differences among the 6 methods with regard to the preoperative HVA, IMA_{1-2}, α, and β. However, in the postoperative analysis, there were significant differences only in IMA_{1-2} and β. There was no significant difference in γ in the preoperative and postoperative analysis.

ICC

The ICCs for the preoperative and postoperative measurements for HVA, IMA_{1-2}, α, β, and γ are shown in Tables 1 and 2.

Intraobserver correlation coefficients for HVA and IMA_{1-2}

The intraobserver correlation coefficients for the preoperative and postoperative HVA measurements ranged from 0.92 to 0.99 and from 0.96 to 0.99, respectively. The overall reliability of the values determined with each method was very high. The intraobserver correlation coefficients for the preoperative and postoperative IMA_{1-2} measurements ranged from 0.68 to 0.96 and from 0.70 to 0.98, respectively. Only method 2 used by observer B preoperatively generated a score of 0.68 (moderate reliability). All other reliabilities of all methods used by the three observers were high or very high.

Interobserver correlation coefficients for HVA and IMA_{1-2}

The interobserver correlation coefficients for the preoperative and postoperative HVA measurements ranged from 0.92 to 0.97 and from 0.85 to 0.97, respectively. The reliabilities of all methods were high or very high. The interobserver correlation coefficients for the preoperative and postoperative IMA_{1-2} measurements ranged from 0.66 to 0.87 and from 0.81 to 0.91, respectively. The preoperative reliability of method 3 was 0.66 (moderate). All the other reliabilities were high or very high.

Interobserver correlation coefficients for α, β, and γ

All interobserver and intraobserver correlation coefficients for preoperative and postoperative α, β, and γ measurements were >0.90, except for the measurement of β using method 6 by observer C postoperatively; nevertheless, the reliability was high. All other reliabilities were very high.

Table 1
Intraobserver reliability of angle as determined with use of ICCs for preoperative and postoperative measurements for hallux valgus angle, IMA_{1-2}, α, β, and γ (N = 39 feet)

	ICC (95% CI)					
Method	1	2	3	4	5	6
Preoperative						
Observer 1						
HVA	0.96	0.93	0.98	0.99	0.97	0.99
IMA_{1-2}	0.96	0.84	0.86	0.94	0.85	0.92
α	0.94	0.93	0.95	0.99	0.96	0.99
β	0.99	0.96	0.95	0.99	0.97	0.98
γ	0.99	0.98	0.99	0.99	0.98	0.99
Observer 2						
HVA	0.97	0.92	0.92	0.95	0.95	0.98
IMA_{1-2}	0.77	0.68	0.91	0.84	0.88	0.88
α	0.98	0.96	0.95	0.95	0.96	0.96
β	0.98	0.92	0.91	0.94	0.92	0.96
γ	0.97	0.96	0.96	0.96	0.96	0.95
Observer 3						
HVA	0.98	0.96	0.96	0.97	0.98	0.98
IMA_{1-2}	0.89	0.85	0.70	0.89	0.90	0.91
α	0.94	0.99	0.98	0.98	0.99	0.99
β	0.98	0.98	0.96	0.99	0.98	0.98
γ	0.96	0.99	0.98	0.99	0.99	0.98
Postoperative						
Observer 1						
HVA	0.98	0.96	0.98	0.99	0.98	0.99
IMA_{1-2}	0.96	0.93	0.98	0.93	0.88	0.93
α	0.98	0.95	0.99	0.98	0.98	0.99
β	0.97	0.96	0.99	0.97	0.95	0.97
γ	0.99	0.98	0.99	0.99	0.99	0.99
Observer 2						
HVA	0.98	0.98	0.96	0.98	0.96	0.97
IMA_{1-2}	0.80	0.87	0.78	0.84	0.71	0.80
α	0.99	0.98	0.96	0.98	0.97	0.98
β	0.96	0.95	0.89	0.95	0.94	0.93
γ	0.95	0.97	0.96	0.94	0.95	0.96
Observer 3						
HVA	0.97	0.98	0.98	0.99	0.97	0.98
IMA_{1-2}	0.88	0.88	0.70	0.89	0.86	0.92
α	0.99	0.99	0.99	0.99	0.98	0.98
β	0.97	0.97	0.95	0.98	0.96	0.77
γ	0.98	0.98	0.95	0.97	0.97	0.95

Abbreviations: CI, confidence interval; HVA, hallux valgus angle; ICC, intraclass correlation coefficient; IMA_{1-2}, first intermetatarsal angle.

Table 2
Interobserver reliability of angle as determined with use of ICCs for preoperative and postoperative measurements for hallux valgus angle, IMA_{1-2}, α, β, and γ (N = 39 feet)

	ICC (95% CI)					
Method	1	2	3	4	5	6
Preoperative						
HVA	0.94	0.92	0.94	0.97	0.96	0.97
IMA_{1-2}	0.82	0.71	0.66	0.87	0.81	0.88
α	0.92	0.93	0.94	0.97	0.96	0.95
β	0.98	0.94	0.93	0.97	0.95	0.97
γ	0.97	0.98	0.99	0.99	0.97	0.93
Postoperative						
HVA	0.96	0.93	0.95	0.97	0.94	0.94
IMA_{1-2}	0.89	0.81	0.91	0.86	0.81	0.81
α	0.96	0.90	0.96	0.98	0.95	0.95
β	0.95	0.90	0.97	0.97	0.89	0.88
γ	0.99	0.96	0.98	0.97	0.96	0.96

Abbreviations: CI, confidence interval; HVA, hallux valgus angle; ICC, intraclass correlation coefficient; IMA_{1-2}, first intermetatarsal angle.

Intraobserver and Interobserver Agreement

The intraobserver and interobserver agreement with 1° discrepancy and their values for HVA and IMA_{1-2} are shown in Table 3. Method 4 and 6 had pre- and postoperative intra- and interobserver agreement >80% within a discrepancy of 4° in HVA. Methods 3, 4, and 6 had pre- and postoperative intra- and interobserver agreement >80% within a discrepancy of 3° in IMA_{1-2}; therefore, methods 4 and 6 yielded the highest agreement in terms of HVA and IMA_{1-2}.

The intraobserver and interobserver agreement within 1° discrepancy and values for α, β, and γ are shown in Table 4. For α, when figures were rounded to 0 decimal places, only method 4 showed >80% intraobserver and interobserver agreement and a discrepancy <2°. For β, methods 1 and 4 showed >80% intraobserver and interobserver agreement within a discrepancy of 2°. For γ, all methods showed >80%

Table 3
Intraobserver and interobserver agreement: percentage of measurement within 1° discrepancy in HVA and IMA_{1-2} (N = 39 feet)

		Intraobserver Percentage Within 1° Discrepancy						
		HVA						
Discrepancy		≤1	>1–2	>2–3	>3–4	>4–5	>5–6	>6
Preoperative method								
	1	43.6	29.9	18.8	4.3	3.4	0	0
	2	41	21.4	13.7	11.1	6.8	2.6	3.4
	3	43.6	25.6	13.7	5.1	8.5	0.9	2.6
	4	46.2	29.9	12.8	6	0.9	1.7	2.6
	5	30.8	30.8	21.4	8.5	7.7	0.9	0
	6	50.4	32.5	9.4	4.3	2.6	0.9	0
Postoperative method								
	1	44.4	29.9	20.5	4.3	0	0	0.9
	2	35	32.5	16.2	6.8	6	2.6	0.9
	3	53	20.5	13.7	10.3	0.9	0.9	1.7
	4	48.7	30.8	11.1	4.3	3.4	1.7	0
	5	37.6	23.1	18.8	12	6	2.6	0
	6	42.7	28.2	16.2	6.8	3.4	1.7	0.9
		IMA_{1-2}						
Discrepancy		≤1	>1–2	>2–3	>3–4	>4–5	>5–6	>6
Preoperative method								
	1	64.1	28.2	2.6	0	2.6	0	2.6
	2	38.5	30.8	20.5	2.6	5.1	2.6	0
	3	41	28.2	17.9	7.7	2.6	2.6	0
	4	56.4	25.6	12.8	2.6	2.6	0	0
	5	48.7	15.4	23.1	2.6	5.1	5.1	0
	6	66.7	20.5	10.3	2.6	0	0	0
Postoperative method								
	1	53.8	30.8	7.7	3.4	3.4	0.9	0
	2	46.2	29.1	18.8	4.3	0.9	0	0.9
	3	55.6	17.1	12.8	8.5	4.3	1.7	0
	4	54.7	29.1	9.4	4.3	2.6	0	0
	5	48.7	27.4	11.1	6.8	5.1	0.9	0
	6	46.2	33.3	11.1	5.1	2.6	0.9	0.9
		Interobserver						
		Percentage Within 1° Discrepancy						
		HVA						
Discrepancy		≤1	>1–2	>2–3	>3–4	>4–5	>5–6	>6
Preoperative method								
	1	23.1	23.1	23.1	17.9	10.3	0	2.6
	2	5.1	23.1	12.8	28.2	7.7	12.8	10.3
	3	5.1	20.5	23.1	38.5	7.7	2.6	2.6
	4	23.1	30.8	25.6	10.3	2.6	0	7.7
	5	20.5	10.3	20.5	28.2	10.3	2.6	7.7
	6	7.7	35.9	35.9	10.3	5.1	2.6	2.6

(*continued*)

Table 3. (*Continued*)

		Intraobserver Percentage Within 1° Discrepancy						
		HVA						
Discrepancy		≤1	>1–2	>2–3	>3–4	>4–5	>5–6	>6
Postoperative method								
	1	10.3	12.8	33.3	17.9	20.5	2.6	2.6
	2	15.4	20.5	15.4	20.5	17.9	5.1	5.1
	3	10.3	28.2	20.5	15.4	17.9	5.1	2.6
	4	28.2	28.2	30.8	2.6	5.1	2.6	2.6
	5	12.8	15.4	28.2	20.5	7.7	12.8	2.6
	6	12.8	33.3	33.3	10.3	5.1	0	5.1
		IMA_{1-2}						
Discrepancy		≤1	>1–2	>2–3	>3–4	>4–5	>5–6	>6
Preoperative method								
	1	46.2	25.6	15.4	2.6	7.7	2.6	0
	2	17.9	28.2	23.1	20.5	10.3	0	0
	3	17.9	28.2	35.9	17.9	0	0	0
	4	25.6	35.9	20.5	15.4	2.6	0	0
	5	20.5	38.5	20.5	17.9	0	2.6	0
	6	30.8	43.6	23.1	0	2.6	0	0
Postoperative method								
	1	23.1	25.6	30.8	10.3	10.3	0	0
	2	20.5	35.9	25.6	5.1	7.7	0	5.1
	3	35.9	30.8	17.9	15.4	0	0	0
	4	23.1	48.7	17.9	10.3	0	0	0
	5	17.9	33.3	33.3	7.7	2.6	2.6	2.6
	6	28.2	46.2	10.3	5.1	10.3	0	0

Abbreviations: HVA, hallux valgus angle; IMA_{1-2}, first intermetatarsal angle.

Table 4
Intraobserver and interobserver agreement is shown percentage of measurement within 1° discrepancy in α, β, and γ (N = 39 feet)

		Intraobserver Percentage Within Discrepancy						
		α						
Discrepancy		≤1	>1–2	>2–3	>3–4	>4–5	>5–6	>6
Preoperative method								
	1	44.4	35.9	15.4	2.6	0.9	0.9	0
	2	39.3	28.2	14.5	10.3	6.8	0	0.9
	3	49.6	29.9	9.4	6.8	4.3	0	0
	4	58.1	24.8	9.4	6	1.7	0	0
	5	49.6	29.9	7.7	6.8	4.3	1.7	0
	6	60.7	28.2	6.8	1.7	2.6	0	0
Postoperative method								
	1	60.7	32.5	5.1	0.9	0.9	0	0
	2	53	24.8	10.3	10.3	1.7	0	0
	3	85.5	12.8	1.7	0	0	0	0
	4	68.4	23.9	4.3	3.4	0	0	0
	5	47.9	30.8	15.4	5.1	0.9	0	0
	6	55.6	29.1	13.7	1.7	0	0	0
		β						
		≤1	>1–2	>2–3	>3–4	>4–5	>5–6	>6
Preoperative method								
	1	69.2	27.4	3.4	0	0	0	0
	2	38.5	35.9	17.9	6	1.7	0	0
	3	51.3	27.4	12.8	4.3	3.4	0	0.9
	4	65	21.4	9.4	2.6	1.7	0	0
	5	68.4	17.1	7.7	1.7	1.7	2.6	0.9
	6	66.7	23.9	6	3.4	0	0	0
Postoperative method								
	1	62.4	29.1	5.1	1.7	1.7	0	0
	2	53.8	32.5	10.3	3.4	0	0	0
	3	59	25.6	8.5	6.8	0	0	0
	4	64.1	22.2	11.1	2.6	0	0	0
	5	48.7	29.9	17.1	4.3	0	0	0
	6	81.2	15.4	2.6	0	0	0	0.9

(*continued*)

Table 4. (*Continued*)

		Intraobserver Percentage Within Discrepancy						
		α						
Discrepancy		≤1	>1–2	>2–3	>3–4	>4–5	>5–6	>6
		γ						
		≤1	>1–2	>2–3	>3–4	>4–5	>5–6	>6
Preoperative method								
	1	70.1	26.5	2.6	0	0	0	0.9
	2	67.5	27.4	5.1	0	0	0	0
	3	76.1	18.8	4.3	0.9	0	0	0
	4	71.8	19.7	8.5	0	0	0	0
	5	68.4	24.8	6.8	0	0	0	0
	6	70.1	22.2	6.8	0.9	0	0	0
Postoperative method								
	1	70.1	28.2	1.7	0	0	0	0
	2	67.5	28.2	4.3	0	0	0	0
	3	71.8	21.4	6.8	0	0	0	0
	4	65	26.5	7.7	0.9	0	0	0
	5	61.5	33.3	5.1	0	0	0	0
	6	64.1	27.4	8.5	0	0	0	0
		Interobserver Percentage Within Discrepancy						
		α						
Discrepancy		≤1	>1–2	>2–3	>3–4	>4–5	>5–6	>6
Preoperative method								
	1	23.1	28.2	28.2	7.7	5.1	2.6	5.1
	2	30.8	28.2	15.4	15.4	2.6	0	7.7
	3	23.1	28.2	25.6	12.8	7.7	0	2.6
	4	71.8	17.9	7.7	0	0	0	2.6
	5	25.6	28.2	17.9	20.5	5.1	2.6	0
	6	41	38.5	12.8	2.6	2.6	0	2.6
Postoperative method								
	1	43.6	25.6	20.5	5.1	2.6	0	2.6
	2	28.2	25.6	17.9	12.8	7.7	2.6	5.1
	3	20.5	33.3	25.6	15.4	2.6	0	2.6
	4	59	20.5	20.5	0	0	0	0
	5	30.8	33.3	12.8	15.4	2.6	5.1	0
	6	28.3	33.3	17.9	12.8	2.6	2.6	2.6
		β						
		≤1	>1– 2	>2–3	>3–4	>4– 5	>5–6	>6
Preoperative method								
	1	64.1	28.2	7.7	0	0	0	0
	2	53.8	28.2	12.8	5.1	0	0	0
	3	38.5	30.8	12.8	10.3	7.7	0	0
	4	41	51.3	2.6	5.1	0	0	0
	5	28.2	46.2	12.8	5.1	7.7	0	0
	6	53.8	33.3	7.7	2.6	2.6	0	0
Postoperative method								
	1	51.3	28.2	15.4	2.6	2.6	0	0
	2	41	20.5	28.2	5.1	5.1	0	0
	3	74.4	20.5	2.6	2.6	0	0	0
	4	66.7	17.9	12.8	2.6	0	0	0
	5	38.5	28.2	23.1	10.3	0	0	0
	6	30.8	38.5	17.9	7.7	2.6	0	2.6
		γ						
		≤1	>1–2	>2–3	>3–4	>4–5	>5–6	>6
Preoperative method								
	1	87.2	5.1	5.1	0	0	0	2.6
	2	69.2	23.1	5.1	2.6	0	0	0
	3	89.7	10.3	0	0	0	0	0
	4	89.7	10.3	0	0	0	0	0
	5	38.5	46.2	15.4	0	0	0	0
	6	61.5	30.8	7.7	0	0	0	0
Postoperative method								
	1	94.9	5.1	0	0	0	0	0
	2	66.7	20.5	7.7	5.1	0	0	0
	3	89.7	7.7	0	0	2.6	0	0
	4	66.7	28.2	5.1	0	0	0	0
	5	38.5	46.2	15.4	0	0	0	0
	6	43.6	46.2	7.7	0	0	2.6	0

(*continued*)

Table 4. (*Continued*)

		Intraobserver Percentage Within Discrepancy						
		α						
Discrepancy		≤1	>1–2	>2–3	>3–4	>4–5	>5–6	>6
Postoperative method								
	1	94.9	5.1	0	0	0	0	0
	2	66.7	20.5	7.7	5.1	0	0	0
	3	89.7	7.7	0	0	2.6	0	0
	4	66.7	28.2	5.1	0	0	0	0
	5	38.5	46.2	15.4	0	0	0	0
	6	43.6	46.2	7.7	0	0	2.6	0

intraobserver and interobserver agreement within a discrepancy of 2°. As a result, for α, β, and γ, method 4 yielded the highest agreement.

Discussion

There are many methods for measuring HVA and IMA_{1-2} (1), and their reliability has been suggested (4,5,7–9,12) to determine the most reliable and valid method because differences in angular measurement methods might lead to inconsistencies in making clinical decisions and incorrect conclusions.

Previous studies (9,10) have presented no other choice but to use PP1 or MT2 axes as references; however, with the development of digital technology, it is possible to evaluate the reliability of all components of HVA and IMA_{1-2} by creating an uniform line repeatedly using PACS software. The reliability and agreement of PP1, MT1, and MT2 may be reflected in this study.

Concerning the reliability of the 6 methods, there were significant differences in the measurement of preoperative HVA and IMA_{1-2} and postoperative IMA_{1-2}. These results suggest that the different methods cause disparate outcomes. Regarding α, β, and γ, there were significant differences in the measurement of preoperative α and β and postoperative β, but not in the measurement of preoperative γ and postoperative α and γ. In particular, variations in establishing reference points for PP1 and MT1 could lead to measurement differences and MT1 seems to be the most variable. These results suggest that the variable reference points of PP1 and MT1 could cause disparate outcomes.

The intraobserver and interobserver correlation coefficients for the preoperative and postoperative HVA, α, β, and γ measurements were high or very high. In IMA_{1-2}, the intraobserver and interobserver correlation coefficients for the preoperative and postoperative measurements were also high or very high except in methods 2 and 3. These results therefore were insufficient for choosing the most reliable method for the modified long oblique procedure.

The difference between the upper limits of mild deformity and the lower limits of a severe deformity is narrow in HVA and IMA_{1-2} (14). Measurement errors could affect the determination of severity. In the digitalized radiographic HVA evaluation in this study, all measurement methods except interobserver preoperative method 2 showed discrepancies within 5° >80% of the time. Likewise, there was discrepancies within 3° in all measurement methods except interobserver preoperative methods 2 and 5 and postoperative method 1 in IMA_{1-2}; therefore, choosing a measurement method with a wide range of discrepancy could lead to severe error.

There was a report that interobserver variability of HVA and IMA_{1-2} can be considered reliable if the respective values determined by 1 observer are no more than 3° for HVA and 2° for IMA_{1-2} different from those measured by another observer approximately 80% of the time (13). This indicates that a difference within 3° for HVA and 2° for IMA_{1-2} might not be clinically relevant. In this study, we considered

measurements of HVA and IMA_{1-2} within a discrepancy of 4° for HVA and 3° for IMA_{1-2} clinically reliable. There could be several reasons for this. Deformity of PP1, MT1, and MT2 in HV could cause a wider range of measurement error than in radiographs of consecutive patients without history of previous foot fracture or surgery, including HV deformity (13). Second, using digitalized radiographs enabled more precise measurements to 1 decimal place than using goniometers with an estimated standard error of measurement $<0.5°$ in manual circumstances. Moreover, this study contained both preoperative and postoperative measurement values; therefore, if bounds to capture 80% of differences in HVA and IMA_{1-2} were applied in this study, methods 4 and 6 meet these requirements.

As mentioned, HVA and IMA_{1-2} are composed of PP, MT1, and MT2 and expressed as α, β, and γ in the present study. For α, method 4 showed the highest pre- and postoperative intraobserver and interobserver agreement.

β is the angle between the MT1 axis and the DSRL; therefore, it is equivalent to measurements in the 2 reports (9,10) because the MT1 axis was measured with the PP1 and MT2 axes fixed. For β, methods 1, 4, and 6 showed reliable agreement. Some authors (10) recommended the method in which a line is drawn from the center of the MT1 head through the center of the base of MT1 because it was found to be the most precise and least biased by postoperative effects after distal metatarsal osteotomy. Other authors (9) also found that the method connecting the centers of the MT1 head and the proximal articular surface of MT1 to define its longitudinal axis yields the best intraobserver and interobserver reliability for the measurement of HVA and IMA_{1-2} in patients of proximal metatarsal crescentic osteotomy. Likewise, when only the MT1 was considered as a factor for choosing the most reliable method, methods 1, 4, and 6 would be applicable in patients of modified long oblique osteotomy; however, when α, another component of HVA, was considered, method 4 was found to be reliable.

When we compare the agreement of α with β, it is presumed that α is a more influential factor on reliability. We inferred that α is more decisive because its preoperative pronation and shorter length than MT1 might be more variable and thus cause measurement error. The reason for more variable α was not clearly revealed. Soft-tissue imbalance (1) or abnormal first metatarsal pronation (15) could cause this, which should be further evaluated.

For γ, all methods showed reliable agreement. We inferred that the axis of MT2 is rarely influenced by metatarsal osteotomy.

This study has several limitations. First, the subjects were randomly selected, which could cause selection bias; however, the number of subjects was greater than similar previous studies (9,10). Second, the 3 orthopedic surgeons who took part in this study had the possibility of showing more reliable results in latter measurements than early measurements.

The present radiographic study suggests that measurement error of HVA and IMA_{1-2} can develop when the axes of PP1, MT1, and MT2 are determined in patients who were managed with a metatarsal shaft osteotomy-modified long oblique osteotomy. According to our data, methods 4 and 6 had agreement of at least 80%, with a discrepancy of 4° in HVA and 3° in IMA_{1-2}. The method to draw a line from the center of the head through the center of the base had high intraobserver and interobserver reliability for the radiographic measurement of preoperative and postoperative α, β, and γ as well as HVA and IMA_{1-2}; therefore, this method is regarded as the least variable among the 6 methods for digitally assessing the radiographic results of operative treatment and evaluating HV deformity.

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