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Intrasubject Radiographic Progression of Hallux Valgus Deformity in Patients With and Without Metatarsus Adductus: Bilateral Asymmetric Hallux Valgus Deformity

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A R T I C L E I N F O

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A B S T R A C T

This study was to analyze intrasubject radiographic progression of the hallux valgus deformity by comparing the mildly and severely affected sides in patients with bilateral asymmetric hallux valgus in the whole group as well as the metatarsus adductus and the nonmetatarsus adductus subgroups. A total of 186 patients with bilateral asymmetrical hallux valgus deformity with a difference of 5° or greater in the hallux valgus angle were included, and 11 radiographic measurements were analyzed. The radiographic differences between the mildly and severely affected sides were compared. Correlation between the changes in the hallux valgus angle and those in other measurements was analyzed, and multiple regression analyses were performed. The anteroposterior talo-second metatarsal angle showed no significant difference between the mildly and severely affected sides. Changes in the intermetatarsal angle and sesamoid rotation angle were significantly associated with the progression of hallux valgus angle in the whole group as well as the nonmetatarsus adductus subgroup. Change in the intermetatarsal angle (p = .006) was the significant factor associated with the progression of hallux valgus angle in the metatarsus adductus subgroup. The anteroposterior talo-second metatarsal angle might be useful in evaluating the overall foot shape in the hallux valgus deformity. Progression of the hallux valgus deformity might be pathophysiologically different between those with and without metatarsus adductus.

Hallux valgus is one of the most common foot deformities causing discomfort and impaired health-related quality of life in patients (1,2). It is a complex 3-dimensional deformity causing valgus deviation of the metatarsophalangeal joint and pronation. Clinical decision-making in the treatment of hallux valgus deformity is dependent on patients' symptoms and radiographs, but sometimes it is not easy to evaluate the deformity accurately due to its 3-dimensional nature.

Metatarsus adductus is known to cause an additional difficulty in treating the hallux valgus deformity (3,4). This deformity reduces the gap between the first and second metatarsal bones and limits the space available for the lateral translation of the first metatarsal head during surgical correction (4). Metatarsus adductus concomitant with hallux valgus might require more extensive surgery (5) and is also reported to be associated with postoperative recurrence (6) and unfavorable surgical outcomes (3,7).

Progression of the hallux valgus deformity has been reported to be associated with flatfoot and an increased distal metatarsal articular angle during a 2 years' observation (8). However, the observation of hallux valgus progression during the long-term follow up is practically difficult and could cause selection bias in a clinical situation where some of patients might undergo surgical treatment. Therefore, the authors assumed that the mildly affected side would progress to become the severely affected side in the hallux valgus deformity in patients with bilateral asymmetric hallux valgus, which could provide physicians with clinical results in a cross-sectional analysis comparable to those from the cohort study.

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No benefits in any form have been received or will be received from any commercial party related directly or indirectly to the subject of this article. We have full control of all primary data and we agree to allow the journal to review our data. Each author certifies that his or her institution has approved the human protocol for this investigation, that all investigations were conducted in conformity with ethical principles of research, and that informed consent for participation in the study was obtained.

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The purposes of this study are (1) to analyze the radiographic difference between the mildly and severely affected sides of hallux valgus in patients with bilateral asymmetric hallux valgus and (2) to investigate radiographic changes associated with changes in the hallux valgus angle in the whole group as well as the metatarsus adductus and nonmetatarsus adductus subgroups of patients.

Patients and Methods

This retrospective study was approved by the institutional review board at our hospital. We reviewed and retrieved the information of patients with bilateral hallux valgus deformity who visited our foot and ankle clinic (tertiary referral center). All patients underwent foot radiography (anteroposterior [AP], lateral, and axial sesamoid views). The hallux valgus deformity was defined as a hallux valgus angle of greater than 15° (9). Of patients with the bilateral hallux valgus deformity, those with an asymmetric deformity with a bilateral difference of 5° or greater in the hallux valgus angle were included. Patients with (1) previous foot and ankle surgery, (2) infection, (3) congenital anomaly, (4) neuromuscular diseases, (5) radiographic evidence of osteoarthritis of the foot, (6) dislocation of the metatarsophalangeal joint, (7) inadequate radiographs, and (8) previous trauma that could change the normal anatomy of the foot and ankle, were excluded from the study.

Fig. 1. Hallux valgus angle is the angle between lines a and b. Intermetatarsal angle is the angle between lines a and d. Interphalangeal angle was the angle between lines b and c. Proximal phalangeal articular angle is the angle between line b and a line perpendicular to line g. Distal metatarsal articular angle is the angle between line a and a line perpendicular to line h. Modified metatarsus adductus angle is the angle between lines d and e. AP talo-first metatarsal angle is the angle between lines a and f. the longitudinal axes of the talus and the first metatarsal. AP talo-second metatarsal angle is the angle between line d and f.

Fig. 2. First metatarsal protrusion distance is the different length between the arcs of the bisecting lines (L1 and L2) of the first and second metatarsals from the common intersection of the 2 lines.

Radiographic Measurements and Reliability Test

Radiographs of the foot were captured using a UT 2000 X-ray machine (Philips Research, Eindhoven, the Netherlands) according to our protocol. The AP view was obtained with the beam inclined at 15° from the vertical axis and centered between the feet on the midtarsal joint, with the patient standing barefoot. The feet were placed 10 cm apart, and the medial borders of both feet were paralleled. The lateral radiograph was captured separately for each foot in the standing position with the beam focusing on

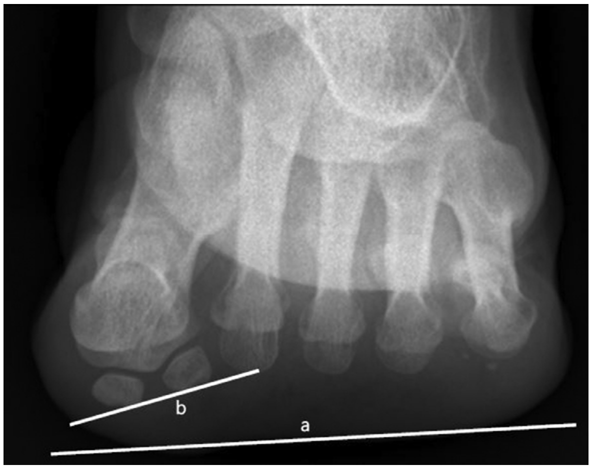

Fig. 3. Sesamoid rotation angle is the angle between lines a and b.

the medial cuneiform. The axial sesamoid view was taken with the toes dorsiflexed and the plantar surface of the foot at 75° to the cassette. The radiograph setting was 60 kVp and 10 mAs at a source-to-image distance of 110 cm. All radiographic images were digitally acquired using a picture archiving and communication system (PACS; Infinitt, Seoul, South Korea), and radiographic measurements were performed using PACS software.

Eleven radiographic measurements evaluating the hallux valgus deformity were determined after the literature review had been conducted: the hallux valgus angle (10), the intermetatarsal angle (10), the interphalangeal angle (11), the proximal phalangeal articular angle (12), the distal metatarsal articular angle (13), the modified metatarsus adductus angle (14,15), the first metatarsal protrusion distance (16), the AP talo-first metatarsal angle (17), the AP talo-second metatarsal angle (18), the sesamoid rotation angle (19), and the lateral talo-first metatarsal angle (5).

On the AP view, the hallux valgus angle was the angle between the longitudinal axis of the first metatarsal bone and that of the proximal phalanx. The intermetatarsal angle was measured between the longitudinal axes of the first and second metatarsal bones. The interphalangeal angle was the angle between the longitudinal axes of the proximal and distal phalanges. The proximal phalangeal articular angle was measured between a line perpendicular to the longitudinal axis of the proximal phalanx and another line representing the proximal articular surface connecting the 2 ends of subchondral sclerosis. The distal metatarsal articular angle was the angle between a line perpendicular to the longitudinal axis of the first metatarsal and another line representing the distal articular surface connecting the 2 endpoints of subchondral sclerosis. The modified metatarsus adductus angle was the angle between the longitudinal axes of the middle cuneiform and the second metatarsal (Fig. 1). The first metatarsal protrusion distance was measured between the arcs of the bisecting lines of the first and second metatarsals from the common intersection of the 2 lines (Fig. 2). The AP talo-first metatarsal angle was the angle between the longitudinal axes of the talus and the first metatarsal. The AP talo-second metatarsal angle was the angle between the longitudinal axes of the talus and the second metatarsal (Fig. 1). The sesamoid rotation angle was the angle between the plantar surface and a line connecting the most inferior aspect of the medial and lateral sesamoids on the sesamoid axial view (Fig. 3). The lateral talo-first metatarsal angle was the angle between the longitudinal axes of the talus and the first metatarsal on the lateral view (Fig. 4).

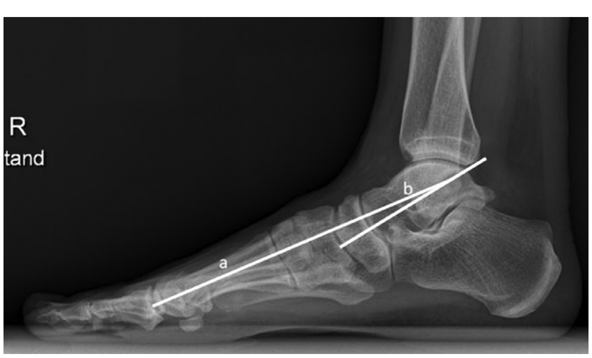

Fig. 4. Lateral talo-first metatarsal angle is the angle between lines a and b.

Data Analysis and Statistics

A descriptive statistical analysis was performed including mean, standard deviation (SD), and frequency. The patients had bilateral asymmetrical hallux valgus deformity with differences of 5° or greater in the hallux valgus angle, and the mildly and severely affected sides were coded. The comparison of radiographic measurements between the mildly and severely affected sides was conducted using the paired t-test. The difference in each radiographic measurement between the mildly and severely affected sides was calculated, and the difference value was hypothesized to be the progressive change of radiographic measurements. The correlation between the changes in radiographic measurements was analyzed using Pearson's correlation coefficient. Multiple regression analysis was performed to assess the changes in radiographic measurements significantly associated with changes in hallux valgus angle after univariate analysis; variables with $p \leq .1$ in univariate analysis were included in multiple regression analysis.

The data were analyzed in the whole group as well as subgroups. The patients were categorized into 2 subgroups, i.e., those with metatarsus adductus and those without metatarsus adductus, where metatarsus adducts was defined as the modified metatarsus adductus angle of greater than 24°(15,20) on either side.

All statistical analyses were performed with SPSS version 20.0 (IBM Co., Chicago, IL), and p value ≤.05 was considered statistically significant.

Results

A total of 186 patients with bilateral asymmetrical hallux valgus were included in the analysis. The mean age of the patients was 62.8 years (SD, 13.0 years), and there were 20 male and 166 female patients. Of these, 97 patients had a modified metatarsus angle of greater than 24° on either side of both feet and were classified as the metatarsus adductus subgroup, and the other 89 patients as the nonmetatarsus adductus subgroup. The mean age of the patients in the metatarsus adductus subgroup was 61.6 years (SD, 13.9 years), and there were 12 male and 85 female patients. The mean age of the patients in the nonmetatarsus adductus subgroup was 64.1 years (SD, 11.8 years), and there were 8 male and 81 female patients.

In the whole group of patients, all radiographic measurements except the AP talo-second metatarsal angles (p = .779) were significantly different between the mildly and severely affected sides (Table 1). Changes in the hallux valgus angle were significantly correlated with those in the intermetatarsal angle (r = 0.404, $p < .001$), the interphalangeal angle (r = -0.181, p = .014), the proximal phalangeal articular angle (r = 0.227, p = .002), the distal metatarsal articular angle (r=0.158, p = .031), and the sesamoid rotation angle (r = 0.349, $p < .001$; Table 2). Multiple regression analysis showed that changes in the

Table 1
Comparison of radiographic measurements between the mildly and severely affected sides in the whole group of patients

	Mild Side	Severe Side	*p* Value
N	186	186	-
Right: Left	75:111	111:75	-
HVA (°)	23.3 (SD 7.3)	34.8 (SD 8.3)	<.001
IMA (°)	11.5 (SD 3.1)	14.3 (SD 3.3)	<.001
IPA (°)	10.6 (SD 6.8)	5.9 (SD 8.6)	<.001
PPAA (°)	-2.0 (SD 4.2)	0.3 (SD 4.2)	<.001
DMAA (°)	11.4 (SD 6.7)	16.0 (SD 8.4)	<.001
MMA (°)	22.3 (SD 5.4)	23.2 (SD 6.3)	.002
1MT PD (mm)	2.3 (SD 2.7)	3.2 (SD 2.7)	<.001
AP talo-1MT (°)	14.1 (SD 7.7)	11.6 (SD 8.3)	<.001
AP talo-2MT (°)	25.8 (SD 7.5)	25.9 (SD 8.3)	.779
SRA (°)	11.8 (SD 11.2)	20.9 (SD 12.9)	<.001
Lat talo-1MT (°)	5.8 (SD 8.1)	7.0 (SD 7.8)	.013

Abbreviations: HVA, hallux valgus angle; IMA, intermetatarsal angle; IPA, interphalangeal angle; PPAA, proximal phalangeal articular angle; DMAA, distal metatarsal articular angle; MMA, modified metatarsus adductus angle; 1MT PD, first metatarsal protrusion distance; AP talo-1MT, AP talo-first metatarsal angle; AP talo-2MT, AP talo-second metatarsal angle; SRA, sesamoid rotation angle; Lat talo-1MT, lateral talo-first metatarsal angle; SD, standard deviation.

Table 2
Correlation between the changes in radiographic measurements in the whole group of patients (N = 186)

	ΔHVA	ΔIMA	ΔIPA	ΔPPAA	ΔDMAA	ΔMMA	Δ1MT PD	ΔAP talo-1MT	ΔAP talo-2MT	ΔSRA
ΔIMA	0.404 (p < .001)									
ΔIPA	-0.181 (p = .014)	-0.155 (p = .035)								
ΔPPAA	0.227 (p = .002)	0.184 (p = .012)	-0.183 (p = .012)							
ΔDMAA	0.158 (p = .031)	0.187 (p = .011)	-0.100 (p = .174)	0.251 (p = .001)						
ΔMMA	0.052 (p = .484)	-0.113 (p = .124)	0.096 (p = .194)	-0.086 (p = .243)	0.024 (p = .741)					
Δ1MT PD	0.045 (p = .539)	0.026 (p = .724)	0.132 (p = .073)	0.115 (p = .117)	0.086 (p = .244)	0.343 (p < .001)				
ΔAP talo-1MT	-0.061 (p = .411)	-0.182 (p = .013)	-0.032 (p = .667)	0.081 (p = .274)	-0.018 (p = .809)	-0.247 (p = .001)	-0.204 (p = .005)			
ΔAP talo-2MT	0.105 (p = .155)	0.282 (p < .001)	-0.071 (p = .338)	0.153 (p = .037)	0.100 (p = .175)	-0.302 (p < .001)	-0.199 (p = .007)	0.869 (p < .001)		
ΔSRA	0.349 (p < .001)	0.321 (p < .001)	-0.117 (p = .112)	0.169 (p = .021)	0.110 (p = .135)	0.071 (p = .339)	0.028 (p = .709)	0.119 (p = .107)	0.234 (p = .001)	
ΔLat talo-1MT	0.104 (p = .158)	0.067 (p = .365)	-0.042 (p = .574)	-0.071 (p = .332)	0.122 (p = .096)	0.099 (p = .178)	-0.144 (p = .050)	0.169 (p = .021)	0.198 (p = .007)	0.201 (p = .006)

Abbreviations: Δ, change; HVA, hallux valgus angle; IMA, intermetatarsal angle; IPA, interphalangeal angle; PPAA, proximal phalangeal articular angle; DMAA, distal metatarsal articular angle; MMA, modified metatarsus adductus angle; 1MT PD, first metatarsal protrusion distance; AP talo-1MT, AP talo-first metatarsal angle; AP talo-2MT, AP talo-second metatarsal angle; SRA, sesamoid rotation angle; Lat talo-1MT, lateral talo-first metatarsal angle.

Table 3
Multiple regression analysis to identify the radiographic changes significantly associated with the progression of hallux valgus angle in the whole group of patients (N = 186)

Radiographic Measurements	Nonstandardized		Standardized Beta	t-Test	p Value
	Beta	Standard Error			
Coefficient	8.263	0.530	-	15.595	<.001
ΔIMA	0.504	0.122	0.291	4.144	<.001
ΔIPA	-0.057	0.044	-0.085	-1.277	.203
ΔPPAA	0.121	0.076	0.110	1.595	.113
ΔDMAA	0.029	0.046	0.044	0.642	.522
ΔSRA	0.121	0.038	0.223	3.223	.002

Abbreviations: Δ, change; IMA, intermetatarsal angle; IPA, interphalangeal angle; PPAA, proximal phalangeal articular angle; DMAA, distal metatarsal articular angle; SRA, sesamoid rotation angle.

hallux valgus angle were significantly associated with those in the intermetatarsal angle (p < .001) and the sesamoid rotation angle (p = .001; Table 3).

In the metatarsus adductus subgroup of patients, all radiographic measurements except the AP talo-second metatarsal angles (p = .930) were significantly different between the mildly and severely affected sides (Table 4). Changes in the hallux valgus angle showed a significant correlation with those in the intermetatarsal angle (r = 0.378, p < .001), the interphalangeal angle (r = -0.208, p = .041), the proximal phalangeal articular angle (r = 0.273, p = .007), the distal metatarsal articular angle (r = 0.201, p = .049), and the sesamoid rotation angle (r = 0.264, p = .009; Table 5). Changes in the intermetatarsal angle (p = .006) were only significantly associated with those in the hallux valgus angle in the metatarsus adductus subgroup in multiple regression analysis (Table 6).

In the nonmetatarsus adductus subgroup, all radiographic measurements except the modified metatarsus adductus angle (p = .741), the AP talo-second metatarsal angle (p = .510), and the lateral talo-first metatarsal angle were significantly different between the mildly and severely affected sides (Table 4). Changes in the hallux valgus angle were significantly correlated with those in the intermetatarsal angle (r = 0.433, p < .001), the AP talo-second metatarsal angle (r = 0.234, p = .028), and the sesamoid rotation angle (r = 0.456, p < .001; Table 7). Multiple regression analysis showed that changes in the hallux valgus angle were significantly associated with those in the intermetatarsal angle (p = .005) and the sesamoid rotation angle (p < .001; Table 8).

Discussion

This study investigated the differences in radiographic measurements between the mildly and severely affected sides due to bilateral asymmetric hallux valgus deformity and radiographic changes associated with the progression of the hallux valgus angle. The results showed that all radiographic measurements were different between the mildly and severely affected sides except the AP talo-second metatarsal angle. Changes in the intermetatarsal angle and the sesamoid rotation angle were significantly associated with the progression of the hallux valgus angle.

Table 4
Comparison of radiographic measurements between the mildly and severely affected sides in the metatarsus adductus and nonmetatarsus adductus subgroups

	Metatarsus Adductus Subgroup			Nonmetatarsus Adductus Subgroup		
	Mild Side	Severe Side	p Value	Mild Side	Severe Side	p Value
N	97	97	-	89	89	-
Right: Left	59: 38	38: 59	-	52: 37	37: 52	-
HVA (°)	24.3 (SD 7.9)	35.6 (SD 8.5)	<.001	22.3 (SD 6.4)	33.8 (SD 8.0)	<.001
IMA (°)	11.3 (SD 3.1)	14.0 (SD 3.2)	<.001	11.7 (SD 3.2)	14.5 (SD 3.5)	<.001
IPA (°)	11.1 (SD 7.1)	6.3 (SD 9.2)	<.001	10.0 (SD 6.5)	5.5 (SD 8.1)	<.001
PPAA (°)	-1.5 (SD 4.4)	0.6 (SD 4.5)	<.001	-2.6 (SD 3.9)	0.05 (SD 3.9)	<.001
DMAA (°)	11.8 (SD 6.8)	16.4 (SD 8.6)	<.001	10.9 (SD 6.6)	15.7 (SD 8.3)	<.001
MMA (°)	25.9 (SD 4.1)	27.7 (SD 4.6)	<.001	18.2 (SD 3.5)	18.3 (SD 3.6)	.741
1MT PD (mm)	3.0 (SD 2.7)	4.0 (SD 2.8)	<.001	1.6 (SD 2.4)	2.2 (SD 2.1)	<.001
AP talo-1MT (°)	14.4 (SD 7.5)	11.7 (SD 9.0)	<.001	13.7 (SD 8.0)	11.5 (SD 7.5)	<.001
AP talo-2MT (°)	25.8 (SD 7.6)	25.7 (SD 9.1)	.930	25.8 (SD 7.4)	26.2 (SD 7.4)	.510
SRA (°)	11.4 (SD 12.1)	20.8 (SD 13.6)	<.001	12.1 (SD 10.2)	21.0 (SD 12.2)	<.001
Lat talo-1MT (°)	6.4 (SD 7.6)	7.8 (SD 8.2)	.042	5.0 (SD 8.6)	6.0 (SD 7.4)	.151

Abbreviations: HVA, hallux valgus angle; IMA, intermetatarsal angle; IPA, interphalangeal angle; PPAA, proximal phalangeal articular angle; DMAA, distal metatarsal articular angle; MMA, modified metatarsus adductus angle; 1MT PD, first metatarsal protrusion distance; AP talo-1MT, AP talo-first metatarsal angle; AP talo-2MT, AP talo-second metatarsal angle; SRA, sesamoid rotation angle; Lat talo-1MT, lateral talo-first metatarsal angle; SD, standard deviation.

Table 5
Correlation between the changes in radiographic measurements in the metatarsus adductus subgroup (N = 97)

	ΔHVA	ΔIMA	ΔIPA	ΔPPAA	ΔDMAA	ΔMMA	Δ1MT PD	ΔAP talo-1MT	ΔAP talo-2MT	ΔSRA
ΔIMA	0.378 ($p < .001$)									
ΔIPA	-0.208 ($p = .041$)	-0.184 ($p = .071$)								
ΔPPAA	0.273 ($p = .007$)	0.177 ($p = .083$)	-0.169 ($p = .098$)							
ΔDMAA	0.201 ($p = .049$)	0.128 ($p = .213$)	-0.138 ($p = .179$)	0.261 ($p = .010$)						
ΔMMA	0.085 ($p = .405$)	-0.069 ($p = .504$)	0.094 ($p = .359$)	-0.126 ($p = .218$)	0.022 ($p = .833$)					
Δ1MT PD	-0.015 ($p = .887$)	-0.056 ($p = .585$)	0.155 ($p = .129$)	0.067 ($p = .515$)	-0.049 ($p = .631$)	0.311 ($p = .002$)				
ΔAP talo-1MT	-0.141 ($p = .169$)	-0.162 ($p = .114$)	-0.056 ($p = .586$)	0.111 ($p = .279$)	0.091 ($p = .376$)	-0.270 ($p = .007$)	-0.235 ($p = .020$)			
ΔAP talo-2MT	0.030 ($p = .774$)	0.278 ($p = .006$)	-0.125 ($p = .222$)	0.184 ($p = .070$)	0.181 ($p = .075$)	-0.313 ($p = .002$)	-0.278 ($p = .006$)	0.894 ($p < .001$)		
ΔSRA	0.264 ($p = .009$)	0.325 ($p = .001$)	-0.122 ($p = .235$)	0.167 ($p = .102$)	0.113 ($p = .269$)	0.086 ($p = .401$)	0.038 ($p = .710$)	0.203 ($p = .046$)	0.329 ($p = .001$)	
ΔLat talo-1MT	0.106 ($p = .302$)	0.045 ($p = .661$)	-0.048 ($p = .638$)	-0.077 ($p = .451$)	0.187 ($p = .067$)	0.136 ($p = .186$)	-0.213 ($p = .036$)	0.256 ($p = .011$)	0.285 ($p = .005$)	0.248 ($p = .014$)

Abbreviations: Δ, change; HVA, hallux valgus angle; IMA, intermetatarsal angle; IPA, interphalangeal angle; PPAA, proximal phalangeal articular angle; DMAA, distal metatarsal articular angle; MMA, modified metatarsus adductus angle; 1MT PD, first metatarsal protrusion distance; AP talo-1MT, AP talo-first metatarsal angle; AP talo-2MT, AP talo-second metatarsal angle; SRA, sesamoid rotation angle; Lat talo-1MT, lateral talo-first metatarsal angle.

Table 6
Multiple regression analysis to identify the radiographic changes significantly associated with the progression of hallux valgus angle in the metatarsus adductus subgroup (N = 97)

	Nonstandardized				
Radiographic Measurements	Beta	Standard Error	Standardized Beta	t-Test	p Value
Coefficient	8.476	0.742	-	11.421	<.001
ΔIMA	0.475	0.170	0.279	2.796	.006
ΔIPA	-0.065	0.061	-0.101	-1.056	.294
ΔPPAA	0.173	0.105	0.161	1.642	.104
ΔDMAA	0.061	0.062	0.095	0.985	.327
ΔSRA	0.065	0.052	0.124	1.255	.213

Abbreviations: Δ, change; IMA, intermetatarsal angle; IPA, interphalangeal angle; PPAA, proximal phalangeal articular angle; DMAA, distal metatarsal articular angle; SRA, sesamoid rotation angle.

On comparison between the mildly and severely affected sides in the whole group, most radiographic measurements showed significant changes according to progression of the hallux valgus angle, while the AP talo-second metatarsal angle remained static. The second metatarsal bone is considered to be the most stable because the second metatarsal base is held in recess formed by the 3 cuneiform bones and Lisfranc ligament (21,22). In the hallux valgus deformity, the first metatarsal bone is medially deviated (adducted), maybe due to progressive instability of the first tarso-metatarsal joint (23). The common radiographic indices of the foot usually focus on the alignment of the first metatarsal bone, and they might not be accurate for the hallux valgus deformity.

The AP talo-first metatarsal angle decreased (adduction of the first metatarsal) and the lateral talo-first metatarsal angle increased (dorsiflexion of the first metatarsal) during the progression of hallux valgus in our study. The flatfoot deformity is usually concurrent with the abduction and dorsiflexion of the first metatarsal, but mismatch of the first metatarsal movement on the AP and lateral views in our study put additional confusion in analyzing the change of foot shape during the hallux valgus progression. Many previous studies have reported the association between hallux valgus and flatfoot (24,25), but these results might need to be reevaluated based on the AP talo-second metatarsal angle.

Changes in the hallux valgus angle were significantly correlated with those in the intermetatarsal angle ($p < .001$), the interphalangeal angle ($p = .014$), the proximal phalangeal articular angle ($p = .002$), the distal metatarsal articular angle ($p = .031$), and the sesamoid rotation angle ($p < .001$). Multiple regression analysis showed only the changes in the intermetatarsal and sesamoid rotation angles as significant factors associated with the progression of hallux valgus. We consider that changes in the interphalangeal, proximal phalangeal articular, and distal metatarsal articular angles might be dependent on the axial rotational deformity of the first ray, which is not a true deformity. These findings could devaluate the clinical relevance of these radiographic measurements.

A prominent difference between the metatarsus adductus and nonmetatarsus adductus subgroups during the progression of hallux valgus was found to be the change in the modified metatarsus adductus angle and the lateral talo-first metatarsal angle (Table 4). Metatarsus adductus is frequently concomitant with forefoot supination (2,3), and adduction of the first metatarsal in the hallux valgus progression would inevitably cause concurrent dorsiflexion of the bone. This change in the metatarsus adductus subgroup could cause pronation of the whole foot. This is supported by the results of multiple regression analysis in which changes in the hallux valgus angle were significantly associated with

Table 7
Correlation between the changes in radiographic measurements in the nonmetatarsus adductus subgroup (N = 89)

	ΔHVA	ΔIMA	ΔIPA	ΔPPAA	ΔDMAA	ΔMMA	Δ1MT PD	ΔAP talo-1MT	ΔAP talo-2MT	ΔSRA
ΔIMA	0.433 ($p < .001$)									
ΔIPA	-0.149 ($p = .162$)	-0.119 ($p = .267$)								
ΔPPAA	0.170 ($p = .111$)	0.191 ($p = .074$)	-0.204 ($p = .055$)							
ΔDMAA	0.105 ($p = .326$)	0.264 ($p = .012$)	-0.050 ($p = .644$)	0.236 ($p = .026$)						
ΔMMA	0.016 ($p = .880$)	-0.178 ($p = .095$)	0.115 ($p = .283$)	-0.002 ($p = .987$)	0.035 ($p = .744$)					
Δ1MT PD	0.127 ($p = .236$)	0.139 ($p = .193$)	0.107 ($p = .320$)	0.194 ($p = .069$)	0.277 ($p = .009$)	0.372 ($p < .001$)				
ΔAP talo-1MT	0.065 ($p = .545$)	-0.227 ($p = .032$)	0.008 ($p = .943$)	0.024 ($p = .820$)	-0.271 ($p = .041$)	-0.187 ($p = .080$)	-0.144 ($p = .179$)			
ΔAP talo-2MT	0.234 ($p = .028$)	0.298 ($p = .005$)	0.024 ($p = .824$)	0.098 ($p = .360$)	-0.049 ($p = .646$)	-0.276 ($p = .009$)	-0.050 ($p = .639$)	0.809 ($p < .001$)		
ΔSRA	0.456 ($p < .001$)	0.317 ($p = .002$)	-0.109 ($p = .307$)	0.174 ($p = .102$)	0.106 ($p = .323$)	0.036 ($p = .741$)	0.007 ($p = .948$)	-0.024 ($p = .824$)	0.073 ($p = .494$)	
ΔLat talo-1MT	0.104 ($p = .334$)	0.095 ($p = .376$)	-0.031 ($p = .771$)	-0.061 ($p = .573$)	0.040 ($p = .708$)	0.034 ($p = .753$)	-0.063 ($p = .555$)	0.031 ($p = .776$)	0.061 ($p = .572$)	0.141 ($p = .188$)

Abbreviations: Δ, change; HVA, hallux valgus angle; IMA, intermetatarsal angle; IPA, interphalangeal angle; PPAA, proximal phalangeal articular angle; DMAA, distal metatarsal articular angle; MMA, modified metatarsus adductus angle; 1MT PD, first metatarsal protrusion distance; AP talo-1MT, AP talo-first metatarsal angle; AP talo-2MT, AP talo-second metatarsal angle; SRA, sesamoid rotation angle; Lat talo-1MT, lateral talo-first metatarsal angle.

Table 8
Multiple regression analysis to identify the radiographic changes significantly associated the progression of hallux valgus angle in the nonmetatarsus adductus subgroup (N = 89)

Radiographic Measurements	Nonstandardized		Standardized Beta	t-Test	*p* Value
	Beta	Standard Error			
Coefficient	8.318	0.700	-	11.878	<.001
ΔIMA	0.502	0.176	0.283	2.857	.005
ΔAP talo-2MT	0.129	0.098	0.123	1.309	.194
ΔSRA	0.203	0.054	0.357	3.767	<.001

Abbreviations: Δ, change; IMA, intermetatarsal angle; AP talo-2MT, AP talo-second metatarsal angle; SRA, sesamoid rotation angle.

those in the intermetatarsal angle and the sesamoid rotation angle in the nonmetatarsus adductus subgroup and with only those in the intermetatarsal angle in the metatarsus adductus subgroup. This means that pronation of the first ray might not be as prominent in the metatarsus adductus subgroup as in the nonmetatarsus adductus subgroup whereas pronation of the whole foot is prominent. This complex 3-dimensional nature of metatarsus adductus deformity could be one of the reasons for a poor surgical outcome in hallux valgus (26,27).

This study has limitations. First, this study was based on the assumption that the mildly affected side would progress to become the severely affected side in patients with bilateral asymmetric hallux valgus deformity. Although this assumption enabled the authors to obtain the results from the cross-sectional data comparable to that from the longitudinal data without unnecessary bias, it has not been strictly supported by an evidence. Second, this study was focused on the radiographic measurements and did not record the data regarding patient discomfort or any other symptoms.

In conclusion, the AP talo-second metatarsal angle might be a more accurate and reliable radiographic measurement than the AP talo-first metatarsal angle in evaluating the overall foot shape in hallux valgus. Progression of hallux valgus concomitant with metatarsus adductus might be pathophysiologically different from that without metatarsus adductus.

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