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Original Article

Relationship between the medial cuneiform bone morphology and the severity of hallux valgus

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ABSTRACT

Background: It has been reported on the relationship between the medial cuneiform bone morphology, especially in terms of obliquity, and the severity of hallux valgus (HV), however, no consensus has been obtained. On the other hand, there are no reports on the relationship between the difference in height between the medial and intermediate cuneiforms and the severity of hallux valgus. The purpose of this study was to clarify the relationship between the medial cuneiform bone morphology and the severity of HV.

Methods: The authors retrospectively analyzed 200 feet of 116 patients who had a weightbearing anteroposterior foot radiograph taken between April 2017 and July 2022 and diagnosed with HV. Measurements included the hallux valgus angle (HVA), the intermetatarsal angle (IMA), the distal medial cuneiform angle (DMCA) and the cuneiform first-second length (C1-2D). HV groups were classified into one of three groups: mild ($15 \leq \text{HVA} < 30^\circ$, $9 < \text{IMA} < 13^\circ$), moderate ($30 \leq \text{HVA} < 40^\circ$, $13 \leq \text{IMA} \leq 20^\circ$) and severe groups ($\text{HVA} \geq 40^\circ$, $\text{IMA} > 20^\circ$), and the relationship to DMCA or the difference in height between the medial and intermediate cuneiforms was analyzed.

Results: A total of 163 feet of 93 patients were included in this study. There were significant correlations between the HVA and the DMCA ($r = 0.47$, $p < 0.001$) or the C1-2D ($r = 0.64$, $p < 0.001$). There was no significant difference in DMCA between the mild and moderate groups ($p = 0.14$). On the other hand, significant differences in C1-2D were observed between the three groups (mild-moderate; $p < 0.001$, moderate-severe; $p = 0.03$, mild-severe; $p < 0.001$). IMA was also positively correlated with the DMCA ($r = 0.30$, $p < 0.001$) or the C1-2D ($r = 0.47$, $p < 0.001$). However, the DMCA ($p = 0.07$) and the C1-2D ($p = 0.39$) did not differ significantly from IMA between the moderate and severe groups.

Conclusions: The difference in height between the medial and intermediate cuneiforms, referred to as C1-2D, is closely associated with the HVA. The C1-2D may influence the progression of HV and be a novel radiographic parameter that indicates severity of HV.

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1. Introduction

Hallux valgus (HV) is the most common cause of forefoot pain, affecting an estimated 20% of adults over the age of 65 [1]. It is characterized by lateral deviation of the big toe, accompanied by soft tissue, bony enlargement of the first metatarsophalangeal joint, and varus deformity with internal rotation of the first metatarsal bone [1,2]. The cause of HV is multifactorial, involving both intrinsic and extrinsic factors. The intrinsic factors include genetics,

ligamentous laxity, metatarsus primus varus, intrinsic muscle imbalance, flat foot, functional hallux limitus, sexual dimorphism, age, metatarsal morphology, first-ray hypermobility and achilles tendon tightness. Extrinsic factors include narrow-toed or high-heeled shoes and excessive weightbearing [1,3,4].

Radiographic parameters such as the hallux valgus angle (HVA), the intermetatarsal angle (IMA) and the distal metatarsal articular angle (DMAA) have been developed in weightbearing anteroposterior foot radiographs to classify the severity of HV [5]. Among these, HVA and IMA are the most commonly valued radiographic parameters, and it has been reported that there is a strong correlation between them [6]. The HVA is formed by drawing a line through the longitudinal axis of the first metatarsal

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and a line drawn through the longitudinal axis of the first proximal phalanx. The IMA is also drawn between the longitudinal axis of the first and second metatarsal [5,6]. In addition, these parameters are used to determine surgical procedures to evaluate their radiographic outcomes [7].

Previous studies have investigated the relationship between bone morphology, especially of the first metatarsal and the medial cuneiform, and the severity of HV. Regarding the first metatarsal, the distal metatarsal articular angle (DMAA) and the length of the first metatarsal are evaluated as the bone morphology [5,8]. Several reports have also examined the relationship between the medial cuneiform morphology and the severity of HV. These studies have examined the distal medial cuneiform angle (DMCA), defined as the angle between the distal joint orientation line of the medial cuneiform and the line perpendicular to the line, which is joining the midpoint of the distal joint orientation line and the midpoint of the proximal joint orientation line, as the medial cuneiform morphology [9–12]. However, the relationship between DMCA and the severity of HV remains controversial [9–12]. In addition, there are no reports investigating the relationship between the difference in height between medial and intermediate cuneiforms and the severity of HV.

The purpose of this study is to clarify the relationship between the medial cuneiform bone morphology and the severity of HV. Upon assessment, the DMCA and the difference in height between the medial and intermediate cuneiforms were examined. It is hypothesized that there is no relationship between the DMCA and HV severity, but that one does exist between the difference in height between the medial and intermediate cuneiforms and the severity of HV.

2. Methods

Institutional review board approval was obtained prior to the initiation of this project. Informed consent was obtained from all patients. This retrospective review included 200 feet of 116 patients who received weightbearing anteroposterior foot radiographs in the outpatient system between April 2017 and July 2022 and who were diagnosed with hallux valgus. When the weightbearing anteroposterior foot radiographs were taken, the patient stood at a normal angle and gait base point, and the radiographic beam was directed cranial to caudal, 15° away from the coronal plane [13]. Patients who had weightbearing anteroposterior foot radiographs taken in the outpatient system and had an HVA of at least 15° or an IMA of at least 9° were also eligible for this study. Exclusion criteria were patients younger than 18 years, patients with a history of foot or ankle trauma or fracture, patients with a history of foot or ankle surgery, and patients with a history of treatment for systemic inflammatory diseases such as rheumatoid arthritis.

Patient demographics including sex, age, side, height, weight, and BMI were obtained. In the radiographic parameter evaluation of the HV, the HVA, IMA, DMCA and the difference in height between the medial and intermediate cuneiforms were examined using an image storage and communication system (PACS, Fuji Film Medical Synapse Version 5.5.000 V4.1, Tokyo, Japan) [3,9,13–17]. The difference in height between the medial and intermediate cuneiforms was defined as the distance between the two points of the distal lateral corner of the medial cuneiform and the distal medial corner of the intermediate cuneiform, named “cuneiform first-second length (C1-2D)” (Fig. 1). The C1-2D was measured using the midpoint between the articular surfaces in cases with the joint appeared to overlap, and the midpoint between the overlapping areas in cases with the bone appeared to overlap. To investigate the relationship between bone morphology of the medial cuneiform and the severity of HV, patients were divided into

three groups according to differences in HVA and IMA, based on Mann RA et al., and Sovilj M et al.: mild ($15 \leq \text{HVA} < 30^\circ$, $9 < \text{IMA} < 13^\circ$), moderate ($30 \leq \text{HVA} < 40^\circ$, $13 \leq \text{IMA} \leq 20^\circ$) and severe ($\text{HVA} \geq 40^\circ$, $\text{IMA} > 20^\circ$) [18,19]. Thereafter, the DMCA and the C1-2D in each the groups were compared. In addition, correlations between the HVA and the DMCA, as well as the C1-2D and correlations between the IMA and the DMCA, as well as the C1-2D, were statistically analyzed. Intra- and inter-rater reliability was calculated using the interclass correlation coefficients (ICCs) for the C1-2D. To test intra-rater reliability, two orthopaedic surgeons took measurements three times over a course of 3-day intervals and drew a parallel between the two data sets.

Statistical analysis was performed using SPSS software (Version 19; IBM, Armonk, NY, USA). *P* values < 0.05 were considered statistically significant. The assumption of normality for the radiographic parameters was evaluated using the Shapiro-Wilk test. Comparison of radiographic parameters such as the HVA, IMA, DMCA and C1-2D, among the 3 groups was performed using one-way analysis of variance (ANOVA) and post hoc analysis. In addition, the linear relationship between the HVA and the DMCA and C1-2D and the linear relationship between the IMA and the DMCA and the C1-2D were statistically assessed using Pearson's correlation coefficient.

3. Results

Of the initial 116 patients with 200 feet enrolled, 5 feet in 3 patients were younger than 18 years, 4 feet in 4 patients had a history of foot or ankle trauma or surgery, and 28 feet in 16 patients were excluded from the study because they had a history of being treated for systemic inflammatory diseases. The remaining 163 feet of 93 patients were analyzed in this study. Seventy-seven patients (84.6%) were female, and the mean age was 68.9 years ($\text{SD} \pm 10.2$). The characteristics of the study population are shown in Table 1.

There were 63 feet in the mild group, 36 feet in the moderate group, and 64 feet in the severe group according to the HVA. In comparing the demographic characteristics between the 3 groups, no significant differences were noted (Table 2). The mean HVA was 24.0° ($\text{SD} \pm 4.7$) in the mild group, 34.1° ($\text{SD} \pm 2.0$) in the moderate group, and 47.0° ($\text{SD} \pm 7.8$) in the severe group, with statistically significant differences between the 3 groups ($p < 0.001$) (Table 2). The mean DMCA was 23.9° ($\text{SD} \pm 6.0$), 26.4° ($\text{SD} \pm 5.3$) and 30.2° ($\text{SD} \pm 4.3$) in the mild, moderate, and severe groups, respectively. The severe group and the mild or moderate group showed significant differences (moderate-severe; $p < 0.001$, mild-severe; $p < 0.001$), but no significant difference was shown between the mild and moderate groups ($p = 0.14$) (Fig. 2). The mean C1-2D was 7.9 mm ($\text{SD} \pm 1.5$) in the mild group, 9.9 mm ($\text{SD} \pm 1.2$) in the moderate group, and 10.7 mm ($\text{SD} \pm 1.3$) in the severe group, with statistically significant differences among the 3 groups (mild-moderate; $p < 0.001$, moderate-severe; $p = 0.03$, mild-severe; $p < 0.001$) (Fig. 2). In addition, there were significant correlations between the HVA and the DMCA ($r = 0.47$, $p < 0.001$) or the C1-2D ($r = 0.64$, $p < 0.001$) (Fig. 3).

There were also 61 feet in the mild group, 85 feet in the moderate group, and 17 feet in the severe group according to the IMA. Comparison of demographic characteristics between the 3 groups showed no significant differences (Table 3). The mean IMA was 11.0° ($\text{SD} \pm 1.9$) in the mild group, 16.6° ($\text{SD} \pm 1.9$) in the moderate group, and 22.9° ($\text{SD} \pm 1.9$) in the severe group, with statistically significant differences between the 3 groups ($p < 0.001$) (Table 3). The mean DMCA was 24.6° ($\text{SD} \pm 6.1$), 27.7° ($\text{SD} \pm 5.4$), and 31.1° ($\text{SD} \pm 4.7$) in the mild, moderate and severe groups, respectively. The mild group and the moderate or severe group showed significant differences (mild-moderate; $p = 0.004$, mild-severe; $p <$

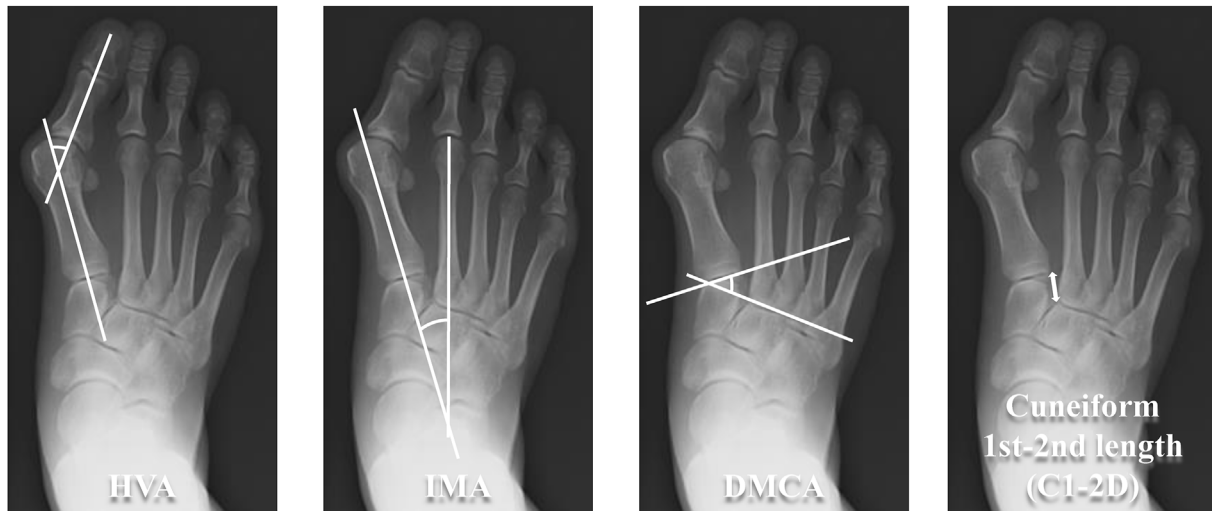


Fig. 1. Measurements of HV on the weightbearing anteroposterior foot radiograph are illustrated and include hallux valgus angle (HVA), intermetatarsal angle (IMA), distal medial cuneiform angle (DMCA). A novel measurement to characterize the difference in height between the medial and intermediate cuneiforms that we described is cuneiform 1st-2nd length (C1-2D) defined as the length between the two points of distal lateral corner of the medial cuneiform and distal medial corner of the intermediate cuneiform.

0.001), but no significant difference was shown between the moderate and severe groups ($p = 0.07$) (Fig. 4). The mean C1-2D was 8.3 mm ($SD \pm 1.7$) in the mid group, 10.0 mm ($SD \pm 1.6$) in the moderate group, and 10.6 mm ($SD \pm 1.5$) in the severe group. The mild group and the moderate or severe group showed significant differences (mild-moderate; $p < 0.001$, mild-severe; $p < 0.001$), but no significant difference was shown between the moderate and severe groups ($p = 0.39$) (Fig. 4). In addition, IMA was also positively correlated with the DMCA ($r = 0.30$, $p < 0.001$) or C1-2D ($r = 0.47$, $p < 0.001$), but with a lesser association than HVA (Fig. 5).

Furthermore, the reproducibility of the C1-2D measurement was high, with an intra-rater reliability of 0.908 ($p < 0.001$) and inter-rater reliability of 0.952 ($p < 0.001$).

4. Discussion

The present study investigated the relationship between the bone morphology of the medial cuneiform and the severity of HV. Morphological evaluation included the obliquity of the distal medial cuneiform and the difference in height between the medial and intermediate cuneiforms. The principal finding of this study was that the difference in height between the medial and intermediate cuneiforms, named C1-2D, was closely associated with the severity of HV, especially with the HVA. On the other hand, the DMCA showed a positive correlation with the HVA as well as the C1-2D, but there was no significant difference in the mean HVA and the mean IMA between the 3 groups.

Many studies have shown the importance of the first tarsometatarsal (TMT) joint as the etiology of HV. Movement of the first TMT joint is reported to account for 41–57% of the medial column, which is very important in the sagittal plane mechanism of the medial column of the foot [20,21]. Therefore, several studies have suggested that hypermobility or instability of the first TMT joint is associated with the severity of HV [22–25]. The bone morphology of the first metatarsal and medial cuneiform that make up the first TMT joint is also very important with respect to the progression and severity of HV, and many studies have investigated the relationship between these bone morphologies and HV.

In these studies, the DMAA and the length of the first metatarsal were assessed as the bone morphology. Subsequently, several reports investigating the relationship between the DMAA and HV severity have shown a relationship between the valgus of the distal articular surface in the first metatarsal bone and HV severity. However, the measured interobserver reliability of the DMAA is low [5], and so the relationship between the DMAA and the severity is controversial [5,12,13,26]. On the other hand, D'Arcangelo et al. have investigated the relationship between the first metatarsal length—defined as the increased length of the first metatarsal relative to the second metatarsal—and HV. This report has demonstrated that the first metatarsal length may be a contributing factor to the development and/or progression of HV [8].

Recently, there are several studies investigating the relationship between the medial cuneiform bone morphology in HV. In all of these previous studies, the distal articular morphology has been assessed as the bone morphology. However, whether or not there is a relationship between the distal articular morphology of the

Table 1
Patient characteristics of study population.

n	163 feet in 93 patients
Sex, M/F	14/79
Age, y	68.9 \pm 10.2
L/R	80/83
Height, m	1.54 \pm 0.62
Weight, kg	51.2 \pm 8.7
BMI, kg/m ²	21.7 \pm 3.3

Abbreviation: BMI, body mass index.

Table 2
Patient characteristics of study population with different degrees of HVA.

	Mild ($15 \leq \text{HVA} < 30$) n=63 feet	Moderate ($30 \leq \text{HVA} < 40$) n=36 feet	Severe ($\text{HVA} \geq 40$) n=64 feet	P
Age, y	67.5 \pm 12.4	71.1 \pm 9.8	71.1 \pm 9.8	0.42
Sex, M/F	9/54	5/31	8/56	0.96
L/R	33/30	17/19	30/34	0.79
Height, m	1.54 \pm 0.69	1.53 \pm 0.52	1.54 \pm 0.64	0.78
Weight, kg	50.4 \pm 8.6	52.1 \pm 7.2	51.4 \pm 9.9	0.82
BMI, kg/m ²	21.3 \pm 3.2	22.3 \pm 3.2	21.7 \pm 3.4	0.49
HVA, degrees	24.0 \pm 4.7	34.1 \pm 2.0	47.0 \pm 7.8	$p < 0.001$

Abbreviation: BMI, body mass index; HVA, hallux valgus angle.
P values represent the differences between 3 groups.

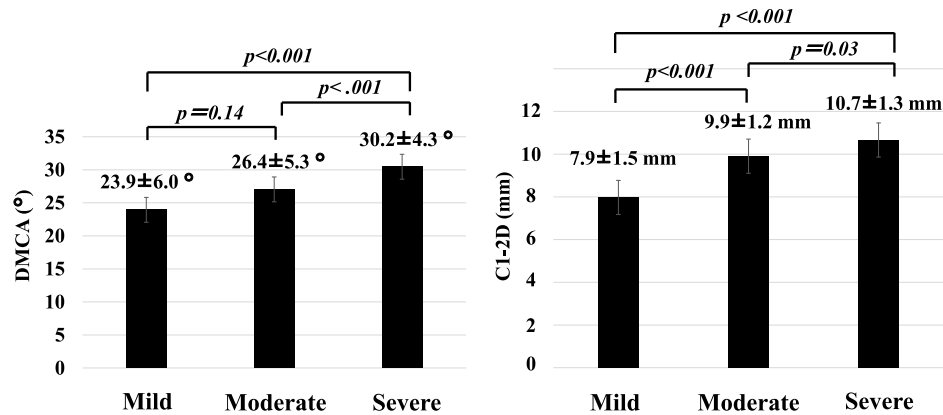


Fig. 2. Post hoc comparisons with different degrees of HVA. Abbreviation: C1-2D, cuneiform 1st-2nd length; DMCA, distal medial cuneiform angle; HVA, hallux valgus angle.

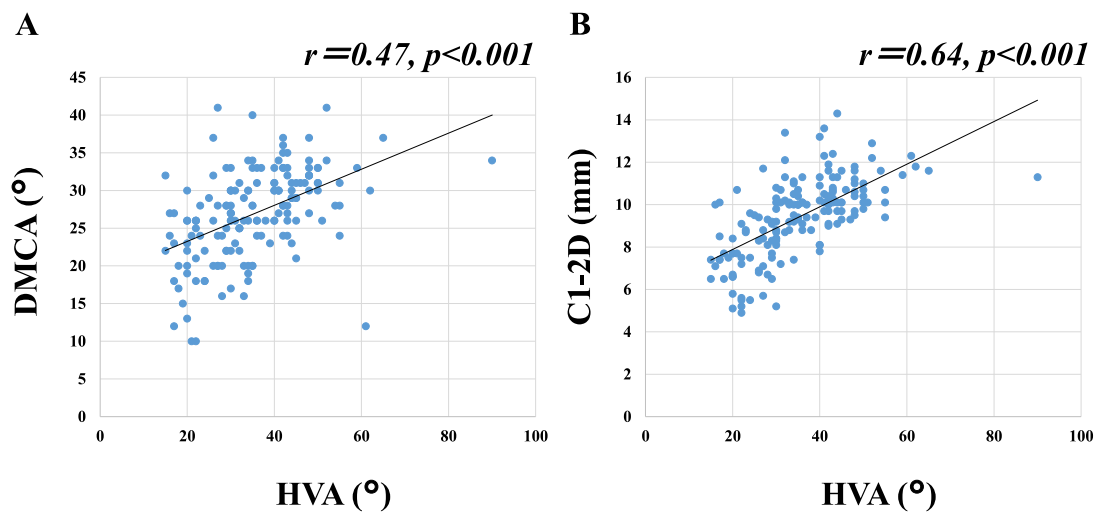


Fig. 3. Correlation analysis of HVA and (A) DMCA and (B) C1-2D. Abbreviation: C1-2D, cuneiform 1st-2nd length; DMCA, distal medial cuneiform angle; IMA, intermetatarsal angle.

medial cuneiform and the severity of HV remains controversial. Erduran et al. reported a correlation of different medial cuneiform radiological measures with the HV severity [10]. This study showed that medial cuneiform obliquity correlated somewhat strongly with HV severity, and that increased medial cuneiform obliquity accelerates the progression of the varus deformity of the first metatarsal. It also stated that there was no statistically significant difference in the medial cuneiform obliquity of the foot in cases with no deformity and those with mild deformity. In a cadaveric

study, Doty JF et al. found a positive correlation between medial cuneiform inclination and HVA, indicating that greater obliquity increases the risk of HV severity [11]. However, Dayton et al. have reported that there is no significant relationship between the medial cuneiform obliquity and the severity of HV [12]. In addition, Hatch et al. have suggested that there is an inverse relationship between the obliquity of the medial cuneiform and the severity of HV [9]. On the other hand, to the best of our knowledge, no report has investigated the relationship between the difference in height between the medial and intermediate cuneiforms and the severity of HV.

In this study, we investigated the relationship between the bone morphology of the medial cuneiform and the severity of HV. The DMCA measurement requires creating three precise lines: the distal joint orientation line of the medial cuneiform, a line connecting the midpoint of the distal joint orientation line and the midpoint of the proximal joint orientation line, and a line perpendicular to it, which may be difficult to accurately evaluate. In addition, the relationship between DMCA and the severity of HV remains controversial in previous studies [9–12]. For this reason, we devised an easier and more accurate way to measure the morphology of the medial cuneiform bone with a single line, devised the C1-2D. This study is the first study to measure C1-2D as the bone morphology. The C1-2D was positively correlated with the HVA, and there were significant differences in the C1-2D between the 3 groups. In addition,

Table 3

Patient characteristics of study population with different degrees of IMA.

	Mild (IMA <13) n=61 feet	Moderate (13 ≤ IMA ≤20) n=85 feet	Severe (IMA >20) n=17 feet	p
Age, y	66.3 ± 13.1	70.7 ± 7.1	69.6 ± 9.6	0.23
Sex, M/F	7/54	12/73	3/14	0.66
L/R	33/28	39/46	5/12	0.61
Height, m	1.54 ± 0.6	1.53 ± 0.59	1.53 ± 0.72	0.43
Weight, kg	50.2 ± 8.3	52.2 ± 9.0	49.3 ± 7.9	0.40
BMI, kg/m ²	21.1 ± 3.3	22.2 ± 3.3	21.0 ± 2.1	0.07
IMA, degrees	11.0 ± 1.9	16.6 ± 1.9	22.9 ± 1.9	p < 0.001

Abbreviation: BMI, body mass index; IMA, intermetatarsal angle.
P values represent the differences between 3 groups.

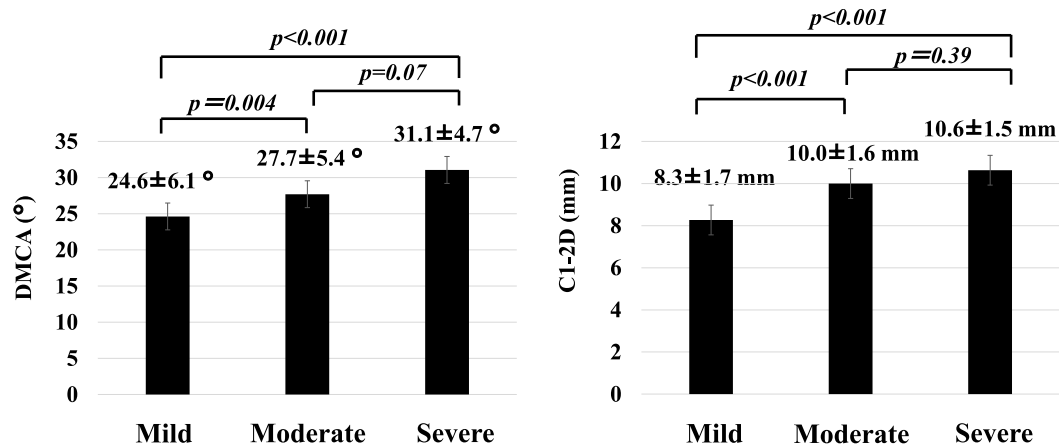


Fig. 4. Post hoc comparisons with different degrees of IMA. Abbreviation: C1-2D, cuneiform 1st-2nd length; DMCA, distal medial cuneiform angle; IMA, intermetatarsal angle.

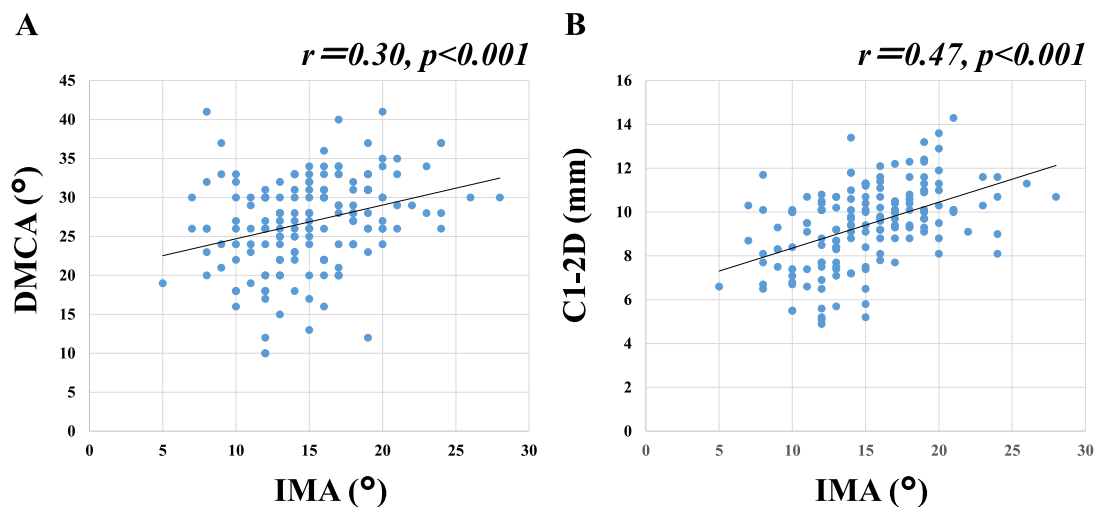


Fig. 5. Correlation analysis of IMA and (A) DMCA and (B) C1-2D. Abbreviation: C1-2D, cuneiform 1st-2nd length; DMCA, distal medial cuneiform angle; IMA, intermetatarsal angle.

the C1-2D had a very high reproducibility (intra-rater reliability 0.908, inter-rater reliability 0.952). Conversely, the DMCA was positively correlated with the HVA, but there were no significant differences in the DMCA between the 3 groups. Thus, the C1-2D may influence the progression of HV and be a novel radiographic parameter for the severity of HV.

This study has several limitations. First, this is a retrospective study conducted at a single institution, so the results may not be generalizable. However, radiographic procedures were standardized in all cases and were taken under exactly the same conditions. Second, this study focused on the bone morphology using plain radiographs of only weightbearing anteroposterior views. Although lateral assessment is necessary for thorough bone morphology evaluation, this proved challenging due to the areas where the cuneiform bones overlapped. In addition, the HVA and IMA, indicators of HV severity, were also assessed only in the anteroposterior view and therefore only anteroposterior views were used in this study. Measurement using only a weightbearing foot radiograph is very simple, which may allow for large cohort studies of HV severity in the future. Third, the C1-2D may depend on foot size, and the larger the foot size, the longer C1-2D may be. However, this study did not consider the effect of foot size on C1-2D. In order to consider the effect of foot size on C1-2D, it is necessary to

investigate not only cases with hallux valgus, but normal feet as well. Furthermore, no comparison was made between the hallux valgus group and the control group, nor was it investigated whether C1-2D is related to the development of HV.

In conclusion, the C1-2D is closely associated with the severity of HV. We believe that the C1-2D may influence the progression of HV and is a novel radiographic parameter that indicates the severity of HV.

Ethical approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Author's contributions

SM and FM contribute to the conception and design of the manuscript. All authors contribute to the data interpretation and preparation of the manuscript. All authors approved the final version of the manuscript.

Declaration of competing interest

The authors declare that they have no competing of interests.

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