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A New Measure of Tibial Sesamoid Position in Hallux Valgus in Relation to the Coronal Rotation of the First Metatarsal in CT Scans

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Abstract

Background: We aimed to find a new radiographic measurement for evaluating first metatarsal pronation and sesamoid position in hallux valgus (HV) deformity.

Methods: Data from a clinical study of 19 control patients (19 feet) with no HV deformity were compared with preoperative data of 138 patients (166 feet) with HV deformities. Using a weightbearing plain radiograph in anteroposterior (AP) view, the intermetatarsal angles (IMAs) and the hallux valgus angles (HVAs) of the control and study groups were measured. Using a semi-weightbearing coronal computed tomography (CT) axial view, the α angle was measured in the control and study groups. In addition, the tibial sesamoid grades in plain radiograph tangential view and the CT axial view were measured. The tibial sesamoid position in an AP view was checked preoperatively. Based on these measurements, 4 types of HV deformities were defined.

Results: The mean values of the α angle in the control and HV deformity groups (control group μ = 13.8 degrees, study group μ = 21.9 degrees) was significantly different. Among 166 HV feet, 145 feet (87.3%) had an α angle of more than 15.8 degrees, which is the upper value of the 95% confidence interval of the control group, indicating the existence of abnormal first metatarsal pronation in HV deformity. Four types of HV deformities were defined based on their α angles and tibial sesamoid grades in CT axial view (CT 4 position). Among 25.9% (43/166) of the study group, abnormal first metatarsal pronation with an absence of sesamoid deviation from its articular facet was observed. The prominent characteristic of this group was that they had high grades in the AP 7 position (≥5); however, in the CT 4 position, their grade was 0. This group was defined as the "pseudo-sesamoid subluxation" group.

Conclusions: Patients with HV deformities had a more pronated first metatarsal than the control group, with a greater α angle. Pseudo-subluxation of the sesamoids existed in 25.9% of our study group. From our results, we suggest that the use of the CT axial view in assessments of HV deformity may benefit surgeons when they make operative choices to correct these deformities. With regard to the pseudo-sesamoid subluxation group, the use of the distal soft tissue procedure is not surgically recommended.

Level of Evidence: Level III, retrospective comparative study.

Keywords: hallux valgus, first metatarsal pronation, sesamoid, CT axial view

Hallux valgus (HV) is a triplanar deformity that is associated with pronation deformity of the first metatarsal and valgus deformity of proximal phalanx, with the sesamoids described as laterally displaced or subluxated into the first intermetatarsal space in the frontal and transverse planes.[1,7-9,14,16,23] The sesamoids are comparably more stable than the first metatarsal head.[16] During HV progression, the metatarsal head drifts medially in relation to the sesamoids.[7] The metatarsosesamoid ligaments that connect the first metatarsal head and sesamoids function as a "driving belt," causing the first metatarsal to pronate as the sesamoids dislocate from their facets laterally.[14] The reduction of the subluxed sesamoids is an important goal in the surgical intervention of HV deformity. Dayton et al[4] demonstrated that the frontal plane component, such as the first metatarsal pronation and sesamoid subluxation, is a key

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component of the first metatarsophalangeal joint (MTPJ) misalignment in HV deformity and must be addressed during the surgical correction to provide anatomic alignment of the first MTPJ.[5]

Current standard radiographic evaluations of the tibial sesamoid position and the first metatarsal do not provide the surgeon with a complete impression of its 3-dimensional (3D) position. Hence, the lack of understanding of this concept has led to incomplete restoration of the first metatarsal and sesamoid complex, possibly contributing to the recurrence of HV deformity.[4] For instance, during our clinical observations, we have found some cases with abnormal tibial sesamoid positions (≥grade 5 by Hardy and Clapham's tibial sesamoid 7 position system in anteroposterior view[10] [AP 7 position, Figure 1]) have remarkably low tibial sesamoid grades, such as grade zero, in a computed tomography (CT) axial view (CT 4 position; Figure 2). This observation indicates that 2-dimensional radiographic analysis, such as the AP 7 position, does not always accurately define the sesamoid position, due to its failure to address the sesamoids and the first metatarsal position in the frontal plane.[4,6,8,12-14,16]

Various procedures in the surgical correction of HV routinely take sagittal and transverse plane deformities into consideration. In contrast, the frontal rotation component has been generally overlooked except in a few studies.[2,8,14,16] In this study, we have undertaken a retrospective evaluation of the tibial sesamoid and the first metatarsal position in the computed tomography (CT) axial view, the weightbearing AP radiographic view, and the tangential view. We aimed to show that HV deformity is triplanar in nature and, therefore, imperative to be addressed as a whole when choosing surgical procedures to correct this deformity. Adequate operative approaches, such as osteotomy and distal soft tissue procedures, should be used in correcting HV deformities, which are triplanar.

Methods

All of the patients were recruited from a tertiary foot and ankle center. The control group was recruited for radiographs and CT scans with other clinical morbidities that did not influence the parameters of the current study. The data were collected from August 2012 to April 2014. The preoperative radiographic data were collected from the control (n = 19) and study groups (n = 166). For the study group, 166 feet from 138 patients who were registered for HV surgery (28 patients received bilateral hallux valgus surgery) with symptomatic and radiologically diagnosed HV were assessed.

The mean ages were 47.2 years (range, 28-68) for the control group and 54.5 years (range, 18-84) for the study group. The sex distribution in the control group was all female. The study group had 16 male and 122 female patients. Overall, 74 clinical cases of right foot HV deformities and 92 clinical cases of left foot HV deformities were observed. Hence, the preoperative radiologic data were collected from 185 feet, including both the control and the study groups, using CT scans and plain radiographic film.

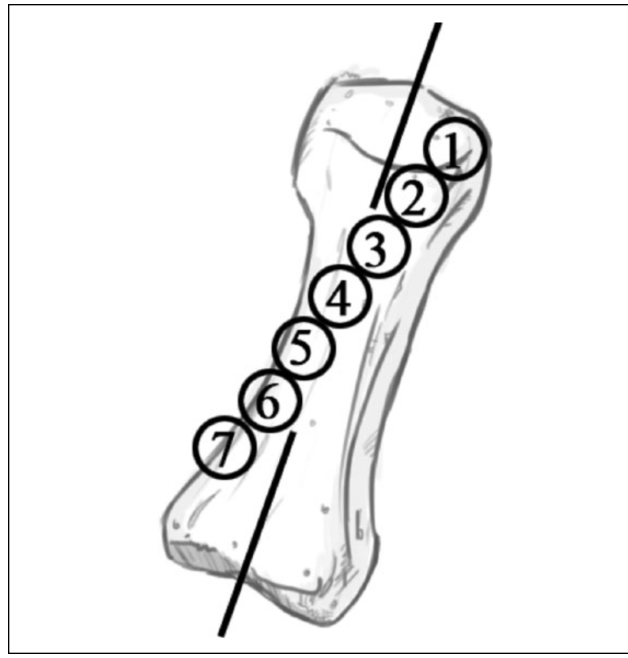

Figure 1. Hardy and Clapham's tibial sesamoid 7 position system in an anteroposterior view (AP 7 position).[10]

Software and Statistical Method

The CT data sets were analyzed using image-processing software (Osirix v. 3.9.1; Antoine Rosset, Geneva, Switzerland). The software allowed the export of 3D coordinates of annotated points to external spreadsheet software (Excel; Microsoft Corp, Redmond, WA). All of the radiographic measurements were statistically compared using a 1-sample *t* test. The correlations between the radiographic measurements were assessed using Pearson's correlation coefficients. Statistical analysis was performed using SPSS 21 (SPSS, Inc, an IBM Company, Chicago, IL). Results yielding a *P* value of less than 5% were considered statistically significant.

Radiographic Measurement Method (HVA, IMA, and α Angle Measurements)

Using a weightbearing plain radiograph AP view, measurements were taken of the intermetatarsal angle (IMA), the hallux valgus angle (HVA), and the first MTPJ congruency for the control and study groups. The preoperative assessment of sesamoid position was conducted by following conventional measurements, namely, the tibial sesamoid 4

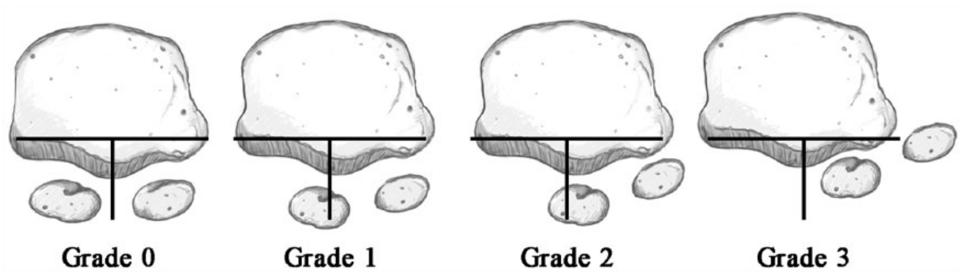

Figure 2. Sesamoid grading according to the position of the tibial sesamoid relative to the intersesamoid ridge. The figure was reproduced from Yildirim et al.[23]

position in weightbearing radiographic tangential view described by Smith et al[19] (tangential 4 position) and the Hardy and Clapham[10] tibial sesamoid position 0-7 in weightbearing plain radiograph (AP 7 position; Figure 1), along with our modified evaluation tool, the tibial sesamoid grade 0-3 in semi-weightbearing CT axial view (CT 4 position; Figure 2). The first metatarsal pronation angle (α angle) was evaluated in a semi-weightbearing coronal CT axial view for the control and study groups. Patients from both groups were positioned supine with the upper body stabilized on the CT platform. A CT scan of each foot was taken in 45 degrees of plantarflexion at the level of ankle, keeping the first MTPJ parallel to the platform. The plantar aspect of the foot was firmly applied to the CT table under a senior radiologist's supervision. All participants were instructed to push their foot downward to generate a semi-weightbearing environment.

To obtain the α angle, first, an inferior line was drawn between the lateral edge of the lateral sulcus and the medial edge of the medial sulcus. Subsequently, a superior line was drawn between the point of the medial and lateral corners of the first metatarsal head. Second, bisections of the above 2 lines were connected to a straight line perpendicular to the horizontal ground axis. Third, the angle was measured between the straight line and the vertical line perpendicular to the ground axis that was obtained from the first step (Figure 3).

In determining sesamoid positions, the 4-stage grading system by Smith et al[19] was evaluated (Figure 2). The 4-stage grading system was used according to the position of the tibial sesamoid relative to the intersesamoid ridge. Grade 0 indicates that the tibial sesamoid is entirely medial to the intersesamoid ridge, grade 1 indicates that less than half the width of the tibial sesamoid is subluxated laterally, grade 2 indicates that more than half the width of the tibial sesamoid is subluxated laterally, and grade 3 indicates that the tibial sesamoid is entirely lateral to the intersesamoid ridge.[19,20,23]

We obtained an axial CT view that cuts the sesamoids' bellies in the frontal plane perpendicular to the longitudinal bisection of the third metatarsal (Figure 4). This method was obtained after a careful evaluation of 19 preliminary data. We found that the parallel axis of the sesamoids did not exist in a perpendicular manner to either the first metatarsal or the second metatarsal but was perpendicular to the third metatarsal. This condition may be due to an insertion of the lateral soft tissues and the transverse head of the adductor muscle tendon around the first metatarsal, the sesamoid complex, and the third metatarsal. The sesamoid complex was parallel to the third metatarsal, as it was tightly anchored by the oblique head of the adductor muscle. An orthopaedic foot and ankle specialist measured each value 3 times to reduce intraobserver error. The same measurement technique was performed for both the control and study groups.

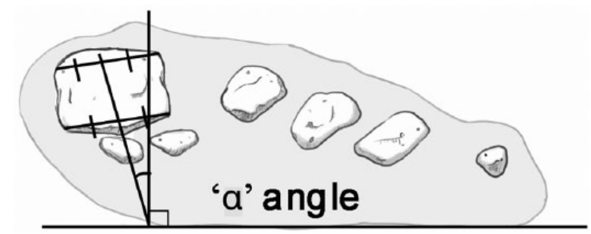

Figure 3. Illustration of the α angle measurement in a semi-weightbearing computed tomography axial view.

Results

Patient Demographics and the α Angle of the Control and Study Groups

Compared with the α value in the non-HV deformity population, which we defined as normal, the control group with no HV deformity was significantly different ($P < .001$, HVA μ = 12 degrees, IMA μ = 8.6 degrees) (Table 1). The mean ± SD values of the α angle (HVA <16 degrees, IMA <10 degrees) were 13.8 ± 4.1 degrees for the control group and 21.9 ± 6 degrees for the study group (Table 1). A noticeable difference was observed between the mean values of the α angles of the 2 groups. The result led to values below 15.8 degrees being regarded as normal α angles (upper value of the 95% confidence interval, $P < .001$). The statistical assessment

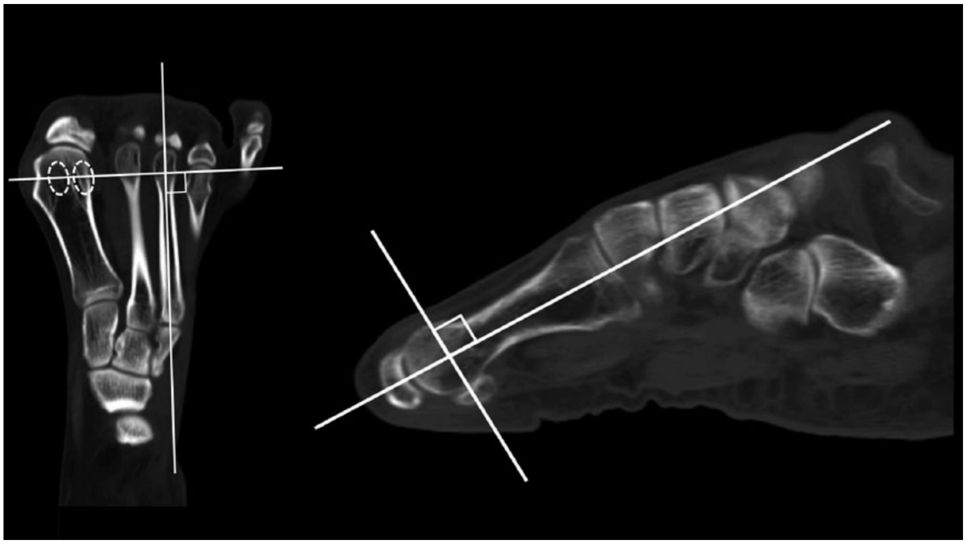

Figure 4. Anteroposterior view (left) and computed tomography axial view (right) illustrations of how we obtained a frontal plane slide of the first metatarsal head and sesamoids that cuts the sesamoids' bellies perpendicular to the longitudinal bisection of the third metatarsal.

Table 1. Patient Demographics and Radiographic Findings of the Mean α Angles From the Control and Study Groups.

Characteristic	Control Group	HV Deformity Group	*P* Value
Population/number of feet (female, male)	19/19 (19, 0)	138/166 (122, 16)	
Age, mean (range), y	47.2 (28-68)	54.5 (18-84)	<.001
Mean HVA, deg	12.0	31.8	<.001
Mean IMA, deg	8.6	15.0	<.001
First metatarsal pronation α angle, mean (SD), deg	13.8 (4.1)	21.9 (6.0)	<.001
95% Confidence interval, deg	11.8-15.8	16.7-23.7	<.001

HV, hallux valgus; HVA, hallux valgus angle; IMA, intermetatarsal angle.

suggested that an α angle greater than 16 degrees should be defined as an abnormal first metatarsal pronation angle.

Correlations Between Preoperative HVA, IMA, CT 4 Position, and α Angle

Among 166 feet with HV deformity, Pearson's correlations of the α angle with respect to HVA ($\rho = .076$, $P < .1$; Figure 5, Table 2) and IMA ($\rho = .144$, $P < .1$; Table 2) showed relatively weak positive relationships. In addition, the correlation between α angle and the grade of sesamoid subluxation in the CT showed a very weak correlation ($\rho = .019$, $P < .1$; Table 2). Therefore, we can conclude that the α angle was an independent measurement that determined the rotational angle of the first metatarsal in comparison to the HVA, the IMA, and the CT 4 position. In contrast to the α angle, which was an independent measurement, a moderate statistical correlation between the CT 4 position and the HVA was noted, with a Spearman's rank correlation coefficient ρ of .477 ($P < .01$) (Table 2).

Prediction of Tibial Sesamoid Position With Conventional Radiographic Measurement

There were noticeable differences in the prediction of the tibial sesamoid position between the tangential 4 position and the CT 4 position among 39.7% (65/166) of the study group. There was no consistency of results when using a different radiographic evaluation tool. For instance, in one-quarter of the study group (40/166 [25.8%]), the CT 4 position predicted more severe subluxation of the tibial sesamoid than the tangential 4 position. In one-tenth of the study group, the tangential 4 position predicted more severe subluxation of the tibial sesamoid compared with the CT 4 position (20/166 [12.9%]).

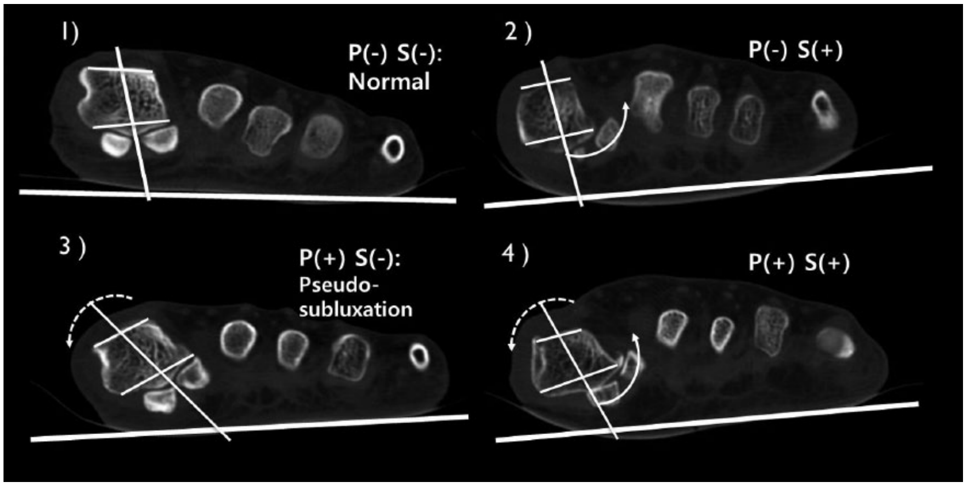

Figure 5. Four different classification groups of hallux valgus deformity. (1) P(–)S(–): normal first metatarsal pronation angle (α angle <15.8 degrees) with no tibial sesamoid subluxation (grade 0). (2) P(–)S(+): normal first metatarsal pronation angle (α angle <15.8 degrees) with tibial sesamoid subluxation (grade 1). (3) P(+)S(–): abnormal first metatarsal pronation angle (α angle 15.8 degrees) with no tibial sesamoid subluxation (grade 0). (4) P(+)S(+): abnormal first metatarsal pronation angle (α angle ≥15.8 degrees) with tibial sesamoid subluxation (grade 1).

Table 2. Spearman Rank Correlation Coefficients Between Radiographic Measurements.

Radiographic Measurement	Spearman Rank Correlation Coefficient (ρ)	*P* value
α angle vs HVA	.076	<.1
α angle vs IMA	.144	<.1
α angle vs CT 4 position	.019	<.1
HVA vs CT 4 position	.477	<.01
HVA vs IMA	.614	<.001

CT, computed tomography; HV, hallux valgus; HVA, hallux valgus angle; IMA, intermetatarsal angle.

During our clinical observation, we noted some cases with abnormal tibial sesamoid positions (≥grade 5) in the AP 7 position that actually did not have subluxed sesamoids when they were reassessed in the CT 4 position (28/166 [16.9%]) and the tangential 4 position (24/166 [14.5%]).

Sesamoid Subluxation Classification System Using the α Angle and the CT 4 Position

Four different classifications of HV deformity groups were obtained in relation to the α angle and the CT 4 position (Table 3, Figure 5). A total of 87.3% (145/166) of the study group presented α angles of more than 15.8 degrees, confirming the existence of abnormal first metatarsal pronation in the sample population. This observation supports the idea that first metatarsal pronation is a characteristic of the HV deformity (Tables 4 and 5).

Table 3. New Hallux Valgus Deformity Classification System Based on First Metatarsal Pronation and Sesamoid Subluxation Using a CT Axial View.

Abbreviation	Definition
P(+)/first metatarsal pronation	α angle ≥15.8 degrees[a]
P(–)/no first metatarsal pronation	α angle <15.8 degrees[a]
S(+)/sesamoid subluxation	CT 4 position ≥1
S(–)/no sesamoid subluxation	CT 4 position <1

CT, computed tomography.
[a]Obtained from the upper 95% confidence interval of the α angle from the control group.

Sesamoid subluxation was identified in 10.3% (17/166) of the study group in the absence of first metatarsal pronation (Table 4). We have adopted the concept of true sesamoid subluxation from the study by Smith et al[19] and

Table 4. Characteristics of the 4-Type Hallux Valgus Deformity Classification System Based on First Metatarsal Pronation and Sesamoid Subluxation According to the Definitions From Table 3.

	S(+)/Sesamoid Subluxation	S(–)/No Sesamoid Subluxation	Total of First Metatarsal Position
P(+)/first metatarsal pronation	P(+)S(+) 61.4% (102/166)	P(+)S(–) 25.9% (43/166) Pseudo sesamoid subluxation	P(+)S(+,–) 87.3% (145/166) First metatarsal pronation
P(–)/no first metatarsal pronation	P(–)S(+) 10.3% (17/166)	P(–)S(–) 2.4% (4/166)	P(–)S(+,–) 12.7% (21/166) No first metatarsal pronation
Total percentage of sesamoid position	P(+,–)S(+) 71.7% (119/166) True sesamoid subluxation	P(+,–)S(–) 28.3% (47/166) No sesamoid subluxation	P(+,–)S(+,–) 100% (166/166)

Table 5. Four-Type Hallux Valgus Deformity Classification System Based on First Metatarsal Pronation and Sesamoid Subluxation.

	P(+)S(+)	P(+)S(–)	P(–)S(+)	P(–)S(–)
Group distribution (166 feet), No. (%)	102 (61.4)	43 (25.9)	17 (10.3)	4 (2.4)
AP view				
HVA, mean (95% CI), deg	34.4 (32.9 to 36)	26.5 (24.2 to 28.9)	31.8 (27.3 to 36.4)	23.3 (14.6 to 32)
P value	<.001	<.001	<.001	<.003
IMA, mean (95% CI)	15.8 (15.1 to 16.4)	13.6 (12.6 to 14.5)	14.5 (12.9 to 16)	14.3 (11.5 to 17)
P value	<.001	<.001	<.001	<.001
Prevalence of incongruence in the group, No. (%)	45/103 (44)	5/44 (11)	5/17 (29)	0/4 (0)
AP 7 position, mean (95% CI)	6.2 (6.1 to 6.4)	5.0 (4.5 to 5.3)	5.5 (4.7 to 6.4)	5.5 (3.4 to 7.6)
p value	<.001	<.001	<.001	<.003
Sesamoid axial view				
Tangential 4 position, mean (95% CI)	1.6 (1.4 to 1.8)	0.4 (0.2 to 0.6)	1.4 (0.8 to 1.9)	0.8 (–0.8 to 2.3)
P value	<.001	<.001	<.001	<.22
CT axial view				
CT 4 position, mean (95% CI)	1.5 (1.3 to 1.6)	0.0 (0)	1.5 (1.1 to 1.9)	0.0 (0)
P value	<.001		<.001	
α angle, mean (95% CI), deg	23.6 (22.6 to 24.7)	22.6 (21.3 to 23.9)	12.2 (10.7 to 13.8)	13.3 (7.7 to 18.8)
P value	<.001	<.001	<.001	<.005

AP, anteroposterior; CI, confidence interval; CT, computed tomography; HV, hallux valgus; HVA, hallux valgus angle; IMA, intermetatarsal angle.

named any anatomical displacement of the sesamoids from their articular facets as true sesamoid subluxation. A total of 71.7% of the study group (119/166) had true subluxation of the sesamoids (Table 4). Among 28.3% (47/166) of the study group, no displacement of the sesamoids relative to the intersesamoidal ridge was noted (Table 4). Furthermore, we identified atypical cases with first metatarsal pronation without the presence of sesamoid displacement. This condition was named "pseudo-sesamoid subluxation," and it was observed in 25.9% (43/166) of the study group (Table 4).

Preoperative Values of the Tibial Sesamoid Position and Congruency in 4 Types of HV Deformity

The means of the HVA, the IMA, the first MTPJ congruency, the tibial sesamoid positions in 3 different radiographic measurements, and the first metatarsal pronation angles of 4 types of HV deformity groups were obtained at the preoperative stage (Table 5). The P(+)S(+) group showed higher values in all of the variables compared with the other groups. This observation indicates that, in comparison to the other groups, the P(+)S(+) group predominantly consists of more severe cases of HV deformity. However, the P(–)S(–) group exhibited lower values in all of the variables compared with the other groups. This group comprised 2.4% of the study group and was regarded as a mild HV deformity group (Table 5). The mean value of the AP 7 position of this group was as high as the other groups ($\mu = 5.5$, $P < .001$) when there was no incongruence of the first MTPJ and no abnormal first metatarsal pronation (<15.8 degrees). The percentage prevalence of incongruence was higher in the P(–)S(+) group compared with the P(+)S(–) group (29% and 11%, respectively) (Table 5). The P(+)S(–) group, also known as the pseudo-sesamoid subluxation group, showed low incongruence (5/44 [11%]) with a high average of the first metatarsal pronation angle ($\mu = 22.6$ degrees, $P < .001$) (Table 5).

Discussion

Our study demonstrated limitations in the current radiographic measurement methods used in assessing the relationship between the first metatarsal and the sesamoid complex. Previous studies have addressed the limitation of the transverse plane measurement of the tibial sesamoid position. However, most critics believe that the tibial sesamoid position should be measured in the frontal plane.[8,9,20,23] The tangential 4 position addresses frontal plane deformity; therefore, it has less technical error, but it presents with some other limitations. Yildirim et al[23] noted that with increasing dorsiflexion of the first MTP joint during the positioning of the tangential view, the moment arm of the flexor hallucis brevis (FHB) is raised; it not only pulls the subluxated sesamoids distally and dorsally but also produces a "bowstringing effect" that brings sesamoid subluxation to a reduced position (decrease in sesamoid subluxation grade).[23] In our study, we used a semi-weightbearing CT scan to eliminate input from dynamic stabilizers such as the FHB in the change of sesamoid position. Our radiographic evaluation of the tibial sesamoid position and the α angle in the CT axial view was comparably less biased than other radiographic measurements in assessing sesamoid positions in relation to the first metatarsal pronation.

Using our method to measure the α angle, we measured a relatively high value for the average first metatarsal pronation angle ($\mu = 21.9$ degrees, $P < .001$) in comparison to the study group. Mortier et al[14] obtained a mean ± SD first metatarsal pronation angle of 12.7 ± 7 degrees from 100 patients with HV deformity, which is lower than our findings. They used weightbearing tangential radiographs that require certain amounts of dorsiflexion of the first MTPJ, possibly causing reduction in the first metatarsal rotation angle.[14] Talbot and Saltzman[20] conducted in vivo and in vitro studies and reported that the mean first metatarsal rotation angle for a control group of 30 samples was 7.2 degrees, which is comparably lower than our findings. It is important to note that measurement for the first metatarsal rotation by Saltzman et al[17] was based on the tilt of the toenail plate using 2 beadlets mounted on the lunula, which is likely to measure the rotation angle of the distal phalanx but not the first metatarsal.

According to recent research from Collan et al[2] using a weightbearing CT, no statistical significance of the first metatarsal pronation was observed in the HV deformity group. They reported that the first proximal phalanx has more dynamic rotational movement compared with the first metatarsal.[2] Although we have not evaluated the rotation angle of the first proximal phalanx, it is possible that the phalangeal rotation may have occurred due to the first metatarsal pronation originating at the level of an unstable first tarsometatarsal joint (TMTJ). The stability of the first TMTJ is influenced by the peroneus longus (PL) muscle, which inserts into the base of the first metatarsal.[15] When the PL muscle is no longer well anchored and its tendon displacement impairs the response to the counterpressure of the ground reaction force (GRF), then the instability of the first TMTJ may increase.[14] Additional phalangeal rotation may occur secondary to the flexible soft tissue compartment located at the metatarsophalangeal complex that is exposed to the HV force.

Pearson's correlation test was conducted to determine if any relevant factors increased with the α angle. Some studies noted a strong relationship between the first metatarsal pronation and the IMA.[8] We found that the α angle was an independent measurement; it determined the rotational angle of the first metatarsal in comparison to other conventional measurements, namely, the HVA, the IMA, and the tibial sesamoid position. An increase in the HVA or the IMA did not necessarily guarantee an increase in the α angle. However, first metatarsal pronation can occur without having HV deformity, especially in populations with a collapse of the medial longitudinal arch.[8] Future studies are required to determine the factors that contribute to increases in the α angle.

Our study named 4 types of HV deformities based on the first metatarsal pronation and the subluxation of sesamoids. The CT axial view classified new subgroups of HV deformity and visually clarified a "true sesamoid subluxation group," where sesamoids dislocate from their facets with or without first metatarsal pronation (Table 4, Figure 4). Smith et al[19] mentioned the concept of "true subluxation" of sesamoids by comparing sesamoid positions in relation to the intersesamoidal ridge of the first metatarsal in a tangential view.[19,23] True subluxation of the sesamoids occurs when sesamoids leave their articular facets located inferior to the first metatarsal head. This condition can occur with or without pronation of the first metatarsal. One drawback to this 4-stage grading system is that it does not consider the degree of the first metatarsal pronation, an important factor in determining the true grade of the sesamoid subluxation.[19,23]

The true sesamoid subluxation group (119/166 [71%]) may have resulted from the following pathomechanics: (1) a medial deviation or elevation of the first metatarsal due to the "drive belt" force of the metatarsosesamoid ligament and the medial collateral ligament (MCL),[14,15,22] (2) an oblique or an unstable tarsometatarsal joint that may encourage slipping of the metatarsal head off of the sesamoid apparatus,[14,15] (3) a relatively stationary appearance of the lateral sesamoid in the intermetatarsal space connected to the head of the second metatarsal by the deep transverse metatarsal ligament,[15] and (4) as the metatarsal head drops off the sesamoid apparatus, it pronates due to the forces of the muscles acting across it. A large true sesamoid subluxation group strongly supports the hypothesis that the abnormality of the metatarsosesamoid joint is a prime etiology of sesamoid subluxation.

The P(+)S(–) group, also known as the pseudo-sesamoid subluxation group, existed in 25.9% (43/166) of the study group. The differential resistance of ligaments in the metatarsophalangeal complex explains the deviance in the characteristics of sesamoid subluxation.[14] In the pseudo-sesamoid subluxation group, it is possible that good resistance in the metatarsosesamoid ligament in conjunction with the phalangeal sesamoid ligament might have prevented separation of the first metatarsosesamoid complex.[14] However, laxity or synovitis in the MCL might have allowed rotation at the level of the first metatarsophlangeal joint (MPJ), causing the entire first metatarsosesamoid complex to pronate. In parallel, sectioning the medial compartment of the first MPJ results in a valgus angulation of more than 20 degrees.[15] Uchiyama et al[21] conducted a cadaveric study and observed an increase in the laxity of the MCL and an alteration in the type and distribution of collagen fibers in patients with HV.

The P(–)S(–) group comprised 2.4% (4/166) of the study group. The common characteristics of this group included high HVA ($\mu = 23.3 \pm 5.4$), IMA ($\mu = 14.3 \pm 1.7$), and AP 7 position ($\mu = 5.5$, $P < .011$). This group showed classic characteristics of HV deformity, where the aim of HV deformity correction surgery is to reduce the subluxation of the sesamoid positions. However, according to our modified definition, this group exhibited normal first metatarsal pronation angles (<15.8 degrees), and the sesamoids were properly centered under the first metatarsal head. Three of 4 patients in this group had first metatarsal pronation values of 15 degrees, 0.8 degrees less than the cutoff value; this difference gave this group its P(–)S(–) rank. These 3 patients may belong to the gray zone, where the level of misclassification risk exists.[3] Further studies are required to clarify the gray zone of the crucial classification system to eliminate potential quantitative errors.[3]

The main goal of the study was to evaluate tridimensional radiographic assessments of first metatarsal pronation and sesamoid positions in the study group for more precise evaluation and improved planning of surgical correction of HV deformity. Surgical correction of these parameters is crucial, and insightful surgical strategies must be implemented after a careful evaluation of the parameters. Our research team is currently investigating the clinical studies for such surgical strategies.

With regard to the pseudo-sesamoid subluxation group, the use of the distal soft tissue procedure (DSTP) is not surgically recommended. There are 2 main surgical goals in performing the DSTP in the correction of HV deformity[11]; 1 goal is to release the contracted adductor hallucis muscle tendon in the lateral complex to reduce incongruency at the first MTPJ.[18] Another goal is to reduce subluxation of the sesamoids by resecting the lateral metatarsosesamoid suspensory ligament.[18] Our radiographic findings suggest that the pseudo-sesamoid subluxation group is not suited for DSTP, since it does not exhibit subluxation of the tibial sesamoid and has a low prevalence of incongruency at the first MTPJ (5/44 [11%]). For this group, the aim of the reconstructional operation should be centered on the anatomical repair of the medial capsule and the alignment of the first MTPJ rather than the DSTP.

Study Limitations

Similar to other retrospective case control studies, our investigation involved several methodological shortcomings that could have biased our results. First, our control group was small (N = 19). Recruiting large numbers of patients with no foot or ankle pathologies to the control group was difficult due to ethical reasons such as radiation exposure. In addition, the sex distribution and the mean age of the control group did not match those of the study group. This circumstance increased the risk for bias since the groups might not be comparable and weakens the study's statistical power. Second, we used the specially designed semi-weightbearing CT posture to simulate a weightbearing environment of the lower extremity CT scan. Collan et al[2] emphasized that a weightbearing lower extremity CT scan is highly beneficial for accurate evaluations of first metatarsal pronation. Ideally, the use of a weightbearing CT could have improved our study's outcome. Unfortunately, at the present time, there is no literature that compares the positions of the first metatarsal and tibial sesamoid in both semi-weightbearing and weightbearing CT environments. Therefore, at present, it is too early to determine the reliability of the semi-weightbearing CT. In addition, the uniformity of the first MTPJ position was not fully ascertained in semi-weightbearing CT views, which may have contributed to the misclassification of sesamoid positions. Future studies should be conducted to eliminate the above issues and to reduce the limitations of the new classification system and the measurement methods of tibial sesamoid position and first metatarsal pronation.

In conclusion, the present study confirmed the existence of pathologic pronation of the metatarsophalangeal apparatus in HV with the aid of several radiologic measurements. The mean values of the α angle in the control and HV deformity groups were both statistically significant (control group $\mu = 13.8$ degrees, study group $\mu = 21.9$ degrees). Our method allowed better radiologic evaluation of the tibial sesamoid subluxation grade using a CT axial view. In addition, we classified 4 different types of HV deformity groups in relation to first metatarsal pronation and sesamoid subluxation. Through this classification system, we identified a unique HV group and named it the pseudo-sesamoid subluxation group (the P(+)S(–) group), which comprised 25.9% of the patients with HV deformity. The etiology of this group is still unclear. Further anatomical research is needed to address the fundamental causes of the deformity in this new group to enable foot and ankle specialists to surgically treat the condition with precision.

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