CHAPTER 29

Weight-Bearing Computed Tomography Evaluation of First Metatarsophalangeal Joint Frontal Plane Rotation in Hallux Abducto Valgus Deformity

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INTRODUCTION

Traditionally two-dimensional radiographic measurements are a staple of preoperative evaluation in surgical treatment of hallux abducto valgus (HAV). Radiographic angles such as the intermetatarsal angle (IMA), hallux abductus angle (HAA), proximal articular set angle (PASA), and tibial sesamoid position are commonly used to better asses the deformity. Recently, in the literature articles have questioned whether these two-dimensional radiographic measurements accurately describe HAV since we can only evaluate changes in the transverse and sagittal planes (1,2). It has been shown in literature that HAV is a triplane deformity, with new studies suggesting that the frontal plane rotational changes are a significant component of the deformity. These findings lead one to conclude that the frontal plane must be addressed for complete deformity correction.

In 2013, Dayton et al (1) performed a study to evaluate the postoperative radiographic changes as well as the relationship between the frontal plane rotation and PASA in patients with HAV deformity who underwent a Lapidus procedure for correction of the HAV deformity. They found a consistent valgus rotation of the first metatarsal in association with HAV deformity and observed a varus rotation of the metatarsal to have occurred when the joint was corrected into congruous alignment using the Lapidus procedure. Thus, they concluded that true correction of the HAV deformity must include frontal plane de-rotation of the metatarsal. They further concluded that the correction of PASA seen on postoperative radiographs was actually due to the frontal plane rotational changes affecting the appearance of the articular surface of the metatarsal head suggesting that PASA is merely a radiographic artifact.

Mortier et al (3) in 2012, performed a cadaveric study showing a statistically significant valgus position of the metatarsal head in feet with bunion deformities compared to those without the deformity. In a follow-up study in 2014, Dayton et al (2) observed changes in radiographic angular relationships of the first ray after frontal plane rotation of the first metatarsal in cadaveric foot models and concluded that this frontal plane rotation is an integral component of the HAV deformity. The concept of the frontal plane rotation in HAV deformity and its effect on other angular relationships seen on two-dimensional radiographs brings into question the true validity and adequacy of plain radiographs in accurately assessing this triplane deformity. With the advent of newer imaging technology, such as the weightbearing computed tomography (CT), the triplane changes, including the frontal plane rotation, which occur in the HAV deformity, can perhaps be more accurately assessed. The weightbearing CT is more accurate because it can obtain a three-dimensional data set of angles that are independent of foot position/orientation and projection and are taken with the patient in full weightbearing stance (4).

The purpose of this study is to use weight-bearing CT images to evaluate the frontal plane rotation of the first metatarsophalangeal joint including the metatarsal head, the sesamoid apparatus and the base of the proximal phalanx, as well as IMA, and HAA, in patients with and without HAV deformity. We hypothesize that because the weightbearing CT allows three-dimensional visualization, the frontal plane rotation will be more accurately assessed and compared to the other angular changes seen in HAV deformity. Furthermore we hypothesized that the frontal plane rotation becomes more significant as we move distally on the first ray. By comparing patients with and without HAV deformity, we can confirm the presence of a frontal plane component as well as its relationship to the other commonly-measured angles and the presumed increase of rotation distal to the metatarsal head.

MATERIALS AND METHODS

Subjects and Methods

Preoperative weightbearing CT images (Figure 1) of 60 adult feet using the PedCAT device (Curvebeam) taken between March 2015 and April 2016 by a single podiatrist (KF) were reviewed. There were 30 subjects with HAV deformity and 30 controls without HAV deformity. All of the control subjects had a pure hallux limitus or rigidus deformity to ensure there was no component of HAV involved. Within the control group, there were 15 males and 15 females. Within the HAV group, there were 7 males and 23 females. All CT images reviewed were at 0.3 mm slab thickness. In all subjects, we measured the standard HAV angles, including the IMA, HAA, TSP on the anteroposterior view. The technique used was consistent with that previously described previously by Gerbert and by Green (5,6).

The frontal plane rotation of the metatarsal head (MFPR) was measured using the angle created between a line parallel to the ground surface and a line drawn tangential to the medial and lateral borders of the crista at the metatarsal head (Figure 2). A positive (MFPR) value equates to a valgus rotation. The frontal plane rotation of the sesamoid apparatus (SFPR) was measured using the angle created between a line parallel to the ground surface and a line drawn tangential to the plantar border of the sesamoids. The frontal plane rotation of the proximal phalanx (PFPR) was measured using the angle created between a line parallel to the ground surface and a line drawn tangential to the base of the proximal phalanx. The IMA and HAA angles were measured in traditional fashion by taking the mid-shaft line of the first metatarsal and second metatarsal and measuring the angle between them for the IMA and taking a mid-shaft line of the first metatarsal and mid-shaft line of proximal phalanx to measure the angle formed for the HAA. Correlations were made among all measurements and compared between the 2 groups.

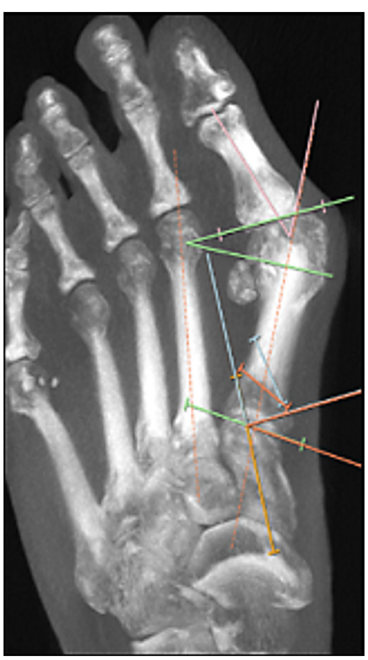

Figure 1. Preoperative weightbearing computed tomography image.

Statistical Analysis

Statistical software SAS, version 9.2 was used to calculate the correlation coefficients (r) and associated *P* values. Graphs were created using Prism 5.0 (Graphpad). The Pearson correlation coefficient for determining association between variables was used for data analysis. *P* values less than or equal to 0.05 (5%) were considered statistically significant. All data included had an adequate sample population.

RESULTS

All of the measures were higher in the HAV group compared to the control group and were statistically significant ($P < 0.001$). The mean IMA was 15.3° (range 9.7-23.0°) in the HAV group, and 8.5° (range 4.3-15.3°) in the control group. The mean HAA was 30.0° (range 10.6-58.4°) in the HAV group, and 5.8° (range 0.4-15°) in the control group. The mean MFPR was 18.9° of valgus rotation (range 4.2-47.1°) in the HAV group and only 0.8° (range 1.0-3.0°) in the control group (Table 1). The mean SFPR was 22.0 (range 10.4-39.3°). The mean PFPR was 24.7 (range 10.4 -48.7).

Overall, in the HAV population the metatarsal frontal plane rotation (MFPR) in the valgus direction had a moderate positive correlation with the IMA (r = 0.51), HAA (r = 0.48) which were not statistically significant but the MFPR and PFPR and SFPR were all statistically significant in the bunion group ($P < 0.001$). There was a very strong correlation between HAV PFPR and SFPR (r = 0.91). The same was true in the control group with (r = 0.89), which was statistically significant. In the control group there was also a strong correlation between the HAA and PFPR (r = 81), which was statistically significant.

There were no significant correlations between preoperative and postoperative bunion as expected due to limited number of postoperative cases and the fact that the frontal plane rotation was not addressed with all head or base procedures. When comparing MFPR with IMA in the

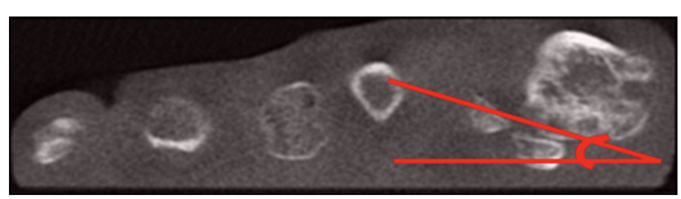

Figure 2. Frontal plane rotation angle.

Table 1. Study results

	HAV		Control		Postop	
Measure	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range
HAA	30.0 ± 11.2	10.6–58.4	5.8 ± 3.9	0.4–15.0	14.4 ± 3.3	5.4–17.4
IMA	15.3 ± 3.2	9.7–23.0	8.5 ± 2.6	4.3–15.3	10.1 ± 1.5	8.1–13.2
MFPR	18.9 ± 9.3	4.2–47.1	2.9 ± 2.1	0.2–9.0	18.9 ± 9.3	4.2–47.1
PFPR	24.7 ± 9.6	10.4–48.7	5.3 ± 3.3	-1.7–13.1	8.5 ± 6.1	-0.6–17.9
SRPR	22.0 ± 8.4	10.4–39.3	5.6 ± 3.5	1.2–14.0	7.0 ± 4.9	1.1- 16.6

control and HAV groups, there was a strong correlation, which was statistically significant comparing the two groups. This was true for SFPR and IMA, and also for SFPR and HAA in postoperative, and SFPR and PFPR in postoperative (Table 1).

DISCUSSION

Studies in the recent literature have suggested that the frontal plane rotational changes in HAV deformity must be addressed in order to obtain complete correction. Furthermore, changes in multiple radiographic measurements have been observed to correspond with rotation of the first metatarsal in the frontal plane (2). There are several studies that assess the components of HAV deformity using two-dimensional radiographs.These may not be adequate in assessing all three planes involved in the deformity, especially the frontal plane rotation.

The weightbearing CT is relatively newer technology that provides a safe, efficient way to obtain 3-dimensional measurements and to assess rotational changes. We used the PedCAT weightbearing CT images to assess the frontal plane rotational changes as well as other commonly analyzed angles including the IMA, HAA, PASA, and TSP in addition to frontal plane rotation of the first metatarsal, sesamoid apparatus, and base of the proximal phalanx. The PedCAT CT is more accurate because it can obtain a three-dimensional dataset of angles, which is independent of foot position/orientation and projection and is taken with the patient in weight-bearing stance. It also adjusts for any malposition of the foot that may occur during image acquisition since the planes of the reformations can be rotated to ensure exact angle measurement. Overall, the PedCAT weightbearing CT is more efficient compared to standard CT or radiographs. The image acquisition time is 70% faster than with standard radiographs and 35% faster than with conventional CT since patient positioning is easy and there is no adjustment of the scanner needed (4). It is also safe for the patient since the radiation dose is relatively low although it is higher than conventional radiographs. The dose of one foot is 1.4 uSv, which is only 5.6% the dose of 1 unilateral conventional CT of foot/ankle and comparable to 6 unilateral plain radiographs (4).

Collan et al (7) used a portable weightbearing CT to evaluate the rotational changes of the first ray using both nonweightbearing and weightbearing images in 10 patients with hallux abducto valgus compared with 5 asymptomatic controls. The measured angles were also compared to angles measure on plain two-dimensional radiographs. They found that the three-D angles correlated very well with the angles measured on plain radiographs. Although they found a slight rotation/pronation of the first metatarsal in the HAV group, it was not statistically significant. However, the first proximal phalanx was noted to have a statistically significant rotation/pronation in the HAV group compared to the controls, and increased when going from nonweight-bearing to weightbearing. Their study showed that the rotational changes of bones of the forefoot can be reliably measured using a weightbearing CT.

Kim et al (8) retrospectively evaluated the tibial sesamoid and first metatarsal position in the conventional CT axial view, the weightbearing anteroposterior radiographic view, and the tangential view. The frontal plane rotation of the first metatarsal at the head was measured using a line that bisects the medial and lateral sulci compared to a line perpendicular to the horizontal ground axis. Their results showed a relatively high value for the average first metatarsal pronation angle of 21.9° in those with HAV compared to 13.8° in those without HAV but found it to be independent of HAA and IMA. They also defined subgroups of hallux valgus deformity where there is "true sesamoid subluxation" with or without first metatarsal pronation. Conventional CT images were obtained with participants in a semi-weight-bearing position produced by pushing their foot downward, and similar to our study, there was no dorsiflexion at the first metatarsophalangeal joint.

Other studies (3,9,10) have assessed both the frontal plane rotation of the first metatarsal and sesamoid position using the sesamoid axial view, which demonstrates the dynamic position that occurs during push off when the fibular sesamoid moves forward and becomes parallel to the tibial sesamoid. The effect of the dynamic stabilizers, such as the flexor hallucis brevis, changes the position of the sesamoids and perhaps, the rotation of the metatarsal head as well. It remains unclear as to which position, dynamic or static, of the first ray provides a better view for assessing the first metatarsal frontal plane rotation and sesamoid position.

Our study used weightbearing CT images to more precisely assess the angular changes and relationships that occur in those with HAV compared to those without the deformity. The results demonstrate the existence of a statistically significant pathologic valgus rotation, or pronation, involved in the HAV deformity, which supports previous clinical and cadaveric studies. The mean valgus rotation was 18.9° in the HAV group compared to 0.8° in the non-HAV control group. The valgus rotation was highly correlated with both IMA and PASA, which further supports the idea that the frontal plane rotation could be contributing to PASA. Also, our results show that as we move more distally, the frontal plane rotation significantly increases. This suggests that the valgus frontal plane rotation may need to be addressed at the metatarsophalangeal joint as much as the head of the metatarsal, mainly by de-rotating the hallux out of valgus. Our results, in conjunction with those of previous research, demonstrate the presence of a significant valgus rotation of the first metatarsophalangeal joint complex including the metatarsal head, sesamoids, and phalanx base contributing to the hallux abducto valgus deformity.

In conclusion, the concept of the frontal plane rotation in HAV deformity and its effect on other angular relationships seen on two-dimensional radiographs brings into question the true validity and adequacy of plain radiographs in accurately assessing this triplane deformity. With the advent of newer imaging technology, such as the weightbearing CT, the triplane changes, including the frontal plane rotation can be more accurately assessed. The weightbearing CT is more accurate because it can obtain a three-dimensional image that is independent of foot position/orientation and projection and is taken with the patient in full weightbearing stance (4). The purpose of this study was to use weightbearing CT images to evaluate the frontal plane rotation of the first metatarsophalangeal joint. We have demonstrated that the frontal plane rotation becomes more significant as we move distally on the first ray. By comparing patients with and without HAV deformity, we can confirm the presence of a frontal plane component as well as its relationship to the other commonly measured angles and the increase of rotation distally, which will bring a bigger role to the intra-operative positioning of the great toe.

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