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Original Research

Observed Changes in Radiographic Measurements of the First Ray after Frontal and Transverse Plane Rotation of the Hallux: Does the Hallux Drive the Metatarsal in a Bunion Deformity?

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ABSTRACT

It is well known that the pathologic positions of the hallux and the first metatarsal in a bunion deformity are multiplanar. It is not universally understood whether the pathologic changes in the hallux or first metatarsal drive the deformity. We have observed that frontal plane rotation of the hallux can result in concurrent positional changes proximally in the first metatarsal in hallux abducto valgus. In the present study, we observed the changes in common radiographic measurements used to evaluate a bunion deformity in 5 fresh frozen cadaveric limbs. We measured the tibial sesamoid position, 1-2 intermetatarsal angle, and first metatarsal cuneiform angle on anteroposterior radiographs after frontal and transverse plane manipulation of the hallux. When the hallux was moved into an abducted and valgus position, a statistically significant increase was found in the tibial sesamoid position ($p = .016$). However, we did not observe a significant increase in the intermetatarsal angle ($p = .070$) or medial cuneiform angle ($p = .309$). When the hallux was manipulated into an adducted and varus position, a statistically significant decrease in the intermetatarsal angle ($p = .02$) and a decrease in the tibial sesamoid position ($p = .016$) was seen, with no significant change in the medial cuneiform angle ($p = .360$). We also observed a consistent rounding of the lateral aspect of the first metatarsal head and an increase in the concavity of the lateral metatarsal shaft, with valgus rotation of the hallux. From these observations, it is possible that the hallux could drive the proximal changes in the first ray that lead to metatarsus primus adducto valgus deformity.

It is well known that a bunion is a multiplanar deformity with components at both the hallux and the first metatarsal. The pathologic positions are in the transverse, sagittal, and frontal or third plane (1–6). This multiplanar deformity results in the hallux deviated away from the midline of the body in the transverse plane (abducted) and everted in the frontal plane (valgus). This was the basis for the term *hallux abducto valgus*. The pathologic metatarsal position in the deformity is also multiplanar; it is deviated toward the midline of the body in the transverse plane (adducted) and everted in the frontal plane (valgus). This was the basis for a newly proposed term *metatarsus primus adducto valgus* (7). In addition, a sagittal plane component might or might not be present.

Although the deformed position is understood, the pathologic factors leading to the deformed position are not universally understood. Researchers have attempted to isolate the component pathologic features of the hallux, the first metatarsal, and the associated soft tissue structures and thereby describe the etiology of bunion formation. Some have focused on the effects of equinus on foot function and the subsequent effect it will have on first ray mechanics and position. Hansen (8) postulated that a tight Achilles tendon can predispose an individual to hallux valgus because of early and increased forefoot loading causing progressive malposition. Several researchers have focused on the contribution of soft tissue and tendon components of the first ray and great toe (8,9). Others have proposed that the structural shape of the medial cuneiform is the pathologic cause of the deformity and the level at which the deformity begins.

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Table 1
Sample characteristics (N = 5)

Test	Angle	Mean Change (°)	p Value
Hallux valgus	IMA	−1.6 ± 1.52	.07
Hallux valgus	TSP	1.6 ± 0.89	.016
Hallux valgus	Obliquity of MCA	−5.8 ± 11.14	.309
Hallux varus	IMA	−1.4 ± 0.89	.025
Hallux varus	TSP	−0.80 ± 0.447	.016
Hallux varus	Obliquity of MCA	2.2 ± 4.76	.36

Abbreviations: IMA, intermetatarsal angle; MCA, medial cuneiform angle; TSP, tibial sesamoid position.
Data presented as mean ± standard deviation.

Those who consider the “atavistic” cuneiform as the primary factor in bunion occurrence have also made the case for metatarsal deviation as the primary pathologic factor and postulated that metatarsal deviation leads to the change in the hallux position (10–12). Studies have correlated the changes in first ray position with a change in the obliquity and atavistic appearance of the medial cuneiform present on anteroposterior (AP) radiographs in patients with a bunion deformity (13,14). Several studies have also discussed a distal pathologic origin (15–19). These investigators have proposed that deviation and rotation of the hallux is the driving force in the development of a bunion and that this leads to the first metatarsal deviation present in the deformity (15–19).

The purpose of the present study was to observe the AP radiographic changes in the first ray as the great toe position was altered in the transverse and frontal planes. Changes in the metatarsal position consistent with the pathologic position in a bunion would be expected if the hallux were the driving force of the metatarsal pathologic entity in the deformity. Our hypothesis was that abduction and the valgus position of the great toe will create adduction and a valgus position of the metatarsal and that a radiographic positional change will be observed at the first tarsal–metatarsal joint as a result of rotation of the first ray.

Materials and Methods

Five fresh frozen cadaveric specimens were obtained for the purpose of our study: 2 males and 3 females. We used the left feet from 2 and the right feet from 3. The mean age at death was 69 (range 67 to 70) years. Before data collection, 5 identical wooden platforms were prepared and marked by a line drawn down the midline of the platform. The first ray for each specimen was aligned with the center line of the platform. Each foot was fixated to a platform using Kirschner wires. The wires were inserted through the shaft of the fifth metatarsal, the body of the cuboid, and the ankle joint to stabilize the ankle and subtalar joints. A screw was placed in the posterior calcaneus to stabilize the foot on the platform.

Screws were placed in the first proximal phalanx and the first metatarsal to act as points of rotation. Once all the screws and wires were in place and the feet secured, a

Table 2
IMA, TSP, and MCA of specimens A to E (N = 5)

Specimen	IMA (°)	TSP (°)	MCA (°)
A	10	4	105
B	11	4	112
C	9	4	103
D	8	3	96
E	8	2	95

Abbreviations: IMA, intermetatarsal angle; MCA, medial cuneiform angle; TSP, tibial sesamoid position.

baseline AP radiograph was taken. Manipulation was achieved by attaching rubber bands to the screws in the bone and a screw on the medial or lateral side of the platform. The hallux was then manipulated into a position of maximum abduction and maximum valgus. AP radiographs were obtained with the hallux in this position. Next, the hallux was manipulated into a position of maximum adduction and maximum varus, and additional AP radiographs were obtained. Each radiograph was randomized and blinded before measurement of the intermetatarsal angle (IMA), first metatarsal–cuneiform joint angle (MCA), and tibial sesamoid position (TSP). The lead author (P.D.) and an additional contributing author (N.C.) measured each radiograph. The measurements were used to calculate the mean for each of the characteristics measured. The mean value of each characteristic was used in the statistical analysis with a paired t test. Alpha was set at $p \leq .05$ as the level of significance for all analyses.

Results

In the position of maximum hallux abducto valgus, the TSP, IMA, and MCA were measured (Tables 1 and 2). A significant increase was found in the TSP ($p = .016$) compared with the baseline value; however, we did not find a significant increase in the IMA ($p = .070$) or MCA ($p = .309$). When the hallux was manipulated into an adducted and varus position, we measured a significant decrease in the IMA ($p = .02$) and a decrease in the TSP ($p = .016$) compared with the baseline value. However, we did not find a significant decrease in the MCA ($p = .360$). We also noted visual findings of the lateral rounding of the metatarsal head and increased concavity of the lateral shaft of the metatarsal with manipulation of the hallux into a maximally abducted and valgus position compared with the baseline radiograph (Figs. 1–4).

Discussion

Multiple mechanisms could drive the pathologic process by which the deformity hallux abducto valgus with metatarsus primus adducto valgus occurs. The basic deformity correction principles require an understanding of the pathologic position of the bones and joints involved to select procedures with the best chance of favorable outcomes. Furthermore, understanding the pathologic process

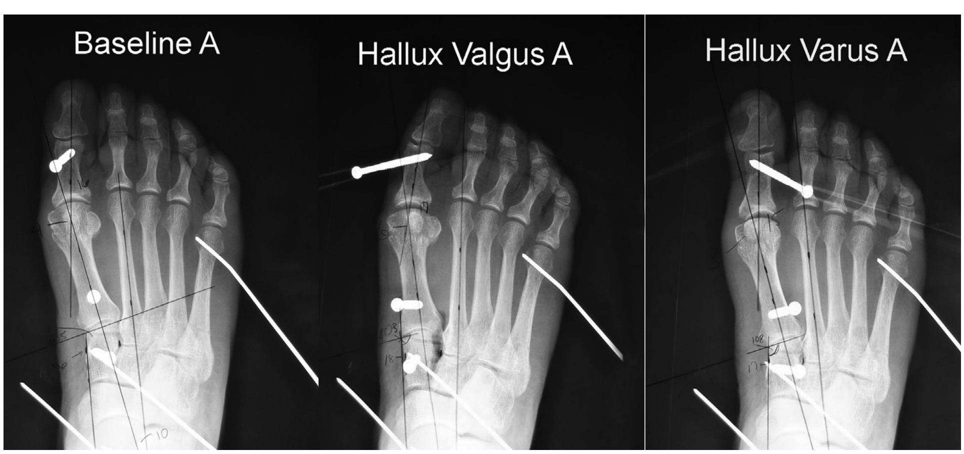

Fig. 1. Anteroposterior radiographs of foot at baseline and at hallux valgus and hallux varus manipulation.

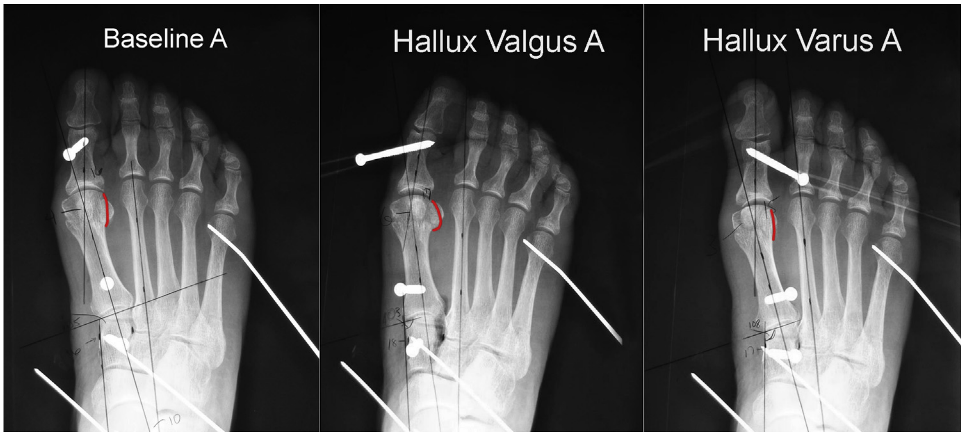

Fig. 2. Anteroposterior radiographs of foot at baseline and at hallux valgus and hallux varus manipulation showing rounding of the metatarsal head.

leading to a deformity will be a vital part of the characterization of a deformity.

Studies have been conducted that have demonstrated how the lateral deviation of the hallux can drive the medial deviation of the first metatarsal (15–18). Munuera et al (15) examined the differences in the measurements of the IMA and hallux abductus angle between a control group and a mild hallux valgus deformity group. They found a statistically significant difference in the IMA between these 2 groups, drawing the conclusion that an abducted hallux preceded an increase in the IMA (15). They described the concept of ground reactive forces acting on the hallux in the propulsive phase of gait and producing a medial vector force that increasingly deviates the first metatarsal medially as the lateral angle of deviation of the first toe occurs. In addition to the direct forces from the hallux on the proximal structures, a bowstringing effect of the flexor hallucis longus tendon and extensor hallucis longus tendon that reinforces the abductory force on the hallux and first metatarsal (15). Lamur et al (21) and Dobson et al (22) described the position of the flexor hallucis longus tendon with respect to the first metatarsal and noted that this relationship contributed to an increase in the lateral deviation of the hallux more so than the position of the extensor hallucis longus tendon. Snijders et al (23) elaborated on the fact that the medial deviation of the first metatarsal increases with progression of the hallux abducto valgus deformity, with the flexor hallucis longus tendon having a more prominent role than the extensor hallucis longus tendon. In the present experiment, we have shown that movements of the hallux result in proximal deviations of the metatarsal, reinforcing the idea that the hallux can indeed lead to the pathologic position of the metatarsal. As the deviation progresses, tendon misalignment and angular forces can drive the progression of the deformity. However, a component of tarsal metatarsal or intertarsal instability must also be present for this to occur.

In the present study, we found that rotation of the hallux resulted in positional changes proximally in the first ray. In particular, we were able to show that rotation of the hallux into a valgus attitude produced valgus rotation of the first metatarsal, as evidenced by the TSP. This finding correlated with what we know of the pathologic positions of the hallux, first metatarsal, and sesamoids to be in a bunion and with what we have found in our previous work (24). In contrast, rotation of the hallux into a varus attitude produced varus rotation of the first metatarsal, which was shown by the TSP (Fig. 4). We produced a deformed positional state of the first metatarsal and sesamoids through hallux angulation and rotation. This was consistent with the positions of these structures described by Talbot and Saltzman (18), who noted a statistically significant difference in hallux rotation and lateral sesamoid deviation between a nonbunion control group and bunion group. Feet with hallux valgus were shown to have a mean change of 12° of additional hallucal pronation, or valgus position, than normal feet (18). Our findings also correlated with the findings of Piggott (17), who demonstrated rotation of the hallux in the frontal plane in patients with hallux valgus deformity. He also showed that lateral deviation and frontal plane rotation of the hallux was almost always associated with displacement of the sesamoids of the first metatarsal phalangeal joint (17).

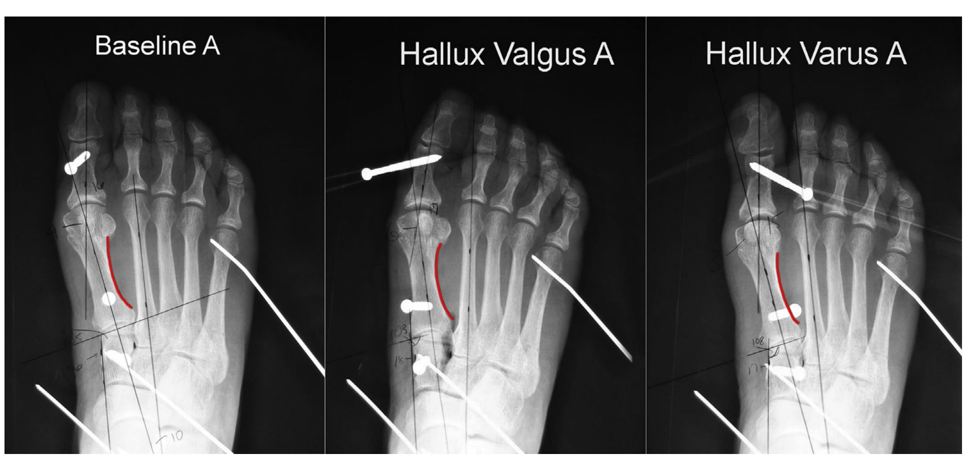

Fig. 3. Anteroposterior radiographs of foot at baseline and at hallux valgus and hallux varus manipulation showing lateral curvature of the metatarsal shaft.

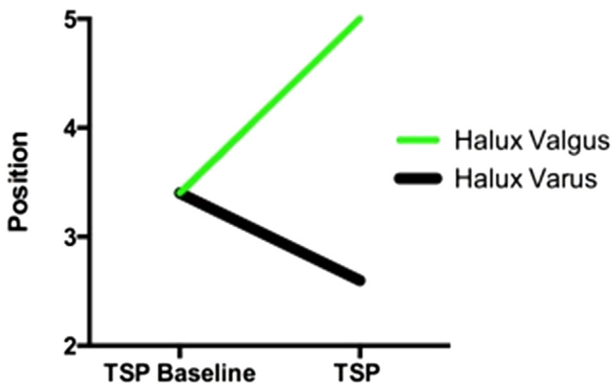

Fig. 4. Results of paired *t* test showing tibial sesamoid position change with hallux valgus and hallux varus manipulation.

In the present study, we also observed radiographic changes that would indicate frontal plane rotation of the first metatarsal, including lateral rounding of the metatarsal head and increased concavity of the metatarsal shaft. Okuda et al (25) found that 91.6% of adolescents with a hallux valgus deformity had a laterally rounded metatarsal head on the AP radiograph. They concluded this could be the defining characteristic showing the valgus rotation of the metatarsal in the deformity (25). D'Amico et al (26) described a lateral curvature of the first metatarsal shaft when manipulated into a valgus position. This radiographic finding was caused by the plantar surface of the metatarsal being projected laterally (26). Both the lateral rounding of the metatarsal head and the lateral curvature of the metatarsal shaft were observed in the present study (Figs. 1–3).

We know from previous studies that the first metatarsal is everted in a bunion deformity (1,13,19,20,25–27). Mortier et al (27) studied the eversion of the first metatarsal in the bunion deformity and noted instability in the frontal plane at the first tarsal metatarsal joint that they believed contributed to the overall pathologic progression of hallux valgus. It has been shown that varus rotation of the first metatarsal at the metatarsal cuneiform joint aids in the alignment of the first metatarsal and the first metatarsal phalangeal joint when used in a modified Lapidus arthrodesis (1). It has also been shown that varus rotation, or inversion, at the first tarsal metatarsal joint in normal cadaveric feet decreases the IMA and TSP, with eversion of the metatarsal causing an increase in both values (1). It is clear that multiplanar changes occur in the position of both the hallux and the first metatarsal in a bunion deformity. Although we could not state conclusively that it is the hallux position driving the proximal deformity, our results suggest that this distal to proximal pathologic progression is certainly possible.

We have demonstrated from our study that frontal plane rotation of the hallux, along with a change in transverse plane positioning, will produce a significant change in the IMA and TSP. This provides evidence to support the hypothesis that the hallux position might drive the proximal deformities at the sesamoids and first metatarsal seen with hallux abducto valgus with metatarsus primus adducto valgus.

The study limitations included the small sample size. Also, the use of cadaveric specimens with artificially induced manipulation of the hallux might not be completely representative of pathologically induced rotation observed in a bunion. Also, because these were artificially induced manipulations and all attempts were made to prevent other resultant alterations in alignment, small variations could have occurred. Additionally, the angle of the x-ray beam from radiograph to radiograph and a measurement bias could be considered possible limitations, although we believe these were not likely of any significant effect.

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