

Observed Changes in First Metatarsal and Medial Cuneiform Positions after First Metatarsophalangeal Joint Arthrodesis

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ABSTRACT

The first intermetatarsal angle (IMA) is known to decrease after first metatarsophalangeal joint arthrodesis, although the exact mechanism by which this decrease occurs is not known. We measured the first IMA and obliquity of the medial cuneiform on anteroposterior weightbearing preoperative and postoperative radiographs in 86 feet and analyzed the statistical correlation between the IMA and the medial cuneiform angle. A change in the first IMA after first metatarsophalangeal joint fusion showed a strong positive correlation with a change in cuneiform obliquity ($p < .0001$). This finding was consistent in the direction and magnitude in each of 3 clinical subgroups: normal, $p = .087$; moderate deformity, $p = .011$; and severe deformity, $p = .10$. A comparison of the preoperative IMA and cuneiform obliquity revealed a trend toward a positive relationship but did not reach statistical significance ($p = .08$). The preoperative association between the IMA and medial cuneiform obliquity was not significant in any clinical subgroup, and the postoperative association between the IMA and cuneiform obliquity was not significant ($p = .65$). Clinical subgroup analysis showed no significant association between the IMA and the normal ($p = .73$) and moderately ($p = .69$) deformed feet, although the postoperative association between the IMA and cuneiform obliquity in the severely deformed group was significantly ($p = .034$) positive. A linear relationship between the reduction of the first IMA and medial cuneiform obliquity after metatarsophalangeal joint fusion was observed. Our findings suggest that frontal plane rotation influences cuneiform obliquity.

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As early as 1882, reports had proposed that the primary level of a bunion deformity resided at the first metatarsocuneiform joint. Researchers have also proposed an association between hallux valgus and the shape of the first metatarsocuneiform joint (1,2). Procedures for the correction of bunion deformities at the first metatarsocuneiform joint were first referenced in 1911 (3) and were later advocated by Lapidus (4). In 1925, Truslow (5) suggested the term *metatarsus primus varus* to describe the deformity, highlighting the deviation of the first metatarsal medially as the primary concern and not the hallux deviating laterally. A review of these reports suggested that the terminology *metatarsus primus varus* did not refer to the frontal plane

motion, such as it sometimes does today; rather, it meant a first metatarsal that deviated toward the midline of the body (5). This dual interpretation of the term *metatarsus primus varus* has led to ambiguity when discussing the components of a bunion deformity.

Morton (6) and Lapidus (4) agreed that the evolutionary history of *Homo sapiens* gave rise to the bunion deformity and cited primate feet with an oblique medial cuneiform and first metatarsal interface as a potential evolutionary cause of hallux valgus deformity. Lapidus (4) compared developing human feet with those of other primates and showed similar cuneiform obliquity in different species. He also noted that the obliquity decreased as a human fetus developed (4); however, in the adult primate, it remained. This “atavistic” or ancestral-type cuneiform with its oblique articulation has been purported to be a predisposing feature to the development of bunion deformity (4,6). Various measurements of this angulation have been made, although no accepted standard has been reported. Several investigators have measured this obliquity in association with bunion deformities, each using different parameters (4–8). Despite descriptions of an

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association between an oblique or atavistic cuneiform and a bunion deformity, we have no proof of the exact role that medial cuneiform obliquity plays in the cause or development of the deformity.

The term *hallux valgus* has also been used to describe the bunion deformity. This terminology was first introduced by Carl Hueter in 1870 (9) and was used to describe a deformity in which the hallux had moved away from the midline of the body. This term is widely used today in describing a bunion deformity and its use implies that the primary deformity resides at the metatarsophalangeal joint (MTPJ). Despite its widespread use and implied understanding, the term *hallux valgus* fails to fully characterize the 3 planar components of a bunion. Munuera et al (10) found that an abducted hallux preceded an increase in the intermetatarsal angle (1-2 IMA), leading to the conclusion that hallux valgus precedes a medially deviated first metatarsal. Snijders et al (11) used a biomechanical study to measure the force vectors and noted that the motions produced while walking caused the hallux to deviate laterally. They concluded that this force increased the 1-2 IMA. Thus, the hallux valgus caused deviation of the first metatarsal. This relationship was reinforced by reports that showed a reduction in the 1-2 IMA after first MTPJ fusion (12–14). Although not often discussed, frontal plane rotation has also been thought to be a component of hallux abducto valgus and metatarsus primus adductus and has been shown to be a part of the pathologic development of bunion deformities (15–17). Additionally, rotation has been shown to have an influence on the radiographic appearance of medial cuneiform obliquity (7). Furthermore, valgus metatarsal rotation has been shown to be an element in the correction of a bunion deformity (18).

Thus, it is clear that a variety of terms and concepts have been used to describe the bunion deformity but that no consensus has been reached regarding the etiology and progression of the deformity. The aim of the present investigation was to quantify the medial cuneiform obliquity before and after first MTPJ fusion. We hypothesized that if the oblique cuneiform were a predisposing factor in the development of a bunion deformity, its atavistic appearance would remain constant as the first IMA decreased after first MTPJ fusion owing to the forces of the hallux acting on the nonrigid first ray. These forces are relieved by MTPJ release and realignment, such that spontaneous frontal plane derotation of the first ray occurs, along with a reduction of the first

IMA, thereby altering the radiographic appearance of the obliquity of the cuneiform.

Patients and Methods

A nonconsecutive sample of radiographic records that included only those patients who had undergone first MTPJ fusion for correction of pathologic features of the first ray were retrieved from the database of the senior author's (P.D.) practice. The radiographs pertained to patients who had undergone first MTPJ fusion between June 2008 and June 2012 and were identified by searching the electronic records for procedure code 28750. These radiographs were reviewed, and the final cases for inclusion were selected only by the completeness of the radiographic records and evidence of isolated first MTPJ fusion. No clinical selection criteria such as patient health, preoperative complaint, surgical indications, or operative outcome were considered. The Des Moines University institutional review board approved the records review. The senior author (P.D.) performed the measurements for the first IMA and the medial cuneiform angle. Measurement of the first IMA was consistent with that described by Gerbert (19). The obliquity of the first tarsometatarsal joint (TMTJ) was assessed using 3 lines: line A, formed by taking the most proximal medial point of the medial cuneiform and drawing a line connecting it with the most distal medial point of the medial cuneiform; line B, formed by drawing a line connecting the medial and lateral points at which the cuneiform articulates with the first metatarsal, which serves as the first arm of the angle measuring the obliquity of the first cuneiform; and line C, formed by drawing a line perpendicular to line A, serving as the second arm of the angle (Fig. 1).

The full data set was analyzed using linear regression to evaluate the relationship between (1) the preoperative first IMA and preoperative cuneiform obliquity, (2) the postoperative IMA and postoperative cuneiform obliquity, and (3) the preoperative to postoperative change in the IMA and cuneiform obliquity. The data were then stratified into 3 groups of preoperative IMA values according to the following radiographic definitions: normal, represented by an IMA of 0° to 10°; moderate, represented by an IMA of greater than 10° to 15°; and severe, represented by an IMA of greater than 15°. These strata were selected because they represented clinically significant differences in the hallux valgus deformity. The stratified data were then analyzed using linear regression as described to investigate the differences in these relationships among clinically relevant preoperative IMA classes. The statistical analyses were performed by J.S.K.K. using IBM SPSS Statistics for Windows, Version 19.0, data analysis software (IBM, Armonk, NY), and statistical significance was defined at the 5% ($p \leq .05$) level.

Results

Of the 107 potentially eligible sets of radiographs, 86 met our inclusion criteria and were included in the analyses. The mean values and standard deviations for the measurements in our 86 samples are presented in the Table. The change in the IMA showed a strong

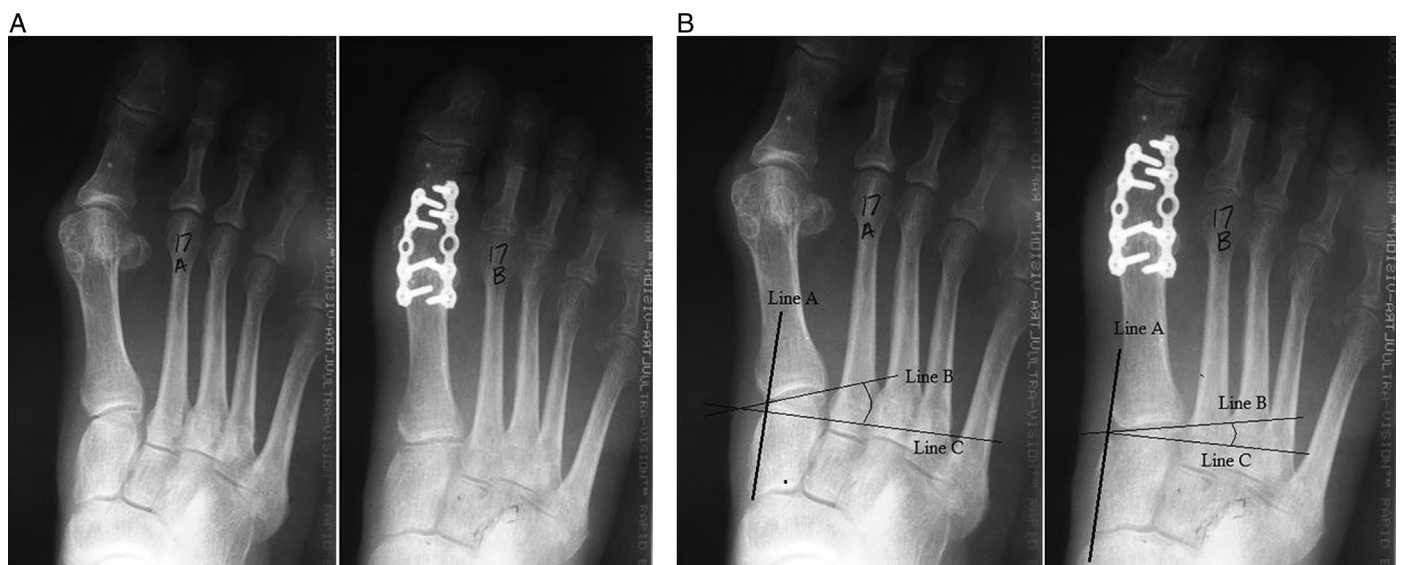


Fig. 1. Metatarsophalangeal joint fusion. Preoperative and postoperative views. (A) Preoperative and postoperative anteroposterior radiograph of foot with hallux valgus and metatarsus primus varus. (B) Preoperative and postoperative anteroposterior radiographs with lines drawn for measurement of cuneiform obliquity. Line A connects the most proximal medial and most distal medial points of the medial cuneiform. Line B connects the lateral and medial points of the first metatarsal medial cuneiform articulation. Line C is perpendicular to Line A. The angle measured is between Lines A and C.

Table
Sample characteristics

	Radiographs (n)	IMA (°)			MCA (°)		
		Preoperative	Postoperative	Change	Preoperative	Postoperative	Change
Normal	26	8.9 ± 1.5	7.2 ± 2.1	-1.7 ± 2.0	21.3 ± 6.3	20.0 ± 4.4	-1.3 ± 5.2
Moderate deformity	32	12.9 ± 1.5	8.8 ± 2.6	-4.2 ± 2.5	24.3 ± 5.8	16.7 ± 5.6	-5.8 ± 4.3
Severe deformity	28	17.8 ± 2.3	11.1 ± 2.8	-6.6 ± 2.6	23.1 ± 6.5	16.9 ± 5.7	-6.5 ± 4.8
All	86	13.3 ± 3.9	9.1 ± 2.9	-4.2 ± 3.1	22.3 ± 6.6	17.8 ± 5.5	-4.7 ± 5.2

Abbreviations: IMA, intermetatarsal angle; MCA, obliquity of medial cuneiform.

Data presented as mean ± standard deviation.

Normal, preoperative IMA of 0° to 10°; moderately deformed, preoperative IMA >10° to 15°; severely deformed, preoperative IMA >15°.

positive association with the change in cuneiform obliquity ($p < .0001$; Fig. 2). The associated change was consistent in direction and magnitude in each of the clinical subgroups (normal, $p = .087$; moderate deformity, $p = .011$; and severe deformity, $p = .10$). A comparison of the relationship preoperative IMA and preoperative cuneiform obliquity but did not reach statistical significance ($p = .08$; Fig. 3). The preoperative IMA and preoperative cuneiform obliquity association was not significant in any of the clinical subgroups. We failed to detect a statistically significant association between the postoperative IMA and postoperative cuneiform obliquity ($p = .65$). An analysis of the clinical subgroups of the first IMA also showed no statistically significant association in the normal or moderately deformed groups (normal, $p = .73$, moderate $p = .69$). However, a significant positive relationship was seen between the postoperative IMA and postoperative cuneiform obliquity in the severely deformed group ($p = .034$).

Discussion

In the present series, a decrease in the 1-2 IMA and a concomitant decrease in the observed obliquity of the medial cuneiform was noted after first MTPJ arthrodesis (Table). These changes were linear and statistically significant ($p < .001$). As such, the correlation between the reduction of the first IMA and the reduction of cuneiform obliquity was not likely a chance association. If first MTPJ fusion induces proximal radiographic changes at the metatarsocuneiform joint, this would indicate that motion of the metatarsal and medial cuneiform occurs because of the fusion. We believe it is likely that frontal plane rotation of the metatarsal and cuneiform occurs spontaneously after first MTPJ fusion, in conjunction with the transverse plane (IMA 1-2)

reduction that is normally expected. Thus, release of the deforming forces induced by the laterally deviated hallux pushing the first metatarsal medially seems to allow spontaneous movement of the first ray in both the transverse and frontal planes. There could also be sagittal plane motion; however, we had no reference for measurement of this in our study.

That these proximal radiographic changes occur after a distal procedure raises the question of whether the “atavistic” cuneiform is an anatomic deformity of the medial cuneiform or a radiographic observation based on position. Because no surgical manipulation of the joints proximal to the first MTPJ was undertaken in the patients we analyzed radiographically, the changes we observed do not appear to have resulted from the intrinsic shape of the cuneiform but, instead, appeared to have resulted from positional differences in the relative projection of the anteroposterior radiographs. As noted, we believe the changes in cuneiform obliquity and changes in the first IMA are best explained by spontaneous transverse and frontal plane rotation of the first ray, which occurs after the distal deforming forces have been relieved (and the first MTPJ fused). It has been shown that movement of the first ray occurs in all 3 cardinal planes of the foot, including the frontal plane, and this rotation affects the radiographic appearance of hallux abducto valgus deformities. The effect of positional changes in the first ray on the perceived atavism of the cuneiform was noted in 2002 when Sanicola et al (7) found that dorsiflexion, plantarflexion, inversion, and eversion of the first ray all changed the apparent obliquity. Ebisui (15) noted correlation of metatarsal frontal plane rotation and the radiographic appearance of feet with hallux valgus and stated that this rotation might be an important part of the pathomechanics of a bunion deformity. Although conflicting reports exist regarding the direction of motion of

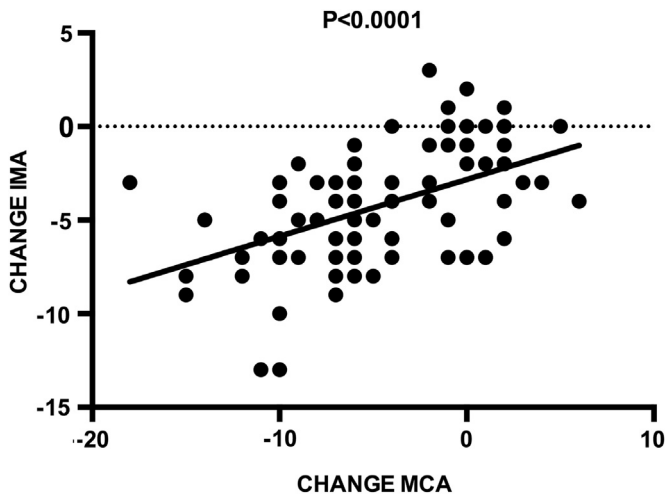


Fig. 2. Linear regression of change in intermetatarsal angle (IMA) versus change in obliquity of the medial cuneiform (MCA).

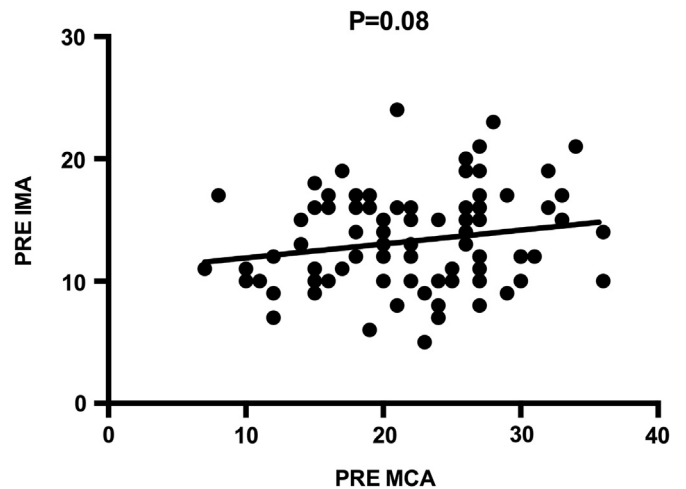


Fig. 3. Linear regression of the preoperative intermetatarsal angle (IMA) and preoperative obliquity of the medial cuneiform (MCA).

the first ray in normal feet and in those with bunion deformities, frontal plane eversion of the first ray has been consistently reported (14,16,17,19). Scranton and Rutkowski (16) showed an average of 14.5° of eversion of the first ray in deformed feet and a 3.1° average of eversion in normal feet. Recently, Dayton et al (18) showed that metatarsal eversion was a component of hallux abducto valgus and metatarsus primus adductus and that rotational correction of metatarsal eversion at the TMTJ is an important component of anatomic reduction of hallux abducto valgus deformity.

Additional analysis of the data from our clinical series showed a linear relationship between preoperative IMA and preoperative medial cuneiform angle; however, in our series, this association did not reach statistical significance. This finding was also observed in our 3 clinical subgroups (IMA of 0°–10°, 11°–15°, >15°). It is unclear why the changes in the preoperative and postoperative angles showed strong linear correlations, but the preoperative association did not reach statistical significance. Our study was not able to significantly confirm statistically the hypothesis that cuneiform obliquity and an increased IMA occur concurrently before first MTPJ fusion. This might have been because our data set lacked a sufficient number of foot radiographs with either a low or high first IMA (type 2 statistical error). Alternatively, a larger sample of normal and abnormal feet might have been needed to clarify the exact relationship between hallux abducto valgus and cuneiform obliquity. An interesting study would be to quantify the relationship between cuneiform obliquity (atavism) and hallux abducto valgus, which has been commonly stated as fact but has had minimal supporting data. We hypothesized that the preoperative cuneiform angle is related to some other factor beyond the actual cuneiform shape (i.e., atavism). This might be related to a combination of frontal, sagittal, or transverse plane motion of the first ray, including motion of the medial cuneiform.

In addition to the type 2 statistical error, other limitations of this observational investigation included possible inconsistencies in the study population, because we selected nonconsecutive primary first MTPJ fusions from a single practice setting. Since we were not testing a therapeutic or diagnostic intervention and simply observing a potential association we feel that use of non-consecutive patients does not harm our conclusions. We also appreciate the potential biases related to coding and electronic record keeping, and this might also have biased our identification of potentially eligible radiographs for inclusion in our study. Observer and measurement biases could also have influenced our findings, because the senior author (P.D.) selected the radiographs and made the measurements. Despite the limitations in the present series, we were able to show a connection between the first metatarsal and medial cuneiform

radiographic changes after first MTPJ fusion. Additional research is needed to further clarify the contribution of frontal, sagittal, and transverse plane motion on the development of hallux abducto valgus and other first ray deformities.

In conclusion, we have shown a linear relationship between reduction in IMA and decreased medial cuneiform after first MTPJ arthrodesis. Based on available research on frontal plane rotation of the first metatarsal as a component of HAV deformity we feel that the change in the observed cuneiform obliquity was a result of frontal plane rotational change altering the radiographic appearance of the cuneiform.

References

1. LeBoucq H. Le développement du premier metatarsien et de son articulation arsienne chez l'homme. *Arch Biol* 3:335, 1882.
2. Picque L. Note sur une cas d'hallux valgus. *Bull Mem Soc Chir* 28:518–525, 1902.
3. Albrecht GH. The pathology and treatment of hallux valgus. *Russ Vrach* 10:14, 1911.
4. Lapidus PW. The operative correction of metatarsus primus varus in hallux valgus. *Surg Gynecol Obstet* 58:183, 1934.
5. Truslow W. Metatarsus primus varus or hallux valgus. *J Bone Joint Surg* 7:98–108, 1925.
6. Morton DJ. Metatarsus atavicus: the identification of a distinctive type of foot disorder. *J Bone Joint Surg* 9:531, 1927.
7. Sanicola SM, Arnold TB, Osher L. Is the radiographic appearance of the hallux tarsometatarsal joint representative of its true anatomical structure? *J Am Podiatr Med Assoc* 92:491–498, 2002.
8. Tanaka Y, Takakura Y, Kumai T, Samoto N, Tamai S. Radiographic analysis of hallux valgus: a two dimensional coordinate system. *J Bone Joint Surg* 77:205–213, 1995.
9. Kelikian H. *Hallux Valgus, Allied Deformities of the Forefoot and Metatarsalgia*. WB Saunders, Philadelphia, 1965.
10. Munuera PV, Dominguez G, Polo J, Rebollo J. Medial deviation of the first metatarsal in incipient hallux valgus deformity. *Foot Ankle Int* 27:1030–1035, 2006.
11. Snijders CJ, Snijder JG, Philippens MM. Biomechanics of hallux valgus and spread foot. *Foot Ankle Int* 7:26–39, 1986.
12. Cronin JJ, Limbers JP, Kutty S, Stephens MM. Intermetatarsal angle after first metatarsophalangeal joint arthrodesis for hallux valgus. *Foot Ankle Int* 27:104–109, 2006.
13. Mann RA, Katcherian DA. Relationship of metatarsophalangeal joint fusion on the intermetatarsal angle. *Foot Ankle Int* 10:8–11, 1989.
14. Dayton P, LoPiccolo J, Kiley J. Reduction of the intermetatarsal angle after first metatarsophalangeal joint arthrodesis in patients with moderate and severe metatarsus primus adductus. *J Foot Ankle Surg* 41:316–319, 2002.
15. Ebisui JM. The first ray axis and the first metatarsophalangeal joint: an anatomical and pathomechanical study. *J Am Podiatr Med Assoc* 58:160–168, 1968.
16. Scranton PE, Rutkowski R. Anatomic variations in the first ray—part 1: anatomic aspects related to bunion surgery. *Clin Orthop Rel Res* 151:244–255, 1980.
17. Grode SE, McCarthy DJ. The anatomical implications of hallux abducto valgus: a cryomicrotomic study. *J Am Podiatr Med Assoc* 70:539–551, 1980.
18. Dayton P, Feilmeier M, Kauwe M, Hirschi J. Relationship of frontal plane rotation of first metatarsal to proximal articular set angle and hallux alignment in patients undergoing tarsometatarsal arthrodesis for hallux abducto valgus: a case series and critical review of the literature. *J Foot Ankle Surg* 52:348–354, 2013.
19. *Textbook of Bunions Surgery*, edited by J Gerbert, WB Saunders, Philadelphia, 2001.