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Original Research

Sagittal Plane Alignment for First Metatarsal Phalangeal Arthrodesis Correlated with Postoperative Function: What is the Optimal Position?

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ABSTRACT

There have been many reports describing the proposed alignment of a first metatarsal phalangeal arthrodesis to obtain optimum function. Most of these recommendations are based upon historical and anecdotal evidence. Furthermore, there are few reports directly comparing alignment to patient reported function. We studied radiographic sagittal plane alignment in a group of 60 patients (80 feet) who had undergone a first metatarsal phalangeal joint arthrodesis (20 of the 60 had bilateral arthrodesis) to better understand how this component of the arthrodesis position translates to real world function. The patients in this study had completed a functional survey in 2022 at a mean of 28.4 (median 27.8; range 13.2-45.7) months with very high satisfaction for return to activities of daily living and recreational sports. We measured the sagittal plane position of the first metatarsal relative to the proximal phalanx in this cohort with known post operative activity data. We found that a mean (standard of deviation) sagittal plane angle (angle between the anatomic axis of the first metatarsal and the proximal phalanx) of 15.4 (SD 7.4) degrees and a proximal phalanx head to ground height of 12.7 (SD 3.3) mm was present in this group. Comparing the functional and positional results we conclude that this sagittal plane position provides a good recommendation for alignment.

Introduction

Metatarsal phalangeal (MTP) arthrodesis has a long track record of satisfactory patient outcomes including relief of pain, deformity correction and return to activity including sport (1-4). As with all arthrodesis procedures, position is critical to achieve high function and patient satisfaction. Although there are many anecdotal recommendations for first MTP arthrodesis positioning, studies comparing position to patient reported function are lacking. Specifically, sagittal plane alignment can be challenging to obtain in a reproducible manner intraoperatively. Although anecdotal recommendations exist for sagittal plane positioning, studies have not linked the sagittal plane position to documented functional outcomes. Because of this, we felt it important to focus our work on this important component of the procedure.

Two common sagittal plane relationships that have been described are the sagittal plane angle (SPA) as the angle between the phalanx and the first metatarsal, and the proximal phalanx angle (PPA) as the angle of the proximal phalanx to the floor or relative to a flat weight bearing surface (See Figure 1 A and 1B). Tanabe et al. described the importance of the metatarsal declination angle influencing the amount of the sagittal plane angle (5). It has been reported the dorsiflexion angle ranges from 15-40 degrees with a mean of 20-25 degrees (6-8). Additionally, past authors have described the frontal plane alignment of the hallux to be 10-15 degrees in valgus (9), while others have stated a neutral position is desirable (10). The most ideal transverse plane alignment of the hallux has been described as 10-25 degrees abducted (11-13). Others suggest the hallux alignment should be parallel to the second digit (13). A recent study compared radiographic and functional outcomes (PROMIS) of patients undergoing a first MTP arthrodesis for both hallux valgus and hallux rigidus (8). This study concluded that there was no difference in outcomes between hallux valgus and hallux rigidus. In their cohort they had a mean sagittal plane angle of 23.4 degrees.

A published report by 2 of the authors of this work (MD, PD) highlighted a robust return to activities of daily living (ADL's) and an encouraging finding of continued and increased sports activity following first MTP arthrodesis (2). This study included 60 patients, with 20 of the patients having bilateral procedures, yielding a total of 80 feet to radiographically assess. The surgery was performed by the same 2

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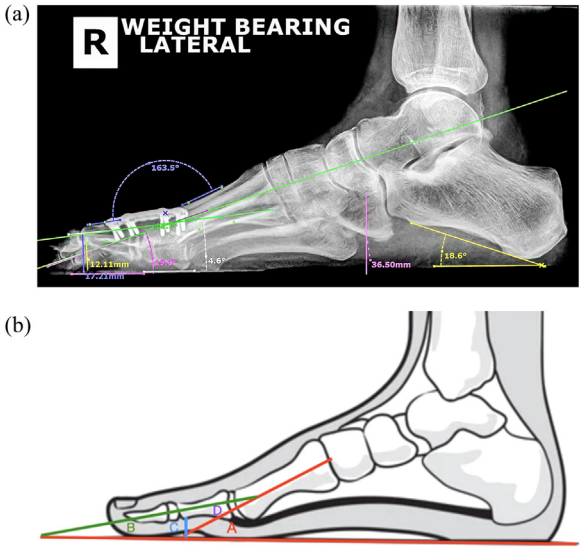

Fig.1. (*a*) Radiographic example of calculations. Green line- sagittal plane angle (SPA); Blue-163.5° is the dorsal cortical angle (DCA); yellow -12.11 mm is the phalangeal height (PH); white 4.6 is phalangeal angle; lavender 19° is the metatarsal declination angle (MDC). (*b*) Schematic view A = Metatarsal Declination Angle (MDA); B = Phalangeal angle (in this case a negative value); C = Phalangeal Height (PH) in millimeters; D = Sagittal Plane Angle (SPA).

authors (MD, PD) in a consistent manner for positioning of the hallux in all three planes. Positioning of the hallux in the sagittal plane was achieved by placing a 2 mm spacer under the head of the proximal phalanx as the foot was loaded to simulate weight bearing with the ankle joint at 90 degrees and subtalar joint neutral position. The hallux was positioned neutral to slightly supinated in the frontal plane and parallel to the second digit in the transverse plane. Highlights of the study concluded that 97% of the subjects returned to all daily activities without restriction; 98% could walk at a normal pace; and 95% reported that loss of motion at the first metatarsal phalangeal joint did not affect daily activities. Lastly, for those that participated in recreational sports, they all returned to their same sporting activities postoperatively.

We hypothesize that studying the sagittal plane position in this group of patients with known functional outcomes will provide a better understanding of an acceptable sagittal plane positional alignment for first MTP arthrodesis.

Patients and Methods

We utilized the patient data set that was recently published by Dayton et al. which reported patient reported outcomes post first MTP arthrodesis for hallux valgus for this analysis (2). Use of this data set allowed us to compare the outcomes of a group of patients with a known functional outcome relative to the sagittal plane position that we measured radiographically as a part of this work. IRB exemption was obtained for this review. Foot function assessment was based upon postural function, activities of daily living, and walking ability.

The data set used had radiographs available at a mean of 9.8 months postoperatively. Radiographic measurements were performed by one author (DH). The following radiographic measurements were made utilizing the Opal Rad® software (20-20 imaging, a division of Konica Minolta Healthcare, Wayne, New Jersey): calcaneal inclination angle (CIA), the navicular height (NH) from the weight bearing surface, first metatarsal declination angle (MDA), sagittal plane angle (SPA) of the first MTP utilizing the anatomic axis of the metatarsal and the proximal phalanx in the sagittal plane, dorsal cortical angle (DCA) of the first metatarsal and proximal phalanx, the proximal phalangeal angle (PPA) angle of the proximal phalanx to the floor and the phalangeal height (PH) (distance in millimeters of the inferior surface of the head of the proximal phalanx to the ground) (see Figure 1a and 1b). Measurements for the transverse plane hallux valgus angle for each subject was extrapolated from the previous data set as were the patient reported functional outcomes (2).

Table 1
Summary Statistics

Variable	N	Mean	STD Dev	Median	Minimum	Maximum
CIA	80	20.061	5.695	20.000	.0500	35.200
SPA	80	15.389	7.434	15.900	.200	31.300
DCA	80	17.176	7.861	18.450	−.400	33.300
MDA	80	18.390	4.759	19.400	4.100	27.800
Prox Phal Ground Angle	80	−1.994	7.810	.250	−20.200	16.200
Prox Phal Height	80	12.711	3.303	12.400	6.000	21.300
Navicular Height	80	32.085	6.567	32.700	18.200	47.800

Abbreviations: CIA = calcaneal inclination angle; SPA = Sagittal plane angle; DCA = Dorsal cortical angle; MDA = metatarsal declination angle.

Data Evaluation/Analysis

The bivariate Pearson Correlation was used to assess correlation. It produces a sample correlation coefficient, r, which measures the strength and direction of linear relationships between pairs of continuous variables. By extension, it evaluates whether there is statistical evidence for a linear relationship among the same pairs of variables in the population. Proportionality was assessed using linear regression. All analyses were performed using SAS 9.3 (SAS Institute, Cary, NC)

Results

A summary of the statistical results is shown in Table 1.

We compared pairs of measurements to attempt to extrapolate measurements that produced satisfactory patient outcomes. In comparing these measurements taken, the majority had a statistically significant linear relationship. However, the metatarsal declination angle and the dorsal cortical angle do not have a statistically significant linear relationship ($r = 0.18$, $p = .12$). The mean sagittal plane angle was 15.39 degrees (SD 7.43). The mean proximal phalanx angle to the ground was minus 2 degrees (SD 7.81). The mean proximal phalangeal height was 12.71 mm. (SD 3.3).

Discussion

The authors of this study advocate a triplane alignment method for first MTP arthrodesis to reduce the intermetatarsal angle and aid in the maintenance of the deformity correction and allow for optimal function. The frontal plane is usually neutral (nail straight up) or slightly supinated. The transverse plane alignment is relative to the position of the second digit (parallel), assuming that the second digit is rectus. The sagittal plane alignment is achieved with a 2 mm spacer under the proximal phalangeal head while simulating weight bearing. This positioning resulted in high level of function in the 60 patients in this data set.

Authors have advocated a sagittal plane angle range from zero to forty degrees (3,8,12,13,14) (Figure 2). Chraim et al. reported 15-20 degrees of sagittal plane angle (14). Chodaba et al. stated their mean sagittal plane angle was 23.4 degrees (8). Hamilton et al. recommended a sagittal plane angle of 30 degrees (12). Fernandez de Retana et al. stated the ideal sagittal plane angle is 15-30 degrees (15). The problem with a defined sagittal plane angle is the variability in the metatarsal declination angle (13). A cavus foot type will have a relatively higher angle than a flatfoot. As such, Conti and Dhawan and Womach and Ishikawa recommend not using a defined sagittal plane angle (16,17). We agree that utilization of the sagittal plane angle can provide inconsistent results and is difficult to assess intraoperatively. Our statistical analysis showed a weak correlation between the sagittal plane angle and the metatarsal declination and the phalangeal height.

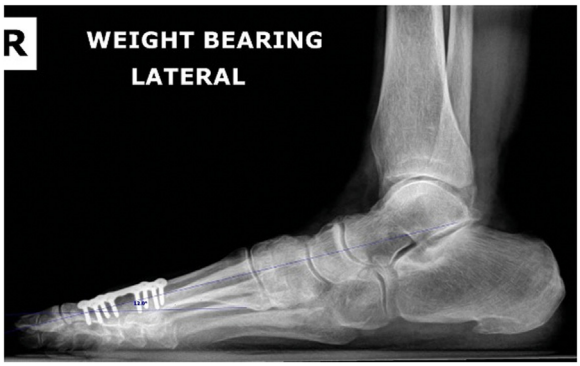

Fig. 2. Sagittal plane angle-(SPA).

Pre-bent specialty plates have been recommended by some to simulate and fit to the dorsal cortical angle of the first metatarsal and proximal phalanx. Leasburg et al. in 2019 described the variability in pre-bent plates and final metatarsal phalangeal alignment (18). DeOrio pointed out that a 5-degree pre-bent plate would achieve approximately a 25-degree dorsiflexion angle (19). Lewis et al. furthermore showed the importance of plate position in final alignment (7). Measuring angles relative to the first metatarsal intraoperatively can vary widely based on the foot type. Also, fixation plates that attempt to set the position based on design fall short because of the variance in foot type and metatarsal and phalangeal contour. For that reason, we feel that using the weight bearing surface as the reference for phalangeal head height is a simple, reliable, and reproducible way to obtain functional sagittal plane position as indicated by the functional results.

Previous researchers have referenced the proximal phalanx angle to the ground. We have called this the proximal phalangeal angle (Figure 3). A positive value is dorsiflexed and a negative value in our study indicates the phalanx is plantarflexed relative to the ground. Kelikian indicated that the angle should be approximately 10-15 degrees dorsiflexed with 15 degrees ideal for a 2-inch heel (9). Weber et al. suggested the angle be 0-15 degrees dorsiflexed (20), while Womach et al. indicated an angle of 10-15 degrees dorsiflexed (17). Many other authors have stated 10-15 degrees dorsiflexed to the weight bearing surface is ideal (12,13,16,17,21,22). Harper et al. suggested that the proximal phalanx be parallel to the ground (11). It is interesting in our study that some patients with a high functional outcome had plantarly deviated proximal phalangeal angle (34/80). The average in the plantarflexion group was negative 9.5 degrees. Overall, the mean proximal phalangeal angle was negative 2 degrees. This is certainly less than the reported averages of other authors. Given variables in anatomy and the influence of the metatarsal declination angle on the final position, we question the utility of using angles to predict or intraoperatively set the hallux sagittal plane position. The ideal position may be a proximal phalangeal angle of zero degrees or essentially parallel to the floor as recommended by Conti et al. and Harper (11,16). This also raises the question of how to set the position during surgery. As described, we used a 2 mm height of the proximal phalanx head relative to the ground which was simulated by loading the foot maximally with the ankle at 90 degrees and subtalar joint neutral (Figure 4). This method of positioning seems effective based on the functional outcomes of the patients in this dataset as previously reported, which showed a very high level of function and satisfaction, with 97% of the subjects returning to all daily activities; 98% walking at a normal pace; and 95% reporting that loss of motion at the first metatarsal phalangeal joint did not affect daily activities.

Fig. 4. Intra-operative method to set the sagittal plane position based on Phalangeal Height-PH.

Other authors have advocated the alignment of the tuft of the hallux to the ground be just of the weightbearing surface at the midstance phase of gait (23,24) (Figure 5). Conti et al. stated that the head of the proximal phalanx should be off the floor by 5-10 mm (16). These findings were also supported by Koutsouradis et al. in 2021 (22). Alexander stated that the tip of the toe should be 4-8 mm off the weight bearing surface (25). Kumar et al. mentioned that the toe is flush with a plate while the heel is off the weightbearing surface by 1 inch (26). There is wide variability in the thickness of the plantar skin of the toe and the dimensions of the phalanx which induces error in angular measurements. Also, it is known that the interphalangeal joint (IPJ) may be fixed or mobile in the sagittal plane. We advocate functional alignment by utilizing the head of the proximal phalanx to the weight bearing surface because this negates the influence of joint mobility at the IPJ as well as the other foot type variables already discussed.

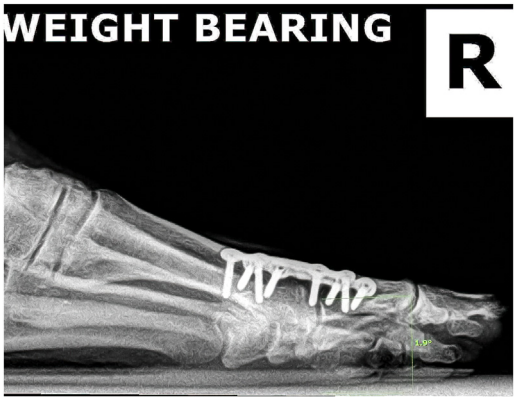

Fig. 3. Proximal Phalanx Angle-PPA.

Fig. 5. Radiographic measurement of Phalangeal Height-PH.

Lastly, authors have suggested that a straight plate be utilized as an alignment guide over the first MTP (27). Our dorsal cortical angle average was 17 degrees, indicating that a straight dorsal surface would potentially be too plantarflexed. The variability of the anatomy of the dorsal MTP joint surface and the fact that with many preparation systems the dorsal metatarsal head is convex makes using a standardized plate bend unreliable. It has also been noted that variabilities in plate positioning distal to proximal produces changes to the alignment of the first MTP even when using the same plate angle which is also an effect of bone contour and metatarsal declination (7). Unless the bone contours are predictable and consistent a standardized dorsal plate will not produce consistent results for sagittal plane position.

Surgeons clearly understand the importance of alignment and that the results of over and under correction can be devastating. In fact, one of the most challenging aspects of a first MTP arthrodesis is obtaining the proper alignment intraoperatively. An elevated hallux may lead to a hallux interphalangeal joint flexion contracture and shoe irritation, while also leading to increased plantar pressures under the sesamoid complex. A hallux positioned below the axis of the first metatarsal results in distal pressure on the hallux and poor weight distribution and an increased potential for hallux interphalangeal arthrosis. Additionally, transverse, and frontal plane malalignment can cause both functional and shoe wear issues. In the data set we utilized, the mean final HVA and IMA were 13.3 degrees and 10.3 degrees respectively, resulting in a hallux position that is close to normal anatomic position. Additionally, the frontal plane position which was assessed by the nail plate position relative to the ground was neutral to slightly supinated. Although we feel that the sagittal plane position has the highest priority, all 3 planes must be corrected to obtain a functional result.

There was a very weak correlation between the metatarsal declination angle and the sagittal plane angle, as well as a weak correlation between the metatarsal declination angle and dorsal cortical angle. As such, the reference of the metatarsal declination angle in positioning is a poor choice. This was also the conclusion of Conti et al. and Womach et al (16,17). The sagittal plane angle and the phalangeal height had a linear relationship, but the strength of the association was weak. Conversely, there was a strong correlation between the proximal phalangeal angle and the phalangeal height. Our data indicates that either the proximal phalangeal angle or the phalangeal height would be a satisfactory surgical alignment indicator to achieve optimal outcomes. This is based upon the linear relationships of the measurements and the easiest to reproduce in a surgical setting. Reproducible intraoperative sagittal plane positioning of the hallux with the head and the plantar soft tissues under the proximal phalanx off the platform by 2 mm's achieves an average (SD) sagittal plane angle of 15.4 (SD 7.4) degrees and phalangeal height of 12.7 (SD 3.3) mm. This alignment method has been shown to achieve good functional outcomes.

Limitations of this study include potential radiographic inconsistencies based on positioning during performance of the exam and inherent measurement error. Also, on the lateral view the proximal phalanx has considerable changes in contour that influence the anatomic axis measurements. We acknowledge comparing data to a group with less functional outcomes would be beneficial. Further research should be incorporated focusing on phalangeal angle and phalangeal height.

It was identified that the phalangeal height was the most statistically reliable intra operative method to establish optimal position. Our study revealed that our mean phalangeal angle was negative 2 degrees and the mean phalangeal height was 12.7 mm. For every millimeter of height increase between the head of the phalanx to the ground, the phalangeal angle increased by 1.36 degrees. Accounting for variables in skin thickness and osseous variabilities of hallux; the phalangeal height of approximately 14.1 mm would achieve a parallel proximal phalanx to the ground.

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