Neuropathic first metatarsophalangeal arthrodesis: Deforming force of flexor hallucis longus tendon

Thomas A. Brosky II, DPM, FACFAS¹, Brian Carpenter, DPM, FACFAS², Adam Port, DPM³, Charles Penvose, DPM, AACFAS⁴, Chandler Ligas, DPM⁵

1 - Attending Surgeon Emory Decatur Hospital, Decatur, GA; Foot and Ankle Clinic of Oakwood, Oakwood, GA
2 - Professor Department of Orthopaedics The University of North Texas Health Science Center, Fort Worth, Texas
3 - Attending Surgeon Emory Decatur Hospital, Decatur, GA; Ankle and Foot Centers of Georgia, Norcross GA
4 - Fellow at Foot & Ankle Specialists of Central Ohio, Newark, OH
5 - Resident Emory Decatur Hospital, Decatur, GA

Background Deformity of the Hallux interphalangeal joint (HIPJ) is a common complication following neuropathic 1st MPJ arthrodesis. Although largely asymptomatic, there have been no such studies evaluating the incidence of deformity and degeneration following 1st MPJ arthrodesis, in the neuropathic patient population. The aim of this paper was to highlight the incidence of deformity and degenerative changes at the HIPJ following 1st MPJ arthrodesis in neuropathic patients.

Methodology/Procedures Retrospective radiographic review of 324 patients who underwent 1st MPJ arthrodesis, of these patients, 42 patients met inclusion criteria with a diagnosis of peripheral neuropathy due to all causes (diabetic, idiopathic, alcoholic). Preoperative, 12 weeks postoperative and long term (average of 48 weeks) weight bearing radiographs were evaluated for degenerative changes and angular deformity of the hallux interphalangeal joint. The evaluated angles include the hallux interphalangeal joint angle (HIA), the plantar distal hallucus angle (PDHA), and the hallux to ground angle (H-G angle).

Results Deformity and/or degenerative changes of the HIPJ were seen in 80.9% of patients at long term follow up as evaluated from the HIPJ angle and the PDHA angle. The mean percentage change of the HIPJ angle from preoperative to final postoperative follow up was 19.8% and from preoperative to long term follow up was 37.4%. The percentage change of the PDHA angle was 1.39% from preoperative to final follow up and 13.87% from preoperative to long term follow up. A paired t test was performed to showcase statistical significance and was found to be significant for the HIPJ angle preoperatively to final postoperative (p-value < 0.0076) and the preoperative to long term follow up for the HIPJ angle (P-value <0.001). The PDHA angle was statistically significant at long term follow up (p <0.0001). These results demonstrate the degree of deformity and subsequent degeneration that is present in the HIPJ following first MPJ arthrodesis in neuropathic patients.

Discussion The senior surgeons have identified a higher incidence of HIPJ deformity in neuropathic patients after 1st MPJ arthrodesis compared to historic literature incidence. These findings at the HIPJ that, if not addressed, could result in eventual breakdown of the joint with significant deformity. The results of this analysis suggest that a prophylactic flexor hallucis longus (FHL) tenotomy should be performed simultaneously with 1st MPJ arthrodesis to prevent progression of deformity and degeneration in this joint in the neuropathic population. This finding would be best explored in future studies as a prospective review.

Keywords: metatarsophalangeal arthrodesis, hallux interphalangeal joint, flexor hallucis longus, deforming force, charcot neuroarthropathy, neuropathy, diabetic

First metatarsophalangeal joint arthrodesis is a common procedure used for the treatment of a variety of pathologies that affect the first metatarsophalangeal joint (1st MPJ) [1]. The 1st MPJ arthrodesis is versatile in treating common first ray pathologies due to its ability to reduce deformity and provide long term patient satisfaction scores [2,3]. There has been discussion in the literature regarding this procedure including potential biomechanical risk factors, appropriate positioning, appropriate fixation, and early weight bearing [4,5]. Inherent problems and/or complications have been reported following 1st MPJ arthrodesis. The most common complication reported in literature appears to be malunion [4]. Roukis reported a 6.1% malunion rate in a review of 2818 cases. The nonunion rate was 5.4% and only 1.8% of nonunions were symptomatic. There was an 8.5% hardware complication rate [4,6].
It is well documented in the literature that joint degeneration in surrounding joints following arthrodesis is a common occurrence due to increased forces [7]. Fitzgerald evaluated HIPJ arthritis following 1st MPJ arthrodesis and classified the extent of the arthritis into four groups. In a series of 100 patients with 10 to 17 year follow up, 56% percent of the study population had some degree of degenerative changes either radiographically or clinically. Of these, only 10% had symptomatic HIPJ arthritis [8]. Shah et al. explored the rate of symptomatic postoperative 1st MPJ arthrodesis with concomitant HIPJ arthritis. In the study of 107 procedures with a two year follow up, no instances of symptomatic arthritis were reported at the HIPJ. Some early post operative reports showcase a decrease in the ideal HIPJ angle on radiographs as early as 3 months postoperatively. Although the authors did not comment on the reason for the degree of deviation this early postoperative finding at the HIPJ is concerning [9].

The HIPJ degeneration and/or deformity, although commonly asymptomatic, may pose a threat of subsequent ulceration to the patient (Figures 2).

Ulcetration may lead to wound complications, late sequelae osteomyelitis, Charcot neuroarthropathy, and amputation. The primary aim of this retrospective radiographic review is to explore the incidence of deformity at the HIPJ that may occur in neuropathic patients undergoing 1st MPJ arthrodesis. If deformity develops at the HIPJ, this can lead to the

first metatarsophalangeal joint arthrodesis in neuropathic patients (Figure 1).
above-mentioned complications putting neuropathic patients at risk for morbidity and mortality. The secondary aim of the review is to determine the forces responsible for the deformation of the hallux interphalangeal joint.

**Materials and Methods**

A retrospective chart review was conducted by searching CPT code of 28750 from electronic health records from authors TB and BC from 01/01/2013 to 12/31/2018. From identified surgical patients during the selected time period charts were collected for review. Chart review for all patients included specific procedures performed including any concomitant surgical procedures (Hammertoe correction, Weil Osteotomy, etc), age, past medical history, and length of follow up. Overall, 324 patients were identified who underwent 1st MPJ arthrodesis. All patients with a diagnosis of diabetic neuropathy, alcoholic neuropathy or idiopathic neuropathy were included in the analysis. Neuropathy was defined as subjective findings of tingling/burning and objective finding of decreased protective sensation as tested with a 5.07 Semmes Weinstein Monofilament at the level of the forefoot. Of the 324 patients, 42 patients met the inclusion criteria and were included in this study for further radiographic evaluation. Exclusion criteria included any patient who underwent revisional 1st MPJ arthrodesis, 1st MPJ arthrodesis with structural bone graft, and a negative history of neuropathy. The radiographic evaluation included anterior-posterior and lateral views. Comparison was made between pre-operative, 12 week postoperative and long term postoperative radiographs (mean = 48 weeks).

Surgical technique was performed similarly by both physicians. Both authors utilize anatomic dissection, removal of all cartilage and subchondral plate with a combination of hand/power instrumentation and positioning the hallux with the use of a load bearing plate intraoperatively. This intraoperative positioning technique is implemented to simulate weight bearing and to ensure that the final position of the hallux is sufficient for weight bearing; this technique additionally negates the common pitfall of dorsiflexing the hallux on the 1st metatarsal past normal established limits (greater than 10 degrees) [6,10]. Fixation was achieved with the use of crossing lock pin k-wires, compression screws and a standard dorsal locking plate. Specific radiographic measurements were taken of Hallux Interphalangeal Angle (HIA), Plantar Distal Hallux Angle (PDHA), and the Hallux-Ground Angle (H-G Angle). Measurements were evaluated by an independent board-certified radiologist and two PGY-3 podiatric surgical residents. The normal measurement of the Hallux Interphalangeal Angle (HIA) is 0-10 degrees as measured on the AP weight bearing radiograph [11]. This angle is determined from the intersection of lines formed by the bisection of the distal phalanx of the hallux and the bisection of the proximal phalanx of the hallux. The HIA was used to assess the transverse plane deviation of the distal phalanx on the proximal phalanx (Figure 3).

**Figure 3 HIPJ angle.**

The Plantar Distal Hallux Angle (PDHA) is the angle formed between the anatomic axis of the proximal phalanx of the hallux and the articular line of the distal phalanx as seen on the lateral weight-bearing radiograph. The normal range is 75-85 degrees (Figure 4) [11].
This PDHA angle was used to assess the sagittal plane deviation of the distal phalanx on the proximal phalanx. The H-G Angle is the bisection of the anatomical axis of the proximal phalanx of the hallux to the parallel line of the weightbearing surface as seen on the lateral radiograph. The normal range is 0-10 degrees (Figure 5).

Statistical analysis was based on the means of sample population, these results were placed into a table (Table 1). Percent change of radiographic measurements was evaluated between preoperative and 12 weeks postoperative views, and between preoperative and long term follow up (mean 48 weeks). The equation for percentage change was defined as the means of the radiographic measure at pre, post and long term follow up. The specific mean of each value was then placed into the equation as (Post-Op Mean Number – Pre-Op Mean Number)/(Pre-Operative Mean Number) x 100. This same equation was then used for the Long Term Mean Number. A paired t test was used to determine the statistical significance of our results.

**Results**

Forty-two patients underwent radiographic retrospective review. 10 patients were male, 32 patients were female. 22 left feet were evaluated and 20 right feet. Average age of the patients was 63 years old. The average length of follow up for the postoperative group was 14 weeks. The average length of follow up for the long term follow up group was 48 weeks (Table 1).

<table>
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**Table 1 Demographics.**

The mean HIA increased from 10.2 ± 6.42 preoperatively to 14.975 ± 5.82 at long term follow up. This signifies a greater degree of deviation in the transverse plane, in a more abducted position (Figures 6 and 7).
The mean PDHA angle decreased from 79.02 ± 6.05 degrees preoperatively to 69.39 ± 9.38 degrees at long term follow up. This decrease signifies that the distal phalanx plantarflexes in the sagittal plane (Figures 8 and 9).

These results showcase that the deviation of the HIPJ occurs in a plantarflexory and lateral direction. The Hallux-Ground angle at preoperative, postoperative and long term follow up was 5.3 ± 4.02, 8 ± 3.82 and 7.52 ± 3.63. These results show that the positioning of the hallux was adequate and below the upper limits of abnormal of greater than 10 degrees dorsiflexed in reference to the weightbearing surface of the ground [6,10] (Table 2). A statistical analysis of the transverse (HIA) and sagittal (PDHA) plane deviation of the hallux was performed by utilizing the percent change and a paired t-test. The HIA Angle percentage change from preoperative to 12-week post operative was 19.76%, the percentage change from pre-operative to long term follow up was 37.37% (Table 3). The percentage change of the PDHA from pre-operative to 12-week post operative was 1.39%, from preoperative-long to long term follow up was 13.87%. (Table 3).

The paired t-test of the HIPJ angle showed statistically significant differences from preoperative to 12-week postoperative (p = 0.0076) and from preoperative to long term (p = 0.0001) (Table 3). The results of the paired t-test on the PDHA values were less remarkable with pre to final measurement (p = 0.344), which is not a statistically significant finding. Additionally, there was a statistically significant difference between the pre to long term measurement of the PDHA value (p = 0.001) (Table 3).
There was a significant degree of deformity in the sagittal plane and the transverse plane at the HIPJ following 1st MPJ arthrodesis in neuropathic patients. Through the paired t test showing statistically significant results in the long-term patients, we can infer that there is an association of these radiographic findings that can cause profound long-term problems. These problems could include Charcot and/or deformity associated with ulceration. This abnormality can present as early as 12-weeks postoperatively and is even more profound as time progresses in the neuropathic population. The association showcases that the HIPJ deformity occurs in the transverse and sagittal plane, more specifically in a lateral and plantarflexory direction. Failure to address this deformity and the force behind it, leads to increased morbidity in this at-risk neuropathic population. It is the authors theory that the flexor hallucis longus (FHL) is the force behind the deviation seen at the HIPJ following the first MPJ arthrodesis in the neuropathic population.

The degree of deviation of the hallux interphalangeus has been investigated following the correction of hallux valgus deformity in previous studies. Dixon’s radiographic review of 92 feet with hallux valgus deformity showed that there was a strong correlation between correcting the hallux valgus deformity and worsening of the HIA. Their group also showed a moderate correlation between the correction of hallux valgus and worsening of the proximal phalangeal articular angle (PPAA) and Total Distal Deformity angle (TDD) [12]. They ultimately discuss that a possible theory for the underappreciation of the hallux interphalangeus deformity is due to the pronation component of hallux valgus deformity and therefore appears to be normal preoperatively. Although this theory was not proven in their study, the results from our radiographic review highlight similar results with an increase in abnormality at the HIPJ following correction of hallux valgus through 1st MPJ arthrodesis. This finding supports the underappreciation of the hallux interphalangeus deformity on preoperative radiographs. However, this finding does not support the progression of

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Table 2 Highlight Mean, Confidence Interval, Standard Deviation.

<table>
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<th>Variable</th>
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<td>Pre-Final Post Op</td>
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<td>P = 0.0076</td>
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<tr>
<td>Pre- Long Term</td>
<td>37.37%</td>
<td>P = 0.0001</td>
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<tr>
<td>PDHA</td>
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<tr>
<td>Pre-Final Post Op</td>
<td>1.39%</td>
<td>P = 0.344</td>
</tr>
<tr>
<td>Pre-Long Term</td>
<td>13.87%</td>
<td>P = 0.001</td>
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</table>

Table 3 Statistics.

Discussion
deformity that occurred in our patient population from final follow up to long term follow up. The increased deformity in the sagittal and transverse plane from our final follow up group to long term post operative group, shows that over time the deformity worsens. Due to the FHL being the only soft tissue attached to the distal phalanx, it is apparent that this muscle contributes to the progression of the deformity.

The pull of the FHL tendon has been studied through the biomechanics of hallux valgus. Snijders et al. studied the FHL in patients with hallux valgus due to the muscle having the greatest force during flexion on the distal phalanx of the hallux. Their results showed that an increase in the HVA appeared to have a greater pull of the FHL in a valgus direction at the distal phalanx of the hallux. They further remark that this force happens due to the line of pull of the FHL being in a lateral and proximal direction. This lateral pull of the FHL in hallux valgus patients is due to the sesamoid complex being lateral to the first metatarsal [13]. With correction of the 1st metatarsal to a more normal position following 1st MPJ arthrodesis, there may still be a lateral pull of the FHL. This theory is supported with the sesamoid complex, although corrected, may still have a degree of lateral orientation to the 1st metatarsal.

Although the discussion has been centered around the hallux valgus patient population, there are still studies that support the deformity of the HIPJ following 1st MPJ arthrodesis treated for hallux limitus [8,9]. These findings with our results further support our theory that the FHL is the primary pathologic deforming force on the distal phalanx following 1st MPJ arthrodesis in the neuropathic patients.

There are multiple secondary effects that could contribute to the deformity that occurs at the HIPJ following neuropathic 1st MPJ arthrodesis. Passive and active tension at specific tendons has been studied in the neuropathic patient population. Passive stiffness, resistance to elongation, or the change in tension per unit change in length. Active tension is generated when the muscle receives input at the neuromuscular junction. Anderson and colleagues found that subjects with diabetes mellitus and peripheral neuropathy had decreased plantar flexor muscle peak torque compared with control subjects and therefore decreased ankle joint motion in this population [14,15]. Mueller expanded upon this research. Subjects with diabetes mellitus and peripheral neuropathy were evaluated for plantar flexor stiffness (change in passive torque per unit change in joint angle) and passive torque at 5 degrees of dorsiflexion and age matched controls. Their findings confirmed that subjects with diabetes mellitus and peripheral neuropathy demonstrated a decreased maximal dorsiflexion angle and decreased plantar flexor muscle excursion in the absence of increased passive plantar flexor muscle stiffness when compared to age matched control subjects without pathology [16]. Over time this decrease in maximal dorsiflexion could result in the development of a plantarflexion contracture [16]. Although these reports are specifically evaluating the ankle joint, the passive stiffness also affects the flexor hallucis longus. We theorize that this passive stiffness creates an uneven tautness/torque creating a lateral deviation of the distal phalanx on the proximal phalanx following 1st MPJ Arthrodesis in neuropathic patients.

This theory is further validated by the increase of external rotation seen through gait which partially alleviates pathologic equinus. Increased external rotation of the transverse plane deviation at the HIPJ is seen in patients with 1st MPJ arthrodesis. The ability of the joint to compensate for this pathologic gait would only be able to occur at the HIPJ during propulsion. As is seen from previous studies, the hallux has increased peak pressures and therefore with altered gait mechanics in the neuropathic population, the only motion to occur is an increased abductory force on the HIPJ [10].

There are further biomechanical reasons for the degrees of deviation to occur at the HIPJ following neuropathic 1st MPJ arthrodesis. DeFrinco showed there was a compensatory decrease in ankle plantarflexion after 1st MPJ arthrodesis to maintain the body’s center of gravity. After 1st MPJ arthrodesis patients must adapt to a rigid hallux that increases the length of the lever arm of the foot. As the patients push off with the longer lever arm, a longer step is made [17]. DeFrinco et al concluded that 1st MPJ arthrodesis does not re-establish a normal gait pattern but rather creates a compensated gait for the increase in rigidity. As a result, this longer step and longer lever arm in patients with neuropathy causes the FHL to create a deforming force at the HIPJ. These findings are confirmed with the radiographic findings of our study.
The degree of deviation at the HIPJ following 1st MPJ arthrodesis is not a new finding [8,9]. However, the treatment for these patients with hallux interphalangeus after 1st MPJ arthrodesis is challenging to treat. Prominent hardware and fixation concerns negate a potential for an akin osteotomy in conjunction with the 1st MPJ arthrodesis. Operative treatment algorithms have been proposed in the setting of HIPJ instability, arthrosis and deformation [18]. However, these treatments involve take down resection MPJ arthroplasty with HIPJ arthrodesis. Other options would be HIPJ arthroplasty with or without interposition of tissue graft [19]. This would be a viable option in patients with sensation, however, would be a potential concern in the neuropathy patient population due to the abovementioned deforming condition of gait and continual soft tissue adaptation.

To diminish the incidence of deformity at the hallux interphalangeal joint, the authors propose a technique to reduce the deforming force on the HIPJ after arthrodesis in neuropathic patients. Hyer et al has discussed off-set reaming perpendicular to the interphalangeal joint, to correct for interphalangeus while attempting 1st MPJ arthrodesis. Although this could be a good method for correcting pre-existing hallux interphalangeus it would not correct for the deforming force on the hallux post operatively [20]. For this reason, surgeons should consider the deforming force of the FHL on the HIPJ following neuropathic 1st MPJ arthrodesis. From early findings the primary investigators have started to perform flexor hallucis longus tenotomies in conjunction with the 1st MPJ arthrodesis on neuropathic individuals which seems to reduce the incidence of HIPJ deformity. This is analogous to performing a tendo-achilles lengthening in neuropathic patients to prevent midfoot collapse in Charcot deformities.

As this study was retrospective, we cannot be certain whether there was clinical correlation between the deformity of the HIPJ. We were unable to fully appreciate the morbidity associated with this lateral and plantarflexion deformity; therefore, more research should be done to clarify this association. Additionally, our small sample size limits the power of our results. Although there has been a postulation to the prophylactic procedure of the FHL tenotomy concurrently with neuropathic 1st MPJ arthrodesis; our research cannot comment on the viability of this procedure. Therefore, further research needs to be conducted regarding prophylactic FHL tenotomy in neuropathic 1st MPJ arthrodesis.

**Conclusion**

First MPJ arthrodesis is a powerful procedure, but adjunct procedures may be needed to protect neuropathic patients from complications associated with this comorbidity as discussed above. We further conclude that when the radiographic parameters (HIA, PDHA) are outside the normal range after 1st MPJ arthrodesis, there is increased risk for developing deformity or degeneration at the HIPJ. It has been the authors experience that performing an FHL tenotomy on neuropathic patients undergoing 1st MPJ arthrodesis, reduces the risk of deviation and deformity at the HIPJ which can result in ulceration, infection and amputation.

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**Conflicts of Interest:** None reported as outlined in the Conflict of Interest Document

**Declaration of Patient Consent:** Informed consent was obtained from patients prior to publication including pictures taken in the operating room and documentation obtained in procedure work ups.

**Acknowledgements:** None

**IRB Statement:** Emory University Institutional Review Board determined this project to be non-human subject research and did not require IRB approval.

**References**


