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Correlation of Dorsiflexion Angle and Plantar Pressure Following Arthrodesis of the First Metatarsophalangeal Joint

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Abstract

Background: The correlation between angle of fusion of the first metatarsophalangeal (1MTTP) joint and pressures under metatarsal heads and hallux has not been well characterized. The main purpose was to investigate the correlation between fusion dorsiflexion angle of the 1MTTP joint and plantar pressures under the first metatarsal head and hallux during gait.
Methods: Patients who underwent arthrodesis of the 1MTTP joint from 2005 to 2010 were seen for a follow-up examination. Of 27 patients, 15 (22 feet) with a mean follow-up of 26.2 months were evaluated in the study. Main outcomes included the fusion clinical and radiological dorsiflexion angles and the mean and maximum dynamic plantar pressures under all 5 metatarsal heads and under the hallux. Plantar pressures were measured through an in-shoe system while patients walked normally along a corridor.
Results: The dorsiflexion angle was positively correlated with mean dynamic plantar pressures under the first metatarsal head: P = .02 (r = 0.5) for clinical angle, and P = .01 (r = 0.58) for radiological angle. Patients with 15 degrees or more of clinical dorsiflexion angle demonstrated higher mean dynamic plantar pressure under the first metatarsal head (P = .05) and higher maximum dynamic plantar pressure under the second metatarsal head (P = .04) compared with patients with less than 15 degrees. In contrast, the latter patients demonstrated higher mean dynamic plantar pressure beneath the hallux (P = .04). Patients with 30 degrees or more of radiological dorsiflexion angle demonstrated significantly higher mean dynamic plantar pressure under the first metatarsal head (P = .04) compared with patients with less than 30 degrees.
Conclusion: Higher dorsiflexion angles correlate with higher plantar pressures under the first metatarsal head. Lower dorsiflexion angles increase plantar pressures beneath the hallux during gait.
Clinical Relevance: Significant increase in plantar pressure under the first metatarsal head may be avoided by performing the arthrodesis of the 1MTTP joint below 30° and 15° for the radiological and clinical dorsiflexion angles, respectively.

Keywords: first metatarsophalangeal arthrodesis, dorsiflexion angle, plantar pressure

Arthropathy of the first metatarsophalangeal (1MTTP) joint is a common disorder in foot and ankle clinics.[6,17,22,30] Arthrodesis of the 1MTTP joint is an accepted treatment for patients with degenerative joint disease, hallux rigidus, rheumatoid forefoot, or revision of failed hallux valgus correction.[6,13,18,22] This procedure consists of fusion of the first metatarsus to the proximal phalanx of the hallux, usually through a dorsal plate and screws, crossed screws, or staples.[3,5,23] Excellent outcomes after arthrodesis of 1MTTP joint in terms of bone union, symptom improvement, and patient satisfaction have been reported by several authors.[2,8,15,16,31]

The optimum fusion of the 1MTTP joint is suggested to range from 20 to 25 degrees of dorsiflexion[2,7,8,14-16] and from 15 to 20 degrees of valgus.[7,8,16,22] Several authors have suggested a relationship between arthrodesis of the 1MTTP joint and plantar pressures.[6,8,11,15] Although some studies found an increased plantar pressure beneath the hallux after arthrodesis of the 1MTTP joint,[6,8,11] values of plantar

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pressure beneath the first metatarsal head may be more controversial.[6,8,11,15] Coughlin et al[8] found an increase in plantar pressure beneath the first metatarsal head in 33% of patients (7 feet from a total of 21) undergoing arthrodesis of the 1MTTP joint but not in the rest of the sample, for a mean radiological dorsiflexion angle of 21.9 degrees. Other authors found no change in plantar pressure under the first metatarsal head after arthrodesis of the 1MTTP joint.[11,15] These studies were not aimed to investigate the correlation between fusion angles and plantar pressures during gait. Recently, Bayomy et al[1] performed a robotic cadaveric study in which specimens underwent arthrodesis of the 1MTTP joint, and dynamic plantar pressures were measured through a robotic gait simulator. The authors demonstrated a negative correlation between dorsiflexion angle and dynamic plantar pressures beneath the hallux, whereas a positive correlation was obtained between the dorsiflexion angle and the dynamic plantar pressures beneath the first metatarsal head.[1] The interesting findings reported by Bayomy et al were obtained in cadavers. This in vitro model may not reproduce normal gait considering the absence of participation of intrinsic muscles of the foot and the neuromuscular control of the leg. To the best of our knowledge, there are no studies investigating the correlation between fusion angles of arthrodesis of the 1MTTP joint and plantar pressures in vivo.

The main purpose of this study was to investigate the correlation between the fusion dorsiflexion angle and the plantar pressures in patients undergoing arthrodesis of the 1MTTP joint. It was hypothesized that high dorsiflexion angles would result in high plantar pressure beneath the first metatarsal head and that low dorsiflexion angles would result in high plantar pressure beneath the hallux during gait. Additionally, this investigation aimed to assess the clinical implications of fusion dorsiflexion angles in terms of metatarsalgia, callosities, and functionality through the American Orthopaedic Foot & Ankle Society (AOFAS) score.

Methods

From 2005 to 2010, all patients undergoing arthrodesis of the 1MTTP joint were approached for eligibility. Patients were excluded if they had any temporal or permanent gait impairment, refused to give informed consent to participate in the study, or demonstrated no signs of clinical and radiological fusion. All patients were contacted by phone and asked to return for examination. From a total of 27 patients who underwent an operation during the included period, 15 were finally engaged in the study. Reasons not to participate included no-show for examination (5 patients), moved to another city (2 patients), unable to contact (2 patients), recent unrelated surgery (2 patients), or refused to participate (1 patient). Data collection from the 15 patients was performed by the Physical Medicine and Rehabilitation Department and Orthopedic Surgery Department of our hospital. This study was approved by our institutional review board. Seven patients had a bilateral arthrodesis, so a total of 22 feet were studied. The diagnosis in all 22 cases included 14 feet (63.7%) with rheumatoid foot, 5 feet (22.7%) with hallux rigidus, 2 feet (9.1%) with severe hallux valgus, and 1 foot (4.5%) with failure of hallux valgus surgery. The demographic characteristics of the 22 cases were 17 women (77.3%) and 5 men (22.7%), 12 right feet (54.5%) and 10 left feet (45.5%), mean and standard deviation (SD) age 61.1 years (10.1 years), weight 73.2 kg (9.8 kg), height 1.59 m (0.06 m), and body mass index 28.9 (3.3). The mean (SD) follow-up period was 26.2 months (16.3 months).

Outcome Measurements

The variables collected for this cross-sectional study included (1) demographic characteristics; (2) surgical characteristics (fixation method for the arthrodesis, associated surgical procedures, and history of other surgeries in the lower limb); (3) dorsiflexion and valgus angles of fusion measured both clinically and through plain radiographs; (4) presence and localization of plantar or dorsal callosities; (5) presence and localization of pain in plantar or dorsal callosities upon palpation; (6) AOFAS score for the hallux metatarsophalangeal-interphalangeal (forefoot),[21] and (7) dynamic (during gait) plantar pressures under all 5 metatarsal heads and under the hallux.

The clinical assessment of fusion angles was conducted by 2 independent observers, and the mean value was considered for the statistical analysis. The patients were placed standing barefoot, and a manual goniometer was used to measure both the dorsiflexion and hallux valgus angles. For the hallux valgus angle, 1 arm of the goniometer was placed along the dorsal aspect of the diaphysis of the first metatarsal and the other arm along the dorsal aspect of the hallux. For the dorsiflexion angle, 1 arm of the goniometer was positioned on the floor and the other arm was placed along the medial aspect of the hallux.

The radiological analysis of fusion angles was also conducted by 2 independent observers after standard anteroposterior (AP) and lateral weight-bearing radiographs of the foot were made. The mean value between both measures was considered for the statistical analysis. For the hallux valgus angle, reference points were placed at the midpoint of the proximal and distal aspects of the diaphyses of the proximal phalanx of the hallux and first metatarsal on the AP radiographic view.[28] Therefore, the hallux valgus angle was subtended by the axes of the proximal phalanx and first metatarsal. The dorsiflexion angle was obtained by a line parallel to the dorsal edge of the diaphysis of the first metatarsal and a line perpendicular to the line bisecting the narrowest region of the proximal phalanx of the hallux in the lateral radiographic view.[20]

Plantar pressures were measured in dynamic (during gait) conditions using the Biofoot v5.0 (IBV, Valencia, Spain) instrumented insole system.[24] This measurement method has good reliability and repeatability for the assessment of plantar pressures. It consists of 64 piezoelectrical ceramic 0.5-mm-thick, 5-mm-diameter sensors distributed into a flexible polyester 0.7-mm-thick insole. The insoles had a greater density of sensors under bony areas where pressures tend to be high, especially under the forefoot. The insole was placed into the patient's shoe and then connected into an amplifier fixed at the patient's tibia by an elastic band. The amplifier was in turn connected to a transmission module attached to the subject's waist that converted the electrical signals provided by the amplifier into numerical data. Collected data were sent by digital telemetry from the amplifier to be logged on a computer and then processed by the specific software that reported the pressure, contact time, and cadence parameters. The digital telemetry system allowed the patient to move freely around the testing area. The system used kilopascal units (1 kPa = 1/98 kg/cm^2).

All patients had their plantar pressures measured through a standardized protocol. A thorough physical examination of both feet was carried out to identify the closest sensors to all metatarsal heads and the proximal phalanx of the hallux. The insoles were placed inside the shoes at the shoe-foot interface under strict supervision of the investigators. All subjects used the same standardized shoe adapted to patient's foot size. Then all of the system's connections were attached to the legs and waist, as described above. The system was calibrated before each measurement according to the manufacturer's instructions. Patients were allowed to familiarize with the testing procedure by walking for 2 minutes before beginning the registration. Then the patient was asked to walk in a 10-m-long corridor with a normal and comfortable velocity to measure the dynamic plantar pressures. The patient was not aware of the moment at which the recording of the pressures began. The beginning and end of the walk were avoided to ensure that the normal walking cadence of the patient was reached. Dynamic plantar pressures were registered for 6 seconds at 100 Hz (optimal for walking measurements),[24] corresponding to approximately 4 or 5 steps by each foot. After each measurement, a check was made to verify that the logging had been correctly completed. The maximum dynamic plantar pressures were obtained for all metatarsal heads and the hallux. The mean plantar pressure was only calculated for the head of the first and second metatarsal and for the hallux.

Statistical Analysis

Descriptive statistics were used to summarize all collected data. The Spearman's correlation coefficient was used to study the relationship between dorsiflexion angles and the plantar pressures. Additionally, the sample was divided between those patients with less or more than 15 degrees of clinical dorsiflexion angle and less or more than 30 degrees of radiological dorsiflexion angle. These cutoff points corresponded to the 50 percentile. A Mann-Whitney *U* test was used to detect statistically significant differences in plantar pressures among these subgroups. This test was also used to analyze the plantar pressures under the metatarsal heads depending on the presence or absence of plantar callosity under each metatarsal head. A chi-square test or Fisher exact test was used to detect significant differences in both clinical and radiological dorsiflexion angles depending on the variables related to callosities. The intraclass correlation coefficient was used to assess the reliability of angles measurements between the 2 independent observers. The alpha level was set at 0.05. Statistical analyses were performed with SPSS v.16.0 (SPSS Inc, Chicago, IL).

Table 1. Characteristics of the Sample Related to Surgical and Callosity Characteristics[a]

Variable	Yes	No
Associated tenotomy of lesser toes	3 (13.6)	18 (81.8)[b]
Associated Weil's osteotomy	3 (13.6)	18 (81.8)[b]
Associated IP arthroplasty	8 (36.4)	14 (63.6)
Associated MTT realignment	12 (54.5)	10 (45.5)
Past history of chevron osteotomy	4 (18.2)	17 (77.3)[b]
Past history of IP arthroplasty	3 (13.6)	19 (86.4)
History of tenotomy	4 (18.2)	17 (77.3)[b]
History of Weil's osteotomy	0 (0)	21 (95.5)[b]
History of MTT realignment	2 (9.1)	20 (90.9)
Dorsal callosity	0 (0)	22 (100)
Pain in dorsal callosity	0 (0)	22 (100)
Plantar callosity	15 (68.2)	7 (31.8)
Pain in plantar callosity	5 (22.7)	17 (77.3)
History of hip surgery	2 (9.1)	20 (90.9)
History of knee surgery	3 (13.6)	19 (86.4)
History of ankle surgery	3 (13.6)	19 (86.4)

Abbreviations: IP, interphalangeal joint; MTT, metatarsal.
[a]Values are n (%).
[b]One missing value.

Results

Table 1 shows the descriptive statistics for the outcome measurements related to operative and callosity characteristics. The localization of plantar callosities in the 15 patients was as follows: first metatarsal head, 4 patients (18.2%); second metatarsal head, 1 patient (4.5%); fifth metatarsal head, 1 patient (4.5%); from second to fifth metatarsal heads, 1 patient (4.5%); first, second, and fifth metatarsal heads, 3 patients (13.6%); first, second, and third metatarsal heads, 3 patients (13.6%); all metatarsal heads,

Table 2. Fusion Angles and AOFAS Score in the Sample

Variable	Mean	Range
Clinical hallux angle[a]	14.7	0-40
Clinical dorsiflexion angle[a]	15.9	0-29
Radiological hallux angle[a]	20.4	0-47.9
Radiological dorsiflexion angle[a]	31.2	14.3-46.7
AOFAS score	63.2	30-90

Abbreviations: AOFAS, American Orthopaedic Foot & Ankle Society; SD, standard deviation.
[a]Angles in degrees.

Table 3. Correlation of Maximum Plantar Pressures and Fusion Dorsiflexion Angles

	CDA		RDA	
Plantar Pressures	CC (*r*)	*P* Value	CC (*r*)	*P* Value
Dynamic hallux	–0.07	.76	–0.08	.76
Dynamic 1MTT	0.39	.14	0.24	.41
Dynamic 2MTT	0.41	.07	0.39	.11
Dynamic 3MTT	0.19	.43	0.04	.89
Dynamic 4MTT	–0.02	.93	–0.15	.53
Dynamic 5MTT	0.09	.7	0.11	.66
Dynamic hallux[a]	–0.15	.52	–0.23	.37
Dynamic 1MTT[a]	0.5	.02[b]	0.58	.01[b]
Dynamic 2MTT[a]	0.41	.07	0.39	.11

Abbreviations: CC, correlation coefficient; CDA, clinical dorsiflexion angle; MTT, metatarsal head;; *r*, Spearman's rho; RDA, radiological dorsiflexion angle.
[a]Mean values of plantar pressure.
[b]Statistically significant ($P < .05$).

2 patients (9.1%). The fixation method in the 22 feet was a plate and screws in 9 cases (40.9%) and staples in 13 cases (59.1%). Table 2 shows the mean and SD of the fusion angles and AOFAS score in the sample.

The dorsiflexion angle was positively correlated with mean dynamic plantar pressures under the first metatarsal head: $P = .02$ ($r = 0.5$) for the clinical angle and $P = .01$ ($r = 0.58$) for the radiological angle. Table 3 shows all correlations between fusion dorsiflexion angles and plantar pressures. The intraclass correlation coefficient (95% confidence interval) for the angle measurements was clinical hallux angle 0.81 (0.54-0.93), clinical dorsiflexion angle 0.89 (0.7-0.96), radiological hallux angle 0.95 (0.87-0.98), and radiological dorsiflexion angle 0.75 (0.36-0.9).

A subgroup analysis performed for plantar pressures depending on both the clinical and radiological dorsiflexion angles with a cutoff point determined by the 50th percentile yielded statistically significant differences for the hallux and the first and second metatarsal heads (Table 4). Specifically, patients with 15 degrees or more of fusion clinical dorsiflexion angle demonstrated higher mean dynamic plantar pressure under the first metatarsal head ($P = .05$) and higher maximum dynamic plantar pressure under the second metatarsal head ($P = .04$) compared with patients with less than 15 degrees (Table 4). In contrast, patients with less than 15 degrees of fusion clinical dorsiflexion angle demonstrated higher mean dynamic plantar pressure beneath the hallux ($P = .04$) (Table 4). Patients with 30 degrees or more of fusion radiological dorsiflexion angle demonstrated significantly higher mean dynamic plantar pressure under the first metatarsal head ($P = .04$) compared with patients with less than 30 degrees.

With the available sample size, the 2 subgroups of patients in both the clinical and radiological dorsiflexion angles did not demonstrate significant differences in the presence of plantar callosities ($P = .9$ for both clinical and radiological angles) and presence of pain in plantar callosities upon palpation ($P = .9$ for both clinical and radiological angles). Similarly, the AOFAS score did not differ between subgroups of dorsiflexion angle ($P = .089$). There were no significant differences in plantar pressures between patients with presence or absence of plantar callosity under each metatarsal head ($P = .79$ and $P = .22$ for maximum and mean dynamic plantar pressure under the first metatarsal head, respectively; $P = .79$ and $P = .41$ for maximum and mean dynamic plantar pressure under the second metatarsal head, respectively; and $P = .06$, $P = .47$, and $P = .55$ for maximum dynamic plantar pressure under the third, fourth, and fifth metatarsal heads, respectively).

Discussion

The main purpose of this study was to investigate the correlation between fusion dorsiflexion angle and plantar pressures in patients undergoing arthrodesis of the 1MTTP joint. The principal finding of this investigation was that the greater the dorsiflexion angle of the 1MTTP joint, the greater the plantar pressure under the first metatarsal head. It was also demonstrated that patients with low dorsiflexion angles of the 1MTTP joint had higher mean dynamic plantar pressures under the hallux compared with patients with greater angles. To the best of our knowledge, this is the first in vivo study investigating the influence of fusion dorsiflexion angles on plantar pressures in patients undergoing arthrodesis of the 1MTTP joint.

Arthrodesis of the 1MTTP joint is an accepted treatment for patients with hallux rigidus, rheumatoid forefoot, or revision of failed hallux valgus correction.[6,13,18,22] This acceptance is sustained by favorable results with respect to bone fusion rates, quality of life, symptom improvement, functionality (gait), patient satisfaction, and complication rates with 6-month to 8-year follow-up.[2,4,8,11,14-16,31] Also, several studies favor arthrodesis over other treatments such as total replacement arthroplasty, hemiarthroplasty, or Keller's arthroplasty in comparative level II evidence investigations.[15,19,26] These desirable results depend on numerous

Table 4. Comparison of Maximum Plantar Pressures (kPa) in Subgroups of Patients Depending on Fusion Angles

	CDA <15 Degrees	CDA ≥15 Degrees		RDA <30 Degrees	RDA ≥30 Degrees	
Plantar Pressures	Mean (SD)	Mean (SD)	*P*	Mean (SD)	Mean (SD)	*P*
Dynamic hallux	173.8 (194.7)	53.6 (46.7)	.11	157.7 (198.6)	72.9 (73.6)	.36
Dynamic 1MTT	217 (290.3)	546.8 (546.3)	.21	215.8 (291.2)	480.4 (504)	.24
Dynamic 2MTT	168.8 (293.7)	430.5 (349.5)	.04[a]	185.5 (306.4)	426.8 (386.9)	.11
Dynamic 3MTT	194.9 (350.2)	492.4 (429.3)	.09	263.9 (387.5)	497.9 (488.4)	.37
Dynamic 4MTT	30.9 (24.5)	119.4 (208)	.92	31.2 (23.3)	99.2 (236.4)	.31
Dynamic 5MTT	171.8 (202.9)	220.5 (257.9)	1	232.2 (291.8)	196.5 (139.3)	1
Dynamic hallux[b]	80.2 (116.3)	19.2 (36.7)	.04[a]	78 (117.6)	24.3 (39.9)	.14
Dynamic 1MTT[b]	78.9 (157.6)	326.1 (299.9)	.05[a]	78.8 (157.6)	372.6 (313.4)	.04[a]
Dynamic 2MTT[b]	110 (191.2)	170.5 (177.4)	.15	177.8 (248.6)	125.6 (115)	.8

Abbreviations: CDA, clinical dorsiflexion angle; MTT, metatarsal head; RDA, radiological dorsiflexion angle; SD, standard deviation.
[a]Statistically significant ($P < .05$).
[b]Mean values of plantar pressure.

issues, the study of which may help improve both the operative technique and clinical outcomes. The fusion dorsiflexion angle may be an important technical aspect to consider in order to avoid shoe complaints and abnormal plantar pressure distribution.[1,9,10,12] Several studies have investigated in vivo plantar pressures after arthrodesis of the 1MTTP joint.[6,8,11,15,22,27,29] None of these studies were specifically conducted to investigate the relationship between fusion dorsiflexion angles and plantar pressures. Thus, the exact relationship between both variables needs further investigation.

The study of plantar pressures in the literature is based on different assessment methods that may not be completely comparable to that used in our study. Some studies have used the Harris mat method to investigate the issue of plantar pressures.[6,8,22] This method produces a weight-bearing imprint of the foot; the darker the area in the imprint, the higher the plantar pressure in that point. Coughlin[6] retrospectively reviewed the results of 58 rheumatoid feet on which arthrodesis of the 1MTTP joint was carried out. Using the Harris mat method, the author found that all feet left a clear imprint of the hallux and 10 of 58 feet had an increased plantar pressure in the region of the lesser metatarsophalangeal joints. The mean fusion dorsiflexion angle for these findings was 22 degrees (range, 10-33 degrees), but it should be noticed that the author dealt with rheumatoid patients who all needed metatarsal realignment (resection arthroplasty of the metatarsal heads of the lesser toes).[6] In a different study, Coughlin et al[8] reported pain, function, and radiographic outcomes after a mean follow-up of 8.2 years in patients undergoing arthrodesis of the 1MTTP joint. Using the Harris mat method, the authors found clear imprints under the hallux in 20 of 21 feet and under the first metatarsal head in 7 of 21, for a mean dorsiflexion angle of 21.9 degrees.[8] The Harris mat method was also used by Mann and Thompson.[22] The authors reported the outcomes of rheumatoid patients undergoing arthrodesis of the 1MTTP joint at a mean follow-up of 4.1 years. They found a clear imprint for the hallux in 16 of 18 cases, with a mean dorsiflexion angle of 29.3 degrees (range, 16-50 degrees), but no information was provided for the metatarsal heads.[22] The Harris mat method only provides qualitative information about plantar pressures, so comparisons with our result may not be reliable. Overall, studies using this method agree that arthrodesis of the 1MTTP joint may produce an increased pressure beneath the hallux, but only a minority of patient would experience an increased pressure beneath the metatarsal heads.

Using pressure platforms, DeFrino et al[11] compared a pedobarographic analysis of 10 feet of patients with severe hallux rigidus before and after undergoing arthrodesis of the 1MTTP joint. The authors found no changes in the contact area, maximum force, and peak pressure under the metatarsal heads between preoperative and postoperative evaluations. However, the contact area, maximum force, and peak pressure increased under the hallux when comparing preoperative and postoperative values.[11] Given that the mean dorsiflexion angle in operated patients was 15.7 degrees (SD, 6.9 degrees), it might be argued that the increased pressure beneath the hallux would be explained by a too low fusion angle of dorsiflexion.[2,7,8,14-16]

Only very few studies have used the insole system to investigate the issue of plantar pressures in patients undergoing arthrodesis of the 1MTTP joint.[15,27,29] Gibson and Thomson[15] compared arthrodesis versus total replacement arthroplasty of the 1MTTP joint in patients with hallux rigidus. The assessed outcomes included pain intensity, plantar pressures, AOFAS scale, callosities, plain radiographs, and whole costs of care. Plantar pressures were measured with an in-shoe insole system using a similar protocol as used in our investigation.[15] For a mean dorsiflexion angle of 26 degrees, the authors found a nonsignificant increase in values of plantar pressures under the first and fifth metatarsal heads with respect to preoperative data in the arthrodesis group. A relationship between dorsiflexion angle and plantar pressures was not established in this study. The other 2 studies using the insole system analysis of plantar pressures did not consider the influence of dorsiflexion angles when comparing the arthrodesis with dorsal wedge osteotomy[29] and Keller's procedure[27] in patients with hallux rigidus.

Recently, Bayomy et al[1] conducted a robotic cadaver study to specifically investigate the relationship between dorsiflexion angle and plantar pressures in the arthrodesis of the 1MTTP joint. Six cadaver foot specimens were used to simulate different dorsiflexion angles of the 1MTTP joint, and dynamic plantar pressures were measured with a robotic gait simulator system. The authors found that peak pressure and pressure-time integral under the hallux were negatively correlated with dorsiflexion angle, whereas both pressure measurements were positively correlated with dorsiflexion angle under the first metatarsal head. They demonstrated that the intersection of the regression lines that represented the angle at which peak pressure and pressure-time integral were minimized was 24.7 degrees and 21.3 degrees, respectively.[1] The study by Bayomy et al was important in that an angle-pressure relationship was demonstrated. The results of our study partially support the findings of Bayomy et al. When applying the Spearman's correlation coefficient, we found a significant positive correlation between dorsiflexion angle and mean dynamic plantar pressures under the first metatarsal head, but we could not find a significant negative correlation between the same parameters under the hallux. However, when conducting a subgroup analysis on clinical and radiological dorsiflexion angles, we found that patients with a clinical angle of less than 15 degrees had higher mean dynamic pressure under the hallux. This difference may correspond to the findings by Bayomy et al, as higher dorsiflexion angles imply lower plantar pressures beneath the hallux. Unfortunately, with the available sample size, the Spearman's test did not elicit a significant correlation between dorsiflexion angle and plantar pressure under the hallux, nor did the Mann-Whitney *U* test subgroup analysis for radiological dorsiflexion angle demonstrate significant differences for plantar pressures under the hallux between low (<30 degrees) and high (≥30 degrees) angles. In any case, our results support the idea that the higher the dorsiflexion angle, the higher the plantar pressure beneath the first metatarsal head, and the lower the dorsiflexion angle, the higher the plantar pressure under the hallux during gait. Interestingly, this study found that higher dorsiflexion angles (clinical dorsiflexion angle of ≥15 degrees) was associated with higher maximum dynamic plantar pressure under the second metatarsal head. Therefore, this study shows that there may be a load transfer to lesser metatarsal heads when the 1MTTP joint is fused, and, probably, the higher the dorsiflexion angle the higher the load transfer to the second metatarsal head. Bayomy et al[1] were not able to demonstrate a significant relationship between plantar pressure under the second metatarsal head and dorsiflexion angle, which was attributed by the authors to the small number of feet used in their study.

The mean radiological dorsiflexion angle in our study is slightly higher than that recommended by some authors[6,8,11,14,16] but is similar to others.[15,19,22] It was suggested that a high dorsiflexion angle would produce hallux dorsal impingement and footwear difficulties.[9,10,12] However, our patients had no dorsal callosities, pain on dorsal aspect of toes, or complaints with shoes, as evidenced by the presence of 19 of 22 cases (86.3%) with no need of shoe modifications in the item of shoes of the AOFAS scale. Considering the existing literature, it would have been desirable to place the cutoff point of radiological dorsiflexion angle at 25 degrees instead of 30 degrees in the subgroup analysis. However, the risk of a type II error would have increased due to a small sample size (only 8 patients had dorsiflexion angles <25 degrees).

The absence (with the available sample size) of differences in mean dynamic plantar pressure under the hallux for the radiological dorsiflexion angle and not for the clinical angle may be explained by differing values of first metatarsal inclination (ie, internal arch height). Although Mann and Thompson[22] suggested that a clinical dorsiflexion angle of the 1MTTP joint of 15 degrees from the floor would approximately equal 30 degrees with respect to the first metatarsal, we believe that this equivalence may not be completely fulfilled in those patients with abnormal inclination of the first metatarsal.

The absence (with the available sample size) of statistically significant differences in plantar pressure under metatarsal heads between patients with presence or absence of plantar callosity is consistent with the results by Coughlin et al.[8] The authors found no plantar callosity under lesser metatarsal heads where increased pressure with the Harris mat method was demonstrated. Further research is needed to elucidate the clinical implications of increased plantar pressures.

There are several limitations to this study. First, there was a considerable loss of patients at follow-up (12/27 patients), but we believe that this may have a limited impact in terms of potential sources of bias for the conclusions of this study given the cross-sectional, correlational nature of this investigation. Second, the sample size may be too small; therefore, the risk of type II error in nonsignificant correlations or between-subgroup comparisons may not be negligible. However, the potential limitation of the sample size does not affect the main conclusions of this study, where significant differences were found. Third, the clinical dorsiflexion angle was measured with the use of the floor as a reference, which may not take into account differences in internal arch height.[25] Fourth, the associated metatarsal realignment in 12 patients may have modified the values of plantar pressures under the lesser metatarsal heads. However, this is a required associated procedure in many patients with rheumatoid arthritis. Fifth, the results of this study in terms of plantar pressures were obtained using the Biofoot instrumented insole system; these results may be better compared with data coming from the same measurement system.

In conclusion, this study demonstrated that a relationship between fusion dorsiflexion angle and plantar pressure does exist in patients undergoing arthrodesis of the 1MTTP joint. High dorsiflexion angles correlated with higher plantar pressures under the first metatarsal head. Also, low dorsiflexion angles increased plantar pressures beneath the hallux during gait. However, we were not able to find clear clinical implications to the study of plantar pressures.

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Dr Eduard Alentorn-Geli and Dr Sergi Gil contributed equally to this work. The corresponding author certifies that each author has participated in the design of the study, has contributed to the collection of the data, has participated in the writing of the manuscript, and assumes full responsibility for the content of the manuscript.

Declaration of Conflicting Interests

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