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Digital Deformity Assessment Prior to Percutaneous Flexor Tenotomy for Managing Diabetic Foot Ulcers on the Toes

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ABSTRACT

The aim of this study is to evaluate the prevalence of digital deformities in patients with diabetes mellitus according to the McGlamry classification and relate the types of digital deformities with the history of digital ulcer. A cross-sectional study was performed in the diabetic foot unit between September 2016 and September 2017. All consecutive patients were classified by digital deformities according to the McGlamry classification (flexor stabilization, flexor substitution, and extensor substitution) using slow-motion videos. In all patients, the Foot Posture Index 6 was performed and previous toe ulceration, toe calluses, and nail dystrophy were evaluated. A total of 142 feet were evaluated, in which 29 (20.27%) feet did not show dynamic deformities, 65 (57.5%) were classified as flexor stabilization, 9 (8%) as flexor substitution, and 39 (34.5%) as extensor substitution. In total, 23% the feet with previous ulcer were classified as extensor substitution. A previous toe ulcer on the tip ($p = .033$; confidence interval [CI] 1.06 to 4.99; odds ratio [OR] 2.3), pronated foot according to the Foot Posture Index 6 ($p = .048$; 95% CI 0.9 to 8.9; OR 2.9), and callus on the tip ($p = .002$; 95% CI 1.47 to 6.41; OR 3.07) were associated with flexor stabilization deformities. Flexor stabilization, associated with the pronated foot, was the most prevalent dynamic deformity. Extensor substitution was present in approximately 40% of the patients and in 20% of the patients with previous ulcer, in whom flexor tenotomy could aggravate the digital deformity. An evaluation of dynamic deformities during gait should be included as a presurgical assessment to achieve successful surgical results.

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The lifetime incidence of foot ulcers among persons with diabetes is approximately 19% to 34% (1). The development of diabetic foot ulcers is multifactorial and frequently associated with peripheral neuropathy and foot deformity (2).

Toe deformities such as hammer toes and claw toes have been associated with the development of diabetic foot ulcers (3). The dorsal, apical, and plantar aspects of the toes are particularly vulnerable locations (4). Ulcers occur on the toes in 43% to 55.5% of all foot ulcer cases. Although they tend to be smaller and heal faster than the forefoot or heel ulcers, they may precede up to 64% of diabetic limb amputations (5).

During gait, insensate and deformed toes can result in repetitive trauma to the distal tip of the toe and result in callus formation, the first stage of ulcer development. Claw toes in patients with diabetes are associated with the distal displacement of the protective submetatarsal head fat pads and an increase in plantar foot pressures in these regions (3,6).

Toe deformities in patients with diabetes are usually attributed to motor neuropathy. Dysfunction of the intrinsic foot muscles, mainly the interossei and lumbricals, leads to imbalances between the intrinsic and extrinsic muscles across the metatarsophalangeal joints (MTPJs) and interphalangeal joints (7). When the intrinsic muscles become atrophic and overpowered by the extrinsic muscles the stabilizing action is lost, which may eventually result in claw toe (8).

Although the exact cause of lesser digital deformities is multifactorial, biomechanical dysfunction is widely accepted as a contributing factor to abnormal digital function. The 3 major categories that McGlamry proposed to explain lesser MTPJ dynamic muscle imbalances include flexor substitution, extensor substitution, and flexor stabilization (9).

Off-loading pressure from ulcer sites is considered the gold standard treatment for promoting healing and preventing recurrence (10). Shoe correction, a silicone orthosis to elevate the toe individually adjusted by a podiatrist, and callus removal were used as standard treatments previously. However, robust evidence of the efficacy of such interventions is lacking and commonly results in poor patient adherence (11).

Previous studies suggested that certain surgical interventions can reduce the risk of recurrence of the foot ulcer located on the apex in patients with diabetes and diabetic neuropathy (12). Surgical interventions such as flexor tenotomy are often considered when a toe

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deformity has been identified as a contributing factor to toe ulcer and conservative options have been unsuccessful (13–17). Such an intervention was suggested to be an effective, safe, and easy way to achieve toe ulcer healing and to prevent its recurrence. The procedure is advocated for flexible toe deformities and can be performed prophylactically or curatively to alleviate the focal pressure on ulcerated areas (18). Two systematic reviews (18,19) evaluated the effectiveness of this surgical procedure and investigated its ability to heal and prevent diabetes-related toe, with all ulcers located on the apex (distal tip) of the toe. The literature reports that in 6 studies, flexor tenotomies were performed in 264 toes with ulcers and in 57 toes were performed as a prophylactic procedure. The rate of ulcer recurrence was 6% and the rate of complications was overall low.

However, no study to date has discriminated the etiology of dynamic deformities. We suspect that some proportion of patients have an extensor substitution deformity, and the flexor tenotomy could not be indicated. Furthermore, several studies recommended this technique as a prophylactic surgery, but none included a control group. The surgical procedure is performed indiscriminately, making standardization difficult.

The use of this technique in all patients without a previous etiopathogenic diagnosis is risky; the treatment should be indicated after a biomechanical evaluation and not generalized in every toe deformity. Flexor tenotomy is an easy, fast, and safe procedure; for this reason, it is interesting to determine whether this technique could be standardized in all toes with deformities and applied systematically. Our aims were to evaluate the prevalence of digital deformities according to the McGlamry classification in patients with diabetes mellitus, and to relate the types of digital deformities with the history of digital ulcer.

Patients and Methods

This cross-sectional study was performed in the diabetic foot unit between September 2016 and September 2017. All consecutive patients with diabetes mellitus diagnosed according to American Diabetes Association criteria (20) were evaluated for digital deformities. The exclusion criteria were as follows: no digital deformities in a non-weightbearing situation, rigid toe deformities, active ulcer, patients with other causes of neuropathy, history of previous transmetatarsal or major amputation, previous diagnosis of Charcot foot, rheumatoid disease, and the need for walking aids.

Peripheral neuropathy classification is based on neuropathy disability score (21,22). The neuropathy disability score ≥ 6 of 10 is considered abnormal. Peripheral arterial disease was defined as a nonpalpable dorsalis pedis or posterior tibial arterial pulse, ankle-brachial index < 0.9 , toe arterial systolic pressure < 55 mm Hg, and toe-brachial index < 0.7 (23).

The following data were registered for all patients: previous ulceration on the toe (on the tip or over the dorsum), previous toe amputation, calluses on the tip, calluses over the dorsum, and nail dystrophy.

Foot Posture Index

The examination was performed with the participants standing in their stance position, with double-limb support, their arms by the side, and looking straight ahead. The validated protocol of the Foot Posture Index 6 (FPI-6) (24–26) involves the rating of 3 criteria in the rearfoot:

- Talar head palpation: This is the only palpation criterion. The head of the talus is palpated on the medial and lateral sides of the anterior aspect of the ankle. The more pronation, the more palpable the head is in the medial side and the less it is in the lateral side. The opposite is true in the supinated foot.
- Supra- and infralateral malleolar curvature: This involves the observation and comparison of the curves above and below the lateral ankle malleoli. In the pronated foot, the curve below the malleolus will be more acute than the curve above. The opposite is true in the supinated foot.
- Calcaneal frontal plane position: This is an observational equivalent of the measurement of the neutral calcaneal stance position, which was measured using a goniometer. The neutral foot is 0°. Calcaneus is clearly pronated when it has > 5 grades everted. More than 5 grades inverted are clearly supinated.

In addition, there are 3 criteria on the forefoot:

- Prominence in the region of the talonavicular joint (TNJ): In the neutral foot, the area of the skin immediately superficial to the TNJ will be flat. The TNJ becomes more

prominent if the head of the talus is adducted in rearfoot pronation. In the supinated foot, this area may be indented.

- Congruence of the medial longitudinal arch (MLA): This observation is made by taking both the arch height and the arch congruence into consideration. In a neutral foot, the curvature of the arch is considered similar to a segment of the circumference. In the pronated foot, the MLA becomes flattened in the center. In the supinated foot, the curve of the MLA becomes acute at the posterior end of the arch.
- Abduction and adduction of the forefoot on the rearfoot: In this observation, the observer views the forefoot from directly behind and in line with the long axis of the heel. In the pronated foot, the forefoot is more visible in the lateral side (the “too many toes sign”). In the supinated foot, the forefoot is more visible in the medial side.

Each item is graded by a 5-point Likert type scale, from -2 to +2: 0 for neutral, with a minimum score of -2 for clear signs of supination and +2 for positive signs of pronation.

The final FPI-6 score is a whole number between -12 and +12. A total FPI-6 score between 0 and +5 indicates a neutral foot, a score $> +6$ indicates a pronated or highly pronated foot, and a score between -1 and -12 indicates a supinated or highly supinated foot.

Deformities

One clinician (J.L.M.) performed all foot examinations to identify rigid or flexible deformities.

The evaluation of the flexible deformities was performed using the Kelikian push-up test. If the deformity corrects by the application of pressure at the base of the MTPJ, it is then considered flexible; in contrast, the persistence of clawing indicates a rigid deformity (27).

The patients were classified according to the McGlamry deformity classification (9) using slow-motion videos, where the dynamic deformities were recorded. One explorer (I.S.C.) recorded 4 videos per patient during the walk: 2 in the frontal vision and two in the lateral vision. The videos were recorded by the same mobile device and subsequently edited in slow motion 2 times slower than normal speed.

Two researchers (I.S.C. and R.M.B.) evaluated the videos separately and determined each patient's deformity type. The researchers were blinded to the clinical findings of previous examination. Disagreements were settled by discussion until consensus was reached.

Toe Deformity Stratification

Flexor stabilization was stratified when a toe deformity was evident in the late phase of gait. Flexor substitution was identified when the deformity was visible in the heel lift phase of gait. Extensor substitution was identified when the deformity was apparent during the swing phase of gait. The lack of a dynamic deformity was identified when no deformities were visible in any phase of gait.

Statistical Analysis

Statistical analyses were performed (by I.S.C.) using SPSS version 22.0 (SPSS, Chicago, IL). Qualitative variables are described using frequency distributions and percentages, whereas quantitative variables are described as mean and standard deviation. χ^2 test was used to identify the differences in qualitative variables. Odds ratios (ORs) and their 95% confidence intervals (CIs) were determined through univariate analysis. Differences $< 5\%$ were assumed to be significant for type I errors ($p \leq .05$).

Because the population was unknown, the number of patients was determined by the statistic formula $n = Z\alpha^2 \times p \times q/d^2$ (n = sample size; Z = value corresponding to the Gauss distribution, 1.96, when $\alpha = 0.05$; p = prevalence of the characteristic of the study; $q = 1 - p$; and d = error tolerance). The result was $n = 1.96^2 \times 0.59 \times 0.41/(0.1)^2 = 93$ patients. The prevalence of the digital deformities was used from the Lázaro-Martínez et al (28) study that reports 59% of the prevalence of digital deformities. Finally, we recollected 106 patients, a greater number of the sample, because we assumed a loss of approximately 10% of the sample.

To determine the interobserver reliability between the 2 researchers, Fleiss' kappa was carried out. To interpret kappa values, Landis and Koch gave the following ranges: poor (< 0.00), slight (0.00/0.20), fair (0.21/0.40), moderate (0.41/0.60), good (0.61/0.80), and very good (0.81/1.00) reliability (29).

Ethical Approval

Ethical approval was obtained from the responsible committee and the study was completed in accordance with its ethical standards. Informed consent was obtained from each patient. The authors declare that the study protocol complied with the Declaration of Helsinki code of ethics (30).

Table 1
Demographic data of patients (N = 106 patients)

Characteristic	n (%)
Gender	
Male	72 (67.9)
Female	34 (32)
Type of DM (type 2)	91 (85.8)
Retinopathy	31 (29.2)
Renal disease	9 (8.4)
Peripheral vascular disease	24 (22.6)
Neuropathy	46 (43.3)
	Mean ± SD
Age (y)	63.6 ± 14.2
DM duration (y)	15.9 ± 11.5
Body mass index (kg/cm ²)	27.9 ± 4.9
HbA1c (%)	8.2 ± 8.7
mmol/mL	66.1 ± 7.1

Abbreviations: DM, diabetes mellitus; SD, standard deviation.

Results

In total, 106 consecutive patients with diabetes (212 feet) were evaluated, of which 35 (16.5%) feet had no toe deformities in a non-weight-bearing situation and were excluded. Other exclusions included 21 (9.9%) feet with rigid deformities, 4 (1.8%) feet with other causes of neuropathy, 4 (1.8%) feet with a history of transmetatarsal amputation, and 6 (2.8%) feet with Charcot foot. Thus, ultimately, 142 (66.9%) feet with deformities were included in the study.

Demographic characteristics of the sample (Table 1) and the clinical characteristics of the 142 feet (Table 2) were evaluated. When the 142 feet were evaluated by the researchers after the slow-motion videos, no dynamic deformities were seen in 29 (20.27%) feet, whereas dynamic deformities were seen in the other 113 (79.57%) feet. Of the deformities, 65 (57.5%) feet were classified as flexor stabilization, 9 (8%) as flexor substitution, and 39 (34.5%) as extensor substitution.

Analysis of the 35 (24.6%) feet with a history of previous ulceration on the tip revealed that 23 (62.9%) feet had flexor stabilization, 4 (11.4%) had flexor substitution, and 9 (25.7%) had an extensor substitution. The McGlamry classification showed good interobserver reliability of 0.701 ($p < .001$). The distribution of the toe deformities is shown in the flowchart (Fig.).

Univariate analysis by χ^2 test (Table 3) showed that a previous toe ulcer on the tip ($p = .033$; 95% CI 1.06 to 4.99; OR 2.3), pronated foot according to the FPI-6 ($p = .048$; 95% CI 0.9 to 8.9; OR 2.9), and callus on the tip ($p = .002$; 95% CI 1.47 to 6.41; OR 3.07) were associated with flexor stabilization deformities.

Discussion

This study showed that 67% of the sample had any type of toe deformity. According to the dynamic deformities, 57.5% had flexor stabilization, 8% had flexor substitution, and almost 35% had an extensor substitution. The patients with an extensor substitution develop toe deformity in a non-weightbearing situation. The etiology of this deformity is not the flexors muscles; rather, it involves excessive digital contraction in the extensors (9).

We observed the different feet in an off-loading situation with toe deformity and could not distinguish among their etiologies; thus, all were considered candidates for flexor tenotomy. However, it is likely that some of these patients likely had an extensor substitution deformity, for which this surgical approach would be incorrect. Our results revealed that 23% of the patients who had a history of ulcers on the tip had an extensor substitution. Because flexor tenotomy in these patients would not solve the problem, the ulcers could recur.

Table 2
Clinical data of feet with dynamic deformities (N = 142 feet)

Characteristic	n (%)
History of toe amputation	30 (21.1)
History of toe ulceration	
On the tip	35 (24.6)
Over the dorsum	7 (4.9)
Callus on toe	
On the tip	45 (31.7)
Over the dorsum	10 (7)
Nail dystrophy	59 (41.5)
Foot type (FPI-6)	
Neutral foot	110 (76.9)
Supinated foot	16 (11.3)
Pronated foot	16 (11.3)

Abbreviation: FPI, Foot Posture Index.

Furthermore, 20% of the sample with flexible deformities did not show dynamic deformities during the slow-motion videos. The deformities in these patients were identified only in a static situation, and the researchers could not classify any of them in the dynamic examination. If, for all toes observed, we standardized this technique to have deformities in the off-loading situation, all results would be not satisfactory.

In this study, we showed an association between a history of toe ulcer and the flexor stabilization deformity. Flexor tenotomy could be indicated to correct flexor deformity and prevent ulcer formation (19). Several studies (15,16,19,31–34) have evaluated this technique as a procedure to heal or prevent toe ulcers, but none have classified the toe deformities.

In our results, a callus on the toes was associated with flexor stabilization deformity. Several studies considered callus formation as one of the main risks of foot ulcer development on the same location in patients with diabetes (35).

The use of flexor tenotomy to prevent diabetes-related toe ulcers is an emerging practice, and is generally indicated in the cases in which extensive callus is present because of the increased risk of ulceration (34,36). Although the findings of these studies are very promising, it remains uncertain whether ulcers would have developed without prophylactic flexor tenotomy; therefore, some caution is required (16).

Prophylactic flexor tenotomies have been described only once (34), but their effectiveness was not described. That study suggested that flexor tenotomy may be a promising measure for prevention and should be considered before ulcer development. However, it is important to note that the sample size was small ($n = 9$); thus, more studies are needed before considering this technique as an early-stage treatment.

The guidelines of the International Working Group on the Diabetic Foot recommend that flexor tenotomy be considered when conservative treatment fails, or when high-risk patients with diabetes have digital deformities with preulcerative signs or an ulcer present on the distal toe (37). However, all studies of a systematic review (11) lacked a control group, and it was difficult to determine whether the reported benefits resulted from the prophylactic flexor tenotomy.

In our study, we observed an association between the pronated foot, evaluated by the FPI-6, and flexor stabilization deformity. The flexible valgus feet with excessive subtalar joint pronation is a common way in which the flexors gain an advantage (9). Although flexor tenotomy should be considered in these patients, there should be caution in performing it in an isolated toe, because the rest of the flexor tendons would then need to fire harder, which may further aggravate the deformity.

The literature has long defended that, as a consequence of diabetic neuropathy, a cavus foot with claw toes is the most prevalent type of foot in patients with diabetes. If that were the case, no patient would

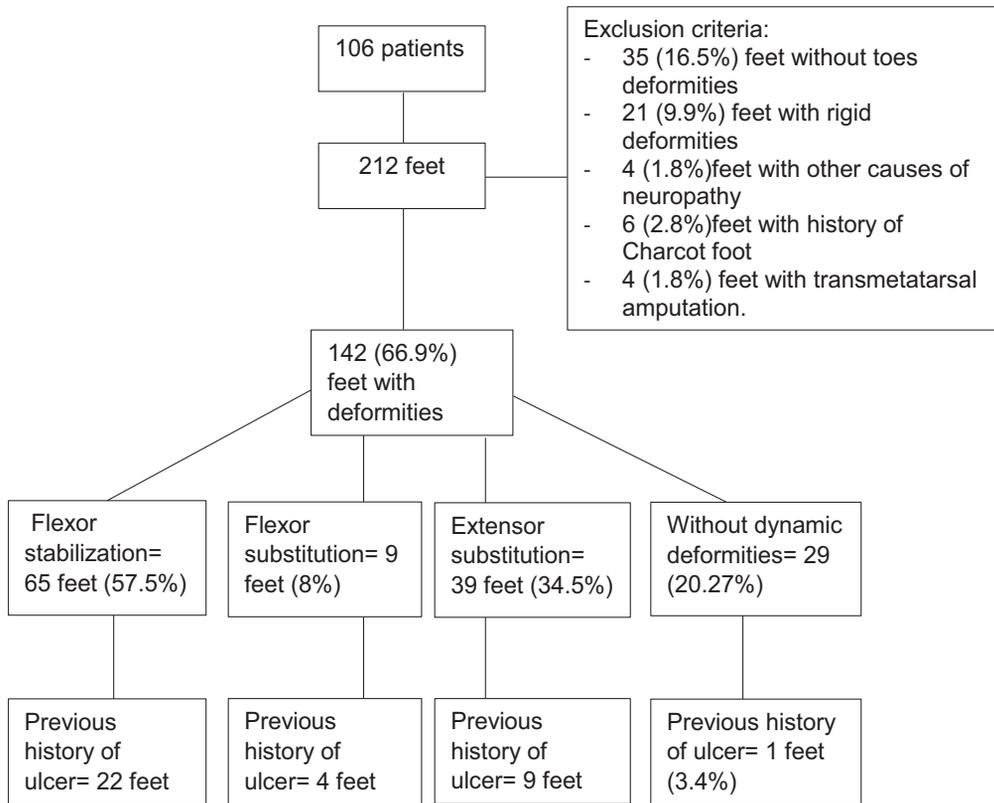


Fig. Flowchart showing the distribution of the patients and the toe deformities.

have been a candidate for flexor tenotomy because this deformity is characteristic of extensor substitution (38).

Pronated foot has been demonstrated as the type of foot most prevalent in patients with diabetic neuropathy (39). Pronated foot carries a

higher risk of forefoot ulceration than other foot types such as supinated or neutral groups (40).

For this reason, it is important to analyze the biomechanical condition of the foot to learn whether the toe deformity is on a pronated foot

Table 3
Association between the classification of dynamic deformities and clinical characteristics using χ^2 test (N = 142 feet)

	Previous Ulcer on the Tip	Neuropathy	FPI-6	Callus on the Tip	Nail Dystrophy
Flexor stabilization	$p = .033^*$; CI 1.06 to 4.99; OR 2.3	$p = .054$; CI 0.9 to 7.5; OR 2.7	Pronated foot $p = .048^*$; CI 0.9 to 8.9; OR 2.9 Supinated foot $p = .48$; CI 0.3 to 1.9; OR 0.48 Neutral foot $p = .92$; CI 0.4 to 1.8; OR 0.9	$p = .002^*$; CI 1.47 to 6.41; OR 3.07	$p = .08$; CI 0.9 to 3.5; OR 1.7
Flexor substitution	$p = .57$; CI 0.3 to 6.3; OR 1.5	$p = .56$; CI 0.09 to 3.7; OR 0.5	Pronated foot $p = .26$; N/A Supinated foot $p = .28$; CI 0.4 to 12.8; OR 2.4 Neutral foot $p = .96$; CI 0.2 to 3.7; OR 0.9	$p = .91$; CI 0.2 to 4.5; OR 1.08	$p = .85$; CI 0.2 to 4.4; OR 1.1
Extensor substitution	$p = .41$; CI 0.2 to 1.6; OR 0.6	$p = .16$; CI 0.1 to 1.4; OR 0.4	Pronated foot $p = .053$; CI 0.12 to 1.2; OR 0.1 Supinated foot $p = .81$; CI 0.2 to 2.8; OR 0.8 Neutral foot $p = .33$; CI 0.3 to 1.4; OR 0.6	$p = .06$; CI 0.1 to 0.9; OR 0.3	$p = .64$; CI 0.3 to 1.7; OR 0.8
Without dynamic deformity	$p = .055$; CI 0.07 to 0.9; OR 0.2	$p = .61$; CI 0.2 to 2.4; OR 0.7	Pronated foot $p = .63$; CI 0.4 to 4.5; OR 1.3 Supinated foot $p = .63$; CI 0.4 to 4.5; OR 1.3 Neutral foot $p = .22$; CI 0.7 to 3.7; OR 1.6	$p = .15$; CI 0.1 to 1.3; OR 0.4	$p = .08$; CI 0.1 to 1.1; OR 0.4

Abbreviations: CI, confidence interval; FPI, Foot Posture Index; CI, information coefficient; N/A, not applicable; OR, odds ratio.

* p value with statistically significant difference.

or a supinated foot. To prevent future toe deformities and ulcer formation, we must manage the biomechanics of the foot to prevent surgical failure (41).

The limitations of this study are related to the sample type. The prevalence of toe deformities in our sample was elevated. All patients were recruited from the diabetic foot unit and had a greater probability of having a pathology associated with foot deformity.

In further studies, it may be interesting to assess the risk factors and their association with the deformities according to the McGlamry classification by a logistic regression model with multivariate analysis. However, this is the first study to demonstrate the percentage of patients with the 3 types of toe deformities and analyze these deformities in a load-bearing situation. The stand view can show the foot morphotype and the associated toe deformity. We believe that the results of this study could be used to develop future prospective studies to focus on the surgical outcomes based on the evaluation of dynamic deformities.

In conclusion, flexor stabilization associated with the pronated foot was the most prevalent dynamic deformity noted in this study. Extensor substitution was present in approximately 40% of the patients evaluated and in 20% of the patients with previous ulcer in whom flexor tenotomy could aggravate the digital deformity. There was a high prevalence of flexor mechanisms related to ulcer risk; therefore, an evaluation of dynamic deformities during gait should be included as a presurgical assessment. The biomechanics of each patient should be evaluated in a loading situation, and the toe deformity etiology should be analyzed to achieve successful surgical results.

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