BENHA MEDICAL JOURNAL bmj
Print ISSN 1110-208X
Online ISSN 2357-0016

original article

Diabetic Sensory Neuropathy and Plantar Pressure Changes

Mayada S. Khalel[a], Ismail kandil[b], Mohamad Motawea[c]

[a] Department internal Medicine, Faculty of Medicine, Mansoura University, Egypt
[b] Department of geriatric medicine, Faculty of Medicine, Mansoura University, Egypt.
[c] Department of diabetes and endocrinology, Faculty of Medicine, Mansoura University, Egypt

Corresponding to: Mohamad Motawea. Department of diabetes and endocrinology, Faculty of Medicine, Mansoura University, Egypt

Email: drmotawe3@mans.edu.eg

Received: 29 August 2023

Accepted: 16 September 2023

Abstract

Background: Diabetic neuropathy usually leads to changes in foot structure and gait cycle pattern. Diabetic patients with elevated foot pressures get foot ulcers more than without. This work **aims** to study the impact of diabetic sensory neuropathy on plantar pressure changes which could help in predicting the site of future ulceration. ***Subjects and methods****:* A case control study including 88 participants; 73 diabetics subdivided into with and without sensory neuropathy and 15 age and sex matched healthy controls. Pressure time integral (PTI), and peak pressure (PP) were measured separately for each foot at different foot sites. Six steps of normal gait were done, and calculation was taken on the average. ***Results***. PP was significantly higher in neuropathic versus diabetic and control groups in the right foot at **toe1, *(P=0.008)***, **toe2, *(P=0.048)* and toe3, *(P=0.019),*** all other areas of the right foot apart from toes4, 5 although were higher in the neuropathic group versus diabetic group but statistically were not significant**.** In the left foot PP was significantly higher in neuropathic versus diabetic and control groups at **lateral-heel *(P=0.044)***, **midfoot *(P=0.037)***, and at **toe 1 *(P*=0.005*),*** all other areas of the left foot although were higher in the neuropathic group versus diabetic and control groups but statistically were not significant ***Conclusion.*** plantar pressure distribution was different in neuropathic patients in comparison to diabetic patients without neuropathy and controls which signifies the necessity of plantar pressure and neuropathy assessment in predicting the sites of future ulceration and guiding the management of care.

Keywords: Neuropathy, plantar pressure, pressure time integral, peak pressure, sensory neuropathy

Introduction

Peripheral neuropathy is damage of the peripheral nerves. The most common cause of neuropathy is diabetes, it's prevalence in patients with diabetes is approximately 30 - 50 % [(1)].

Diabetes mellitus is associated with many different degrees of neuropathy, ranging from a mild sensory disturbance to the debilitating pain and weakness [(2)]. Distal symmetric polyneuropathy is the most common type of diabetic neuropathy [(3)].

Diabetic polyneuropathy (DPN) can lead to structural foot changes and severe alterations in the gait cycle, which together can lead to impairment of the foot biomechanics with subsequent appearance of foot ulceration in areas subjected to excessive weight-bearing [**(4)**].

Boulton and his associates were the first group to study the relationship between high plantar pressures and foot ulceration [(5)].

It was reported that individuals with diabetes and high foot pressures have double the risk to develop a foot ulceration than those with lower foot pressures [(6)].

DPN is defined as "the presence of symptoms and/or signs of peripheral nerve dysfunction in people with diabetes after the exclusion of other causes". Several instruments for diagnosis of DPN have been developed and validated [(7)].

Several scoring systems have been used to assess clinical signs, and diagnosis of DPN have been developed and validated. Modified Neuropathy Disability Score (NDS) is one of these systems that is increasingly used and can be easily performed completely in the clinic in a couple of minutes using 4 parameters [**Vibration perception threshold** using 128- Hz tuning fork at the apex of big toe normal = can distinguish vibrating/non vibrating, (normal=0, abnormal=1), **Temperature perception on dorsum of the foot** using tuning fork with beaker of ice/warm water, (normal=0, abnormal=1), **Pinprick by** applying pin proximal to big toenail just enough to deform the skin, trial nail = sharp; blunt, normal=can distinguish between sharp/not sharp, (normal=0, abnormal=1), **Achilles reflex,** (present = 0, present with reinforcement = 1, absent = 2)]. The maximum deficit score that indicates complete loss of sensation to all sensory modalities and absent reflexes is ten [(8)].

This work aims to study the impact of diabetic sensory neuropathy on plantar pressure changes which could help in predicting the sites of future ulceration and guiding the management of care by alleviating these high-pressure areas by different offloading modalities.

Subjects and methods:

This study is a case-control study that includes 73 patients with type 2 diabetes mellitus **(cases)** recruited from diabetes outpatient clinics of Mansoura Specialized Medical Hospital from October 2022 to December 2022, in addition to 15 age and sex matched healthy controls **(control**

group). Diabetes was diagnosed according to the revised American Diabetes Association criteria ***(American Diabetes Association, 2020).*** The study was approved by the ethical committee of the faculty of the medicine. Informed written consent was obtained from each participant.

All participants were divided into three groups, **group (N)** (57 diabetic patients with diabetic peripheral sensory neuropathy (PSN)), (26 males and 31 females), with mean age of 53.91±5.53 years, **group (D)** (16 Diabetic patients without peripheral neuropathy), (8 males and 8 females), with mean age of 50.38± 7.56 years, **group (C)** (The control group) consists of 15 healthy subjects (8 males and 7 females) with a mean age of 50.93± 5.65 years. Patients included in the study were type 2 diabetic patients. They were treated with either insulin and/or oral antihyperglycemic drugs, diagnosis of peripheral diabetic sensory neuropathy was based on NDS, presence of leg pain was questioned with grading of its severity according to visual analogue pain scale. The exclusion criteria involved the presence of foot deformity, serum creatinine > 1.4 mg/dl in females and 1.5 mg/dl in males, liver cell failure, other causes of neuropathy apart from diabetes mellitus and patients with central nervous system disorders. NDS ≥ 6 was used for diagnosis of diabetic peripheral neuropathy [(9)]**.**

Planter pressure assessment

Planter pressure was recorded during walking barefoot using plantar software of the Mat Scan: Tekscan, Inc (USA), V 6.3, serial #25385. Pressure time integral (PTI), and peak pressure (PP) were measured separately for each foot at the following sites: total foot (TF), medial heel (MH), lateral heel (LH), midfoot (MF), metatarsal heads 1,2,3,4 and 5 in addition to toes 1,2,3 and 4,5. Six steps of normal gait were done, and calculation was taken on the average.

Statistical Analysis

The data of the study was analyzed by SPPS 22. Qualitative data was expressed as number and percentage and compared by chi-square test. The numerical data was expressed as mean and standard deviation (SD) and compared by one-way ANOVA test if more than two groups; significant results were followed by Post-hoc Turkey HSD tests, Student's t-test was used to compare between mean of two groups of numerical (parametric) data, and Kruskal Wallis test was used to compare between more than two groups of numerical (non-parametric) data followed by Mann-Whitney for multiple comparisons. The P value was considered significant if $p<0.05$.

Results:

The study included 57 diabetic patients with PSN, 16 diabetic patients without PSN and 15 age and sex matched control subjects. There was no statistically significant difference in the mean age of patients in group (**N)** (54±5.5 years) and group **(D)** or **(C)** (50.4±7.6 and 51±5.6 years, respectively) (P=0.053). Regarding the gender M/F (N/%) ratio, there was no statistically significant difference between the three groups: group (**N)** 26 (45.6%)/31 (54.4 %), group **(D)** 8(50%) / 8(50%) and group **(C)** 8 (53.3%)/ 7 (46.7%) (P=0.850), (Table 1).

Skin lesions show no significant difference among various groups ***(P=0.220)***; no skin lesions were found in 80.7 % (46 patients) of the **N** group versus 100% (16 patients) of the **D** group and 93.3% (14 subject) of the **C** group, while skin fissure was found in 5.3% (3 patients) of the **N** group and was absent in both **D** and **C** groups , callus was found in 1.8% (1 patients) of the **N** group, 6.7% (1 subjects) of the **C** groups and was absent in the **D** group , and fungal infections were found in 12.3% (7 patients) of the **N** group and was absent in both **D** and **C** groups (Table 1).

The NDS ≥6 is diagnostic for PSN. It was significantly higher in group (**N)** versus group (**D)** and group (**C)**; [8(6-10), 2(0-4) &0(0-0%) respectively] (**P<0.001).**

Vibration perception threshold score, temperature perception score, pin prick sensation score and Achilles reflex score were significantly higher in group (**N**) versus group (**D**) and group (**C**)**;** ***(P<0.001)*** (Table 2).

Pressure time integral (PTI) and peak pressure (PP) were measured separately by Teksan during walking and measurements of both feet were taken for all patients at the following sites: total foot (TF), medial heel (MH), lateral heel (LH), midfoot (MF), metatarsal heads 1,2,3,4 and 5 in addition to toes 1,2,3 and 4,5. Six steps of normal gait was done, and calculation was taken on the average. There was not statistically significantly difference in all PTI parameters between the three groups, (Table 3, 4).

Peak pressure (PP) was significantly higher in in group (**N**) versus group (**D**) and group (**C**) in the RT foot at **T1** [170(62-263), 114(31-218) & 168(91-192) KPa respectively] ***(P=0.008)***, also at **T2**; pp was significantly higher in group (**N**) versus group (**D**) and group (**C**) [103(33-157), 68(11-185) & 97(61-153) KPa respectively] ***(P=0.048)*** and at **T3**; pp was significantly higher in in group (**N**) versus group (**D**) and group (**C**) [89(22-148), 54(10-185) & 84(39-137) KPa respectively] ***(P=0.019),*** all other areas of the RT foot apart from T4, 5 although were higher in the in group (**N**) versus group (**D**) but statistically were not significant (Table 5). Peak pressure (PP) was significantly higher in group (**N**) versus group (**D**) and group (**C**)in the LT foot at **LH** [189(64 -246), 124(56 -260) & 164(78 -236) KPa respectively], ***(P=0.044)***, **MF** [131(41 -244), 91(38 -221) & 107(51 -172) KPa respectively], ***(P=0.037)***, and at **T1**[171(33-239), 103(21 -246)& 150(75 -213), KPa respectively], ***(P*=0.005*),*** all other areas of the LT foot although were higher in the neuropathic group versus diabetic group but statistically were not significant (Table 6).

Table (1): Demographic and clinical data

Data		Groups			P
		Neuropathic	**Diabetic**	**control**	
Age (years)	**Mean**	53.9	50.4	50.9	**0.05**
	±SD	5.54	7.56	5.65	**A**
Gender (N/%)	**Male**	26 (45.6%)	8(50%)	8 (53.3%)	**0.85**
	Female	31 (54.4%)	8(50%)	7 (46.7%)	**C**
BMI (kg/m2)	**Median**	32	36	32	**0.49**
	range	28-38	27.7-41	26-36	**B**
	No	17(29.8%)	7(43.8%)	15(100%)	
DM duration (years)	**Median**	14	4	0	**<0.001**
	Range	8.5-20	1.1-9.5	0-0	**B**
DM treatment	**SU.**	8 (14%)	4 (25 %)	0(0%)	
(N/%)	**Insulin**	11 (19.3%)	8 (50 %)	0(0%)	**<0.001**
	Insulin + metformin	31(54.4%)	0(0%)	0(0%)	**C**
	SU+ metformin	7 (12.3%)	4(25%)	4(25%)	
SMOKING	**NO**	49 (86%)	12 (75%)	11 (73.3%)	**0.174**
(N/%)	**Mild**	2 (3.5%)	0 (0%)	2 (13.3%)	**C**
	Moderate	4 (7%)	4 (25%)	2 (13.3%)	
	Sever	2 (3.5%)	0 (0%)	0 (0%)	
Diabetic retinopathy	**NO**	35 (61.4%)	15 (93.8%)	15 (100%)	**0.009**
(N/%)	**Background**	13 (22.8%)	1(6.2%)	0 (0%)	**C**
	Proliferative	9 (15.8%)	0 (0%)	0 (0%)	
Skin lesions	**No**	46(80.7%)	16(100%)	14(93.3%)	**0.220C**
(N/%)	**Fissure**	3(5.3%)	0(0%)	0(0%)	
	Callus	1(1.8%)	0(0%)	1(6.7%)	
	Fungal Infection	7(12.3%)	0(0%)	0(0%)	
	Ulcer	0(0%)	0(0%)	0(0%)	

P: probability, **SD**, standard deviation. **BMI**, Body mass index, **SU**, Sulphonyl urea, **Test used: A:** ANOVA test followed by post-hoc Tukey for multiple comparisons if statistically significant, **B:** Kruskal-Walli's test followed by Mann-Whitney for multiple comparisons if statistically significant, **C:** Qui-square test(X2).

Table (2): Neuropathy disability score of the three groups

Data		Groups			P
		Group (N)	Group (D)	Group (C)	
NDS: total score	**Median**	8	2	0	**<0.001**
	range	6-10	0-4	0-0	**B**
Vibration P. (RT)	**Median**	1	0	0	**<0.001**
	range	1-1	0-1	0-0	**B**
Vibration P. (LT)	**Median**	1	0	0	**<0.001**
	Range	1-1	0-1	0-0	**B**
Temperature P. (RT)	**Median**	1	0	0	**<0.001**
	Range	0-1	0-0	0-0	**B**
Temperature P. (LT)	**Median**	1	0	0	**<0.001**
	Range	0-1	0-0	0-0	**B**
Pin prick (RT)	**Median**	1	0	0	**<0.001**
	range	1-1	0-0	0-0	**B**
Pin prick (LT)	**Median**	1	0	0	**<0.001**
	Range	1-1	0-0	0-0	**B**
Achilles reflex (RT)	**Median**	2	0	0	**<0.001**
	range	1-2	0-0	0-0	**B**
Achilles reflex (LT)	**Median**	2	0	0	**<0.001**
	range	2-2	0-2	0-0	**B**

P: probability, **NDS:** neuropathy disability score, **RT:** right foot, **LT**: left foot**, Test used: B:** Kruskal-Walli's test followed by Mann-Whitney for multiple comparisons if statistically significant.

Table (3): pressure time integral (PTI) of right foot in the three groups

Data	Groups			P
	Neuropathic	**Diabetic**	**Control**	
PTI TF (RT) (KPa)*s	72.6 (31.10-114.70)	66.6 (27.3 -131.30)	64.2 (34.6-108.3)	**0.47**
PTI MH (RT)	69.3 (14-109.2)	55.4 (17.2-124.2)	50 (26.8-86.6)	**0.4**
PTI LH (RT)	74.5 (13.9-94.7)	58.8 (16-112)	49 (23.6-95)	**0.3**
PTI MF (RT)	54.8 (11-84)	37.6 (10-109.5)	39.6 (13.8-81)	**0.3**
PTI MT1 (RT)	44 (20.2 -114)	47.5 (16-110)	36.7 (12.4-82)	**0.3**
PTI MT2 (RT)	55.6 (26-131)	60.7 (17.3-132)	51.5 (18.2-99)	**0.54**
PTI MT3 (RT)	72 (36-136)	69 (16.5-136.5)	61.6 (29-106.7)	**0.6**
PTI MT4 (RT)	65.4 (25.7-122)	61.7 (16-133)	56.4 (24.3-108)	**0.57**
PTI MT5 (RT)	52 (15.7-105)	47 (12.9-104.6)	43 (13.5-95)	**0.58**
PTI T1 (RT)	48.5 (14.8-112)	47.3 (13-128)	51.8 (26.8-92.6)	**0.84**
PTI T2 (RT)	46 (12.3-69.5)	38.4 (8.7-86)	37.6 (18.2-69)	**0.85**
PTI T3 (RT)	38.3 (3-65)	27 (0.8-74)	32 (13-64)	**0.75**
PTI T4,5 (RT)	13 (3-43)	15 (0-56.2)	15.2 (0-46)	**0.7**

P: probability**, PTI**: pressure time integral, **TF**: total foot, **LH**: lateral heel, **MH**: medial heel, **MF**: midfoot, **MT**: metatarsal, **T**: toe, **RT**: right, **KPa*s:** kilopascal/second, Data is median (minimum – maximum). Test of significance is Kruskal-Wallis H-test followed by Mann-Whitney for multiple comparisons if statistically significant.

Table (4): Pressure time integral (PTI) of left foot in the three groups

Data	Groups			P
	Neuropathic	Diabetic	Control	
PTI TF (LT) (KPa*s)	69.4 (9 – 164.2)	84.2 (25.7 – 111.7)	61.8 (30.8 – 120.1)	0.48
PTI MH (LT)	63.2 (7.3 - 193)	91.6 (17.5 – 1083)	53.5 (19.9 – 106.4)	0.21
PTI LH (LT)	58.1 (8.4 – 194.8)	82.9 (16.2 – 110.1)	47.6 (19 – 100.5)	0.17
PTI MF (LT)	37.8 (9.4 – 107.4)	53.5 (8.1 – 88.1)	32.4 (19.4 – 66.6)	0.11
PTI MT1 (LT)	49 (3.3 – 107.2)	42.8 (13.3 – 92)	39.6 (16 – 59.3)	0.34
PTI MT2 (LT)	58.4 (18.1 – 155.4)	62.2 (12.7 – 110.6)	50 (25 – 107.3)	0.78
PTI MT3 (LT)	65.4 (17.5 – 166.1)	68.4 (15.2 – 110.7)	60 (32.7 – 138.5)	0.83
PTI MT4 (LT)	58 (16.9 – 167.6)	71.3 (14.8 – 112.4)	52.6 (25.7 – 114.8)	0.61
PTI MT5 (LT)	46.4 (14.6 – 125.8)	57.6 (11.6 – 104.8)	42 (19.7 – 76.2)	0.61
PTI T1 (LT)	46 (7 – 152)	62.7 (7.9 – 105.8)	41.8 (15.4 – 108.9)	0.63
PTI T2(LT)	35.9 (9.2 – 145.4)	43.3 (5.3 – 86)	35.5 (13 – 72.1)	0.81
PTI T3 (LT)	32.2 (1.2 – 116.9)	31.9 (2.4 – 73.9)	32.7 (8.7 – 87.4)	0.59
PTI T4,5 (LT)	16 (0.0 – 109.6)	13.2 (0.2 – 53.8)	19 (0.0 – 48.3)	0.87

P: probability**, PTI**: pressure time integral, **TF**: total foot, **LH**: lateral heel, **MH**: medial heel, **MF**: midfoot, **MT**: metatarsal, **T**: toe, **LT**: left, **KPa*s:** kilopascal/second, Data is median (minimum – maximum). Test of significance is Kruskal-Wallis H-test followed by Mann-Whitney for multiple comparisons if statistically significant.

Table (5): Peak pressure (PP) of right foot of the three groups

Data	Groups			P
	neuropathic	**diabetic**	**control**	
PP TF (RT) KPa	237.5 (99-315)	177 (28-31)	224 (124-275)	0.09
PP MH (RT)	175.5 (41-220)	113 (24.7-240)	161 (98-205)	0.09
PP LH (RT)	161.5 (46-200)	109 (29-210)	150 (81-204)	0.10
PP MF (RT)	111.5 (43-191)	84 (21-182)	89 (47-191)	0.07
PP MT1 (RT)	107.5 (63-236)	106 (12.8-257)	106 (37-243)	0.88
PP MT2 (RT)	153 (77-284)	109 (21.2-250)	158 (53-245)	0.29
PP MT3 (RT)	207.5 (85-313)	149 (13-292)	198 (86-254)	0.14
PP MT4 (RT)	182.5 (59-278)	138 (15.8-296)	182 (89-237)	0.18
PP MT5 (RT)	112.5 (31-208)	92 (3.5-257)	127 (45-212)	0.14
PP T1 (RT)	170 (62-263)	114 (31-218)	168 (91-192)	0.01
PP T2 (RT)	103 (33-157)	68 (11-185)	97 (61-153)	0.05
PP T3 (RT)	89 (22-148)	54 (10-185)	84 (39-137)	0.02
PP T4,5 (RT)	27 (12-105)	32 (0-158)	44 (0-99)	0.18

P: probability**, pp:** peak pressure, **TF**: total foot, **LH**: lateral heel, **MH**: medial heel, **MF**: midfoot, **MT**: Metatarsal, **T**: toe, **RT**: right, **KPa:** kilopascal, **Test used: B:** Kruskal-Willi's test followed by Mann-Whitney for multiple comparisons if statistically significant.

Table (6): Peak pressure of left foot in the three groups

Data	Groups			P
	Neuropathic	Diabetic	Control	
PP TF (LT) KPa	240(78 -296)	170(90 -315)	216(127 -314)	0.1
PP MH (LT)	202(58 -289)	125(62 -314)	179(81 -241)	0.56
PP LH (LT)	189(64 -246)	124(56 -260)	164(78 -236)	0.04
PP MF (LT)	131(41 -244)	91(38 -221)	107(51 -172)	0.04
PP MT1 (LT)	101(39 -224)	93(26 -226)	87(52 -177)	0.97
PP MT2 (LT)	140(42 -244)	116(48 -241)	145(71 -268)	0.26
PP MT3 (LT)	166.5(52 -265)	145(37 -284)	184(98 -312)	0.08
PP MT4 (LT)	164.5(44 -275)	124(31 -268)	162(72 -272)	0.1
PP MT5 (LT)	115(32 -250)	86(30 -238)	117(40 -205)	0.21
PP T1 (LT)	171(33-239)	103(21 -246)	150(75 -213)	0.01
PP T2 (LT)	97(24 -185)	72(25 -172)	93(36 -206)	0.15
PP T3 (LT)	70.5(9 -185)	61(11 -152)	74(29 -167)	0.63
PP T45 (LT)	35(7 -121)	32(0 -91)	45(0 -113)	0.2

P: probability**, pp:** peak pressure, **TF**: total foot, **LH**: lateral heel, **MH**: medial heel, **MF**: midfoot, **MT**: metatarsal, **T**: toe, **LT**: left. Data is median (minimum – maximum). Test of significance is Kruskal-Wallis H-test.

Discussion

There was no significant difference in age between the three groups ***(P=0.053)***. Although the age is a well-known risk factors for PDN in all studies [10, 11], we can't study its' effect in this work as we choose our patients in the age group between 40 and 65 and all groups are age matched.

In this work males represents **47.7%** of all participated subjects while females constituted **52.3%** and all groups are sex matched ***(P=0.850).*** Although female gender in some studies was associated with peripheral DPN [12, 13, 14] and male gender was associated with peripheral DPN in one study [14]**,** in this work all groups are sex matched so the gender effect can't be assessed.

NDS was significantly higher in group (**N**) versus group (**D**) and group (**C**) ***(P<0.001)***.

Planter pressure evaluation of our patients revealed significant elevation in peak pressure (PP) among group (**N**) versus group (**D**) and group (**C**) at T1, T2 &T3 in the RT foot and at LH, MF and T1 in the LT foot. However, Pressure time integral (PTI) measurement at all regions shows no significant difference among the three groups. Neuropathy is known to affect gait

cycle and consequently affect planter pressure distribution [15].

Boulton et al., (1983) examined patients with and without diabetes, and this diabetic group were subdivided to group with and without neuropathy to evaluate the relationships between neuropathy, foot pressures and ulceration. Their results showed that 51% of diabetic patients with peripheral neuropathy had abnormally high pressures below the metatarsal heads compared with 17% of diabetic patients without peripheral neuropathy and 7% of subjects without diabetes. So, foot pressure measurement may be useful for predicting the occurrence of foot ulceration and guiding the management of foot care because areas with high foot pressure susceptible to ulceration could be determined [5]. Another study by Abri et al., (2019) comparing peak plantar pressure in patients with different degrees of neuropathy and they found that the peak pressure mainly of the midfoot differ with the degree of the neuropathy [16].

In this study, plantar pressure distribution was different in neuropathic patients in comparison to diabetic patients without neuropathy and controls with statistically significant difference in few areas in both feet, this may be attributed to short diabetes duration, exclusion of patients with foot deformities including prominent metatarsal heads which are one of the main causes of diabetic foot ulcers underneath the metatarsal plantar heads [15]. Although, after these exclusions there is still high peak pressure in nearly all areas of patient with sensory neuropathy compared to other groups with statistically significant difference in only few areas.

Conclusions

Plantar pressure distribution was different in neuropathic patients in comparison to diabetic patients without neuropathy and controls which signifies the necessity of plantar pressure and neuropathy assessment in predicting the sites of future ulceration and guiding the management of care by alleviating these high-pressure areas by different offloading modalities.

Limitations of the study

1. It is single center study that need to be done on a large scale to confirm our results.
2. Add in the inclusion criteria foot deformities related to diabetic neuropathy and follow up all patients for future ulceration and plot the relationship between plantar pressure and ulceration sites

List of abbreviations

CA (contact area), **DPN** (diabetic polyneuropathy), **PSN** (peripheral sensory neuropathy), **LH** (lateral heel), MH (medial heel), **MF** (midfoot), MNSI (Michigan Neuropathy Screening Instrument), **NDS** (Neuropathy Disability Score), **PTI** (Pressure time integral), **PP** (peak pressure), TF (total foot).

References

1. **Callaghan C.,Cheng T.,Stables L.,Smith, L., &Feldman, L.(2012).** Diabetic neuropathy:

clinical manifestations and current treatments. *The Lancet Neurology*; 11:521-534. https://doi.org/10.1016/S1474-4422(12)70065-0

2. **Tracy, J. A. & Dyck, P. B. (2008).** The spectrum of diabetic neuropathies. Phys Med Rehabil Clin N Am, 19(1),1-26. https://doi.org/10.1016/j.pmr.2007.10.010
3. **Pasnoor, M., Dimachkie, M.M., Kluding, P. & Barohn, R. J. (2013).** Diabetic neuropathy part 1: overview and symmetric phenotypes. *Neurologic clinics*, 31 (2), 425-445. https://doi.org/10.1016/j.ncl.2013.02.004
4. **Luger, E., Nissan, M., Karpf, A., Steinberg, E., & Dekel, S. (2001).** Dynamic pressures on the diabetic foot. *FAI*, *22*(9), 715-719. https://doi.org/10.1177/107110070102200905
5. **Boulton, A. J., Hardisty, C. A., Betts, R. P., Franks, C. I., Worth, R. C., Ward, J. D., & Duckworth, T. (1983).** Dynamic foot pressure and other studies as diagnostic and management aids in diabetic neuropathy. *Diabetes care*, *6*(1), 26-33. https://doi.org/10.2337/diacare.6.1.26
6. **Lavery, L. A., Armstrong, D. G., Wunderlich, R. P., Tredwell, J., & Boulton, A. J. (2003).** Predictive value of foot pressure assessment as part of a population-based diabetes disease management program. *Diabetes care*, *26*(4), 1069-1073. https://doi.org/10.2337/diacare.26.4.1069
7. **Boulton, A. J., Vinik, A. I., Arezzo, J. C., Bril, V., Feldman, E. L., Freeman, R., & Ziegler, D. (2005).** Diabetic neuropathies a statement by the American Diabetes Association. *Diabetes care*, *28*(4), 956-962. https://doi.org/10.2337/diacare.28.4.956
8. **Abbott, C., Carrington, A., Ashe, H., Bath, S., Every, L., Griffiths, J., & Johnson, K. (2002).** The North-West Diabetes Foot Care Study: incidence of, and risk factors for, new diabetic foot ulceration in a community-based patient cohort. *Diabetic Medicine*, *19*(5), 377-384. https://doi.org/10.1046/j.1464-5491.2002.00698.x
9. **Boulton, A. J., Malik, R. A., Arezzo, J. C., & Sosenko, J. M. (2004).** Diabetic somatic neuropathies. *Diabetes care*, *27*(6), 1458-1486. https://doi.org/10.2337/diacare.27.6.1458
10. **Tesfaye, S., Chaturvedi, N., Eaton, S. E., Ward, J. D., Manes, C., Ionescu-Tirgoviste, C., & Fuller, J. H. (2005).** Vascular risk factors and diabetic neuropathy. *NEJM*, *352*(4), 341-350. DOI: 10.1056/NEJMoa032782
11. **Shaw JE, Zimmet PZ, Gries FA, Ziegler D.(2003).** Epidemiology of diabetic neuropathy. In: Gries FA, Cameron NE, Low PA,Ziegler D, editors. Textbook of diabetic neuropathy. Stuttgard:Thieme; p. 64–82. doi: 10.1016/j.ncl.2013.02.004
12. **Abbott, C. A., Malik, R. A., van Ross, E. R., Kulkarni, J., & Boulton, A. J. (2011).** Prevalence and characteristics of painful diabetic neuropathy in a large community-based diabetic population in the UK. *Diabetes care*, *34*(10), 2220-2224. https://doi.org/10.2337/dc11-1108
13. **Halawa, M. R., Karawagh, A., Zeidan, A., Mahmoud, A.-E.-D. H., Sakr, M., & Hegazy, A. (2010).** Prevalence of painful diabetic peripheral neuropathy among patients suffering from diabetes mellitus in Saudi Arabia. *Current medical research and opinion*, *26*(2), 337-343. https://doi.org/10.1185/03007990903471940
14. **Jambart, S., Ammache, Z., Haddad, F., Younes, A., Hassoun, A., Abdalla, K., & Youseif, E. (2011).** Prevalence of painful diabetic peripheral neuropathy among patients with diabetes mellitus in the Middle East region. *JIMR*, *39*(2), 366-377. https://doi.org/10.1177/147323001103900204
15. **Kilicoglu O.I., Demirel M., Aktas S.** New trends in the orthopaedic management of diabetic foot. *EFORT Open Rev*. 2018;3:269–277. Doi: 10.1302/2058-5241.3.170073.
16. **Abri, H., Aalaa, M., Sanjari, M., Amini, M. R., Mohajeri-Tehrani, M. R., & Larijani, B.** (2019). Plantar pressure distribution in diverse stages of diabetic neuropathy. *J Diabetes Metab Disord*, 18(1), 33-39. doi: 10.1007/s40200-019-00387-

To cite this article: Mayada S. Khalel, Ismail kandil, Mohamad Motawea. Diabetic Sensory Neuropathy and Plantar Pressure Changes. BMFJ 2023;40(2): 597-608.