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PLANTAR PRESSURE PATTERNS DURING GAIT OF DIFFERENT DEGREES OF DIABETIC NEUROPATHY SEVERITY CLASSIFIED BY A FUZZY EXPERT MODEL

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SUMMARY

Clinical diagnosis and classification of diabetic polyneuropathy (DP) have inherent uncertainties that compromise the definition of its onset and differentiation of severity stages. A fuzzy expert system could improve the precision of this process, since it takes those uncertainties into account and combines different assessment methods to reach the final decision. This could help the understanding of how plantar pressure alterations evolve throughout different severity degrees of the disease. The aim of this study was to evaluate the plantar pressure distribution (PEDAR-X system) in diabetic subjects in different stages of evolution of DP (absent DP, n=38; mild DP, n=20; moderate DP, n=47; severe DP, n=24) during gait. Plantar pressures were analyzed at rearfoot, midfoot, lateral and medial forefoot and hallux. Mild DP already displays an increase in peak pressure at the heel and lateral forefoot and higher pressure-time integral at midfoot, indicating overloads from rearfoot to lateral forefoot. This pattern continues to be present in moderate and severe degrees, but there is also an increase in peak pressure and pressure-time integral in medial forefoot and hallux, indicating higher loads in areas with greater incidence of plantar ulceration. These changes may be related to atrophy of intrinsic foot muscles, reduction of distal muscle activity and joint stiffness that are developed with the aggravation of DP. Therefore, therapeutic intervention should begin already in mild stages of DP to prevent further consequences of the disease.

INTRODUCTION

DP has been associated to plantar pressure alterations during gait for almost thirty years, however, little has been reported on how these pressure alterations progresses along with the worsening of the disease. The literature that reports plantar pressure distribution patterns in distinct diabetic groups uses diverse classification criteria which are not consistent among studies. A fuzzy expert system could improve the precision of this classification, since it takes into account uncertainties that are inherent to the process of diagnosis and combines different assessment methods to reach the final decision. The aim of this study was to evaluate the plantar pressure patterns during gait in diabetic patients with different severity degrees of evolution of DP.

METHODS

129 adults volunteers with diabetes mellitus were evaluated and classified into four groups by means of a fuzzy expert system (table 1): diabetic group without neuropathy (D, n=38), mild diabetic neuropathy (MiN, n=20), moderate diabetic neuropathy (MoN, n=47) and severe diabetic neuropathy (SN, n=24). The fuzzy expert system, based on Picon et al. [1], used vibratory perception (128Hz tuning fork), tactile sensitivity (10g Semmes-Weinstein monofilament), and symptoms assessment (based on *MNSI questionnaire*) as the system´s inputs, and the combination among them determined the the final "neuropathy degree score" by the center of area defuzzification process. This value was sorted into the disease classes with the following division, with x being the score value: (i) $x \leq 2.5$: absent neuropathy; (ii) $2.5 < x < 5.0$: mild neuropathy; (iii) $5.0 \leq x < 8.0$: moderate neuropathy; (iv) $x \geq 8.0$: severe neuropathy.

Table 1: Clinical and sociodemographic data of studied groups.

	D	MiN	MoN	SN
Males (%)[a]	52%	17%	53%	67%
Age (yrs)	56.5±7.0	56.4±6.2	58.8±4.9	58.5±5.1
Body mass (kg)	75.4±13.3	74.6±10.9	80.9±16.2	78.8±12.4
Height (m)	1.6±0.1 [1]	1.6±0.1 [2, 3]	1.7±0.1 [2]	1.7±0.1 [1, 3]
BMI (m/kg^2)	28.7±4.4	29.5±4.3	29.4±4.9	28.2±3.5
Glycemia (mg/dL)	147.2±59.9	172.2±77.9	186.2±91.6	189.8±91.6
Time of diabetes (yrs)	7.2±6.2 [4, 5]	9.0±7.7[6, 7]	13.7±7.7 [4, 6]	13.0±7.1 [5, 7]

Numbers from 1 to 7 represent significant different groups between them (p<0.05)

Groups did not differ on age, weight, body mass index and glycemia, but the time of diabetes mellitus was longer for the ones with neuropathy, which was already expected.

The contact area, peak pressure and pressure-time integral were assessed over the rearfoot, midfoot, lateral and medial forefoot, and hallux using the Pedar-X system (Novel, Munich, Germany) with a sampling rate of 100Hz. Subjects walked at a self-selected cadence in a 10 meter walkway, with the insoles inside anti-skid socks.

All the variables followed a non-normal distribution, and were compared among groups by Kruskal-Wallis test and Mann-Whitney as post-hoc test. The level of statistical significance was set at $p<0.05$

RESULTS AND DISCUSSION

The overall results showed increasingly higher loads with the worsening of the disease severity. MiN group presented an increase in peak pressure at the heel and lateral forefoot and higher pressure-time integral at midfoot when compared to D group (Table 2), indicating overloads in the areas that first receives the body weight and begin the process of foot rollover.

This pattern continues to be present in moderate and severe degrees, with even higher values of peak pressure at lateral forefoot and pressure-time integral in rearfoot. Furthermore, there is also an increase in both variables over the medial forefoot and hallux (Table 2), indicating higher loads in areas with greater incidence of plantar ulceration [2] but especially in more advanced stages of the disease.

The contact area at the forefoot was significantly larger for the neuropathic groups, with medial forefoot having a greater contact in all groups with neural impairment and lateral forefoot contact being higher in MoN and SN groups (Table 2). This might indicate a tendency of higher weight shifting to the forefoot area even at mild degrees of DP, although this variable does not directly measure the magnitude of plantar loads.

These alterations in plantar pressure patterns may be associated with atrophy of the intrinsic foot muscles [3], stiffness of foot joints [4] and reduction of distal muscle activity [5] with the aggravation of DN.

The use a fuzzy system for the classification of different severity degree of disease seems to have been successful at better defining how plantar pressure distribution changes along with the state of DP. It may also be useful to compare these data with a healthy control group, so it would clarify if there is an altered pattern of load distribution that may be caused by diabetes mellitus itself, since there is evidence of higher plantar pressures in diabetic patients during gait [6].

CONCLUSIONS

The fuzzy expert system was successful at separating the stages of DP, allowing the identification of a progression of changes in plantar pressure along with the worsening of the disease. Diabetic patients with mild degrees of DP start to present higher loads in rearfoot, midfoot and lateral forefoot, and this pattern progressed with increasing loads over the whole forefoot and hallux, areas that are more prone to plantar ulceration.

The identification of higher plantar pressures in subclinical stages of DP may allow better therapeutic interventions to prevent other consequences of DP.

REFERENCES

1. Picon AP, et al., *Clinics.* **67**(2):151-6, 2012.
2. Bowling FL, et al., Curr Diabetes Rev. 7(3):159-63, 2011
3. Bus SA, et al., Diabetes Care. 25:1444-50, 2002
4. Giacomozzi C, et al., BMC musculoskelet Disord. 9:99, 2008
5. Kwon OY, et al., Gait Posture. 18(1):105-13, 2003
   Ko M, et al., *Physiother Res Int.* **17**(1):29-35, 2011

Table 2: Mean and standard deviation of peak pressure, pressure-time integral and contact area of each plantar area and studied group.

		Absent (n=38)	Mild (n=20)	Moderate (n=47)	Severe (n= 24)	p[1]
Peak pressure (kPa)	**Rearfoot**	279.5 ± 63.4*	267.7 ± 62.1*	289.8 ± 68.0	297.1 ± 63.1	<0.001
	Midfoot	116.6 ± 38.3	120.1 ± 46.9	115.0 ± 42.8	118.5 ± 40.5	0.343
	Lateral forefoot	269.3 ± 64.7*	255.8 ± 69.0*	313.2 ± 84.5*	281.9 ± 75.6*	<0.001
	Medial forefoot	287.1 ± 70.2[ab]	282.9 ± 66.0[cd]	330.0 ± 100.8[ac]	321.1 ± 92.9[bd]	<0.001
	Hallux	205.2 83.8[a]	207.1 ± 85.2[b]	224.9 ± 93.9[ab]	212.0 ± 107.0	0.001
Contact area (cm^2)	**Rearfoot**	30.6 ± 3.1	30.8 ± 3.7	31.1 ± 3.6	32.1 ± 3.9*	<0.001
	Midfoot	23.3 ± 6.4*	25.9 ± 7.6	25.8 ± 7.3	24.7 ± 7.0	<0.001
	Lateral forefoot	19.9 2.0	19.8 ± 2.8	20.7 ± 2.3*	21.4 ± 2.1*	<0.001
	Medial forefoot	22.3 ± 2.6*	23.1 ± 2.9	23.2 ± 3.1	23.7 ± 2.9	<0.001
	Hallux	8.4 ± 1.4	8.2 ±1.8	8.3 ±1.3	8.3 ± 1.5	0.561
Pressure-time integral (kPa.s)	**Rearfoot**	67.9 ±15.4	68.6 ±13.2	79.2 ± 21.1*	73.5 ± 18.5*	<0.001
	Midfoot	37.9 ± 13.7[a]	41.3. 16.2[ab]	39.6 ± 15.4	39.9 ± 13.7[b]	0.030
	Lateral forefoot	77.2 ± 18.1	78.6 ±24.2	91.3 ± 22.6	86.3 ± 23.2	<0.001
	Medial forefoot	79.2 ± 18.6[ab]	83.7 ±21.4[cd]	93.3 ± 26.0[ac]	94.9 ± 29.0[bd]	<0.001
	Hallux	44.4 ± 20.4[a]	45.1 ± 22.4	48.9 ± 24.2[a]	45.7 ± 24.0	0.075

[1] Kruskal-Wallis test followed by Mann-Whitney post hoc test. [a; b; c; d; e] represents different values between them; * represents statistically significant differences between groups ($p<0.05$).