Changes in gait parameters and sensory-motor deficit associated with peripheral diabetic neuropathy

Alterações dos parâmetros da marcha e déficit sensório-motor associado à neuropatia diabética periférica

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ABSTRACT

Peripheral nervous system impairment, with sensory and motor loss, as observed in diabetic neuropathy, can induce serious effects on balance control and gait in this population. **Objective:** To evaluate the performance of the gait and the sensory-motor changes, stemming from peripheral diabetic neuropathy (PDN). **Method:** Twenty-four individuals with PDN participated along with twenty-eight healthy individuals with no glycemic alterations indicative of diabetes. Participants were first subjected to clinical evaluations to confirm the clinical diagnosis of diabetic neuropathy by testing the tactile sensitivity of the soles of the feet with a monofilament test. Subsequently, ankle angle variations in static posture and during the gait were investigated through kinematics. The ankle muscle strength was investigated using a digital dynamometer. **Results:** The diabetic neuropathy group showed longer duration in double support and full support periods of gait than the control group, confirming greater difficulty in dynamic balance for these individuals. The group with neuropathy demonstrated reduced muscle strength, as much in the dorsiflexors as in the plantar flexors of the ankle. **Conclusion:** The sensory-motor losses stemming from PDN may cause impairment in gait performance, with consequent loss of balance.

Keywords: Gait, Muscle Strength, Postural Balance, Diabetic Neuropathies

RESUMO

Quando há dano no sistema nervoso periférico, com prejuízos sensoriais e motores, como observado em neuropatas diabéticos, podem ocorrer graves repercussões sobre o equilíbrio e a locomoção nesta população. **Objetivo:** Avaliar o desempenho da marcha e alterações sensório-motoras, decorrentes da neuropatia diabética periférica. **Método:** Participaram 24 indivíduos neuropatas diabéticos e 28 indivíduos saudáveis sem alterações glicêmicas indicativas de diabete. Os participantes foram submetidos inicialmente a avaliações clínicas para confirmação de diagnóstico de neuropatia diabética por meio de teste de sensibilidade tátil da sola dos pés com monofilamentos. Posteriormente, foram submetidos à avaliação da variação angular do tornozelo, em condição estática e durante a marcha, por meio de cinemetria. A força muscular do tornozelo foi investigada por meio de dinamometria digital. **Resultados:** Foi demonstrado maior duração nos períodos de duplo apoio e apoio total da marcha em indivíduos com neuropatia diabética quando comparados com o grupo controle, confirmando uma maior dificuldade no equilíbrio dinâmico destes indivíduos. Para o grupo experimental de indivíduos neuropatas foi evidenciado redução da força muscular, tanto para os músculos dorsiflexores, quanto para os plantiflexores de tornozelo. **Conclusão:** As perdas sensório-motoras decorrentes da NDP podem implicar em prejuízo no desempenho da marcha, com consequente perda de equilíbrio.

Palavras-chave: Marcha, Força Muscular, Equilíbrio Postural, Neuropatias Diabéticas

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INTRODUCTION

Peripheral diabetic neuropathy (PDN) is the most common complication of *diabetes mellitus* (DM), causing sensory-motor impairment depending on the severity of the pathology.[1,2] The manifestations are more evident in the lower limbs, with tissue and structural damage to the feet,[1] which diminishes the sensory information necessary for proper motor control.[3,4] When there is damage to the peripheral nervous system, a significant loss of muscle strength,[3,5] restricted joint mobility,[6] reduction of tactile sensitivity as well as proprioceptive loss may be evident, which can lead to losses in the strategies necessary for maintaining gait stability.[7-10]

Studies have been investigating the postural instability in neuropathic diabetic individuals, especially in stationary posture[11,12] when there are important losses of peripheral somatosensory information.[13] However, Nardone *et al.*[14] pointed out the importance of postural control in the dynamic condition, and that maintaining the standing posture by itself is not an evidence of possible alterations of this system in the neuropathic diabetes.

The execution of more elaborate tasks that demand greater postural control is fundamental for better comprehension of the interaction of the sensory-motor system.[15] Furthermore, on an unstable support surface or when there is locomotion, information from the vestibular and visual systems is crucial to maintaining stability, considering that postural control and locomotion are multisensory processes.[11,16] Although some authors have demonstrated disturbances in the postural control system under various conditions, few studies have emphasized its behavior under dynamic conditions by means of adaptations in the gait parameters coming from the sensory-motor damages provoked by PDN.[13] Identifying the main triggering factors of imbalance in diabetic neuropathies makes it possible to prevent the complications inherent to PDN.

OBJECTIVE

The objective of the present study was to investigate static stability, gait parameters (dynamic balance), alterations in the tactile sensitivity of the feet, and the diminution of isometric ankle strength in diabetic neuropathic individuals.

METHOD

Design of the study

This was an observational cross-sectional study developed in the Laboratory of Clinical Studies on Physiotherapy (LECFisio) of the College of Sciences and Technology, Paulista State University - (FCT/UNESP). The research was developed under the approval of the local ethics committee (Protocol nº 21/2009) and all the participants, in agreement with the objectives and procedures of the study, signed the "Terms of Free and Informed Consent" before any data was collected.

Sample and selection criteria

This study involved 52 participants of both genders divided into two groups: a control group (CO), composed of healthy older people with no DM (n = 28); and a group of diabetic neuropaths (PDN), composed of people with confirmed medical diagnoses of *diabetes mellitus* n = 24. The groups were paired by age.

The postprandial glucose test was made for both groups-as a safety measure for the PDN group, and as an exclusion from the DM diagnosis for the control group. The Michigan Neuropathy Screening Instrument (MNSI) (Michigan Diabetes Research and Training Center, 2008) was applied for confirmation of the PDN diagnosis. Individuals were included if their score was equal to or greater than 8 on the MNSI.[17] All the participants included in the PDN group had confirmed medical diagnoses of DM. Individuals were excluded from the study if they had osteoarticular deformities, plantar ulcers, total or partial amputation of the feet, walked with assistive devices, acute neuritis (with or without the use of medication), diagnosis of another neurological illness that would affect the normal gait, important and uncorrected visual deficit, body mass index (BMI) greater than 40 kg/m^2, and comprehension disabilities that would hamper the tests.

Evaluations and equipment

The participants were submitted to an initial postprandial glucose test and instructed to fill in a questionnaire on peripheral diabetic neuropathy (MNSI) for classification into the groups.

A Semmes-Weinstein tactile sensitivity evaluation (SORRI Bauru®, Brazil) was then done using an assortment of nylon monofilament threads. Tactile sensitivity of the feet was defined by the pressure of the finest monofilament sensed in each tested area,

each of which refer to the dermatome of the fibular and posterior tibial nerves common to both feet.[18]

Next, a measurement of isometric strength was taken for the ankle dorsiflexors and plantar flexors using a digital dynamometer (model DD-300 Instrutherm, São Paulo, Brazil); the instrument was coupled to a platform designed to assess the isometric strength of the ankle.[19]

To evaluate the balance under static conditions, the anteroposterior sway of the ankle was analyzed by measuring the angular variations with a kinematic system.[20] Two cameras were used for this, with a sampling rate of 60 Hz and with reflective markers affixed at pre-established anatomical points.

Finally, the balance under dynamic conditions was evaluated using a gait analysis platform (FootWalk Pro®), measuring the duration of the periods of simple support, double support (initial and final) and total support.[21]

Procedures

To evaluate the muscle strength of the participants' ankles, the lower limbs were properly positioned and stabilized with reference to the platform according to the muscle group being tested. Three maximum isometric contractions were made for each movement of dorsiflexion and plantar flexion of both limbs, dominant and non-dominant.

In evaluating static balance, reflective markers were first affixed at the greater trochanter of the femur, the joint line of the knee, the head of the fifth metatarsal, the lateral malleolus, and the head of the fibula. Participants were instructed to remain in an orthostatic position, with feet parallel and shoulder-width apart, arms at their sides, looking straight ahead (2 meters away), and remain as static as possible for 30 seconds. Images of each limb were recorded for 30 seconds.

Lastly, to evaluate the time-based parameters of the gait preceding the recording of data, each participant was instructed to walk on a runway (8.0 meters) at a comfortable pace of their choice until they were accustomed to the test area, and then they would begin collecting data, within the useful range of the equipment (approximately 2.0 meters).

Processing the data

The muscle strength was calculated by the average of three attempts at each movement with each limb, dominant and non-dominant, seeking to improve the precision of the results.

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To analyze the kinematic data, the images were transferred and processed by software from the Ariel Performance Analysis System (APAS, version 1.4) using a fourth-order Butterworth low-pass filter with a 5Hz cutoff. The average sway amplitudes were obtained by calculating the standard deviation of the ankle's angular anteroposterior movement of each attempt, after removing the average. Sway was given in degrees and corresponds to the variance of the angles, where smaller angles indicate less sway, which means better performance of the postural control system.

To analyze the gait parameters (periods of simple support, double support, and total support), three complete cycles of gait were recorded and the data analyzed by the FootWork Pro software (version 3.2.0.1).

Statistical analysis

Descriptive statistics were used to characterize the samples (average and standard deviation) to compare independent samples. Tactile sensitivity was compared between groups (CO and PDN) using the Mann-Whitney test, considering that the presuppositions of normality were not met and the dependent variable was the number of points not sensitive to the pressure of monofilaments greater than 10g for the feet, dominant and non-dominant. Variance tests (ANOVA) were used for the other variables in the study, as specified in the results.

The significance level was kept at 5% for all the variables analyzed and the program used for statistical treatment was the SPSS (Statistical Package for Social Sciences, 17.0 version).

RESULTS

Characterization of the sample (Table 1) shows a significant difference for the body mass index (BMI) and the glucose level between the CO and PDN groups.

To analyze the angular variations of the ankle in the anteroposterior direction (Table 2), a two-way variance analysis (ANOVA) was done: 2 (groups: CO and PDN) x 2 (leg: dominant and non-dominant) with repeated measurements for the second factor. The results showed that there was no significant main effect by group, $F_{(2.49)} = 2.64$, $p = 0.082$ and leg $F_{(2.52)} = 2.66$, $p = 0.084$, with no interaction effect.

A two-way ANOVA test was used to analyze dynamic balance: 2 (group: CO and PDN) x 3 (gait phases: duration of the simple support, double support, and total support

Table 1. Characterization of the sample by the average (standard deviation) of the control (CO) and the neuropathic (PDN) groups for the variables of age (years), body mass index (BMI) (kg/m²), and postprandial glucose level (mg/dl)

Variables	CO	NDP	p
Age	64.21 (6.26)	61.88 (8.11)	0.246
BMI	26.03 (3.72)	29.06 (5.25)	< 0.05*
Postprandial glucose	112.75 (12.88)	172.5 (68.01)	< 0.001**

* $p < 0.05$ (significant difference) and ** $p < 0.001$ (extremely significant difference)

Table 2. Angular variation of the ankle joint (in degrees) on average (standard deviation) of the dominant (D) and the non-dominant (ND) lower limb in the static position, referring to the control (CO) and neuropathic (PDN) groups

Variables	CO	NDP	p
Angular variation of D	0.26 (0.08)	0.31 (0.12)	$p > 0.05$
Angular variation of ND	0.20 (0.07)	0.30 (0.22)	$p > 0.05$

* $p < 0.05$ (significant difference)

periods). The results revealed a significant difference for the main factor, that is, group, $F_{(3.48)} = 3.127$, $p < 0.05$. A difference was demonstrated in the duration of the double support $F_{(1.50)} = 4.708$, $p < 0.05$ and the total support $F_{(1.50)} = 6.416$, $p < 0.05$ (Table 3), with no significant interaction.

Figure 1 presents the average values and standard deviations of the variables related to isometric ankle strength - as much for dorsiflexion as for plantar flexion. To analyze the muscle strength of the ankle, a two-way ANOVA test was done: 2 (group: CO and PDN) x 2 (leg: dominant and non-dominant), with repeated measurements for the second factor. The results indicated a significant main effect for group, $F_{(2.47)} = 13.635$, $p < 0.001$. The ANOVA test revealed a significant difference between the control group and the neuropathic one, as lesser values of muscle strength were found for the PDN group for ankle dorsiflexion $F_{(1.48)} = 14.955$, $p < 0.001$ and plantar flexion $F_{(1.48)} = 25.501$, $p < 0.001$.

DISCUSSION

The purpose of the present study was to investigate static stability, the parameters of gait, the possible alterations in tactile sensitivity of the feet, and the lessening of isometric strength in the ankles of those individuals with diabetic neuropathy. The results demonstrated compromised stability in locomotion with longer periods of double support and total support. These findings may be related to the loss of tactile sensitivity and diminished isometric strength in the ankle-alterations evidenced in the PDN group.

With the progression of DM, followed by compromised sensitivity, damage is seen in the distal motor innervation.[11] The results of this study showed a reduction in muscle strength in individuals in the PDN group, in the dorsiflexor as well as the plantar flexor muscles of the ankle, which can lead to alterations in the gait parameters, which would corroborate the findings of Allet *et al.*[7] and Menz *et al.*[8]

Nonetheless, the reduced ankle strength had no repercussions on the ankle's sway angle when comparing the PDN and CO groups. These findings contradict the results of previous studies that showed the need to adopt suitable ankle strategies, associated with the swaying in the anteroposterior plane to maintain static posture.[11,18]

One possible explanation for the differing results is that the sensory alterations combined with the biomechanical restrictions of movement, such as diminished perception of movement and deficits in the walking direction, can by themselves lead to compromised postural stability.[19] Other studies also demonstrate that alterations in some gait parameters are directly linked to sensory deficit among neuropathic diabetics, just as shown in the present study.[3,4,21]

In another study neuropathic patients free of other infirmities, such as in the present study, showed alterations in their gait style, probably due to deficient motor innervation of the muscles associated with the development of the step, especially the dorsal and plantar flexors of the feet.[20,22] Sensory losses can jeopardize the proprioceptive mechanisms of plantar overload and increasingly compromise, among other factors, the

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Table 3. Space-time variables of the gait in terms of averages (standard deviations) of the control group (CO) and the neuropathic group (PDN) for the variables of double support (ms), total support (ms), and simple support (ms) during dynamic evaluation

Variables	CO	PDN	p
Double support period	282.13 (61.93)	320.35 (64.93)	$p < 0.05$
Total support period	698.57 (90.17)	769.16 (110.8)	$p < 0.05$
Simple support period	416.44 (72.88)	448.81 (110.05)	$p > 0.05$

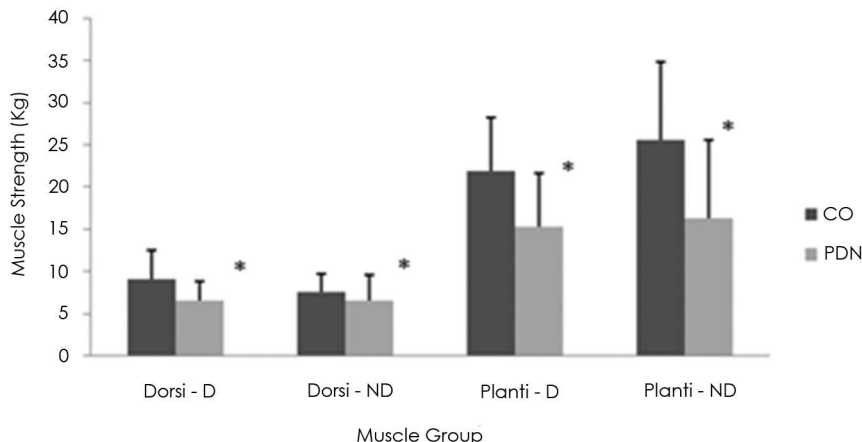* $p < 0.05$ (significant difference)

Figure 1. Average values and standard deviation for ankle strength (Kg) for the dorsiflexor (Dorsi) and plantar flexor (Planti) muscles for the dominant (D) and non-dominant (ND) hemibody, and between the control group (CO) and the diabetic neuropathic group (PDN)

gait parameters.[23] Cutaneous plantar sensory feedback is integrated at all levels into the central nervous system during motor neural control of the gait and posture via transcortical passages and mediated by the spinal oligosynaptic pathway.[24]

When the participants were submitted to evaluation of their gait, being that this is a more complex activity that static balance, the results revealed a compromised dynamic equilibrium, with alterations in the temporal organization parameters of the gait for the PDN group. These alterations were shown by a longer duration in the double support and total support periods, linked to damage to the sensory-motor system, as detected by the MNSI questionnaire. The findings of the present study corroborate those of Richardson et al.[25] in which diabetic individuals oscillated more than asymptomatic individuals during more elaborate activities.

In the study by Sacco et al.[26] with PDN sufferers, a longer period of double support was found in their gait, suggesting this was the result of musculoskeletal compensation mechanisms seeking to improve balance during gait.

Hence the gait compensations shown in the PDN group may be linked to a postural control instability related to the degree of impairment of the sensory-motor system and to the degree of difficulty in executing the task.[15,18]

Studies must be made in the future with this population in different situations and levels of complexity, which make greater demands on the musculoskeletal system. It is also suggested that new studies relate the findings of the present study to evaluations of the whole sensory system involved in the process of postural control.

CONCLUSION

The methodologies and procedures used in the present study have shown themselves to be effective in identifying the complications inherent to peripheral diabetic neuropathy. Sensory deficits combined with the ankle muscle weakness stemming from PDN jeopardize the gait and therefore have repercussions on dynamic stability and can create serious complications for the diabetic population.

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