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original article

Gait stability in diabetic peripheral neuropathy

Estabilidade da marcha na neuropatia diabética periférica

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Abstract – The aim of this study was to evaluate gait stability in diabetic patients with peripheral neuropathy in three conditions: habitual walking with eyes open, walking with eyes closed, and walking with eyes open and narrow base of support. The study included 41 subjects, 18 with neuropathy (NG) and 23 controls. Gait stability was evaluated on a baropodometer using the Footwalk Pro software. The following data were obtained: gait speed and percentage of time spent in double stance and single stance. Significant differences were observed between groups in all three conditions for gait speed and single stance time, which were reduced in NG ($p<0.05$), and for double stance time, which was increased in NG ($p<0.05$). For gait speed, double stance time and single stance time, the eyes open condition differed from the eyes closed ($p<0.001$) and narrow base of support ($p<0.001$) conditions. In the three conditions studied, patients of NG presented a deficit in gait stability and this performance was even more compromised in the two conditions that required greater postural control. These gait changes resulting from the complexity imposed by the different conditions suggest the inclusion of these conditions in the evaluation and treatment of this population.

Key words: Balance; Diabetic neuropathies; Gait; Physiotherapy.

Resumo – *O objetivo do estudo foi verificar a estabilidade da marcha em diabéticos com neuropatia periférica, em três situações: marcha habitual com os olhos abertos; marcha com os olhos fechados e marcha com olhos abertos e diminuição da base de sustentação. Participaram do estudo 41 indivíduos, sendo 18 do grupo neuropata (GN) e 23 do grupo controle (GC). A avaliação da estabilidade foi realizada por meio de um baropodômetro associado ao software Footwalk Pro. Os dados obtidos foram: velocidade da marcha e porcentagens de tempo de duplo apoio e de apoio simples. Foram encontradas diferenças significantes nas três situações entre os grupos para a velocidade e tempo de apoio simples, com diminuição para o GN ($p<0,05$), e tempo de duplo apoio, com aumento para o GN ($p<0,05$) em todas as condições. Para os dados de velocidade, tempo de duplo apoio e tempo de apoio simples, a condição de olho aberto foi diferente da de olho fechado ($p=0,001$) e da condição com diminuição da base de sustentação ($p=0,001$). Foi possível observar que nas três situações avaliadas, o GN apresentou déficit na estabilidade do ato de locomoção e tal desempenho foi ainda mais comprometido nas duas situações que exigiam mais do controle postural. Tais modificações da marcha, decorrentes da complexidade imposta pelas diferentes condições, sugerem a inserção destas na avaliação e no tratamento dessa população.*

Palavras-chave: *Equilíbrio postural; Fisioterapia; Marcha; Neuropatias diabéticas.*

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INTRODUCTION

The number of people with diabetes has increased as a result of factors such as population growth and aging, urbanization, obesity, and physical inactivity[1]. In Brazil, the number of people with diabetes is estimated to increase from 7,633,000 in 2010 to 12,708,000 in 2030, with Brazil becoming the country with the fifth largest population of diabetics in the world[2].

One of the complications caused by diabetes mellitus is diabetic peripheral neuropathy (DPN)[3], a condition characterized by sensory[4] and motor[5] alterations that can culminate in gait impairment[6].

During walking, patients with a certain disease may develop changes in neuromotor control that can impair the maintenance of gait stability[7].

The sensory component, particularly the proprioceptive system[7], is important for the maintenance of gait stability. This component conducts afferents to the central nervous system so that this system, together with other information for postural control, can make the necessary adjustments to maintain gait stability[8]. These adjustments also depend on visual and vestibular information, which permits to obtain information from the body and environment and relationship between these two[9].

In this respect, gait performance in diabetic neuropathic patients has been a matter of concern and studies have evaluated different variables such as speed[10], variation in gait cycle time[10], step time variability[11], and double and single stance time[12].

In addition, falls are common among diabetic neuropathic patients and generally occur during walking[13]. It is therefore important to study gait characteristics and stability under different conditions.

Few studies have investigated gait behavior during more complex activities, such as walking on irregular surfaces, in an attempt to detect clinically relevant deficiencies[11,14-16]. However, there are still gaps that involve visual or base of support variations, demonstrating greater requirement of the neuromuscular control system, particularly the proprioceptive system.

It is therefore necessary to evaluate gait stability in patients with neuropathy in different conditions; for example, walking with the eyes closed in order to determine the capacity of these individuals to compensate the absence of vision through more effective participation of the proprioceptive system, and a narrow base of support which requires greater neuromuscular control.

The objective of the present study was to evaluate gait stability in subjects with DPN in three different conditions: habitual walking with eyes open, walking with eyes closed, and walking with eyes open and narrow base of support.

METHODOLOGICAL PROCEDURES

A cross-sectional observational study was conducted at the Laboratory of Clinical Studies in Physiotherapy (Laboratório de Estudos Clínicos em Fisioterapia - LECFisio), School of Science and Technology, Paulista State

University (Faculdade de Ciências e Tecnologia da Universidade Estadual Paulista - FCT/UNESP), Presidente Prudente. The study was approved by the local Ethics Committee (Protocol No. 30/2010). The participants received detailed information about the procedures and objectives of the study and agreed to participate by signing a free informed consent form.

Sample

Forty-one subjects of both genders were divided into two groups: neuropathy group consisting of patients with type 2 diabetes mellitus and DPN (n=18), and a control group consisting of healthy non-diabetic subjects (n=23). Patients of the neuropathy group were recruited from the University Extension Project "Diabetic Foot Program" (Projeto de Extensão Universitária "Programa Pé Diabético") of FCT/UNESP, Presidente Prudente.

Procedures

Anthropometric data (body weight, height, and body mass index) were collected from all participants. Postprandial blood glucose was measured to confirm the diagnosis of diabetes in the neuropathy group and to exclude possible asymptomatic diabetic patients in the control group.

The diagnosis of DPN was made by somatosensory evaluation using Semmes-Weinstein monofilaments (SorriBauru®, Bauru, Brazil). The monofilaments were applied to the plantar and dorsal surfaces of the feet, which correspond to the sensitive dermatomes of the anterior tibial and common fibular nerves, bilaterally. The test was performed with the subject in dorsal decubitus and wearing a blindfold. The examiner exerted pressure of the monofilament on the skin until it bended, permitting standardization of the pressure exerted. The subject was asked to always report when he/she felt the touch. The test is defined as positive in the presence of insensitivity to the 10-g monofilament[17].

The Michigan Neuropathy Screening Instrument was used for confirmation of the diagnosis of DPN. The instrument consists of a questionnaire and physical assessment of the feet. The score ranges from 0 to 23, with a score ≥ 8 indicating the presence of neuropathy[18].

Criteria for exclusion from the two groups were osteoarticular deformities; plantar ulcers; amputation of regions of the foot; assisted walking; claudication; neurological disease of central origin or other peripheral diseases; inability to understand the tests; uncorrected visual impairment, and presence of some symptom detected by a dizziness questionnaire.

Evaluation of gait stability

Gait stability was analyzed with a baropodometer (FootWalk Pro, AM CUBE, France; sampling rate of 200 Hz) consisting of a 2-m pressure platform and a 6-m walkway (total of 8 m), which permits gait acceleration and deceleration in the initial and final 3 m. The data were analyzed using the Footwork Pro software, version 3.2.0.1 (IST Informatique - Intelligence Service et Tecnique, France).

The subjects walked on the walkway at a comfortable and self-selected speed in three conditions: habitual walking with eyes open (EO); walking with eyes closed (EC), and walking with eyes open and narrow base of support (NB). For assessment of the EC condition, the subjects walked only in the working area of the baropodometer and were asked to close the eyes, walk the 2-m distance, open the eyes, turn, and walk back the same distance again with the eyes closed. For evaluation of the NB condition, the subjects also walked only in the working area of the baropodometer within two parallel lines marked on the surface of the walkway separated at a distance of 21 cm. Thus, the maximum width of the base of support was reduced to this value.

For all conditions, the subjects walked once before the recording was started: in the first condition, to minimize alterations due to the lack of adaptation to the equipment, and in the second and third conditions so that the subjects would understand the test. Six gait cycles were recorded automatically by the platform for each condition.

The following variables were calculated for the two lower limbs: gait speed, double stance time and single stance time corresponding to three gait cycles.

Double stance and single stance

The stance time variables (in milliseconds) were extracted from the graph generated by the software, separately for the right and left foot (Figure 1).

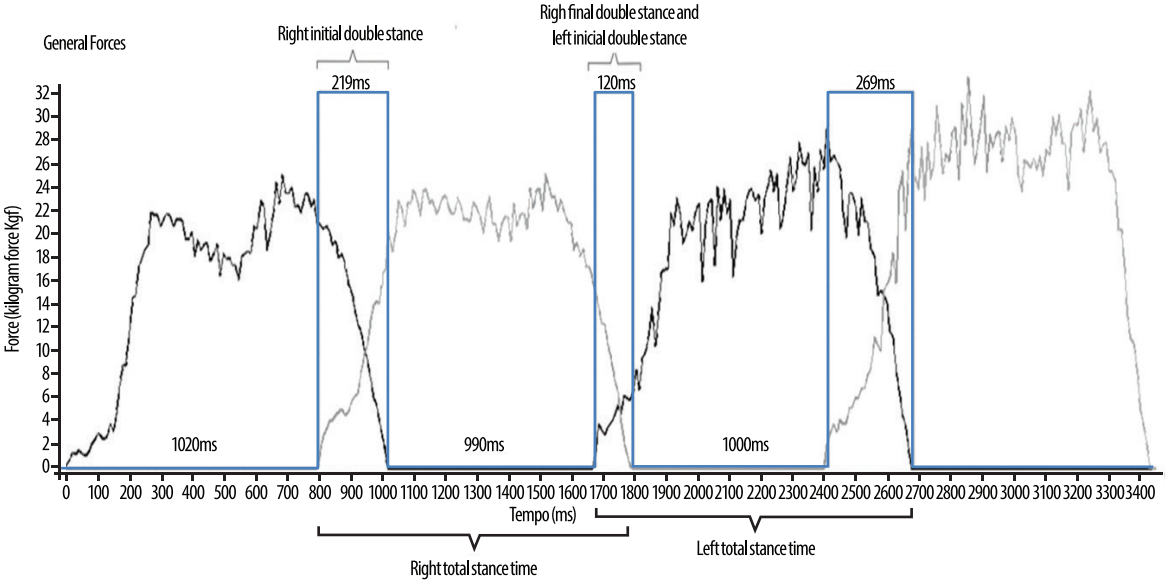

Figure 1. Schematic representation of the image generated by the FootWorkPro software, version 3.2.0.1, used for the analysis of stance time.

Total stance time and initial and final double stance time were collected. Single stance time, which was not provided by the software, was calculated by subtracting the double stance times from total stance time using the following equation (Equation 1):

Single stance = total stance – (initial double stance+double final stance) **Equation 1**

Next, the initial and final double stance times were summed to obtain a single value of double stance time.

Gait speed

Gait speed was calculated by dividing the step length by the cycle time, separately for each limb, and the mean of this value was then calculated (Equation 2):

$$\text{Speed (m/s)} = \frac{\text{Step length}}{\text{Cycle time}} \qquad \textbf{Equation 2}$$

Step length was calculated as the sum of the length of two consecutive steps, expressed in centimeters, and these values were transformed into meters (Figure 2; Equation 3):

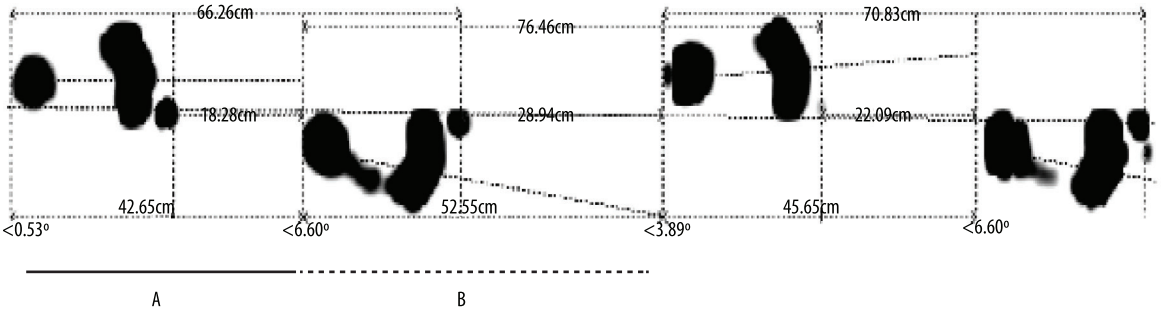

Figure 2. Schematic representation of the image generated by the FootWork Pro software, version 3.2.0.1, used for the calculation of step length.

$$\text{Length of the left step} = A+B \qquad \textbf{Equation 3}$$

Gait cycle time was obtained by the sum of total stance times of the right and left foot and subtracting double stance times, expressed in milliseconds, and was then transformed into seconds.

Statistical analysis

Descriptive statistics (mean and standard deviation) was used for characterization of the sample. The variables met the assumptions for normality (Kolmogorov-Smirnov) and sphericity (Mauchly's). The Student t-test for independent samples was applied to the separate analysis of differences in the quantitative variables between groups. Repeated-measures ANOVA was used to determine the relationship between group and gait condition for the dependent variables (gait speed, percentage of time spent in double and single stance), followed by the post hoc Fisher least significant difference (LSD) test to localize differences.

The data obtained for the two lower limbs were compared and no significant difference was observed. Therefore, since DPN is a symmetrical disease[19], the data obtained for all variables were analyzed together by calculating the mean of the right and left limb.

A level of significance of 5% was adopted for all tests. Statistical analysis was performed using the Statistical Package for the Social Sciences (SPSS), version 19.0.

RESULTS

Table 1 shows the characteristics of the sample. Diabetic peripheral neuropathy was diagnosed based on insensitivity to a 10-g monofilament and on a score ≥ 8 in the Michigan Neuropathy Screening Instrument.

Table 2 shows the gait variables obtained for the two groups in the different conditions.

Table 1. Characteristics of the sample (n=41).

Variable	CG	NG	p-value
Age (years)	62.96 ± 5.97	64.33 ± 6.45	0.483
Body weight (kg)	67.73 ± 11.47	76.71 ± 16.37	0.046*
Height (m)	1.59 ± 0.10	1.61 ± 0.08	0.603
BMI (kg/m^2)	26.63 ± 3.25	31.51 ± 6.92	0.005*
Glycemia (mg/dL)	124.09 ± 24.99	164.56 ± 43.34	0.001*

Values are the mean ± standard deviation. CG: control group (n=23); NG: neuropathy group (n=18); BMI: body mass index. *p<0.05.

Table 2. Gait variables of speed, percentage of time spent in double and single stance obtained for patients with neuropathy and control subjects in the conditions of eyes open (EO), eyes closed (EC), and narrow base of support (NB).

Variable		CG	NG	p-value
Speed (m/s)	EO	0.93 ± 0.11	0.83 ± 0.13	0.004*
	EC	0.66 ± 0.13	0.43 ± 0.12	0.001*
	NB	0.59 ± 0.12	0.41 ± 0.07	0.001*
Double stance (%)	EO	38.04 ± 4.06	42.42 ± 5.01	0.004*
	EC	46.56 ± 4.37	53.56 ± 7.25	0.001*
	NB	47.54 ± 4.37	54.13 ± 6.09	0.001*
Single stance (%)	EO	61.96 ± 4.06	57.58 ± 5.01	0.004*
	EC	53.41 ± 4.37	46.46 ± 7.24	0.001*
	NB	52.46 ± 4.37	45.86 ± 6.09	0.001*

Values are the mean ± standard deviation. CG: control group (n=23); NG: neuropathy group (n=18). *p<0.05.

Since the gait speed of patients with DPN was lower than that of control subjects, the absolute values of double and single stance times were transformed into percentages, taking total stance as 100%

The Student t-test for independent measures also detected a difference in the percentage of time spent in double stance and single stance between groups (Table 2). Patients with DPN presented a higher percentage of time in double stance and a lower percentage of time in single stance in all conditions.

Repeated-measures ANOVA confirmed the results obtained by the Student t-test and revealed a difference in gait speed between the three conditions for the two groups (p=0.001). This finding was confirmed by the post hoc test (EO x EC, p=0.001; EO x NB, p=0.001; EC x NB, p=0.032). An interaction was observed between group and condition; patients with DPN presented a greater reduction in speed when the gait condition was modified (p=0.023).

ANOVA also showed a difference in the percentage of time spent in double and single stance between the three conditions for the two groups (p=0.001). The post hoc test indicated an increase in the percentage of time spent in double stance in the EC (p=0.001) and NB (p=0.001) conditions when compared to the EO condition. There was no difference between EC and NB conditions (p=0.899). The opposite was observed for the percentage of time spent in single stance, with a reduction in the EC (p=0.001) and NB (p=0.001) conditions compared to the EO condition. No difference was found between the EC and NB conditions (p=0.898). There was no group x condition interaction for the percentage of time spent in double stance (p=0.291) or single stance (p=0.295).

DISCUSSION

Characterization of the sample showed that neuropathic subjects had a higher BMI as a result of the higher body weight seen in this population[12,15]. This finding can probably be explained by the reduced functionality and consequent decrease in mobility of the diabetic population.

Subjects with DPN presented poor gait stability in the three conditions tested. This performance was even more compromised in the two conditions that required greater contribution of the postural control system (EC and NB). Gait speed was reduced in subjects with DPN and in the two groups for the conditions requiring greater postural control. However, an interaction was observed between group and condition, with subjects with DPN being more susceptible to a reduction in gait speed in the EC and NB conditions.

In agreement with the present study, some authors reported a reduction in gait speed in the diabetic population[10,21]. This reduction is more pronounced as the degree of difficulty increases, such as when walking on irregular surfaces [10,14], a conditions associated with an increased risk of falls[21]. This reduced gait speed may indicate an attempt to promote safe walking in order to avoid instabilities[22]. However, there are no studies in the literature that evaluate gait in other functional situations such as walking with eyes closed and with a narrow base of support as done in the present study. Although some studies have reported a reduction in gait speed in neuropathic patients with a history of falls when walking on an irregular surface under low light compared to those walking on a regular surface under good light conditions[16], the authors did not differentiate whether the greater difficulty observed was due to the irregular surface, low light, or both.

The percentages of time spent in double and single stance were also altered in the group with DPN and in the EC and NB conditions in both the control group and subjects with DPN. No group x condition interaction was observed for double stance time or single stance time; thus, the groups responded similarly to the different gait conditions, showing poor performance in the conditions that required greater postural control. The two gait conditions (EC and NB) did not include a period of acceleration

and deceleration as used in the EO condition to guarantee the safety of the subjects; however, this does not invalidate the differences observed since the data were obtained in a common area for the three conditions.

Sacco et al.[12] evaluated temporal and dynamic parameters of self-selected gait and also found shorter single stance time and longer double stance time in patients with DPN. Costa et al.[23] attributed this alteration in stance times to a compensation in order to improve gait stability.

The integrity of the postural control, sensory (visual, vestibular and somatosensory) and motor systems is necessary to maintain stability during static and dynamic tasks[24]. The differences between the EO and EC conditions may therefore be due to the importance of visual information for the control of stability, providing the spatial information necessary for body readjustment during locomotion. In this respect, both groups presented poorer performance during walking with the eyes closed.

Although both groups performed worse in the conditions that required greater postural control, subjects with DPN presented greater gait instability in the EC condition, characterized by lower gait speed, longer double stance time, and shorter single stance time. This result can be explained by the reduced sensory feedback[25] in neuropathic patients, increasing gait instability[26].

According to Menz et al.[15], the alterations in gait stability seen in neuropathic patients are due to the importance of peripheral sensory information for the control of stability during locomotion, with this information exerting a predominant effect on vision and muscle strength. As a consequence, in the case of loss of proprioceptive and tactile input, the visual component becomes more necessary for the adjustment of postural control[9]. This fact may explain the present finding that gait speed was more compromised in neuropathic subjects in the EC condition. The poor performance of subjects with DPN in the NB condition might be related to the reduction in sensitivity, muscle strength[27] and range of motion[28] generally observed in this population.

The greater gait instability in the NB condition observed in the present study might be explained by a possible reduction in neuromuscular control of distal joints. Gomes et al.[28], studying peak plantarflexor activity and ankle range of motion at different gait cadences in diabetic neuropathic patients, suggested a reduction in neuromuscular control around distal joints.

The assessment technique used in the present study permitted a better understanding of the neuromotor component involved in gait stability in subjects with DPN. The present findings may therefore contribute to clinical practice, in which the treatment of diabetic individuals should include gait trainings in different conditions that require greater neuromotor control.

One limitation of the present study is the small number of subjects evaluated, since many of them needed to be excluded because of associated comorbidities. Further studies including a larger population are therefore needed to confirm the differences observed. In addition, other everyday life situations of this population, such as walking over an obstacle course,

changes in direction and presence of degrees, should be evaluated to determine the functional condition of these individuals and to assist with treatment and rehabilitation. We also emphasize the importance of intervention studies consisting of gait trainings under the conditions used in this study in order to determine the efficacy of this treatment to maintain gait stability in subjects with DPN.

CONCLUSIONS

Subjects with DPN presented greater gait instability than control subjects in the three conditions tested: habitual walking with eyes open; walking with eyes closed, and walking with eyes open and narrow base of support. Greater gait instability was also observed in neuropathic and control subjects in the EC and NB conditions when compared to the EO condition. This instability was characterized by a lower gait speed, longer double stance time, and shorter single stance time. On the basis of stance times, the response to the difficulties was similar in the two groups. However, neuropathic subjects presented poorer performance in terms of gait speed, i.e., DPN increased the difficulty during walking in the EC and NB conditions.

The changes observed in the gait pattern resulting from instability in the different gait conditions suggest the use of these conditions for both the evaluation and elaboration of strategies that would detect alterations and support activities designed to improve stability and functionality in this population.

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