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ASSESSMENT OF MOTOR SENSORY LOSSES IN THE FOOT AND ANKLE DUE TO DIABETIC NEUROPATHY

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ABSTRACT

Objective: To identify motor sensory deficits in the feet of neuropathic diabetic patients and compare their deficits with a group of healthy subjects. Method: 49 neuropathic diabetics (group NG) and 22 controls (group CG) underwent a three-stage protocol: (1) an interview using a questionnaire to characterize the neuropathy and symptoms; (2) assessment of muscle function and range of motion, and functional tests on the feet and ankles; (3) assessment of tactile and thermal sensitivity. The groups were compared using the chi-squared, Mann-Whitney and Student t tests ($p < 0.05$). Results: NG presented significant losses of tactile and thermal sensitivity in comparison with CG, especially in the heels (49.0% of NG and 97.3% of CG). Muscle function was decreased in NG, with predominance of loss of grade 5. The muscles most affected were the interossei (23.4%), extensor hallucis (42.5%) and triceps surae (43.2%), while all muscle function was preserved in CG. All ranges of motion in NG were reduced in comparison with CG. The functional tests on the ankles in NG presented a decrease of around 50%. Conclusion: There were significant differences between the groups with regard to sensitivity, muscle function, range of motion and functional losses. These differences can be attributed to the diabetic neuropathy.

Key words: sensitivity, diabetes, diabetic neuropathy, assessment, physical therapy.

INTRODUCTION

Diabetes mellitus can be considered to be a universal health problem, affecting populations in countries at all stages of development. According to data from the World Health Organization (WHO), Brazil has around 10 million diabetics and is the sixth biggest country in the world in terms of number of people with diabetes[1]. The highest rate found among Brazilian state capitals is in São Paulo: 10 cases for every 100,000 inhabitants[2].

Diabetes mellitus leads to a variety of chronic complications that contribute towards increased morbidity and mortality among patients. Among these are vascular complications that cause retinopathy and nephropathy, systemic arterial hypertension, dyslipidemia and neuropathies. These reach the peripheral nervous system, and the main form is symmetrical distal diabetic polyneuropathy, which accounts for around 75% of all the neuropathies among these diagnoses[3]. The diabetic neuropathy may lead to trophic disorders of the skin and of the osteoarticular structure of the foot, which leads to the condition known as diabetic foot. Diabetic patients who present lack of sensitivity, muscle weaknesses and decreased range of motion have a greater risk of developing foot ulcerations[4].

The movements most affected are flexion, inversion and eversion of the ankle and movements of the first metatarsophalangeal (fetlock) joint[5]. When these movements are limited, this decreases the ability of the foot complex to absorb shock and transversal rotations during the gait, which contributes towards the pathogenesis of ulceration on the soles of insensitive feet[6]. Deformities appear, such as hammer and claw fingers and displacement of the fatty pads under the metatarsus heads, thereby increasing the plantar pressures in these regions and predisposing towards ulceration, infections and necrosis[7].

The muscle atrophy observed in patients with diabetic neuropathy, especially in intrinsic foot muscles, can cause deformities, decrease the range of foot and ankle movements and also contribute towards increased plantar pressures[4]. Ulceration is the most common complication of diabetic foot and is responsible for over 90% of osteomyelitis cases[8].

Sacco et al.[9] drew up a simple and easily applied protocol that evaluated losses of sensitivity, movement amplitude, muscle function and leg functionality among neuropathic

diabetics, and observed that these patients presented significant losses in relation to these characteristics. However, there was no comparison with a control group, and therefore it is unknown whether these changes are exclusive to neuropathy or whether they are due to other factors such as age, obesity or physical inactivity.

Considering that motor-sensory complications lead to great morbidity among these patients, it becomes necessary to identify predisposing risk factors, so that they can be avoided. Thus, the aim of the present study was to evaluate and compare types of somatosensory plantar sensitivity, joint amplitude and musculoskeletal function of the foot and ankle among neuropathic diabetics and non-diabetic asymptomatic individuals, in order to investigate whether the likely losses are exclusively due to neuropathic diabetes.

MATERIAL AND METHODS

Sample

The experimental sample was formed by a diabetic group (GD) of 49 neuropathic diabetic volunteers who had been diagnosed clinically as type 1 or 2, with a score of at least 2 in the initial interview[10], and by a control group (GC) composed of 22 non-diabetic adults.

To form the GD group, 198 neuropathic diabetics were interviewed using a validated questionnaire[10] that evaluated the severity of the diabetic neuropathy. This questionnaire investigated symptoms, presence of plantar ulcers in the patient's clinical history and functional difficulties. When a score of 2 or more was obtained (out of a total of 15), the diabetic patient was considered to be neuropathic. Among these 198 patients, 49 met the criteria for inclusion.

The GC individuals were recruited after gathering the data on the GD, such that the controls were matched for the variables of age, body mass index (BMI) and physical activity levels, and they also came from the institution where the study was performed. There was some difficulty in selecting this sample, and it was not possible to attain the same number of subjects as in the GD. However, inferential analysis enabled comparisons to be made between the groups, even with the difference in numbers, without compromising the statistical results, since the tests applied took such differences into consideration.

The inclusion criteria for the groups were: both sexes, subjects less than 60 years old, independent walking, absence of macroangiopathy or osteoarthritis in the legs, no history of neurological, muscle or rheumatic diseases apart from the etiology of diabetes, no history of alcoholism and no foot amputation bilaterally, either totally or partially from metatarsus level.

All individuals were made aware of the experimental procedures through a free and informed consent statement that had been approved by the local Ethics Committee (Protocol no. 262/02).

Experimental protocol

The experimental protocol consisted of two stages, which had an approximate duration of fifty minutes: (1) evaluation of somatosensory tactile and thermal sensitivity; and (2) evaluation of joint amplitude, muscle function and ankle and foot functionality.

In the first stage of the experimental protocol, the types of tactile and thermal sensitivities were evaluated in five areas of the sole: medial forefoot, lateral forefoot, midfoot, heel and hallux [11]. Tactile sensitivity was evaluated using a set of nylon monofilaments of Semmes-Weinstein type (SORRI Bauru®)[5]. These monofilaments were pressed on the plantar sites until they bent, going from the thinnest to the thickest filaments. The thinnest monofilament felt by the individual defined his tactile sensitivity level. Three monofilaments were used: 4.17; 5.07 and 6.10. Thermal sensitivity was evaluated by placing a metal test body of 0.5 cm in diameter on the plantar surface: one heated for 30 seconds, one cooled by immersion in ice for one minute and one neutral test body. The neutral test body was applied before applying the hot or cold test bodies. This type of thermal evaluation is used in outpatient clinics[10], although there is no consensus in clinical practice or in the literature in relation to the size or temperature of the test body or even with regard to the use of a neutral temperature between the evaluations.

The second stage consisted of a functional evaluation, in which muscle function, joint amplitude and functional tests in daily activities were performed. The muscle function tests were based on the protocols established by Kendall et al.[12], which graded muscle function from 0 to 5. These tests were applied to the foot muscles (flexors and extensors of the toes and hallux, lumbrical muscles and interossei muscles), and to the flexor muscles (tibialis anterior) and extensor muscles (triceps surae) of the ankle. The range of motion of the foot and ankle joints (flexion and extension, inversion and eversion) was evaluated according to the methodology adopted by Marques[13], using a universal goniometer.

The functional evaluation of the legs was done using some tests described by Palmer & Epler (2000)[14], using the number of repetitions accomplished by the individual in each test as the scale for data analysis. While standing, the subject was asked to lift his toes and forefoot off the floor (dorsiflexion), lift his heel off the floor (plantar flexion), lift the lateral part of the foot off the floor (eversion) and lift the medial part of the foot off the floor (inversion). While seated, the individual had to pick up some cotton wool using his toes (toe flexion) and lift only the toes off the floor (toe extension). The number of repetitions was counted over a period of 30 seconds. The instruction given to the patients was that they should to repeat the movement as many times as possible. For the foot eversion and inversion tests, the following classification was used: no repetitions – not functional; one to two repetitions – barely functional; three to four repetitions – reasonably functional; and five to six repetitions – functional.

For the other flexion and extension tests on the ankle and toes, the following scale was used: no repetitions – not functional; one to four repetitions – barely functional; five to nine repetitions – reasonably functional; and ten to fifteen repetitions – functional. Thus, the patients were divided into four levels for data analysis (not functional, barely functional, reasonably functional and functional).

Statistical treatment

The variables of age, body mass, height, BMI, joint range of motion and number of repetitions in the functional tests were analyzed using parametric and non-parametric tests, according to whether or not the distribution was normal. For comparison of the anthropometrical and range-of-motion variables between the two groups, Student's t test was used. Ordinal-scale variables such as muscle function, tactile and proprioceptive sensitivity, general score in the Feldman questionnaire and functional tests were compared between GD and GC using the Mann-Whitney test. The thermal sensitivity (nominal scale) was compared using the chi-squared test. For all the evaluations, similarities between the responses from the left and right feet were investigated using the chi-squared test. Thus, comparisons were made between the groups without distinguishing between right and left, giving a total of 98 feet evaluated in GD and 44 in GC. Statistical differences were deemed significant when the significance level was less than or equal to 0.05.

PRESENTATION OF THE RESULTS

The two groups were similar regarding age (GC: 53.3 ± 4.3 years; GD: 58.5 ± 11.0 years), body mass index (GC: 25.4 ± 6.7 kg/m^2; GD: 27.4 ± 6.8) and physical inactivity (GC: 81.8%; GD: 73.5%). The mean length time for which the patients had had diabetes was 13.1 ± 7.5 years and their last fasting blood glucose level was 182.8 ± 81.7. With regard to the scoring from Feldman's questionnaire, the two groups were statistically different in relation to the medians (GC -1, GD - 6). The rest of the results are presented in the following.

With regard to range of motion, GD presented means that were lower than in GC. It was ankle extension that showed the significant difference in joint movement.

Both the tactile and the thermal sensitivity were lower in GD than in GC, with significant differences in all plantar regions, especially in the heels.

Muscle function was also statistically lower in GD than in GC, in all the muscle groups tested. The muscles groups most affected were the interossei, triceps surae and finger extensors.

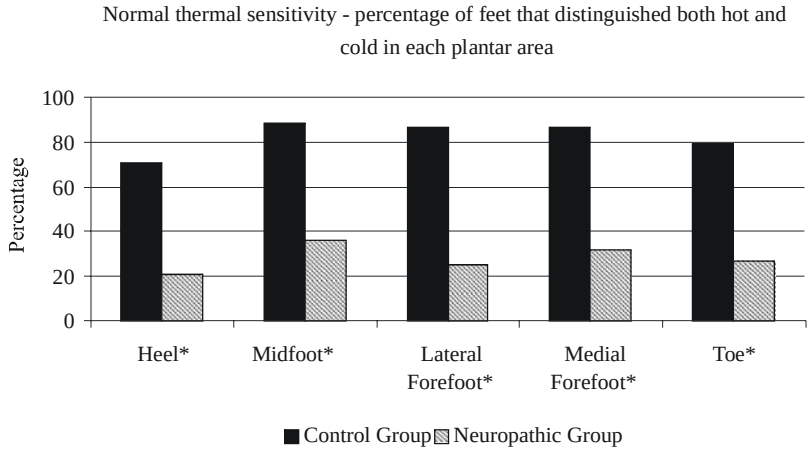

Figure 1. Percentage distribution of feet that distinguished both hot and cold temperatures in each plantar region of the two groups (* for p< 0.05).

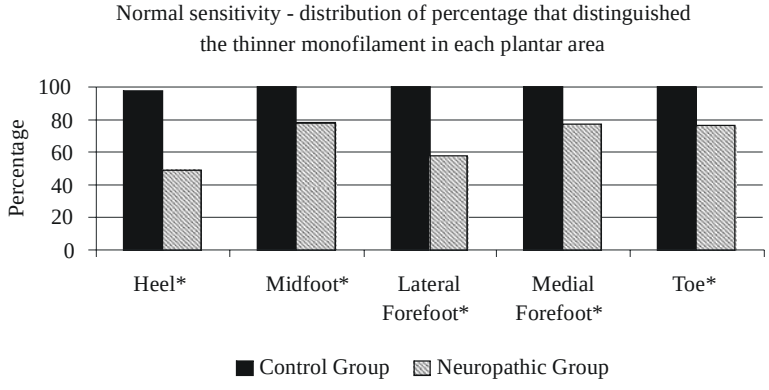

Figure 2. Percentage distribution of feet that distinguished the thinner monofilament in each plantar region of the two groups (* for p< 0.05).

Table 1. Means and standard deviations for the range of motion of the ankles (* for p< 0.05).

Joint Movement	Control Group	Neuropathic Group
Ankle extension (normal: 0 – 45°)	38.7 ± 6.1	31.1 ± 10.3 *
Ankle dorsiflexion (normal: 0 – 20°)	12.9 ± 5.5	10.7 ± 7.7
Ankle inversion (normal: 0 – 40°)	27.8 ± 8.4	17.5 ± 6.9
Ankle eversion (normal: 0 – 20°)	17.2 ± 6.9	10.6 ± 6.3

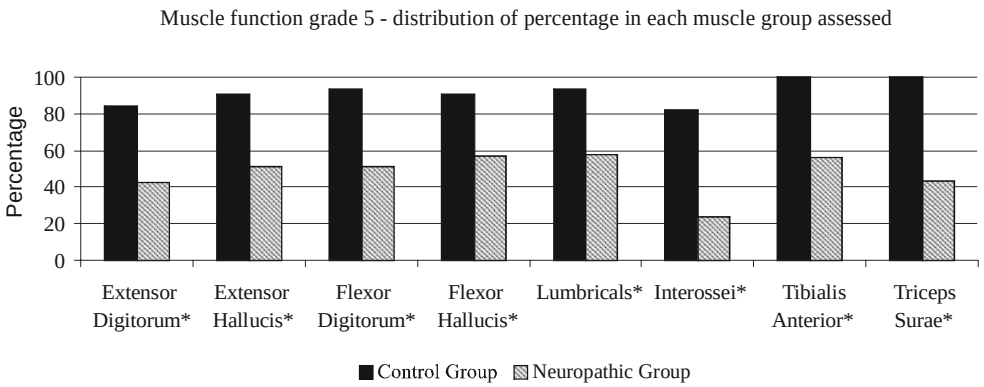

Figure 3. Percentage distribution of muscle function grade 5, assessed in the two groups (* for p< 0.05).

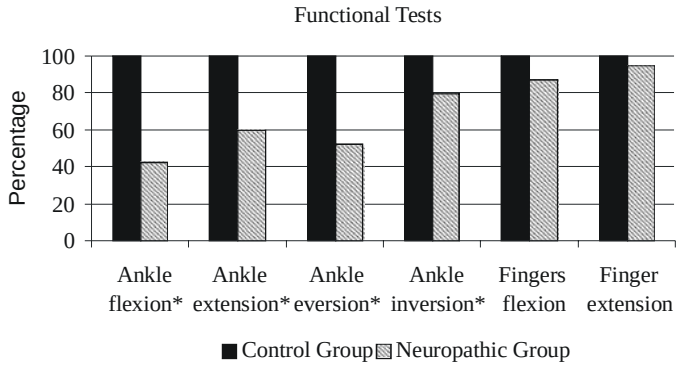

Figure 4. Percentage distribution of functional test results for feet and ankles, according to the functional classification of each movement test, for the two groups (* for p< 0.05).

The functional tests showed that the results in the group of neuropathic patients were inferior, while GC presented better results in all tests.

DISCUSSION OF THE RESULTS

The decreased joint mobility, muscle function and leg functionality that was observed especially in GD, and also observed to a lesser degree in GC, could be attributed to the natural process of aging. However, both groups consisted of mature adults and not elderly people[15], and therefore it can be assumed that diabetic neuropathy was a factor responsible for the differences found between the two groups.

Both groups presented overweight, according to the WHO definition[16]. Therefore, once again, although the anthropometrical weight distribution between the two groups was unequal, the differences found between the groups cannot be attributed to overweight.

The time elapsed since the individuals evaluated had been diagnosed with diabetes was 13.1 years, and the mean value of the last fasting glycemia measurement was 182.8 mg/dl. This was above the value expected when diabetes is under control, since the value considered normal for this population would be up to 126 mg/dl for fasting glucose[17]. One of the factors that predisposes towards the appearance of peripheral neuropathy is high glycemia values, along with fluctuating glycemia levels[17].

Among the patients evaluated, 73.5% did not perform regular physical activity, even though they knew that physical exercise forms part of their treatment, because it improves

their glucose tolerance and insulin sensitivity. Moreover, physical exercise can also slow down and stop tissue atrophy, thereby improving the load-bearing tolerance of the tissue and decreasing the chance that plantar ulcers might appear[18]. GC also appeared to be mostly composed of inactive individuals (81.8%). This gives the assurance that the differences between GD and GC regarding the observed range of motion and muscle function were unrelated to regular practice of physical activities.

There was great difficulty in finding studies that used evaluations similar to what was done in this study, for comparing the results. There are no sensory and functional evaluations in the literature that have the same parameters as were selected in the present study, or on the same population.

With regard to tactile and thermal somatosensory sensitivities, it can be seen that these were significantly lower GD. Although the Consensus of the Diabetic Foot[19] has established that the monofilament 5.07 is the criterion for diabetic neuropathy, sensory loss found using monofilament 4.12 already indicates loss of protective feeling in the foot, vulnerability to injuries and loss of the ability to distinguish hot from cold, and this draws attention to the onset of the disease. Thus, if this loss can be identified in the beginning, preventive measures can be reinforced and clinical measures can be established in order to avoid complications. Most of the present sample of diabetics was not concentrated in the initial phase, but in a moderately advanced phase, in which only just over half of the responses given by the individuals referred to the thinner monofilament (4.17). Thus, they were predisposed towards more easily suffering injuries and falls than was the same population of healthy individuals.

The heel is the region of the foot that presents the greatest quantity of keratin and fat, exactly because it is one of the most overloaded regions during the tasks of locomotion. It receives sensory innervation from the sural nerve. It is known that this nerve is one of the first to be affected in the progression of diabetic neuropathy[20], and this may explain why the heel is affected more than are other areas. It must be taken into consideration that one important factor influencing the interpretation of the stimulus is the characterization of the plantar tegument. If this tegument is too much or too little keratinized, with a large or small fatty pad, there will be interference with the perceptions of tactile and thermal stimuli[11], which may explain the decreased sensory perception found in GC.

The loss of sensitivity is one of the main factors that contribute towards decreasing the inputs for the motor control system and, therefore, towards decreasing the sense of balance. This causes changes in gait and posture, such as lower cadence, shorter steps and lower acceleration, and also slowness in correcting motor errors or when it is necessary to cross obstacles[21]. Thus, it can be inferred that these neuropathic patients are more inclined to suffer episodes of falls, difficulty in climbing stairs and even difficulty in walking along crowded and uneven streets.

The intrinsic foot muscles are the main agents responsible for maintaining the plantar arches. Weakness in these can cause structural alterations in the feet, thereby creating areas of excessive pressure and predisposing towards the appearance of plantar ulcers[22]. According to what was observed in GD, with weakness of the tibialis anterior muscle, which is one of the first muscles to be affected in diabetic neuropathy[20], the “dropped foot” phenomenon develops. This means that, in the gait support phase, the eccentric action needed to brake the forefoot support movement on the floor is less efficient, thereby increasing the shock to this region of the foot on the ground. This has already been observed by some authors[23]. Thus, there may be increased plantar pressure in the forefoot region because of this situation and a greater chance that plantar ulcer might appear.

This loss of muscle function, among other factors, was reflected in the difficulty that the GD individuals presented when performing the functional tests, in which they received significantly lower scores than did the GC. It was the functional tests of toe extension and flexion that presented the highest correlations ($R = 0.37$ and 0.424, $p=0.00$), albeit not so representative, with the muscle function tests on the long and short toe extensors and plantar interossei muscles. These muscles are effectively the primary motors of these actions. Although the correlation was not so significant, a trend of clinical findings were observed that showed real functional difficulty in the group of patients with neuropathy when they were performing these functional activities. As well as the functional tests, all other tests presented lower scores in GD than in GC, and the difference between the two groups was very clear: all the individuals in the control group were 100% functional.

Both muscle function and the functional tests involved in ankle flexion were impaired. In addition to the sural nerve, the fibular nerve is one of the first to be affected as a result of progression of diabetic neuropathy[20], and this nerve is responsible for innervating the tibialis anterior muscle, which is the primary motor for ankle flexion. It can be inferred that diabetics with neuropathy present decreased ankle function that is fundamentally caused by fibular nerve impairment.

Decreased range of motion is also considered to be a risk factor for the development of plantar ulcers[6,7,15]. In evaluating the joint amplitudes, it was clinically observed that all the mean ranges of motion in GD presented reductions, although the most significant were ankle extension and foot eversion. Although ankle flexion and foot inversion did not presenting statistical differences, there was a notable amplitude reduction in GD, and this may also have been a result from impairment of the tibialis anterior muscle.

Other than the ankle flexion, the functional tests for inversion, eversion and extension of the ankle were the most affected in GD. Several factors may explain the alterations

in the functional tests evaluated: (a) decreased strength and muscle mass[24]; (b) decreased muscle resistance, which has also been described by Andersen[24]; (c) changes in sensitivity; and (d) decreased range of motion. All these factors presented decreases in GD in the present study.

CONCLUSION

Neuropathic diabetics present decreased tactile and thermal sensitivity, particularly in the heels; decreased muscle function, especially with regard to the intrinsic foot muscles, tibialis anterior and triceps surae; and decrease range of motion and ankle function. Thus, it can be concluded that, in fact, diabetic neuropathy was the main agent responsible for the observed changes, since factors such as aging and physical inactivity were present both in the diabetics and in the controls. All these functional, sensory and musculoskeletal reductions may contribute towards decreasing the quality of life and towards the appearance of plantar ulcers. These often imply burdensome hospitalization that could be avoided with an efficient prevention program. Prevention is one of the main points in advice for patients aimed at avoiding complications.

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