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Diabetic patients with and without peripheral neuropathy reveal different hip and ankle biomechanical strategies during stair descent

Pacientes diabéticos com e sem a neuropatia periférica mostram diferentes estratégias biomecânicas de quadril e tornozelo ao descer escada

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Abstract

Background: The progression of diabetes and the challenge of daily tasks may result in changes in biomechanical strategies. Descending stairs is a common task that patients have to deal with, however it still has not been properly studied in this population. Objectives: We describe and compare the net joint moments and kinematics of the lower limbs in diabetic individuals with and without peripheral neuropathy and healthy controls during stair descent. Method: Forty-two adults were assessed: control group (13), diabetic group (14), and neuropathic diabetic group (15). The flexor and extensor net moment peaks and joint angles of the hip, knee, and ankle were described and compared in terms of effect size and ANOVAs (p<0.05). Results: Both diabetic groups presented greater dorsiflexion [large effect size] and a smaller hip extensor moment [large effect size] in the weight acceptance phase. In the propulsion phase, diabetics with and without neuropathy showed a greater hip flexor moment [large effect size] and smaller ankle extension [large effect size]. Conclusion: Diabetic patients, even without neuropathy, revealed poor eccentric control in the weight acceptance phase, and in the propulsion phase, they showed a different hip strategy, where they chose to take the leg off the ground using more flexion torque at the hip instead of using a proper ankle extension function.

Keywords: biomechanics; diabetic polyneuropathy; kinematics; kinetics; motion.

Resumo

Contextualização: A progressão do Diabetes Mellito e as atividades desafiadoras do dia a dia podem resultar em mudanças da estratégia biomecânica adotada. Descer escadas é uma tarefa comum do dia a dia, vivenciada pelos pacientes, mas ainda não foi satisfatoriamente estudada nessa população. Objetivos: Descrever e comparar os momentos articulares e a cinemática de membros inferiores em indivíduos diabéticos com e sem a neuropatia periférica e controles saudáveis durante o descer escadas. Método: Quarenta e dois adultos foram avaliados: grupo controle (13), grupo diabético (15) e grupo de diabéticos neuropatas (14). Os picos flexores e extensores dos momentos articulares e os ângulos articulares de quadril, joelho e tornozelo foram comparados e descritos por análise do tamanho do efeito e ANOVAs (p<0,05). Resultados: Na fase de aceitação do peso, ambos os grupos diabéticos apresentaram maior ângulo de dorsiflexão de tornozelo [tamanho de efeito grande] e menor momento extensor de quadril [tamanho de efeito grande]. Na fase de propulsão, diabéticos com e sem a neuropatia apresentaram maior momento flexor de quadril [tamanho de efeito grande] e menor ângulo de extensão de tornozelo [tamanho de efeito grande]. Conclusão: Pacientes diabéticos, mesmo antes da neuropatia instalada, revelaram um pobre controle excêntrico na fase de aceitação do peso e, na fase de propulsão, esses pacientes mostraram uma estratégia diferente ao levar o membro inferior à frente a partir de um maior torque flexor de quadril ao invés de usar uma função extensora apropriada de tornozelo.

Palavras-chave: biomecânica; polineuropatias diabéticas; cinemática; cinética; movimento.

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Introduction

In the diabetic population, biomechanical alterations during level walking have been extensively discussed in the literature and they show important changes that are related to balance and sensory-motor impairments. However, investigation of other activities of daily living in this population, such as stair negotiation, remains insufficient. In daily life, diabetic individuals have to manage slopes, change directions during locomotion, and ascend and descend steps. These activities play an important role in the functionality and independence of diabetic individuals, and the capacity to perform daily tasks is an important factor of a good quality of life.

It has been shown that diabetic individuals have functional deficits of the knee and ankle extensors during gait and other daily living activities[1-4]. The stair descent task requires greater eccentric control of these lower limb extensor muscles and well preserved and efficient balance, since the body is moving with gravity[5]. If the mechanical demands of the task required are not well managed, they become risk factors for falls in diabetic neuropathic individuals[6-8]. A better comprehension of the biomechanics of this motor task in diabetic individuals can contribute to preventive and rehabilitative actions in this population[9].

Stair descent is characterized mainly by energy absorption mechanisms performed by the knee and ankle joints, which show greater angular excursion as opposite to what the hip joint performs[5,10,11]. The ankle plays an important role[12,13], as its full range of motion allows a suitable distribution of the mechanical energy absorption at the initial foot contact with the step and a proper propulsion at the end of the stance[5].

Ankle function is dramatically affected in diabetic patients since they present a limited range of motion (ROM), lower and delayed triceps surae activity[2,14-16] combined with progressive loss of foot sensitivity. During stair descent, normal ankle ROM and proper muscle eccentric control are even more necessary, and if ankle function is impaired, compensations and adaptations in the kinetics and kinematics of the knee and hip would be expected, as Mueller et al.[17] suggested in level gait. Additionally, stair descent involves greater external forces and consequently more complex musculoskeletal and balance responses that have to be performed by individuals with severe motor and sensorial deficits. These individuals have to adapt their neuromuscular responses to a situation that requires different limb coordination patterns and higher eccentric muscle demands, mainly in the weight acceptance phase, compared to a more common task such as walking.

A few biomechanical descriptions of other daily motor tasks in diabetic subjects have been shown in the literature, but none discussed kinetics and kinematics while descending steps. Maluf et al.[18] observed higher peak pressures in diabetic patients during level walking, ramp climbing, stair climbing, and changing direction compared to level walking. Onodera et al.[16] observed a mechanical disadvantage of the vastus lateralis and gastrocnemius medialis muscles in stair negotiation by diabetic individuals.

No previous study has investigated lower limb net joint moments in diabetic individuals during the performance of challenging daily tasks such as stair descent, nor has previous research determined net joint moments in patients with different severities of diabetes and its chronic complication – peripheral neuropathy. Therefore, it has not been possible to identify differences in kinetic patterns between early and advanced stages of diabetes. Whether lower limb kinetic patterns change during stair descent along with the progression of diabetes remains unclear. The net joint moments can potentially show how diabetic and diabetic neuropathic patients deal with their pathological condition and with the mechanical and balance demands of stair descent.

Taking into account that stair negotiation is a challenging and difficult situation for diabetic and neuropathic patients because of their deficits, we hypothesized that the greater the severity of the disease (progression of diabetes marked by the onset of peripheral neuropathy), the greater the kinetic and kinematic changes during stair descent, mostly in the knee and ankle since these joints are essential to the task of descending stairs[19,20] and are compromised in diabetic individuals. Therefore, the aim of this study was to describe and compare the sagittal net joint moments and kinematics of the main joints of the lower limbs in diabetic individuals with and without peripheral neuropathic and non-diabetic control individuals during stair descent.

Method

Subjects

Forty-two adults (20 men, 22 women) were divided into three groups: a control group composed of 13 non-diabetic asymptomatic individuals (CG, 54.7±7.6 years, 72.1±12.2 kg, 1.69±0.1 m, BMI 25±5 kg/m^2); 15 individuals diagnosed with diabetes (DG, 55±6.9 years, 81.6±16.4 kg, 1.69±0.1 m, BMI 30±6 kg/m^2, 7.1±1.4 years of duration of diabetes, 135.8±39.1 mg/dL of glycaemia, Hb1Ac 6.91%); and 14 diabetic individuals clinically diagnosed with peripheral diabetic neuropathy (DNG, 60.2±4.0 years, 74.7±9.7 kg, 1.66±0.1 m, BMI 27±7 kg/m^2, 13±4.3 years of duration of diabetes, 185.2±87.1 mg/dL of glycaemia, Hb1Ac 9.31%). There were no statistical differences (ANOVA) among the groups (at mean values) in sex (p=0.501, chi square test), height (p=0.507), body mass (p=0.123), age (p=0.060) or BMI (p=0.07). The diabetic groups were statistically different with respect to neuropathy scores (Michigan Neuropathy Screening Instrument questionnaire – MNSI)[21] (p<0.001), duration of diabetes (p<0.001), glycaemic levels (p<0.001), and Hb1Ac levels (p<0.001), as expected, since neuropathic status comes from worse control and/or a longer duration of diabetes.

The inclusion criteria for the diabetic groups were as follows: more than 5 years since the diagnosis of diabetes mellitus; a score equal to or higher than 6 out of 13 on the MNSI; a score equal to or higher than 3 out of 8 on the foot Physical Assessment for the DNG; and a score equal to or lower than 3 out of 13 and 2 out of 8 for the DG (DG, median of 2.5 in the MNSI questionnaire and 2 in the Physical Assessment; DNG, median of 7 in the MNSI questionnaire and 3 in the Physical Assessment). The exclusion criteria for all groups were: over 65 years of age; partial or total amputation; Charcot arthropathy (or any other major orthopaedic foot alteration confirmed by radiography); presence of retinopathy or nephropathy; plantar ulcers at the time of the evaluation; presence of any other musculoskeletal disorder or pain; and inability to descend stairs without the use of a handrail.

All procedures were approved by the Ethics Committee of Hospital das Clínicas da Faculdade de Medicina da Universidade de São Paulo, city of São Paulo, state of São Paulo, Brazil (protocol number 0305/08) (n. 0305/08), and all participants gave written informed consent.

Procedures

Before data acquisition, all subjects were interviewed using the Activities-Specific Balance Confidence Scale (ABC)[22]. This scale was used to better characterize activities related to stair negotiation and stair descent and determine whether they are indeed a challenging motor situation to both diabetic and neuropathic patients. Among the available validated scales, the ABC scale was the most specific to address the task of stair negotiation and related activities. The higher the score is, the higher the subject's confidence. These scores were statistically different among groups (ANOVAs, p<0.01). The CG reached a total score of 98.9 (2.5)%, the DG scored 93.9 (4.8)%, and the DNG scored 82 (10.7)%, indicating a progressive loss in confidence during daily activities, including stair negotiation. In tasks not related to stair negotiation (i.e. "walking around the house", "getting in/out of car", "walking across parking lot"), we did not find any statistical differences among groups. However, in specific activities related to slope negotiation, the groups were statistically different: stair negotiation [CG=99(4)%; DG=90(17)%; DNG=69(22)%, p<0.001], escalator negotiation [CG=99(2)%; DG=83(28)%; DNG=76(28)%, p<0.001], and ramp negotiation [CG=99(2)%; DG=87(7)%; DNG=79(25)%, p=0.047].

Passive-reflective markers (20 mm in diameter) were affixed to the skin with VHB tape (3M®) using a standard Cleveland Clinic marker set[23]. Extra markers were placed bilaterally at the medial knee joint line, medial malleolus, and first metatarsal joint for the static standing trial, in order to determine relative joint centers of rotation. Three non-collinear reflective markers were fixed at two squares (technique clusters) placed over the lateral thigh and over the shank. The laboratory coordinate system was established at one corner of the force plate. Lower limb segment translations and rotations were reported relative to neutral positions defined during the initial standing static trial.

The three-dimensional kinematics was evaluated with six infrared cameras (Optitrack FLEX: V100, Natural Point, OR, USA). The automatic digitizing process, the 3D reconstruction of the markers' positions, and the filtering of kinematic data were performed using Arena software (Natural Point, OR, USA). Ground reaction forces were acquired by a force plate (AMTI OR-6–1000, Watertown, MA, USA) embedded in the floor at the end of the last stair step. Data acquisition was synchronized and sampled by an A/D card (AMTI, DT 3002, 12 bits) at 100 Hz.

Before data acquisition, all participants received the same instructions: to descend barefoot the last three steps of a five-step staircase, without using the handrail, beginning the task with the opposite limb to the one being evaluated, and positioning one foot on each step during the descent. They were also instructed to continue walking after the last descent step. The subjects were instructed to descend the staircase as they would do on a daily basis, but the cadence was controlled by a digital metronome at 96 steps/minute, which was rigorously followed by the subjects in order to reduce the influence of cadence variation within trials and subjects[24]. Each step of the staircase was 32 cm deep, 60 cm wide, and 20 cm high, and the staircase had a 32-degree slope.

Numerical and statistical analysis

All data were processed and the variables were calculated in a custom-written math function in MATLAB v.8 (MathWorks, Inc.). Kinematic data were processed using a second-order low-pass filter with a cutoff frequency of 6 Hz. Ground reaction force data were processed using a zero lag low-pass Butterworth fourth-order filter with a cutoff frequency of 20 Hz.

The 3D inverse dynamic bottom-up method was employed to calculate the net moments of hip, knee, and ankle joints in the sagittal plane, using Visual3D software (C-motion, Waterloo, ON, Canada). The inertial properties were based on Dempster's standard regression equations[25]. A negative net joint moment was considered an extensor moment, and a positive one was considered a flexor moment. Forward motion of the lower segment was regarded as flexion (positive values) and backward motion as extension (negative values)[26].

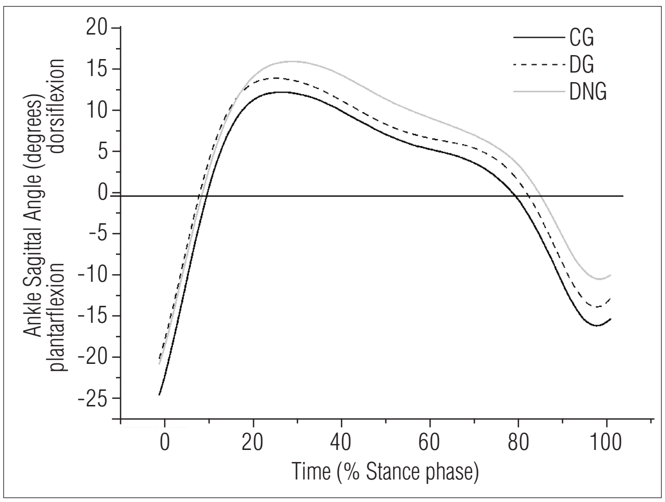

Figure 1. Mean profile of the ankle sagittal angular excursion during stance phase of stair descent for Control (CG), diabetic (DG), and diabetic neuropathic (DNG) groups.

The results were interpreted considering three periods of the stance phase of descending stairs, as proposed by McFadyen and Winter[19]: (i) weight acceptance phase, double stance phase (0-19% of the cycle); (ii) continuance forward phase, horizontal displacement, and body elevation (19-53% of the cycle); and (iii) controlled lowering phase, vertical displacement of the body, and simple stance phase (53-100% of the cycle). In this study, the third stage of the stance phase (controlled lowering) was considered the propulsion phase of level walking, as the subjects stepped on the force plate during the transition to the floor plane.

The vertical (y) and horizontal (x) mean velocities were calculated from the displacement of the pelvic centre during the whole stance phase of stair descent, and compared among groups.

We calculated the maximal flexion and extension angles of each joint, the hip extensor net joint moment peak at the weight acceptance phase (~15% of the stance), the hip flexor net joint moment peak at the propulsion phase (~80% of the stance), the knee flexor net joint moment peak at the forward continuance phase (~30% of the stance), the knee extensor net joint moment peak at the propulsion phase (~60% of the stance), the first ankle flexor net joint moment peak at the weight acceptance phase (~20% of the stance), and the second ankle flexor net joint moment peak at the propulsion phase (~80% of the stance). Data of only one randomly selected lower limb per subject was analyzed and

Table 1. Mean values (standard deviations) of the sagittal kinematics (degrees), effect size and its classification, and p-value of the comparisons among control (CG, 1), diabetic (DG, 2) and diabetic neuropathic (DNG, 3) groups for the hip, knee, and ankle joints of stair descent.

Variables (degrees)	CG (1) (n=13)	DG (2) (n=15)	DNG (3) (n=14)	p-value (ANOVA)	Effect Size (cohen's d)	Effect size Classification
Maximal hip flexion angle (weight acceptance)	27.2 (9.1)	24.4 (6.4)	24.7 (8.0)	0.423	0.62 (1-2) 0.04 (2-3) 0.45 (1-3)	Moderate Small Moderate
Maximal hip extension angle (propulsion)	3.4 (7.8)	1.0 (3.6)	1.0 (2.2)	0.735	0.42 (1-2) 0.00 (2-3) 0.44 (1-3)	Moderate Small Moderate
Maximal knee flexion angle (weight acceptance)	26.5 (3.6)	25.3 (2.9)	21.0 (2.0)	0.145	0.38 (1-2) 1.78 (2-3) 1.98 (1-3)	Small Large Large
Maximal knee extension angle (propulsion)	14.2 (8.9)	12.9 (14.5)	10.8 (4.0)	0.264	0.11 (1-2) 0.20 (2-3) 0.52 (1-3)	Small Small Moderate
Maximal ankle dorsiflexion angle (weight acceptance)	13.7 (0.1)*	16.4 (0.8)	17.4 (3.7)	0.036	4.74 (1-2) 0.39 (2-3) 1.44 (1-3)	Large Small Large
Maximal ankle plantarflexion angle (propulsion)	-17.3 (5.4)*	-10.9 (7.1)	-9.2 (1.6)	0.005	1.04 (1-2) 0.34 (2-3) 2.15 (1-3)	Large Small Large

*represents the different group compared to the others (ANOVA).

compared. Five valid steps performed by the selected limb were used for statistical purposes.

Biomechanical, anthropometric, and demographic variables followed a normal distribution (Shapiro-Wilk Test), and variances were homogeneous (Levene's Test). Statistical tests to compare variables included an analysis of variance (ANOVA), followed by a Newman-Keuls post hoc test. In order to verify the size of the difference between groups of net joint moments and kinematic variables, we calculated the effect size, which quantifies the size of the difference between groups and may be a true measure of the significance of the difference between the groups (Browner, 2006; Thalheimer and Cook, 2002).

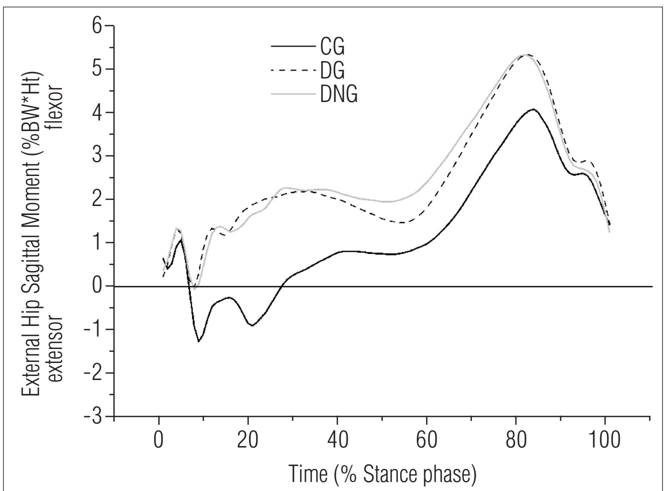

Figure 2. Mean profile of the hip sagittal net moment during stance phase of stair descent for Control (CG), diabetic (DG), and diabetic neuropathic (DNG) groups.

Results

The vertical and horizontal mean velocities were different between diabetic groups and CG. The DNG showed a significantly greater vertical velocity than other groups and presented a large effect size [CG=-0.19 (0.06) m/s, DG=-0.21 (0.05) m/s, and DNG=-0.26(0.08) m/s*]. The DG and DNG showed a significantly lower horizontal velocity (x) than the CG and presented a large effect size [CG=0.82 (0.14) m/s*, DG=0.64 (0.08) m/s, and DNG=0.76 (0.10) m/s].

The DG and DNG showed greater dorsiflexion and lesser plantarflexion compared to the CG, which can be confirmed by the large effect size values (Table 1, Figure 1). The DNG individuals showed less knee flexion (large effect size) in the weight acceptance phase (Table 1).

The effect size calculation for the net moments of the hip revealed large effects among groups, characterized by a smaller extensor moment in the weight acceptance phase and a greater flexor moment at propulsion for both diabetic groups (Table 2, Figure 2).

Discussion

This study aimed at describing and comparing lower limb kinetics and kinematics during stair descent in diabetics patients with and without neuropathy and in healthy individuals. The only difference observed between early (DG) and advanced

Table 2. Mean values (standard deviations) of the sagittal net joint moment variables, effect size and its classification, and p-value of the comparisons among control (CG, 1), diabetic (DG, 2) and diabetic neuropathic (DNG, 3) groups for the hip, knee, and ankle joints of stair descent.

Variable (% BW. Height)	CG (1) (n=13)	DG (2) (n=15)	DNG (3) (n=14)	p-value (ANOVA)	Effect Size (cohen's d)	Effect size Classification
Hip extension moment peak (weight acceptance ~15% of the stance)	-2.5 (1.2)	-1.1 (1.4)	-1.2 (1.9)	0.066	1.11 (1-2) 0.06 (2-3) 0.84 (1-3)	Large Small Large
Hip flexion moment peak (propulsion ~80% of the stance)	4.3 (2.0)	5.9 (1.7)	5.9 (2.1)	0.059	0.90 (1-2) 0.00 (2-3) 0.81 (1-3)	Large Small Large
Knee flexion moment peak (forward continuance ~30% of the stance)	3.0 (1.8)	3.9 (2.7)	4.1 (2.5)	0.443	0.40 (1-2) 0.08 (2-3) 0.52 (1-3)	Moderate Small Moderate
Knee extension moment peak (propulsion ~60% of the stance)	-1.1 (0.7)	-1.4 (1.5)	-1.0 (1.5)	0.795	0.26 (1-2) 0.28 (2-3) 0.09 (1-3)	Small Small Small
1st ankle flexion moment peak (weight acceptance ~20% of the stance)	8.1 (2.1)	8.4 (1.5)	8.8 (1.9)	0.630	0.17 (1-2) 0.24 (2-3) 0.36 (1-3)	Small Small Small
2nd ankle flexion moment peak (propulsion ~80% of the stance)	6.8 (1.2)	7.6 (1.1)	7.5 (1.0)	0.259	0.72 (1-2) 0.10 (2-3) 0.66 (1-3)	Moderate Small Moderate

stages of the disease (DNG) was in the knee kinematics; however, both diabetic groups showed important changes in the ankle kinematics and in the hip kinetics compared to healthy individuals. The hip played a major role in diabetic individuals in late stance producing a greater flexor moment, possibly to compensate the smaller ankle role in the same phase, but in the weight acceptance phase the smaller hip extensor moment could compromise the eccentric control of stair descent.

In the weight acceptance phase, there was an increase in the ankle dorsiflexion angle (large effect) and smaller hip extensor moment in both diabetic groups and a smaller knee flexion in the DNG. In this particular phase, the eccentric muscle activity plays a major role in controlling the deceleration of the whole body and in positioning the lower limb segments properly to allow optimal load absorption.

In the ankle joint, the increased dorsiflexion angle suggests a poor triceps surae eccentric activity. This finding is consistent with the EMG results of the triceps surae, which presents a deficit in its activation in locomotor activities[2,14-16], and it is expected that in a more difficult task that requires more eccentric activity and control, such as descending stairs, the ankle muscles could not respond adequately.

Particularly in diabetic neuropathic patients, the smaller knee flexion reinforces the hypothesis of a poor eccentric control because they assume a posture that saves quadriceps effort. The vastus lateralis delay found in the EMG results in the heel strike phase of level gait in diabetic neuropathic patients[1,2,16] indicates impaired knee extensor muscle function. The diabetic patients' response must be adapted to a higher mechanical demand during stair decent, particularly at the initial contact. Considering all sensorimotor deficits, their response might be inadequate to this new effort.

In the hip joint, the smaller hip extensor moment suggests poor eccentric activity of hip extensor muscles. Although there is no study available that identifies any dysfunction of the hip extensor muscles in diabetic populations, mainly because of methodological difficulties, we can assume that the smaller hip extensor moment may indicate muscle dysfunction.

The greater mean vertical velocity (large effect) observed in neuropathic patients is presumably a consequence of this inadequate eccentric control to manage external forces during stair descent and indicates that their bodies are collapsing during the load acceptance phase.

Riener et al.[5] emphasized that the typical potential energy absorption during stair descent is accomplished by a synchronized and coordinated action of three major lower limb joints, highlighting the important role of the ankle (8-10% of the stance phase) and knee (10-13% of the stance phase) at the beginning of stance, while they are flexed. This greater dorsiflexion in the weight acceptance phase could lead to an impaired return of the elastic energy needed in the propulsion phase. Knowing the importance of the eccentric-concentric cycle in the energy conservation and effectiveness of gait, we suggest that the absorption and generation of elastic potential energy from the ankle may be compromised in stair descent activities in diabetic populations.

In the propulsion phase, the smaller ankle extension and the greater hip flexor moment observed in the propulsion phase of both diabetic groups may corroborate the theory of a major role of a proximal joint in an attempt to compensate for the typical ankle losses in neuropathic diabetic patients but, in the present study, they were seen even before the neuropathy had set in (DG). Despite the neuropathy, diabetic individuals appear to be using the hip to raise the leg off the floor instead of using an efficient ankle extensor function. This particular locomotor strategy has already been pointed out by Mueller et al.[17], who suggested that the greater contribution of the hip joint in the late stance phase occurs because of a lesser ankle contribution.

In this propulsion phase, the muscles that generate the higher flexor moment were able to compensate for the distal losses, unlike the hip extensors in the initial contact phase, when they could not generate higher extensor moments to compensate for the distal losses. This may have occurred because the eccentric activity necessary to overcome the distal losses during the weight acceptance phase is much higher than the concentric activity of the hip flexion needed to pull the leg forward in the propulsion phase of gait. Therefore, the hip could only compensate during the propulsion phase but not at the beginning of stance phase, during the descending stairs.

The biomechanical variables measured in the present study revealed that there are common motor strategies that are adopted by diabetic individuals with or without neuropathy. Even before the neuropathy is installed, diabetic individuals already present altered ankle kinematics and hip kinetics when dealing with higher external forces, more balance control, and greater hip and knee eccentric action while descending stairs. Yavuzer et al.[27] found that diabetic patients without neuropathy had biomechanical impairments during gait similar to those seen in patients with neuropathies, agreeing with the theory that the changes are compounded by losses caused by neuropathy, although they are sometimes evident in diabetics without neuropathy.

It is also important to emphasize that diabetes progression was not treated as a longitudinal factor in this study, as it has been considered elsewhere[28,29]. A transversal design also offers a good understanding of the evolution of the severity of the disease, comparing two groups that vary internally in terms of symptoms and signs of neuropathy, diabetes control, and duration time. Further longitudinal studies are recommended to confirm the hypothesis that diabetic individuals without neuropathy already present noteworthy biomechanical alterations during stair descent.

The results of this study show the need for actions towards more specific therapies for diabetic patients regardless of the presence of neuropathy, such as: work for better ankle joint function; therapeutic actions aiming at allowing better eccentric control essential to the task of descending stairs, particularly through functional training for the thigh and hip muscles, which seem to have an important role in compensating for the ankle deficit.

Conclusion

The present study leads to the conclusion that a diabetic individual, even without the presence of neuropathy, will have significantly greater dorsiflexion throughout the stance phase while descending stairs, with a greater hip role generating higher flexor moments in the late stance, suggesting a hip compensation strategy for the distal function losses. The observed changes should lead health professionals to focus on maintaining and recovering essential motor skills for independent and efficient locomotion in these patients.

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