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Gait pattern alterations in older adults associated with type 2 diabetes in the absence of peripheral neuropathy - Results from the Baltimore Longitudinal Study of Aging

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Abstract

Diabetes may impact gait mechanics before onset of frank neuropathies and other associated threats to mobility. This study aims to characterize gait pattern alterations of type 2 diabetic adults without peripheral neuropathy during walking at maximum speed (fast-walking) as well as at self-selected speed (usual-walking). One-hundred and eighty-six participants aged 60 to 87 from the Baltimore Longitudinal Study of Aging (BLSA) able to walk unassisted and without peripheral neuropathy were classified as non-diabetic (N = 160) or having type 2 diabetes (N=26). Gait parameters from the fast-walking and usual-walking tests were compared between participants with and without type 2 diabetes. Participants with diabetes had a shorter stride length for fast-walking ($p = 0.033$) and a longer percentage of the gait cycle with the knee in 1st flexion for both fast- and usual-walking ($p = 0.033$, and 0.040, respectively) than non-diabetic participants. Participants with diabetes exhibited a smaller hip range of motion in the sagittal plane during usual-walking compared to non-diabetics ($p = 0.049$). During fast-walking, participants with diabetes used lower ankle generative mechanical work expenditure (MWE) and higher knee absorptive MWE compared to non-diabetic persons ($p = 0.021$, and 0.018, respectively). These findings suggest that individuals with type 2 diabetes without overt peripheral neuropathy exhibit altered and less efficient gait patterns than non-diabetic persons. These alterations are more apparent during walking at a maximum speed indicating that maximum gait testing may be useful for identifying early threats to mobility limitations in older adults with type 2 diabetes.

Keywords

type 2 diabetes; aging; gait; mobility limitation; peripheral neuropathy; mechanical work expenditure

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INTRODUCTION

With increasing life expectancy and escalating rates of type 2 diabetes, understanding how diabetes affects physical function and mobility has become increasingly important [1, 2]. Both stable walking and standing are reported negatively affected by diabetes [3]. Although altered gait patterns of diabetic persons are largely related to peripheral neuropathy [4–6], similar aberrations have been detected in diabetic patients free of clinically significant neuropathies [2, 7, 8]. Gaining insight into gait pattern alterations that occur in diabetic individuals free of peripheral neuropathy is essential for developing strategies to effectively prevent mobility impairment in early stage diabetes.

Previous studies found that individuals with diabetes have slower self-selected gait speed and shorter stride length and reduced range of motion and joint moment in the sagittal plane [2, 9]. Only one study has examined gait patterns under challenging conditions designed to mimic real life situations [7], but this work had limited data on functional gait characteristics since it did not include kinetic information or employ three dimensional (3D) observation, which can provide estimates of lower extremity energetics during walking. Latent problems in lower extremity joint function that may be related to diabetes can be better informed with proper understanding of lower extremity kinematics and kinetics in 3D space. Although gait characteristics of persons with type 2 diabetes without peripheral neuropathy, such as mobility, joint torque, and gait speed during self-selected walking speed, have been previously examined using 3D gait analysis [10], mechanical work expenditure, which can assess joint kinematics and kinetics simultaneously during walking, have not been examined. In addition, analyses of gait patterns during maximum speed walking, which may be more sensitive to diabetes-related alteration, have not been conducted.

The present study aims to fill a potentially important gap in the research literature by using 3D gait analyses at different speed walking tests to explore the association between diabetes and gait parameters in persons free of peripheral neuropathy. Full 3D gait analysis provides unique information on biomechanical energy produced by the lower extremities and may be a more sensitive measure of subtle differences between diabetic and non-diabetic individuals than semi-quantitative methods such as spatiotemporal gait parameters. In this study, range of motion and mechanical work expenditure (MWE) of the lower extremity in the sagittal and frontal planes were examined to estimate the contributions of muscle group activations in 3D during walking at maximum and self-selected speed [11, 12].

We hypothesized that persons with diabetes without peripheral neuropathy would exhibit altered gait patterns in kinematics and kinetics as well as spatiotemporal gait parameters while walking at maximum and self-selected gait speeds. We also tested whether diabetes related differences in spatiotemporal gait patterns explained any observed differences in gait kinematics and kinetics.

METHODS

Participants

Data used in this study were from 186 participants in the Baltimore Longitudinal Study of Aging (BLSA) aged 60 to 87 years evaluated in the Clinical Research Branch Gait Laboratory (NIA, NIH) between January 2008 and February 2009. Persons with hip or knee prosthesis, severe joint pain, history of stroke or Parkinson's disease or unable to follow instructions and safely complete the walking tasks (at self-selected and maximum speeds) unaided were excluded from gait testing. Individuals who had ever reported a diagnosis of peripheral neuropathy substantiated and confirmed by a nurse practitioner during a comprehensive physical examination and those with abnormal findings on nerve conduction

studies of the sural sensory or peroneal motor nerves [8, 9] were excluded from the analytic sample. The BLSA protocol was approved by the Intramural Research Program of the National Institute on Aging and the institutional review board of the Medstar Health Research Institute (Baltimore, MD). Participants were given a detailed description of the study and consented to participate.

Type 2 diabetes

All BLSA participants are administered an oral glucose tolerance test (OGTT) unless they are taking insulin or had been taking catabolic steroids such as prednisone within 3 months of their study visit. Following a minimum 10-hour overnight fast, participants are given a standard 75g dextrose solution presented as a 10 ounce flavored carbonated beverage. Both the fasting and 2-hour post-challenge plasma samples are analyzed using a glucose analyzer (Beckman Instrument, Brea, CA). Participants with a fasting plasma glucose greater than or equal to 126 mg/dL, a 2-hour post-OGTT plasma glucose level greater than or equal to 200 mg/dL, or are taking hypoglycemic medications including insulin, are classified as having type 2 diabetes (N = 26). Those did not meet the criteria were classified as non-diabetics (N = 160).

Gait measurements

The procedures for the comprehensive gait analysis performed in the BLSA gait laboratory have been described previously [11, 13]. Briefly, reflective markers are placed on participants at 20 anatomical landmarks: anterior and posterior superior iliac spines (ASIS, PSIS), medial and lateral knees, medial and lateral ankles, toe (second metatarsal head), heel, and lateral wands over the mid-femur and mid-tibia. Proper estimation of hip joint center location is essential for valid assessment of lower extremity kinematics and kinetics [14–16]. Excessive soft tissue covering the anatomical landmarks constitutes the main impediment to accurate identification of the hip joint [17, 18]. Although no clear solution for dealing with excessive soft tissue over the pelvic area has been identified, to minimize error in hip joint center calculation in over-weight and obese participants, we use a tie band in the pelvic area with the distance between the left and right anterior superior iliac spines (ASIS) measured manually. Also, to avoid invalid gait assessment due to excessive soft tissue covering key landmarks, participants with a BMI over 40 were excluded from gait analysis. A Vicon 3D motion capture system with 10 digital cameras (Vicon 612 system, Oxford Metrics Ltd., Oxford, U.K.) measured the 3D locations of all markers placed on the landmarks of lower extremity segments (60 Hz sampling frequency). During gait testing, ground reaction forces were measured with two staggered force platforms (Advanced Mechanical Technologies, Inc., Watertown, MA, USA; 1080 Hz sampling frequency). All markers were positioned either directly on the skin or non-reflective tight-fitting spandex tights. Participants were first asked to walk straight along the 10 m long laboratory walkway at their self-selected walking speed (like “walking in the street”; usual-walking) and to repeat the same task walking as fast as possible (fast-walking). Participants were not informed about the presence or location of force platforms on the walking path. Trials were administered until at least three gait cycles with both the left and right feet landing on a force platform were completed for both usual-walking and fast-walking tasks. The raw coordinate data of marker positions were digitally filtered with a fourth-order zero-lag Butter worth filter with a cutoff at 6 Hz.

Data processing

Calculation of the 3D kinematic and kinetic gait parameters have been described in detail previously [11]. Briefly, the mechanical joint powers of lower extremity rotations in the sagittal and frontal planes were calculated using Visual3D (C-motion, Inc., Germantown, MD, USA). The Bell pelvic model (using the left and right ASISs and PSISs) was used for

hip joint center calculation [19]. Inertial properties of the lower segments were estimated from anthropometric measurements (height and body weight) and landmark locations [20]. Using kinematic measurements, ground reaction forces, and the paradigm of inverse dynamics, kinetic gait parameters including joint moment and joint power were calculated. Mechanical work expenditure (MWE) was computed by numeric integration of joint-specific mechanical power during the stance period using custom software by MATLAB (The Math Works, Inc., Natick, MA, USA). To dissect functional differences in MWE in generative and absorptive modes, joint mechanical powers in positive (generative) and negative (absorptive) modes were integrated separately. Spatiotemporal parameters including gait speed, stride length, cadence, knee first flexion duration, and stride width were calculated by Visual3D, and manually checked by a technician using custom made software written in MATLAB.

Statistical analysis

Study population characteristics are reported by diabetes category as mean values and standard deviations for continuous variables and proportions for categorical variables. Differences in gait parameters for the walking tasks by diabetes category were investigated by multiple regression analysis that adjusted for height, mass, sex, age, and gait speed (except the model predicting gait speed, where adjustment was made only for height, mass, sex, and age). Statistical significance was defined as *p* value less than 0.05. Statistical analyses were performed using SAS 9.1 Statistical Package (SAS Institute, Inc., Cary, North Carolina, USA).

RESULTS

Participant characteristics by diabetes status are summarized in Table 1. Twenty-six persons or 14 % were identified as having type 2 diabetes. Sex and body mass differed between groups ($p = 0.021$, and $p = 0.041$, respectively), while age and height did not. Consistent with diabetes categorization, mean hemoglobin A1c level was significantly higher in the diabetic group ($p < 0.001$) [21].

Differences in gait parameters for the two walking tasks –usual-walking and fast-walking between the two groups are summarized in Table 2. Participants with diabetes had a shorter stride length for fast-walking ($p = 0.033$) and a proportionately longer gait cycle duration for the knee first flexion phase for both usual- and fast-walking ($p = 0.040$, and 0.033 , respectively) than non-diabetic participants. During usual-walking, participants with diabetes exhibited a smaller hip range of motion in the sagittal plane compared to non-diabetics ($p = 0.049$) but this difference vanished after additional adjustment for knee first flexion cycle ($p = 0.159$). During fast-walking, participants with diabetes used lower ankle generative MWE and higher knee absorptive MWE than non-diabetic persons ($p = 0.021$, and 0.018 , respectively). During fast-walking, after adjusting for stride length, the difference in ankle generative MWE between the two groups were no longer significant ($p = 0.128$), while the difference in knee absorptive MWE remained ($p = 0.012$). During late stance, ankle generative MWE and knee absorptive MWE for fast-walking were negatively correlated ($r = -0.433$; $p < 0.001$, Figure 1). There were no differences in walking kinematics or kinetics in the frontal plane for either walk.

DISCUSSION

Individuals with type 2 diabetes who do not have overt evidence of peripheral neuropathy demonstrate altered gait patterns relative to non-diabetic persons independent of age, body weight, height and sex. All gait pattern differences in during fast-walking; e.g., shorter stride length and lower ankle generative MWE and higher knee absorptive MWE, indicate that

persons with diabetes tend to have a less efficient gait pattern with a higher intensity effort. It is noteworthy that these inefficiencies are present in persons in relatively early stages of diabetes who have not yet developed the full range of diabetes complications.

Most gait pattern differences emerged during fast-walking, but extended duration of the first knee flexion phase of the gait cycle was also evident during usual-walking. Longer first knee flexion duration may help diffuse the impact load associated with heavier or excess weight more prevalent in the participants with diabetes. The previously identified association between diabetes and shorter stride [2] was observed for the fast-walking task, while the association between diabetes and slower walking speed [7] was not observed in either walking task. The absence of speed differences is likely due to the generally good health of study participants who were free of peripheral neuropathy and all fit enough to complete at least two walking tasks (at self-selected and maximum speeds) in the gait lab. It would appear that the fast-walking task, which places greater demand on motor control, is an important adjunct to better differentiate gait performance in generally healthy older persons in the early stages of potentially debilitating conditions such as diabetes. Given that high intensity walking (e.g., need to speed up to cross a busy intersection) frequently accompanies normal customary walking activities, subtle gait pattern disturbances and abnormalities in persons with diabetes during fast-walking can have important functional and social implications.

Consistent with previous work, participants with diabetes had a smaller hip range of motion in the sagittal plane during usual-walking than those without diabetes [10]. Reduced hip range of motion has been associated with lower walking efficiency [22] and identified as a risk factor for falling [23]. Interestingly, the longer knee first flexion phase of the gait cycle explained the lower hip range of motion in diabetic persons. This pattern implies that persons with diabetes start knee first extension relatively late in the gait cycle and that this knee rotation pattern reduces hip range of motion which has been associated with lower walking efficiency and increased risk of falling. During fast-walking, participants with diabetes had lower ankle generative MWE in the sagittal plane, which is primarily activated during ankle plantar flexion during late stance by the calf muscle. This finding is consistent with previous gait studies using inverse dynamics [2] and magnetic resonance imaging [24]. The greater knee absorptive MWE also observed in participants with diabetes during fast-walking is likely a function of smaller ankle generative MWE since ankle generative MWE and knee absorptive MWE are negatively correlated. In the present study, the negative correlation between ankle generative MWE and knee absorptive MWE increased during late stance, where both ankle and knee activity are most prominent. During late stance, the knee is in flexion and the ankle is in plantar flexion for the functional demands of forward propulsion while the dominant governing muscle groups are contracted (see Figure 2) to support a portion of body weight before the swing phase. The contracting muscles during ankle plantar flexion (gastrocnemius and soleus) are in generation mode whereas the knee extensor muscles (quadriceps) are in absorption mode and thus complement and compensate for one another in the roles of weight bearing and pushing-off for forward propulsion. During fast-walking, individuals with diabetes produce higher knee motor activity, possibly an adaptive compensation for lower ankle activity. This higher knee activity of energy absorption in diabetic individuals may contribute to orthopedic conditions such as knee osteoarthritis and in the presence of obesity can exacerbate knee burden. Thus, ankle muscle training may be considered for individuals with diabetes to prevent possible knee joint impairment during challenging tasks such as fast-walking. Future studies are needed to examine effective means of modifying gait alterations in diabetic persons. For example, whether training ankle activity can reduce increased knee activity for individuals with diabetes. Ankle activity improvement-training during fast-walking can be evaluated by

examining stride length given that lower ankle generative MWE in diabetic participants was explained by shorter stride length.

Some study limitations should be noted. Due to the fact that participants in this study were limited to those who could complete relatively high intensity walking (fast-walking) with no aids and peripheral neuropathy, the differences related to type 2 diabetes as reported in this study, may underestimate the effect of diabetes. Second, the cross-sectional nature of this data allows for the study of correlation but not causality. The BLSA is currently collecting longitudinal data that will overcome this limitation.

Persons with type 2 diabetes showed altered patterns in spatiotemporal parameters and kinematics and kinetics for walking at self-selected and maximum speeds. For maximum speed walking, ankle activity was lower while knee activity was higher in individuals with diabetes which may represent a compensational pattern for the limited ankle activity associated with diabetes. In addition to revealing gait pattern disturbances associated with diabetes, the present study emphasizes the need for and benefit of including a high intensity walking task for detecting aberrant gait patterns in individuals with early stage diabetes.

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Figure 1.

Correlation between ankle generative mechanical work expenditure (MWE) for ankle plantar flexion and knee absorptive MWE for knee flexion during late stance in the sagittal plane for fast-walking.

Ankle generative MWE: ankle generative mechanical work expenditure for ankle plantar flexion during late stance in the sagittal plane

Knee absorptive MWE: knee absorptive mechanical work expenditure for knee flexion during late stance in the sagittal plane

Figure 2.

Prospected muscle activities for the rotations from knee and ankle during late stance period. knee in flexion: hamstring muscle, which is in contraction is omitted to emphasize dominant muscle activity of quadriceps

Table 1

Characteristics of the study population by diabetes status

Characteristics for participants	Mean (SE) and proportion		P-value
	Non-diabetic (N=160)	Type 2 diabetes (N=26)	
Age, years	70.45 (0.58)	70.00 (1.43)	0.770
Sex, women, %	51	27	0.021
Height, meters	1.67 (0.01)	1.68 (0.02)	0.976
Mass, kilograms	75.65 (1.14)	81.95 (2.83)	0.041
HbA _{1c} , %	5.82 (0.04)	6.86 (0.11)	< 0.001

SE = standard error

HbA_{1c} = Hemoglobin A1C

Table 2

Gait parameters by diabetes status for three walking tasks

	Self-selected speed walking			Maximum speed walking		
	Non-diabetic Mean (SE)	Type 2 diabetes Mean (SE)	p-value	Non-diabetic Mean (SE)	Type 2 diabetes Mean (SE)	p-value
<i>Spatiotemporal parameters</i>						
Speed, m/s	1.15 (0.01)	1.12 (0.03)	0.318	1.68 (0.02)	1.60 (0.05)	0.154
Stride length, m	1.24 (0.01)	1.21 (0.02)	0.106	1.45 (0.01)	1.40 (0.02)	0.033
Cadence, steps/min.	111.46 (0.60)	114.10 (1.53)	0.114	138.47 (0.89)	143.02 (2.29)	0.070
Knee 1 flexion, % gait cycle	13.09 (0.10)	13.68 (0.26)	0.040	14.08 (0.14)	14.89 (0.35)	0.033
Stride width, cm	10.55 (0.16)	10.47 (0.42)	0.860	10.30 (0.17)	9.91 (0.45)	0.432
<i>In the sagittal plane</i>						
Range of motion, degree						
Hip	40.50 (0.30)	38.86 (0.76)	0.049	46.12 (0.38)	44.51 (0.97)	0.123
Knee	55.05 (0.32)	54.26 (0.82)	0.378	57.79 (0.34)	56.67 (0.87)	0.235
Ankle	24.39 (0.29)	23.13 (0.74)	0.122	24.81 (0.33)	24.28 (0.85)	0.566
Generative MWE in, 1000*J/kg						
Hip	158.47 (4.95)	168.33 (12.65)	0.473	288.88 (7.11)	297.44 (18.17)	0.664
Knee	101.81 (3.35)	88.72 (8.56)	0.160	144.86 (5.03)	137.53 (12.84)	0.599
Ankle	202.75 (4.27)	182.53 (10.90)	0.089	277.09 (5.95)	238.71 (15.19)	0.021
Absorptive MWE in, 1000*J/kg						
Hip	266.18 (8.14)	256.18 (20.79)	0.658	324.16 (9.58)	329.44 (24.47)	0.842
Knee	185.08 (6.85)	219.02 (17.48)	0.075	283.16 (7.47)	332.43 (19.09)	0.018
Ankle	130.12 (3.47)	124.97 (8.86)	0.592	96.09 (4.06)	96.00 (10.37)	0.994
<i>In the frontal plane</i>						
Range of motion, degree						
Hip	10.20 (0.16)	9.51 (0.42)	0.127	12.37 (0.21)	12.22 (0.54)	0.796
Knee	9.88 (0.30)	10.78 (0.76)	0.279	9.98 (0.28)	11.13 (0.73)	0.147
Ankle	9.58 (0.23)	9.32 (0.58)	0.681	9.76 (0.26)	9.78 (0.66)	0.979
Generative MWE in, 1000*J/kg						
Hip	72.40 (2.34)	77.47 (5.97)	0.434	76.24 (2.64)	84.20 (6.75)	0.279
Knee	11.67 (0.64)	11.84 (1.64)	0.921	16.77 (0.91)	16.94 (2.33)	0.946

	Self-selected speed walking			Maximum speed walking		
	Non-diabetic Mean (SE)	Type 2 diabetes Mean (SE)	p-value	Non-diabetic Mean (SE)	Type 2 diabetes Mean (SE)	p-value
Ankle	8.81 (0.44)	9.89 (1.14)	0.384	11.42 (0.74)	13.49 (1.89)	0.317
Absorptive MWE in, 1000*/J/kg						
Hip	47.97 (1.63)	54.00 (4.15)	0.183	75.10 (2.69)	81.68 (6.88)	0.379
Knee	18.33 (0.83)	19.42 (2.12)	0.638	22.00 (0.99)	24.92 (2.53)	0.289
Ankle	17.66 (0.72)	15.42 (1.83)	0.262	22.05 (0.99)	21.44 (2.52)	0.824

spatiotemporal parameters were adjusted for height, mass, sex, age
 kinematics and kinetics were adjusted for gait speed, height, mass, sex, and age.